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Which Geoid Model Should Be Used For GPS Heighting On The Toowoomba Bypass Project?

A dissertation submitted by

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in fulfilment of the requirements of

Courses ENG4111 and 4112 Research Project

towards the degree of

Bachelor of Surveying

Submitted: October, 2004

ABSTRACT

Graphical and statistical evaluations of the OSU91A, EGM96, EIGEN2/EGM96, UCPH2/EGM96 and PGM2000A global geoid models and of the bi-cubic and bi-linear interpolations of the SBA Technique, the RBA Technique, AUSGeoid93 and AUSGeoid98 gravimetric geoid models of Australia are made over the Great Dividing Range escarpment at Toowoomba using a set of 116 empirically derived geoid heights. Absolute and relative comparisons made between each geoid model over a 46.2 km Global Positioning System (GPS) and digital levelling traverse, against all 116 control points (6,670 possible baselines) and over Australian Height Datum (AHD) elevations greater than 200 m through to greater than 600 m show that AUSGeoid98 is the superior geoid model for the conversion of GPS-derived ellipsoid heights to AHD elevations on the Toowoomba Bypass project.

The results from this study confirm the benefits of including additional topographic data and satellite altimeter-derived gravity data in the production of the SBA Technique, the RBA Technique and AUSGeoid98, which were not used for AUSGeoid93. Conclusions made in this study are qualified by the fact that empirical validation of gravimetric geoid models on land does not provide an unequivocal assessment of the data, theories and techniques used to compute each geoid model due to the errors residing in the empirical geoid heights estimated to be ±0.0371 m evaluated at the 95% confidence level. However, land-based comparisons with GPS and levelling data remain the most practical method of verifying the integrity of gravimetric geoid models.

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ACKNOWLEDGEMENTS

This research was carried out under the principal supervision of Mr. Peter Gibbings, lecturer at the University of Southern Queensland, Toowoomba. Thanks are due for his advice and guidance.

Appreciation is also extended to Professor Will Featherstone, Professor of Geodesy, Curtin University of Technology, Perth, Western Australia. I am indebted to Professor Featherstone for providing his time, expertise and N values from several prototype geoid models for this project.

Appreciation is also due to Mr. Gary Burton, Senior Surveyor (Engineering Surveying), Geospatial Technologies, Planning Design and Environment, Queensland Department of Main Roads. Thanks are extended to Garry for providing his time, expertise and data from the Toowoomba Bypass project.

Recognition must also be given to the surveyors at RoadTek Consulting Surveys Toowoomba depot (Eric Brown, Chris Welsh, Mick Wockner and Bruce Turpin) who provided me with invaluable assistance with regard to data processing and who also gave very helpful feedback on this project.

Lastly, many thanks are given to Mr. Mick Cuskelly, Manager of RoadTek Consulting Survey Services (Southern Region), for allowing me the opportunity to use resources this year.

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NOMENCLATURE AND ACRONYMS

The following abbreviations have been used throughout the dissertation and appendices:

AGD	Australian Geodetic Datum
AGD84	Geographic Coordinates from the 1984 adjustment of the AGD
AGSO	Australian Geological Survey Organisation (now Geoscience Australia)
AHD	Australian Height Datum
AHDD	Australian Height Datum Derived
AMG	Australian Map Grid
AMG84	UTM Map Grip Coordinates for the AGD84
AMSA	Australian Maritime Safety Authority
ANN	Australian National Network
ANS	Australian National Spheroid
AUSLIG	Australian Surveying and Land Information Group (now National Mapping Division of Geoscience Australia)
BM	Bench Mark
DEM	Digital Elevation Model
DMR	Queensland Department of Main Roads
DNR&M	Queensland Department of Natural Resources and Mines
DTM	Digital Terrain Model
EDM	Electronic Distance Measurement
GA	Geoscience Australia (formerly AGSO)
GDA	Geocentric Datum of Australia
GDA94	Geographic Coordinates from the 1994 adjustment/transformation
GIS	Geographic Information System
GPS	Global Positioning System
ICSM	Inter-governmental Committee of Surveying and Mapping
ITRF	International Terrestrial Reference Frame, e.g., ITRF2000
Main Roads	Queensland Department of Main Roads
MGA	Map Grid of Australia
MGA94	UTM Map Grid Coordinates from the GDA94
PM	Permanent Mark
PSM	Permanent Survey Mark
RL	Reduced Level
RTK	Real Time Kinematic (GPS)
SCDB	Survey Control Data Base
UTM	Universal Transverse Mercator
WGS84	World Geodetic System 1984
XYZ	Cartesian Coordinates relative to the reference ellipsoid

CHAPTER 1

INTRODUCTION

1.1 Background to the Research

Recent advances in gravimetric geoid model data, theories and computation techniques have lead to the production of several new global geoid models and geoid models of Australia. Representing the next generation of gravimetric geoid models, favourable verification results endorsing these improvements may contribute toward the development of a new gravimetric geoid model of Australia. This dissertation presents the results of an evaluation of several commonly used and prototype gravimetric geoid models utilising Main Roads' proposed Toowoomba Bypass project and associated control stations as a test bed of empirically derived control points to determine the spatial integrity of each geoid model over the Great Dividing Range escarpment at Toowoomba.

1.2 The Problem

An integral part of most engineering projects is the provision of suitable horizontal and vertical control. This task is commonly performed using the Global Positioning System (GPS) to provide horizontal coordinates on the national mapping datum, GDA94, and conventional levelling to derive and propagate elevations on the national vertical datum, the Australian Height Datum (AHD). This provides the basis for the production of a Digital Terrain Model (DTM), whether by ground or aerial survey, of the project site from which a civil design is created. However, establishing vertical control on large or extremely undulating engineering projects, such as the Toowoomba Bypass project, can be resource intensive in terms of time, labour etc and it is envisaged that GPS combined with a suitable geoid model could potentially increase survey efficiency by eliminating the need to transfer AHD elevations via conventional levelling.

The primary application of a gravimetric geoid model is to convert GPS-derived ellipsoid heights to elevations on a local height datum such as the AHD. At present, AHD elevations derived from GPS heighting must satisfy the equivalent Australian conventional levelling specifications to be considered acceptable. Continual improvements in gravimetric geoid model accuracy and precision encourage the use of

GPS to derive elevations on the AHD. While nation-wide evaluations of gravimetric geoid models determine overall accuracy trends, many areas of Australia are known to deliver poor results from height transfer using GPS. This represents a considerable gap in the knowledge of the spatial integrity of gravimetric geoid models in regional areas of Australia.

1.3 Research Aim

The aim of this project is to compare the accuracy and reliability of several geoid models against empirically derived geoid heights to determine the suitability of each geoid model for use with GPS heighting on the Great Dividing Range escarpment at Toowoomba.

1.4 Research Approach

The research approach is divided into 4 subparts; the details of each now follow.

Existing literature relating to gravimetric geoid model verification will be reviewed. This is expected to identify current methods used to assess gravimetric geoid models on land and any limitations associated with their application. Several commonly used and prototype gravimetric geoid models will be critically appraised to determine their potential suitability for GPS heighting purposes. Furthermore, a review of previous research is expected to facilitate a comparison of results and provide a basis for confirming or extending existing theory.

Main Roads' proposed Toowoomba Bypass project, the associated control stations and surrounding permanent marks will be used to design a suitable control network for the geoid model comparisons. This will enable GPS and levelling data to be collected at co-located control points and, most importantly, permit the calculation of empirical geoid heights that will form the standard of comparison in the validation of each geoid model. In addition, selection of control stations at varying AHD elevations together with a least-squares adjustment of the GPS data will enable a more thorough analysis of each geoid model using all possible baselines and over increasing AHD height.

Precision estimates will be attached to the GPS-derived ellipsoid heights and levelling derived AHD heights based on the results from appropriate adjustments. This will enable the error to be estimated at each empirically derived geoid height given that the errors in the GPS and levelling data propagate into the empirical geoid heights by virtue of their calculation. Moreover, evaluation of the precision estimates at the 95% confidence level will allow statistically reliable comparisons to be made between each gravimetric geoid model and the control data, while any statistically significant differences noted can be reliably compared with the results from previous research.

Comparisons will be made between several gravimetric geoid models and the empirically derived geoid heights in both an absolute and relative sense. This is expected to determine whether GPS, in conjunction with the geoid model being verified, can achieve an accuracy and precision equivalent to that obtained via conventional levelling on the Toowoomba Bypass project. Furthermore, the comparisons are also expected to reveal whether any of the prototype gravimetric geoid models being validated are more suitable for GPS heighting than the current national gravimetric geoid model, AUSGeoid98, over the Great Dividing Range escarpment at Toowoomba.

1.5 Project Scope and Limitations

The scope of this study will be defined by these limiting factors:

- Geoid model comparisons will only be conducted over the Great Dividing Range escarpment at Toowoomba; specifically restricted to the Toowoomba Bypass project and associated control stations.

- The quality of the levelling data is defined as Australian Height Datum Derived (AHDD) Class D, 4th Order with an estimated average standard deviation (σ_H) evaluated at the 95% confidence level of ±0.0249 m.

- The quality of the GPS data is defined from the combination of rapid static baselines and static point positions, where the estimated average standard deviation (σ_h) of the homogeneous network of ellipsoid heights evaluated at the 95% confidence level is ±0.0262 m.

- The quality of the empirical geoid heights or 'truth values' against which the gravimetric geoid heights are compared have an estimated average standard deviation (σ_N) evaluated at the 95% confidence level of ±0.0371 m.

- For reasons investigated in chapter two, the difference between the GPS-derived ellipsoid heights and the levelling derived AHD heights only provide an *estimate* of the separation between the local height datum (AHD) and the reference ellipsoid (GDA94). This is known to be principally due to errors associated with the definition of the AHD and errors residing in the individual heighting components used to empirically derive the separation. Hence, empirically derived geoid heights can only provide an estimate of the true geoid-ellipsoid separation.

- Comparisons will be limited to only those geoid models being tested.

Considered beyond the scope of this study are:

- An assessment of the computational theories, techniques and data manipulation associated with gravimetric geoid determination.

- Any treatment of the so-called zero-degree term that relates the difference between the mass of the Earth and the mass of the EGM96 global geopotential model.

This dissertation is written under the assumption that the reader possesses a basic knowledge of GPS theory and components.

1.6 Summary

This dissertation aims to compare the accuracy and reliability of several commonly used and prototype gravimetric geoid models against empirically derived geoid heights to determine the suitability of each geoid model for use with GPS heighting over the Great Dividing Range escarpment at Toowoomba.

The research is expected to determine whether GPS used in conjunction with each gravimetric geoid model can achieve an accuracy and precision equivalent to that obtained via conventional levelling on the Toowoomba Bypass project. Furthermore, assessments are also expected to determine whether any of the geoid models tested provide any improvement in accuracy and precision compared with AUSGeoid98 and hence, are more suitable for transferring AHD elevations over the Great Dividing Range escarpment at Toowoomba.

The outcomes of this study will be used to recommend the most suitable gravimetric geoid model for use with GPS heighting on the Toowoomba Bypass project.

Chapter 2 provides a review of literature to establish the current state of theory with regard to geoid model verification.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Chapter one described the problem associated with transferring AHD heights over undulating terrain and the research approach to be implemented to determine whether GPS and a suitable gravimetric geoid model could fulfil this role. The primary application of a gravimetric geoid model is for converting GPS-derived ellipsoid heights to elevations on the local vertical datum. To determine the suitability of a geoid model for this purpose the factors that affect the accuracy and precision of a geoid model must be investigated.

This chapter provides this information by reviewing existing literature to establish the current body of knowledge with regard to geoid model verification.

A brief review of GPS heighting is provided to highlight the relationship between the relevant vertical surfaces. Errors associated with empirically derived geoid heights are also investigated to determine the likely sources of error that may affect the outcome of this study. Following is a review of several commonly used and prototype gravimetric geoid models to determine their current availability and potential suitability for use with GPS applications. The current Australian levelling specifications are briefly reviewed to establish the accuracy required of GPS heighting should the geoid models evaluated in this study be utilised on engineering projects located on the Great Dividing Range escarpment at Toowoomba. Finally, previous studies verifying geoid model accuracy are reviewed to determine the most suitable test schemes for application in this study and which will provide a basis for a comparison of results.

2.2 GPS Heighting

The process of deriving elevations on a local height datum from GPS measurements has been well documented (Gilliland 1986; Kearsley 1988; Mitchell 1988; Collier & Croft 1997; Featherstone *et al*. 1998). One of the main applications of a geoid model is to convert GPS-derived ellipsoid heights to gravity related elevations above a local height datum such as the AHD (Featherstone 1998, p.274). Central to this problem is knowledge of the geoid-ellipsoid separation relative to the GPS reference ellipsoid, WGS84. GPS-derived ellipsoid heights can be converted to approximate AHD elevations in either an absolute or relative sense, depending on observation technique. Figure 2.1(a) illustrates the absolute case where an ellipsoidal height can be converted to an approximate AHD elevation by *algebraically* subtracting the geoid-ellipsoid separation at a discrete point using the following relationship:

$$H = h - N \tag{2.1}$$

(*Source*: Featherstone *et al*. 1998, p.279)

where

H is the orthometric height ≈ an AHD height.

h is the ellipsoid height.

N is the geoid-ellipsoid separation (also known as geoid height or N value) measured along the ellipsoid normal to the geoid. If the geoid is above the ellipsoid, N is positive. If the geoid is below the ellipsoid, N is negative.

It is important to note that the ellipsoid height (h) and the geoid height (N) must refer to the same reference ellipsoid for the relationship to hold.

Featherstone *et al*. (1998, p.279) suggest that as the most accurate GPS applications are performed in the relative mode, equation 2.1 is not very practical for GPS height conversion. Rather, for the majority of surveying applications equation 2.1 can be rearranged to accommodate the relative situation, illustrated in figure 2.1(b), where an AHD elevation is transferred from a known point, A, to an unknown point, B, via the following relationship:

$$H_B = H_A + (h_B - h_A) - (N_B - N_A) \tag{2.2}$$

that can be reduced to:

$$\Delta H_{AB} = \Delta h_{AB} - \Delta N_{AB} \tag{2.3}$$

(*Source*: Kearsley 1988, p.11; Featherstone *et al*. 1998, p.279)

where Δ denotes 'change in'.

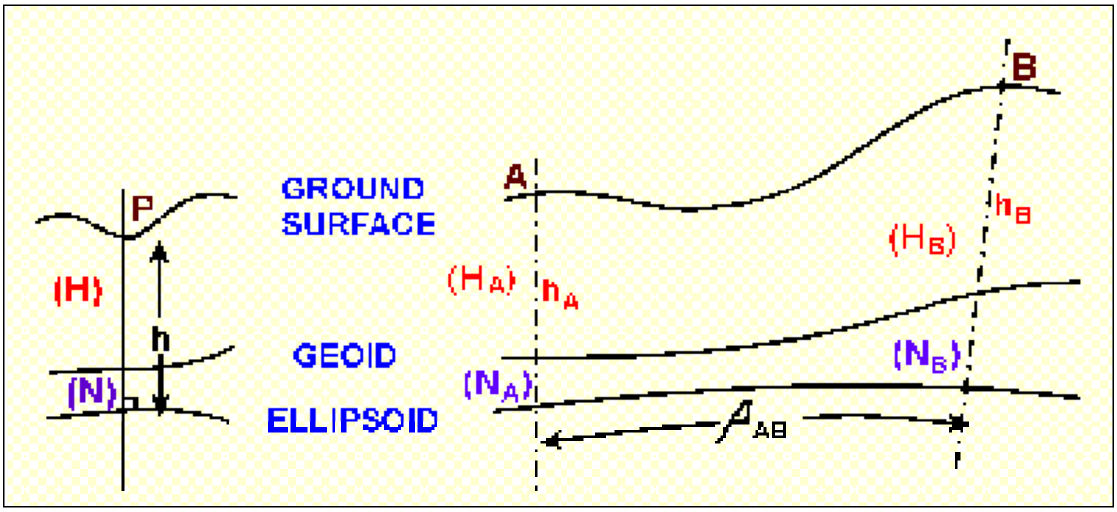

Figure 2.1(a) Figure 2.1(b)

Figure 2.1 Relationship between Ellipsoidal, Orthometric and Geoidal Heights for Absolute (2.1a) and Relative (2.1b) GPS Heighting

(*Source*: UNSW 2004)

2.3 Methods of Modelling the Geoid-Ellipsoid Separation

Several different methods of varying accuracy are available to construct a geoid model. These include a geometric approach (e.g., Collier & Croft 1997, p.16; Featherstone *et al.* 1998, p.281), a gravimetric approach including global geoid models and geoid models of Australia such as the AUSGeoid series (e.g., Collier & Croft 1997, pp.13-14; Featherstone *et al.* 1998, p.280; Featherstone *et al.* 2001, p.313; Featherstone & Alexander 1996, p.30; Geoscience Australia 2003; Johnston & Featherstone 1998; Kearsley 1988, p.12; Kearsley & Govind 1991) and a combined gravimetric-geometric approach (e.g., Featherstone *et al.* 1998, p.289).

Featherstone (2004, p.334) notes that the standard approach for land-based gravimetric geoid model validation is by comparisons with GPS and levelling data observed at co-located points. Furthermore, empirical validation of gravimetric geoid models is subject to the errors residing in the GPS-derived ellipsoid heights and levelling derived AHD heights however, at present, these data form the only practical means of verifying the integrity of geoid models on land.

As seen in earlier figure 2.1, discrete empirical geoid heights can be computed at each co-located point by re-arranging equation 2.1 to form:

$$N = h - H \tag{2.4}$$

while relative empirical geoid height differences can be computed by re-arranging equations 2.2 and 2.3 to give:

$$N_B = N_A + (h_B - h_A) - (H_B - H_A) \tag{2.5}$$

that can be reduced to:

$$\Delta N_{AB} = \Delta h_{AB} - \Delta H_{AB} \tag{2.6}$$

(*Source*: Kearsley 1988, p.11; Featherstone *et al*. 1998, p.279)

The preceding calculations result is an empirical geoid model that can be used in comparisons with geoid heights interpolated from gravimetrically computed geoid models, subject to the errors in the GPS and levelling data previously noted and further described in following section 2.4. This technique is currently being trialled in Papua New Guinea and will be applied in this study as a practical means of providing a standard of comparison to verify geoid models on land using empirically derived control data.

2.4 Errors Associated with Empirical Geoid Heights

The accuracy of empirical geoid heights derived from GPS and levelling observations is a function of the errors residing in these individual heighting components. The sources of error that can combine to degrade the accuracy of empirical geoid heights, computed from equations 2.4 - 2.6, can be broadly classed as errors associated with the acquisition of GPS-derived ellipsoid heights (e.g., ASCE 2000, pp.16-18; Featherstone *et al.* 1998, p.283; Hofmann-Wellenhof *et al.* 1997; Leick 1995), errors associated with the acquisition of elevations on the local vertical datum via conventional levelling (e.g., Featherstone *et al.* 1998, p.286; Johnston 2001; Sargeant & Featherstone 2001) and errors associated with using spatially variable gravity observations as a representation of the true geoid-ellipsoid separation and validating these gravimetric geoid heights with GPS and levelling data (e.g., Featherstone 1998, p.275; Featherstone *et al.* 1998, p.287).

Featherstone (2004, p.334) reaffirms the effect of these error sources suggesting that empirical geoid heights do not provide an unequivocal analysis of the accuracy of gravimetric geoid models however, at present, the use of empirical geoid heights to validate gravimetric geoid models on land is the most practical method available.

As established above, the empirically derived geoid heights are not infallible and an accuracy appraisal will be conducted in chapter 4 to assign precision estimates to the empirical geoid heights. This will permit statistically reliable comparisons with the gravimetric geoid heights interpolated from several commonly used and prototype geoid models described in following section 2.5.

2.5 Publicly Available and Prototype Geoid Models

Recent literature has revealed that a number of commonly used geoid models are available in the public domain, accessible via the Internet, and experimental geoid models available by special request from the appropriate authority. Five global geoid models and four geoid models of Australia, both commonly used in Australia or currently being developed, are investigated to provide a preliminary indication of their suitability for use with GPS heighting over the Great Dividing Range escarpment at Toowoomba.

2.5.1 Global Geoid Models

A number of satellite-only and combined global geoid models have been released (Featherstone & Olliver 2001; Amos & Featherstone 2003). Satellite-only global geoid models are purely constructed from the analysis of Earth-orbiting artificial satellites. Combined global geoid models are constructed from a combination of satellite data, land and ship-track gravity observations, marine gravity data obtained from satellite radar altimetry and, more recently, airborne gravity data (Amos & Featherstone 2003, p.3). Global geoid models provide information relating to the long wavelength component of the geoid; the most accurate of which is commonly used in the production of the various geoid models of Australia. Of most interest to this project are five combined global geoid models: OSU91A (Rapp *et al*. 1991), EGM96 (Lemoine *et al*. 1998), EIGEN2/EGM96 (Amos & Featherstone 2003), UCPH2/EGM96 (Amos & Featherstone 2003) and PGM2000A (Pavlis *et al.* 2000).

The OSU91A global geoid model is a combined model that has been evaluated to spherical harmonic degree (n) and order (m) 360. Derived from a previously released combined global geoid model, GEM-T2 (Marsh *et al*. 1990), the full expansion of the potential coefficients equates to a 30’ x 30’ resolution of the order of approximately 55 km (Featherstone & Alexander 1996, p.30). The practical implication of this resolution being that OSU91A is expected to provide a better fit to the control data over the longer baselines, while possibly exhibiting a bias over the short to medium baselines due to its poor spatial resolution.

The EGM96 global geoid model is complete to spherical harmonic degree (n) and order (m) 360. Referenced to the WGS84 ellipsoid, the potential coefficients have been computed from a global database grid of 30 minute mean free-air gravity anomalies supplemented by satellite altimetry and terrestrial gravity observations to yield a geoid height grid resolution of 15’ x 15’, or approximately 27-30 km (NIMA 2003). Featherstone *et al*. (2001, p.314) comment that, based on the debatably improved computational methods, amount of input data and comparisons with a national control data set (e.g., Kirby *et al*. 1998), the EGM96 global geoid model only provides a marginally better solution over Australia than OSU91A. This was mainly attributed to the errors residing in the GPS and AHD control data. Analysis of the comparisons between EGM96 and each global geoid model with the empirically derived control data is expected to confirm or modify this finding by applying similar comparisons to those made by Featherstone and Guo (2001) in their study of the precision of AUSGeoid93 verses AUSGeoid98 against a national GPS and AHD data set.

The EIGEN2/EGM96 and UCPH2/EGM96 global geoid models are hybrid models complete to spherical harmonic degrees 32/360 and 41/360 respectively and were created for the study by Amos and Featherstone (2003). The EIGEN-2 and UCPH2002_02 satellite-only global geoid models incorporate CHAMP (CHAllenging Mini-satellite Payload) high-low satellite-to-satellite tracking (hl-SST) and accelerometry data, with the EIGEN-2 global geoid model generated purely from CHAMP data. The CHAMP data from the dedicated satellite gravity mission was used to replace the corresponding low-degree coefficients of EGM96 over the Australia-New Zealand test zone to determine the effect of this data on the determination of the long wavelength component of the geoid.

Amos and Featherstone (2003, p.16) found that comparisons between several global models including EIGEN2/EGM96, UCPH2/EGM96 and EGM96 indicate that these hybrid models provide a small, though statistically insignificant, improvement on EGM96 over the Australia-New Zealand test zone. Between the two models, the comparisons suggested that EIGEN2/EGM96 provided a small, though statistically insignificant, improvement on UCPH2/EGM96 and would probably feature in future computations of the Australia-New Zealand geoid. Furthermore, as no zero- or first degree terms were calculated in the computation of these models, resulting in a bias in scale, they caution relying on the mean difference statistic and urge the use of the standard deviation statistic to interpret the fit of the geoid models to the control data.

Thus, comparisons from this study are expected to further advance the conclusions made by Amos and Featherstone (2003) by testing to what extent the EIGEN2/EGM96 and UCPH2/EGM96 global models improve on EGM96, if at all, as analysed from the standard deviations obtained from the comparisons with the control data.

The PGM2000A global geoid model (Pavlis *et al.* 2000) is a combined model complete to spherical harmonic degree (n) and order (m) 360. This model preserves the orbit and land geoid modelling performance of EGM96, although it also includes improved sea surface topography. The practical implication of this variation in gravimetric geoid solution is a marginally finer resolution than EGM96 over the Australian oceanic region that may provide a statistically better result than EMG96 in this study.

Therefore, comparisons between the global geoid models and the empirically derived control data are expected to exhibit a bias over the short to medium baseline lengths due to their coarse geoid height grid resolution, although improved results may be obtained over longer baselines.

2.5.2 Prototype Geoid Models of Australia

A number of experimental geoid models of Australia have been developed (Featherstone *et al.* 2002, Goos *et al.* 2003). Of most interest to this project are two prototype geoid models of Australia based on different gravity gridding techniques: the SBA Technique (Goos *et al.* 2003) and the RBA Technique (Goos *et al.* 2003).

The prototype gravimetric geoid model of Australia known as the SBA Technique was constructed from mean Faye gravity anomalies (as an approximation of mean Helmert anomalies) derived from discrete gravity observations via the simple Bouguer gravity anomaly gridding technique (SBA Technique). The SBA Technique involves gridding simple Bouguer anomalies at discrete gravity observation points on land, interpolating the simple Bouguer anomalies onto a regular 2-arc-minute GDA94 grid as used for AUSGeoid98, reconstructing free-air gravity anomalies using a 9-arc-second DEM grid and then adding the mean terrain correction from all DEM elements within a 2’ x 2’ compartment to produce mean Faye anomalies. The SBA gravimetric geoid model is then computed from this grid of mean Faye gravity anomalies via the classical remove-compute-restore (RCR) technique, which is based on the complete expansion (to degree and order 360) of the EGM96 global geoid model and an [unmodified] Stokes' kernel with no spherical cap radius over the entire data rectangle. The one dimensional Fast Fourier transform (1D-FFT) technique was used to calculate the residual geoid undulations at a 2-arc-minute spatial resolution (Goos *et al.* 2003, pp.99-100). Given that the SBA Technique featured in the production of AUSGeoid98, it is expected that results obtained from these geoid models will be similar in magnitude and consequently, any differences may be inconclusive due to the errors in the control data.

The prototype gravimetric geoid model of Australia known as the RBA Technique was constructed from mean Faye gravity anomalies (as an approximation of mean Helmert gravity anomalies) derived from discrete gravity observations on land using the refined Bouguer gravity anomaly gridding technique (RBA Technique). The RBA Technique involves calculating simple Bouguer anomalies at discrete gravity observation points on land (as per the approach used for the SBA Technique), interpolating the terrain corrections to the gravity observation points (from the nodes of the 9-arc-second grid of previously calculated terrain corrections), interpolating the refined Bouguer anomalies from the observation points to the same nodes as the regular 2-arc-minute GDA94 grid, reconstructing mean Faye gravity anomalies at the 9-arc-second grid nodes via the DEM and producing a 2-arc-minute GDA94 grid of reconstructed mean Faye anomalies as used for AUSGeoid98. The RBA gravimetric geoid model is then constructed using the exact same procedure as for the SBA gravimetric geoid model (Goos *et al.* 2003, p.101). Given the similarity between the RBA Technique, the SBA Technique and AUSGeoid98, it is expected that results obtained from these geoid models will be similar in magnitude and consequently, any differences may be inconclusive due to the errors in the control data.

2.5.3 The AUSGeoid Series

The determination of the Australian Geoid has been the subject of attention for over three decades. The first Australian geoid model was computed by Fischer and Slutsky (1967) using astro-geodetic methods to permit reductions of mean sea level distances on to the former national mapping datum, the Australian National Spheroid (ANS) (Kearsley & Govind 1991, p.30). Featherstone *et al.* (2001, p.313) note that gravimetric geoid models were also computed around this time using gravity data collected during resource exploration. Fryer (1972) subsequently produced a combined gravimetric-astrogeodetic geoid model adopted by the Division of National Mapping (NMC), renamed Australian Land Information Group (AUSLIG) and now the National Mapping Division of Geoscience Australia (GA), as the national standard referenced to the ANS.

Featherstone *et al.* (2001, p.313) explain that during the mid 1980s GPS users in Australia requested that geoid models be referenced to a geocentric datum. This demand was fulfilled by further computations carried out by Allman (1982), Kearsley (1988a, 1988b) and Gilliland (1989). For a more detailed review of both local and geocentric geoid computations in Australia the interested reader is directed to Kearsley and Govind (1991).

The Geodetic Services Section of AUSLIG (now the National Mapping Division of Geoscience Australia) formerly assumed the task of computing a national geoid model in July 1989. In 1991, Geoscience Australia released AUSGeoid91, which was a nation-wide gravimetric geoid model referenced to the WGS84 ellipsoid. This geoid model was computed using the OSU89A global geoid model, the 1980 release of Geoscience Australia's gravity database and the ring integration technique of the spherical Stokes' Integral with a limited spherical cap of 0.5° radius (Featherstone *et al.* 2001, p.313). AUSGeoid91 replaced all previous geoid models as the national standard for converting GPS-derived ellipsoid heights to approximate elevations on the AHD.

In 1993, Geoscience Australia released AUSGeoid93, the second in the series of national gravimetric geoid models, replacing AUSGeoid91 as the national standard. The AUSGeoid93 geoid model consisted of a 10’ x 10’ grid (approximately 20 km) of gravimetric geoid heights with respect to the WGS84 ellipsoid. The geoid heights were computed from the same gravity data and computational procedures as used for AUSGeoid91, although AUSGeoid93 was based on the 360-degree expansion of the OSU91A global geoid model (Featherstone *et al.* 2001, p.313; Geoscience Australia 2004). The result was an improvement in the long wavelength component of AUSGeoid93, as propagated into the solution via OSU91A, which in practice provided GPS users with a more accurate method of converting GPS-derived ellipsoid heights to elevations on the AHD.

The latest in the series of national gravimetric geoid models released by Geoscience Australia is AUSGeoid98. Replacing AUSGeoid93 as the national standard, AUSGeoid98 was released on a 2’ x 2’ (approximately 3.6 km) GRS80 grid covering the area bound by 8° S to 46° S and 108° E to 160° E (Johnston & Featherstone 1998, p.1). Computed using the latest available data at the time of production, it includes:

- The 360-degree expansion of the EGM96 global geoid model.
- N values computed in terms of the GRS80 ellipsoid, compatible with the WGS84 ellipsoid used with GPS.
- The 1996 release of the Geoscience Australia national gravity database.
- The Geoscience Australia GEODATA 9” digital elevation model of Australia.
- Satellite altimeter-derived free-air gravity anomalies offshore to augment Geoscience Australia’s terrestrial gravity database.
- Theories, techniques and software developed by Professor Will Featherstone, Curtin University of Technology, Western Australia.

(Geoscience Australia 2004; Johnston & Featherstone 1998)

Initial testing by Johnston and Featherstone (1998), via absolute and relative comparisons against 906 GPS-AHD control points, concluded that AUSGeoid98 made a considerable improvement over AUSGeoid93 for the conversion of GPS-derived ellipsoid heights to elevations on the AHD. Subsequent testing by Featherstone and Guo (2001), via absolute and relative comparisons against a nation-wide data set of 1,013 GPS-AHD control points, concluded that AUSGeoid98 was the superior model for use with GPS in the more mountainous regions of Australia. Analysis of the comparisons between AUSGeoid98 and each geoid model with the empirically derived control data is expected to further test these inferences by applying similar comparisons to those made by Featherstone and Guo (2001).

The geoid heights from the geoid models of Australia will be obtained using software and interpolation methods described in following section 2.5.4.

2.5.4 Geoscience Australia's WINTER Software

Geoscience Australia facilitates the interpolation of N values from the pre-computed grids of gravimetric geoid heights released as part of the AUSGeoid series by providing Windows Interpolation software (WINTER). WINTER is available for free download at http://www.ga.gov.au/nmd/geodesy/ausgeoid/, requires Windows95/98/NT and will interpolate interactively (one point at a time) or in batch mode (a file of positions) using a bi-cubic or bi-linear interpolation. The positions used to interpolate the data should be on the GDA94/WGS84 (Geoscience Australia 2004).

The geoid heights from the SBA Technique, the RBA Technique, AUSGeoid93 and AUSGeoid98 pre-computed geoid height grids will be obtained using both bi-cubic and bi-linear interpolation. Bi-cubic interpolation uses polynomials of degree three, in two dimensions, to calculate the attribute of a nominated position. Sixteen points are required to use this interpolation method. Bi-linear interpolation uses straight-line interpolation, in two dimensions, to calculate the attribute of a nominated position. Four points are required to use this interpolation method (AUSLIG 1996).

Bi-cubic and bi-linear interpolation methods were used by Featherstone (2001a, p.808) and described in section 2.8.2, who noted that while other interpolation methods are available, bi-cubic and bi-linear interpolation is commonly used to interpolate gravimetric geoid heights. Furthermore, it is beneficial to determine the sensitivity of each interpolation algorithm to the geoid height grid spacing used to compute the geoid model. This inference will be further examined by comparisons using both bi-cubically and bi-linearly interpolated gravimetric geoid heights from each geoid model of Australia with the empirical geoid heights over the Great Dividing Range escarpment at Toowoomba.

2.6 Methods of Geoid Model Verification

Featherstone *et al.* (2001, p.316) indicate that GPS networks co-located with orthometric heights yield discrete, geometric *estimates* of the geoid height with respect to the reference ellipsoid. In effect, this provides the difference between the local height datum, e.g., the AHD, and the reference ellipsoid, e.g., GRS80. However, these data currently provide the only practical means of verifying gravimetric geoid models on land (Featherstone *et al.* 2001, p.316). The verification of gravimetric geoid models using GPS and levelling data can be conducted in an absolute and relative sense; the details of each now follow.

2.6.1 Absolute Verification

Featherstone (2001a, p.808) notes that there are several caveats placed on the absolute verification of the geoid models.

The absolute value of the GPS-derived ellipsoid height must be known relative to the correct reference ellipsoid. Featherstone (2001a, p.809) acknowledges that gravimetric geoid models constructed using Stokes' Integral are incomplete in the zero- and first-degree terms resulting in a bias in scale due to an inexact knowledge of the product of the mass of the Earth and the Universal gravitational constant.

The absolute GPS-derived ellipsoid heights must be connected to an international geodetic network that has been established via satellite positioning methods, such as the International Terrestrial Reference Frame (ITRF). However, GPS data may inadvertently be collected at points on a geodetic network originally established via terrestrial geodetic techniques. The initial WGS84 base station coordinates must be obtained by using a geoid model to transform the orthometric height to an ellipsoid height, which severely diminishes the usefulness of the control data for the absolute verification of geoid models. This requirement is addressed in this study by only utilising control stations that have been previously established using GPS measurements that tie them to the national geodetic datum, GDA94. This is also necessary as GDA94, based on the GRS80 ellipsoid, is compatible with each geoid model being evaluated as these models are referenced to the equivalent ellipsoid, WGS84.

The absolute values of orthometric heights must be known relative to the geoid. This is realised in practice by conducting geodetic levelling on the AHD and incorporating orthometric corrections. However, the AHD is not an accurate realisation of the equipotential geoid for many reasons, e.g., sea surface topography (SST), conventional levelling errors (systematic), adjustment technique, normal gravity on the GRS80 ellipsoid used as opposed to observed gravity for corrections of orthometric heights etc and hence, only estimates of the true geoid-ellipsoid separation can be made (Featherstone 1998; Sargeant & Featherstone 2001).

These limitations aside, Featherstone (2001a, p.809) states that gravimetric geoid models can be validated in an absolute sense by *algebraically* subtracting the levelling derived AHD height (H_{AHDD}) from the GPS-derived ellipsoid height (h) at a number of discrete points that cover the area of interest, e.g., project control stations. As established in section 2.3, the relationship between N, h and H used for the absolute verification of geoid models is $N = h - H$, where each quantity is measured positively away from the geocentre and h and N must refer to the same reference ellipsoid.

Featherstone (2001a, p.809) notes that the approximate equality in equation 2.4 comes from neglecting the deflection of the vertical. The approximation can be calculated by multiplying the orthometric height by the cosine of the deflection of the vertical at the point of interest. From that particular study, the largest deflection of the vertical in the Perth region was approximately 50" and the maximum orthometric height was 350 m AHD, giving an approximation error in equation 2.4 of less than 0.001 m. Applying this principle, a similar calculation was made to validate the use of the absolute verification method in this study. The largest deflection of the vertical with respect to the GRS80 ellipsoid over the Toowoomba Bypass project area is approximately –8.031" and the maximum AHD Derived height is 708.203 m at PM35751, which equates to an approximation error in equation 2.4 of less than 0.001 m. Therefore, the relationship of equation 2.4 holds for the conversion of ellipsoid heights to elevations on a local height datum and the validation of geoid models in an absolute sense for this study, subject to the error sources previously outlined in section 2.4.

2.6.2 Relative Verification

Featherstone (2001a, p.810) notes that relative verification of geoid models requires knowledge of the GPS-derived ellipsoidal height differences (Δh), relative to the same ellipsoid as referenced by the geoid model, and orthometric height differences (ΔH_{AHDD}) over the same baselines. Furthermore, this approach is less susceptible to the restrictions associated with absolute verification in that any errors common to either end of the baseline cancel upon differencing.

Relative geoid model verification is principally conducted to evaluate the accuracy and precision of the gravimetric geoid gradients interpolated from the geoid model being validated. Featherstone (2001a, p.810) indicates that this type of assessment is more informative to the GPS user as most GPS surveys are performed in the relative mode. That is, GPS baselines are observed between control stations to yield a difference in ellipsoid height (Δh), which must be converted to a difference in orthometric height (ΔH) via the appropriate difference in geoid height (ΔN). Thus, for relative geoid verification the difference in orthometric height is *algebraically* subtracted from the difference in ellipsoid height to give the empirical geoid gradient over the baseline. Featherstone (2001a, p.810) suggests that the effect of the approximation error in equations 2.5 and 2.6 is reduced because the relative values are generally less than the absolute values.

Featherstone (2001a, p.810) states that relative differences can be computed, via equation 2.5, over all possible baselines between control stations. This can only be achieved if there is a single homogeneous network of ellipsoid heights, which is obtained via a least-squares adjustment of the GPS data. The number of baselines possible between n points in the control network is then calculated via $n(n-1)/2$, where the baseline length is determined from the latitude and longitude of the control point at each end of the baseline using Vincenty's Inverse formulae (ICSM 2002a, p.4-15). Thus, the Toowoomba Bypass control network will be subject to a least-squares adjustment to achieve a single homogeneous network of ellipsoid heights and to permit a thorough evaluation of the gravimetric geoid models against the empirically derived geoid heights using all possible baselines.

2.7 Standards for Establishing Vertical Control

Given that the principal source of levelling data for this study will be from a Main Roads' observed and adjusted digital level traverse of the Toowoomba Bypass control stations, it is necessary to investigate the guidelines to which level control surveys on Main Roads transport infrastructure projects must adhere.

The principal document that governs the Queensland Department of Main Roads survey operations is the 'Standards for the Provision of Road Transport Infrastructure Surveys' v1.1 June 2001. The section of the Standard that is specific to the establishment of vertical control is Part F – Digital Terrain Modelling Surveys. To summarise, Main Roads' requirements state that the datum for a survey shall be that as indicated by the survey brief, however, wherever practical AHD or AHDD should be adopted. Vertical control must be established from two independent level flights using either an automatic or digital level. The allowable misclose between the two independent level runs at any point must not exceed 3rd Order standard (i.e., $12\sqrt{K}$ mm, where K is the length of the level traverse in kilometres). Furthermore, a DTM generated from the vertical control must be capable of ensuring that the difference between a terrain point's interpolated height, as obtained from a triangulated mesh, and its independently levelled height, must not exceed 100 mm for natural surfaces.

The implication of the Standard to this study is that vertical control established on Main Roads' transport infrastructure projects must adhere to Australian 3rd Order levelling specifications as set out in the 'Standards and Practices for Control Surveys Special Publication 1' (ICSM SP1 2002b). Thus, it can be expected that Main Roads' level data will have been observed on, or derived from, the AHD to a minimum of 3rd Order standard using either an automatic or digital level. This will enable the misclose obtained at each control station to be adopted as an approximation of that point's levelling height standard deviation should the level traverse not be subject to a least-squares adjustment.

The information provided from both Main Roads' survey Standards and the Australian levelling specifications noted in SP1 will be applied in the geoid model comparisons described in chapters 5 and 6. Specifically, each geoid model used in this study will be compared against the equivalent maximum allowable misclose according to 3rd Order levelling specifications as set out in SP1, and adopted by Main Roads, to determine if GPS in conjunction with a particular geoid model being verified can achieve a similar accuracy and precision as obtained by conventional levelling on the Toowoomba Bypass project.

2.8 Geoid Model Verification Studies

Investigation of gravimetric geoid model verification has revealed many test schemes used by previous researchers. Most researchers acknowledge that absolute and relative verification using empirically derived control data provide an, albeit partial, independent analysis of the integrity of a geoid model for use in deriving elevations on a local vertical datum. However, the results obtained must be qualified by the errors residing in the control data.

2.8.1 Evaluations by Featherstone and Guo

Featherstone and Guo (2001) focussed on quantifying the improvements made, if any, by the current national gravimetric geoid model, AUSGeoid98, over the former national gravimetric geoid model, AUSGeoid93. Evaluations were conducted in mountainous and coastal regions on land via map-based, graphical and descriptive statistical comparisons of OSU91A, EGM96, AUSGeoid93, and AUSGeoid98 with a set of 1,013 GPS-AHD control points (512,578 control baselines) located across Australia. They indicated that the geoid model that achieves the best fit to the GPS-AHD control data should be regarded as the most suitable for converting GPS-derived ellipsoid heights to elevations on the AHD. However, this hypothesis is qualified by the errors likely to reside in the control data and that a gravimetric geoid is not an optimal representation of the AHD due to the fundamental differences between the determination of the geoid by gravity observations, e.g., a gravimetric geoid model, and by mean sea level observations, e.g., the AHD.

The comparisons applicable to this study were nation-wide numerical evaluations of each geoid model against all 1,013 control points (512,578 control baselines) and the nation-wide evaluations of AUSGeoid93 and AUSGeoid98 as a function of AHD height using subsets of the control points and control baselines, i.e., all GPS-AHD control points and subsequent baselines with an AHD height >200 m through to >600 m, increasing in 100 m AHD increments. The regional evaluations of AUSGeoid93 and AUSGeoid98 utilised bi-cubically interpolated gravimetric geoid heights obtained via Geoscience Australia's WINTER software previously described in section 2.5.4.

Featherstone and Guo (2001, p.11) concluded that, based on the nation-wide numerical evaluations of OSU91A and EGM96 against all 1,013 control points and over all 512,578 possible baselines, EGM96 provides a small, though statistically insignificant, improvement on OSU91A over the Australian continent for the recovery of AHD heights from GPS measurements and was consistent with the findings of previous researchers (e.g., Kirby *et al.* 1998). Analysis from this study is expected to further examine this finding by applying similar comparisons between OSU91A and EGM96 with the empirically derived control data as described in chapters 5 and 6.

Featherstone and Guo (2001, p.25) found that the absolute and relative comparisons between AUSGeoid93 and AUSGeoid98 indicated that AUSGeoid98 provided the best fit to the 1,013 GPS-AHD control data, both in terms of absolute and relative precision, for each test scheme. Furthermore, AUSGeoid98 was the most accurate model for converting GPS-derived ellipsoid heights to elevations on the AHD, both over the whole of Australia and in areas of higher elevation.

Featherstone and Guo (2001, p.23) concluded from the absolute comparisons as a function of AHD height, that the distribution of geoid heights interpolated from AUSGeoid93 was positively skewed compared to AUSGeoid98 over AHD elevations greater than 200 m through to greater than 500 m, with the positive bias not present for AHD elevations greater than 600 m. Moreover, the positive bias associated with AUSGeoid93 was due, in part, to the omission of corrections for the systematically positive terrain effects on the computed geoid and that a reduction in this bias for AHD heights above 600 m was most probably attributed to increased levelling errors in areas of high elevation, the smaller sample sizes used in the tests or the omission of high-frequency terrain effects due to the use of a DEM with mean elevations that do not represent the true topography.

Featherstone and Guo (2001, p.23) also suggested that from the relative comparisons as a function of AHD height, the range of the distribution, i.e., max-min, was reduced for AUSGeoid98 and that as AUSGeoid98 achieved a generally more stable statistical set for AHD heights greater than 200 m through to greater than 600 m, in both an absolute and relative sense, it was determined to be the most suitable model for the conversion of GPS-derived ellipsoid heights to AHD heights in areas of higher elevation. In contrast, AUSGeoid93 exhibited a more unstable statistical set over the AHD height range and produced generally larger statistical values. The improved fit to the control data in mountainous regions of Australia vindicated the use of terrain corrections in the construction of AUSGeoid98. Thus, analysis from this study is expected to expand upon these results by applying similar comparisons between AUSGeoid93 and AUSGeoid98 with the empirically derived control data as described in chapters 5 and 6.

2.8.2 Evaluations by Featherstone

Featherstone (2001a) verified the former and current national gravimetric geoid models, AUSGeoid93 and AUSGeoid98, and a refined version of AUSGeoid98 against 99 GPS-AHD control points (4,851 control baselines) located across metropolitan Perth, Western Australia. The comparisons were conducted in both an absolute and relative sense using geoid heights bi-cubically and bi-linearly interpolated from their respective pre-computed grids using the WINTER software package described in section 2.5.4. An accuracy appraisal of the control data estimated the mean error of the least-squares adjusted GPS-derived ellipsoid heights to be ±0.012 m, while the mean error of the AHD heights, established to 3rd Order standard, or better, levelling accuracy was more difficult to quantify but estimated to be ±0.020 m.

Featherstone (2001a, p.811) found that the bi-cubic interpolation of the refined version of AUSGeoid98 provided a statistically significantly better fit to the 99 GPS-AHD control points in an absolute sense than either the bi-cubic or bi-linear interpolation of the gravimetric geoid models. However, this finding was to be qualified by the fact that the refined version of AUSGeoid98 had been augmented with additional GPS and AHD data. In arriving at this conclusion, Featherstone (2001a, p.811) indicated that the gravimetric version of AUSGeoid98 achieved a lower root-mean-square (RMS) value than AUSGeoid93 for both interpolation methods, while the gravimetric version of AUSGeoid98 produced a larger standard deviation than AUSGeoid93 for bi-cubic interpolation and a smaller value for bi-linear interpolation. Recalling the GPS-derived ellipsoid height error estimate of ±0.012 m, Featherstone (2001a, p.811) suggested that the difference in standard deviation was inconclusive as it is less than the mean error, while the difference in RMS values were greater and more likely conclusive. Furthermore, the substantially larger number of outliers for AUSGeoid93 suggested that it provided a much worse fit to the control data in the Perth region.

Featherstone (2001a, p.812) stated that the statistical analysis of the relative verification results supported the conclusions drawn from the absolute verification scheme. This being that when using bi-linear interpolation, the gravimetric version of AUSGeoid98 marginally improved on AUSGeoid93, with a major improvement obtained when using the refined version of AUSGeoid98. Conversely, the bi-cubic interpolation of AUSGeoid93 provided a slightly better result than AUSGeoid98, though this was regarded as insignificant when considering the error budget of the control data.

Featherstone (2001a, p.812) suggests that variations obtained using both interpolation methods are partly due to the spacing of the pre-computed geoid height grids, i.e., AUSGeoid93 (10' x 10' grid) and AUSGeoid98 (2' x 2' grid), as it is less reliable to bi-linearly interpolate geoid heights from a coarse grid. This can be attributed to the fewer number of points used in the bi-linear interpolation algorithm as described in section 2.5.4. This was demonstrated in the results where the RMS and standard deviation values for the gravimetric version of AUSGeoid98 were more statistically consistent than for AUSGeoid93 and hence, supported the notion that as the geoid is an undulating surface, bi-cubic interpolation should be selected. Thus, the variability of both the bi-cubic and bi-linear interpolation techniques will be further examined in this study using gravimetric geoid heights interpolated via both methods from the SBA Technique, the RBA Technique, AUSGeoid93 and AUSGeoid98 gravimetric geoid models of Australia.

Featherstone (2001a, p.813) also proposes that it is improper to enforce normal levelling specifications on AHD elevations derived from GPS measurements. This conclusion was based on results showing that the distribution of the magnitude of the relative differences between the refined version of AUSGeoid98 and the control data over all 4,851 control baselines was not consistent with the square root of increasing distance error propagation rule applied to conventional levelling. This inference will be confirmed or modified by production of similar scatter plots illustrating the magnitude of the relative differences over all possible baselines to determine whether this trend is also present in the geoid models being evaluated in this study.

2.8.3 Evaluations by Featherstone and Alexander

Featherstone and Alexander (1996) concentrated on verifying the integrity of the global geoid models GEM-T2 and OSU91A, and the now superseded national gravimetric geoid models AUSGeoid91 and AUSGeoid93, for the recovery of AHD heights utilising a GPS and Class C (3rd Order standard) conventional levelling traverse conducted along 83.1 km of main road in southwest Western Australia. The longest GPS baseline was 27,215 m, the shortest baseline was 145 m and the average baseline length was 2,500 m.

Graphical comparisons involved plotting the residual height differences (ΔH_{GPS} - ΔH_{AHD}) for each global geoid model and geoid model of Australia, i.e., GEM-T2 v OSU91A and AUSGeoid91 v AUSGeoid93, over the entire length of the road, where only the baseline distance accumulated. Featherstone and Alexander (1996, p.33) found that insufficient ambiguity resolution over 4 of the 33 observed GPS baselines appeared as large spikes in the plots of the residual height differences, regardless of the geoid model used. The correlation between AUSGeoid91 and AUSGeoid93 was attributed to the short wavelength (~20 km) residual being generated from the 1980 Geoscience Australia gravity database used to compute each model. Thus, with respect to the likely errors in the control data, the global models exhibited long, medium and short wavelength trends, while the AUSGeoid models exhibited long and short wavelength trends. However, most of the medium wavelength trend associated with the global models was removed by the AUSGeoid models and hence, it was determined from a visual inspection of the plots that the AUSGeoid model height differences were closer to zero and appeared more suitable for GPS heighting in the southwest of Western Australia. This study will also investigate whether, and to what extent, these trends are evident in the current gravimetric geoid models available for use with GPS surveys.

Featherstone and Alexander (1996, p.32) explained that statistical comparisons reveal more information regarding the integrity of the various geoid models over the test profile. The first comparison made was between the misclose, i.e., total height difference, over the entire traverse for each geoid model and the equivalent Class C levelling specifications. With respect to the 83.1 km traverse, the algebraic sum of the GPS/geoid model and levelling derived AHD height differences, i.e., ($\sum\{\Delta H_{GPS} - \Delta H_{AHD}\}$), was required to be less than 0.109 m for the geoid model to be considered as a viable alternative to Class C geodetic levelling. The second evaluation involved comparing the mean and standard deviation of the magnitude of differences, i.e., ($|\Delta H_{GPS} - \Delta H_{AHD}|$), for all observed GPS baselines along the traverse to determine the short wavelength integrity of each geoid model.

Featherstone and Alexander (1996, p.32) noted that AUSGeoid93 satisfied the equivalent Class C levelling specification of 0.109 m over the entire traverse length, i.e., misclose of 0.090 m over 83.1 km, and over each baseline where the GPS integer ambiguity was resolved, though failed over the four baselines in which it was not resolved. Thus, they concluded that adequate GPS data should be collected to achieve a fixed ambiguity solution and, most importantly, accurate ellipsoid heights relative to the reference ellipsoid. However, with respect to this caveat, AUSGeoid93 offered the best solution for deriving AHD heights from GPS over longer baselines in the southwest of Western Australia. This study will also investigate whether GPS, in conjunction with each of the gravimetric geoid models tested, can transfer AHD heights over longer baselines to a minimum of 3rd Order standard. Furthermore, every effort will be made to only utilise GPS baselines that have achieved a fixed ambiguity solution.

Featherstone and Alexander (1996, p.33) indicated that although AUSGeoid93 was the most accurate model, due to its mean difference being closest to zero, neither it nor AUSGeoid91 offered any statistically significant short wavelength improvement over the global models tested. This was suggested to be a result of the baselines being less than the minimum resolution of each model's pre-computed grid of geoid heights. Furthermore, the AUSGeoid models still exhibited a small long wavelength trend, possibly due to the long wavelength errors in the global models propagating into the AUSGeoid solution. Thus, it was concluded that for GPS heighting over distances less than approximately 10 km a locally defined geoid model, utilising GPS observations at AHD benchmarks, was recommended. This study will also investigate the short wavelength integrity of each geoid model being verified to determine whether it is possible to transfer AHD elevations over distances less than approximately 10 km to a minimum of 3rd Order standard using GPS heighting.

2.8.4 Evaluations by Goos *et al*.

Goos *et al*. (2003) focussed on comparing the gridding of simple and refined Bouguer gravity anomalies (SBA and RBA Techniques) for data production onto a regular grid and the effect this had on the precision of the pre-computed geoid height grid. Absolute verification was conducted between the SBA Technique, the RBA Technique, AUSGeoid98 (constructed using the SBA Technique) and EGM96 (complete to degree and order 360) using the same nation-wide dataset of 1,013 GPS-AHD control points as used in the studies by Amos and Featherstone (2003), Featherstone and Guo (2001) and Featherstone *et al*. (2001).

Goos *et al*. (2003, p.109) indicated that the large mean difference obtained between the SBA and RBA Techniques and AUSGeoid98 was due, in part, to the different treatment of the zero-degree term in the production of AUSGeoid98 and the lack of terrestrial gravity data coverage to the north of Australia, i.e., Indonesia and Papua New Guinea. These problems consequently propagated into the SBA and RBA Technique gravimetric geoid solution as no spherical cap radius was applied in their production. However, based on the computed standard deviations for each new model, i.e., SBA Technique = ±0.741m and the RBA Technique = ±0.749m), Goos *et al*. (2003, p.110) concluded that there was no statistically significant difference between the two models considering the likely errors residing in control data. Furthermore, the reasons presented by Featherstone and Kirby (2002) advocating the use of the SBA Technique in Australian geoid model production seemed to be vindicated. This study will further examine these inferences by comparing the SBA and RBA Techniques with the empirical geoid heights in both an absolute and relative sense.

2.9 Conclusion

This chapter has established the current state of knowledge with respect to geoid model verification. Factors affecting the accuracy of empirically derived geoid heights were described. Specifically, it was noted that each GPS heighting component, i.e., ellipsoid, orthometric and geoid height, is subject to error. More importantly, these errors combine to diminish the accuracy of the empirical geoid heights used to verify gravimetric geoid models and thus, steps should be made to qualify the results obtained.

Also established, was that any levelling performed on Main Roads' transport infrastructure projects must satisfy Australian 3rd Order levelling specifications, i.e., $12\sqrt{K}$ mm, as set out in SP1. Furthermore, the misclose at each control point, computed from a level traverse, should be of sufficient accuracy to approximate the standard deviation of the AHD Derived height calculated for the control point.

A review of geoid model verification studies revealed that at present the only reasonable means of evaluating the integrity of gravimetric geoid models on land is using GPS-AHD control data via absolute and relative verification.

Chapter 3 will provide an overview of the research method to be implemented. This will entail a description of the test site, the sources from which the control data will be obtained, the geoid models to be verified and the evaluation techniques to be implemented.

CHAPTER 3

RESEARCH METHOD

3.1 Introduction

Chapter two established the current state of theory with regard to geoid model verification. The successful achievement of the project objective requires synthesis of the theory and techniques established in chapter 2 to develop a testing regime that will adequately evaluate the gravimetric geoid models selected for this study.

This chapter provides this guidance by outlining the research method that will be followed to evaluate the integrity of several geoid models over the Great Dividing Range escarpment at Toowoomba.

A brief description of the test site to be used to evaluate each geoid model is provided. This is followed by a brief outline of the intended method of control data acquisition involving obtaining levelling data and GPS baselines from recent Main Roads survey activities conducted to coordinate the Toowoomba Bypass control stations and supplementing these with a post-processed point positioning survey conducted by the author, calculation of empirical geoid heights at each control point used in this study and attaching an error estimate to these heights. Also presented is a brief description of the geoid models selected for verification and the absolute and relative verification techniques that are used to compare and statistically analyse each geoid model against the control data.

3.2 The Study Area

The location of the study site is the Great Dividing Range escarpment just north of Toowoomba, Queensland. Toowoomba is situated approximately 150 km west of Brisbane and is a large inland regional centre second only to Canberra, the nation's capital city. The regional location of Toowoomba is shown in figure 3.1.

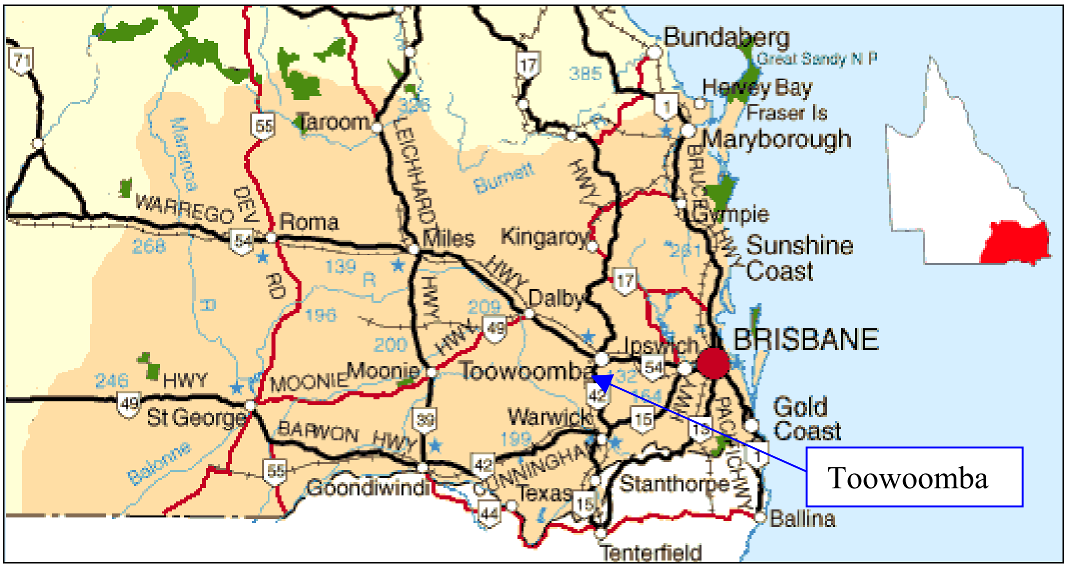

Figure 3.1 Map of Southeast Queensland, Australia

(*Source*: AusCERT 2004)

Toowoomba is situated on the edge of a plateau separated from the Lockyer Valley immediately to the east by a precipitous escarpment. Forming part of the Great Dividing Range, the Toowoomba escarpment lies at the southeast extremity of the western plains of Queensland (Holland 2001). The eastern extent of the Toowoomba Range lies at approximately 300 m AHD and rises to a height of approximately 700 m AHD at the top of the range, forming an escarpment profile of approximately 400 m in height. Beyond the top of the range escarpment, the terrain slopes away to the western plains and an elevation of approximately 520 m AHD on the Gore Highway southwest of Toowoomba. The view from the top of the range escarpment looking east across the Lockyer Valley to Helidon below is shown in figure 3.2, while the view west to Dalby is shown in figure 3.3.

Figure 3.2 Views East Toward Helidon from Top of Toowoomba Range
(*Source*: Author 2003)

Figure 3.3 Views West Toward Dalby from Top of Toowoomba Range
(*Source*: Author 2003)

The eastern section of the study area, encompassing the range escarpment and accompanying foothills, is extremely steep and consists of deep ravines and large sudden changes in elevation over relatively short distances. An example of the range escarpment profile is shown in figure 3.4.

Figure 3.4 View North Showing Toowoomba Range Escarpment Profile
(*Source*: Author 2003)

The existing Warrego Highway crosses the Toowoomba range from west to east, narrowly avoiding the Toowoomba CBD, connecting to the New England Highway to the north and the Gore Highway to the southwest, before continuing west to Dalby.

3.2.1 The Toowoomba Bypass Project

The Toowoomba Bypass is a major civil construction project being undertaken Main Roads. Currently in the planning phase, the proposal is to build a second range crossing to the north of Toowoomba to alleviate the impact of expected traffic volume increases over the next 10-15 years on the existing highway and local road network through which it passes. The general route of the existing Warrego Highway is shown in figure 3.5.

In broad terms, the proposed corridor is approximately 43 km in length, rising 450 m AHD from the start to the top of the range. This equates to maximum design grades of 5.5%, which is almost half as steep as the current range crossing. The reduced vertical gradient will also permit a design speed of 110 km/h compared with 60-80 km/h on the existing alignment (DMR 2003a).

The proposed new road corridor begins just west of the Helidon Spa where it deviates from the Warrego Highway and travels northwest, passing to the north of Withcott. Continuing through the foothills of the Great Dividing Range, the corridor rises to cross the range between Blue Mountain and Mount Kynoch, approximately at the intersection of Hermitage Road and the New England Highway.

Main Roads (2003c) is investigating the feasibility of a tunnel to pass under the existing New England Highway to minimise the design gradient on this steep section of the bypass route. The corridor then sweeps around the north of the city, crossing the Warrego Highway at Charlton, west of Toowoomba. Continuing southwest, the proposed corridor merges with the Gore Highway at Athol, approximately 17 km southwest of Toowoomba (DMR 2003a). The preferred alignment for the Toowoomba Bypass is shown as the red line in figure 3.5.

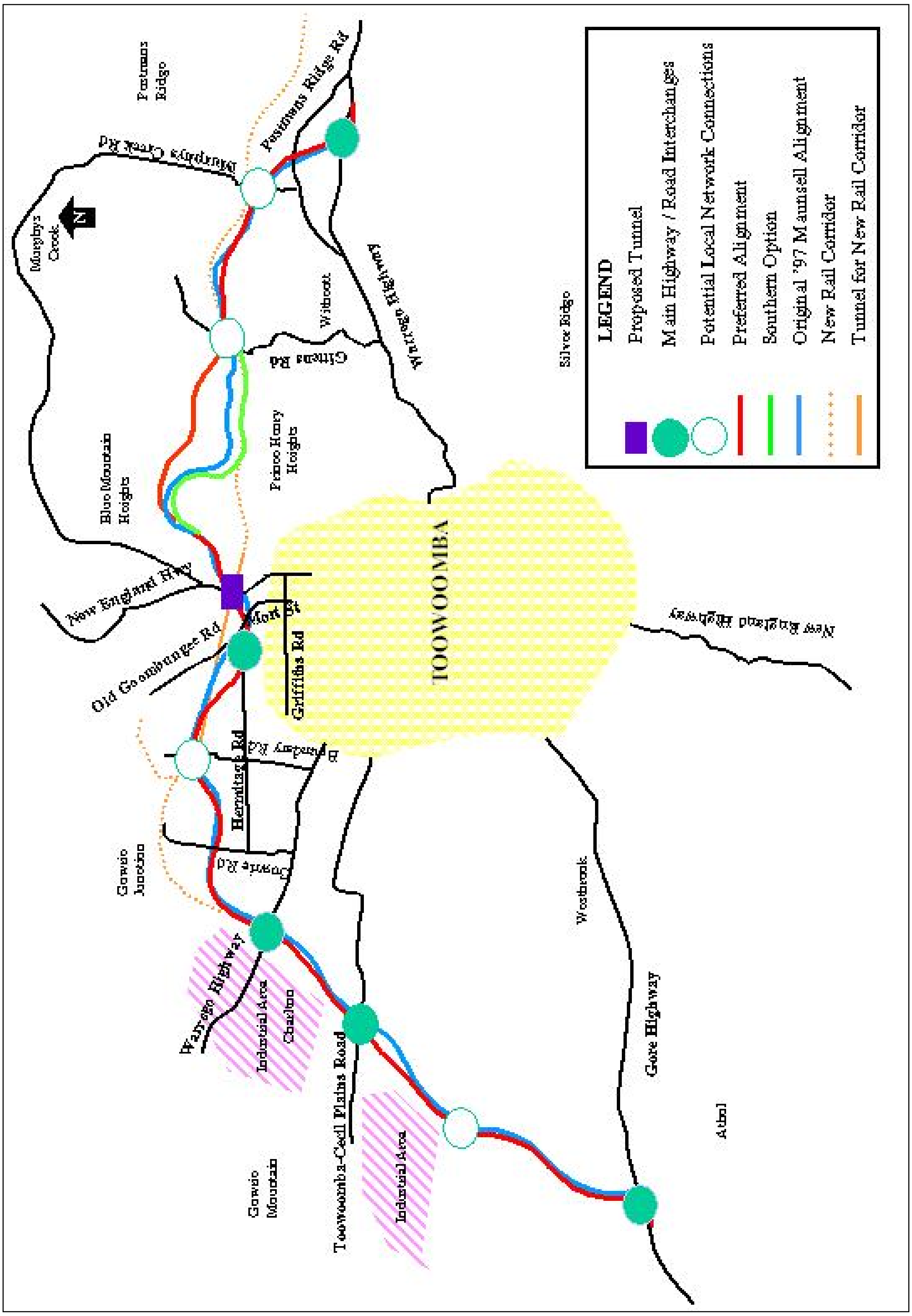

Figure 3.5 Proposed Route of the Toowoomba Bypass

(*Source:* DMR 2003b)

The survey work conducted by Main Roads as part of the pre-planning activities for the proposed Toowoomba Bypass constitutes the primary source of control data for this study.

3.2.2 The Toowoomba Bypass Control Network

The Toowoomba Bypass control stations were placed along the preferred alignment, shown in figure 3.5, in early 1999 to provide ground control for aerial photography that was subsequently flown early in 2000. Main Roads Toowoomba survey office was charged with identifying, placing and coordinating both the control stations and minor photo control points (PCPs) along the proposed corridor.

The control stations were established along the proposed alignment at approximately 500 m intervals in locations that would provide both adequate visibility for the forthcoming GPS control survey and aerial photography, and ensure their preservation well beyond the final construction phase. The physical marks placed were standard Main Roads Type C Benchmarks [2.4 m (8 ft) galvanised star picket and concrete collar], driven wholly into the ground or to refusal, flanked on either side by two protruding star pickets for protection and ease of location. An example of a Toowoomba Bypass control station is shown in figure 3.6.

Figure 3.6 Toowoomba Bypass Control Station 107 flanked by Star Pickets at Helidon Spa on the Warrego Highway east of Toowoomba

(*Source*: Author 2004)

Also forming part of the Toowoomba Bypass control network were several existing permanent marks. The GPS control survey originally performed by Main Roads was to be transformed onto the former Australian national mapping datum, AGD84 (ANS), and several permanent marks of varying class and order (horizontal and vertical) were utilised for this purpose. However, appraisal of this adjustment performed by Main Roads revealed that a number of permanent marks were only established by terrestrial geodetic techniques. These marks then formed the control for the adjustment, rather than permanent marks that had been established by GPS observations as suggested by Featherstone (2001a, p.808) and noted in section 2.8.1 of chapter 2. Adherence to this requirement has meant that only permanent marks established by GPS observations were used to coordinate the control survey and transform it onto the current Australian national mapping datum, GDA94 (GRS80). Thus, the total number of control points used for this study was 116, consisting of 107 Toowoomba Bypass control stations and 9 surrounding permanent marks.

3.3 Data Acquisition

The GPS and levelling control data used for this study will be obtained from many sources. It is important to note that these data are not infallible and hence, cannot be totally relied upon as an unequivocal validation of gravimetric geoid models on land (Featherstone 2001a, p.808; Featherstone *et al.* 2001, p.317). As such, prior to conducting any statistical analysis of the geoid models used in this study, it is necessary to describe how these data were obtained and to explain how the precision estimates were assigned to the control data.

The levelling data will be obtained from a digital level traverse performed and adjusted by Main Roads surveyors between approximately November 1999 and February 2000 to produce Australian Height Datum Derived (AHDD) elevations on the Toowoomba Bypass project control stations.

An estimation of the quality of the digitally levelled AHDD heights will then be provided to determine their reliability at the 95% confidence level. The Class and Order of the level traverse will be assigned according to the *ICSM Standards and Practices for Control Surveys (SP1) Ver. 1.5 May 2002* to determine at which national accuracy standard the level data comply.

Featherstone (2001, p.811) acknowledges that it is difficult to quantify the error present in AHD heights from a tolerance and that the accuracy of the AHD heights becomes less important when considering that the main use of a geoid model is to convert GPS-derived ellipsoid heights to elevations on the AHD. Therefore, the misclose computed at a control station in the level traverse will be adopted as the standard deviation of the AHDD height for that point.

The ellipsoid height data will be obtained from a combined least-squares adjustment of the network of baselines observed by Main Roads as part of the GPS campaign to coordinate control on the Toowoomba Bypass project and post-processed point positions observed by the author. To facilitate the use of all possible baselines in the statistical analysis of each geoid model, a single homogeneous network of ellipsoid heights will be computed. The total number of possible baselines between n control points is given by $n(n-1)/2$, where for this study n = 116 and the total number of possible baselines between these control points will equal 6,670. This is consistent with the suggestion made by Featherstone (2001a, p.810) and noted in section 2.6.2 of chapter 2, to permit a more thorough analysis of the integrity of each geoid model.

An estimation of the quality of the GPS-derived ellipsoid heights will then be provided to determine their reliability at the 95% confidence level. The variance of each GPS-derived ellipsoid height will be obtained from the report generated by the least-squares adjustment program.

The geoid heights that will form the standard of comparison in the verification of each geoid model will be determined by applying equation 2.4 in chapter 2 at each discrete control point, i.e., $N_{CTRL} = h_{GPS} - H_{AHDD}$, to form an empirical geoid model as described in section 2.3 of chapter 2.

The resultant N values will be geometric *estimates* of the separation between the GRS80 ellipsoid and the local vertical datum, i.e., the AHD, as opposed to separations between the GRS80 ellipsoid and the equipotential geoid (Featherstone *et al.* 2001, p.316). Thus, for reasons explained in section 2.4 of chapter 2, the empirically derived geoid heights cannot be relied upon as an unequivocal vindication of the data, theories and techniques used to compute the geoid models being verified. However, at present the use of empirical geoid heights to validate geoid models on land is the most practical method available (Featherstone 2004, p.334).

An estimation of the quality of the empirical geoid heights will be provided. This is achieved by adding the estimated variance of the ellipsoid height (σ_h^2) to the estimated variance of the AHDD height (σ_H^2), both evaluated at the 95% confidence level. This will propagate the estimated variance through the linear equation, i.e., $\sigma_N^2 = \sigma_h^2 + \sigma_H^2$, and result in an estimated variance of the empirical geoid height at each discrete control point, evaluated at the 95% confidence level. This form of control data appraisal was performed by Featherstone (2001a, p.811) and Featherstone *et al*. (2001, p.317), who comment that it is essential to recognise that the GPS and levelling data used in the verification of gravimetric geoid models are subject to their own error budgets. Thus, prior to verifying the integrity of each geoid model, chapter 4 will present the results of the verification of the control data that will determine the accuracy of the empirical geoid heights which are used as the standard of comparison in the geoid model verification schemes described in chapters 5 and 6.

Gravimetric geoid heights to be verified by comparisons with the empirically derived control data will be interpolated at each control point using the geoid models identified in section 2.5 of chapter 2 and interpolation methods described in section 2.5.4.

The empirical geoid heights and gravimetric geoid heights interpolated at each control point from the various geoid models described in section 2.5 of chapter 2 will be placed into several Microsoft Excel spreadsheets to aid the management of the expected large volume of data and to facilitate comparisons and analysis using the mathematical, statistical and graphical functionality of this program.

3.4 Geoid Models to be Verified

The geoid heights that will be compared against the empirical control data over the Great Dividing Range escarpment at Toowoomba have been sourced from several global geoid models and geoid models of Australia. The geoid models described in section 2.5 of chapter 2 were either freely available on the Internet or obtained by special request as detailed below.

3.4.1 OSU91A

The OSU91A global geoid model was obtained from *Trimble Survey Office Ver. 1.5 1998*. The geoid heights were interpolated from the data file *Osu91a.ggf* using *Grid Factory v1.10,* which is a geoid height interpolation program available as part of

Trimble Survey Office. The geoid heights interpolated from the OSU91A global geoid model are listed in Appendix B.

3.4.2 EGM96

The EGM96 global geoid model was obtained online from the US National Imagery and Mapping Agency (NIMA). The geoid height calculator program for Windows 95/NT was downloaded from the NIMA website at http://earth-info.nima.mil/GandG/wgsegm/egm96.html and used to obtain EGM96 geoid heights at each point in the Toowoomba Bypass control network. The geoid heights interpolated from the EGM96 global geoid model are listed in Appendix B.

3.4.3 EIGEN2/EGM96, UCPH2/EGM96 and PGM2000A

Geoid heights from the EIGEN2/EGM96, UCPH2/EGM96 and PGM2000A global geoid models were provided by Professor Will Featherstone, Professor of Geodesy, Curtin University of Technology, Perth, Western Australia. The geoid heights interpolated from the EIGEN2/EGM96, UCPH2/EGM96 and PGM2000A global geoid models are listed in Appendix B.

3.4.4 AUSGeoid93

The former national gravimetric geoid model, AUSGeoid93, was obtained by special request from the National Mapping Division of Geoscience Australia. The geoid heights were both bi-cubically and bi-linearly interpolated from the data file covering the area of interest, *sg56-14.dat*, using Geoscience Australia's freely available geoid height interpolation program, WINTER, the details of which are described in section 2.5.4 of chapter 2. The bi-cubically and bi-linearly interpolated geoid heights from the AUSGeoid93 geoid model of Australia are listed in Appendix B.

It should be noted that AUSGeoid93 is superseded by AUSGeoid98 and was only made available for this project by special request.

3.4.5 AUSGeoid98

The current national gravimetric geoid model, AUSGeoid98, was obtained online from Geoscience Australia. The data file covering the area of interest, *sg56-14.dat*, was available for free download at http://www.ga.gov.au/nmd/geodesy/ausgeoid/files.jsp. The geoid heights were interpolated from the pre-computed grid using both bi-cubic and bi-linear interpolation methods as offered by the WINTER geoid height interpolation program. The bi-cubically and bi-linearly interpolated geoid heights from the AUSGeoid98 geoid model of Australia are listed in Appendix B.

3.4.6 SBA and RBA Techniques

The SBA Technique and the RBA Technique prototype gravimetric geoid models of Australia were provided by Professor Will Featherstone, Professor of Geodesy, Curtin University of Technology, Perth, Western Australia. Both bi-cubically and bi-linearly interpolated geoid heights were obtained from the respective pre-computed geoid height grid files using the associated interpolation software. The bi-cubically and bi-linearly interpolated geoid heights from the SBA Technique and RBA Technique geoid models of Australia are listed in Appendix B.

3.5 Geoid Model Verification Techniques

The empirical validation of each geoid model described in section 3.4 will be conducted in an absolute and relative sense by comparisons with GPS and levelling data. As established in section 2.4 of chapter 2, these data currently provide the most practical means of verifying the accuracy and precision of gravimetric geoid models on land.

Absolute verification will be conducted by *algebraically* subtracting digitally levelled AHD Derived heights from co-located GPS-derived ellipsoid heights, via equation 2.4 in chapter 2, providing empirical geoid heights at each discrete control point. The discrete empirical geoid heights will then be used as a standard of comparison to assess the integrity of gravimetric geoid heights interpolated from each geoid model at these same known control points.

Relative verification will be conducted by *algebraically* subtracting the difference between GPS-derived AHD height differences, calculated using each geoid model in equation 2.3 in chapter 2, and digitally levelled AHD Derived height differences, i.e., ΔH_{GPS} - ΔH_{AHDD}, over all possible baselines in the Toowoomba Bypass GPS control network. Featherstone and Alexander (1996, p.31) indicate that this is equivalent to comparing the relative accuracy and precision of geoid gradients computed using each gravimetric geoid model to geoid gradients derived empirically from the difference in GPS and levelling data over equivalent baselines. The empirical geoid height differences will then be used as a standard of comparison to assess the integrity of gravimetric geoid height differences interpolated from each geoid model described in section 3.4 over the same known control baselines.

As established in section 2.6 of chapter 2, absolute and relative geoid model verification is routinely used by other authors to validate gravimetric geoid models on land by comparisons with GPS and levelling data (e.g., Featherstone & Guo 2001; Featherstone 2001a; Featherstone & Alexander 1996; Fotopoulos *et al.* 1999; Goos *et al*. 2003).

The application of the absolute and relative verification schemes to this study will be described in detail in chapters 5 and 6 respectively.

3.6 Conclusion

This chapter has outlined the research method that will be adopted for this study.

107 Toowoomba Bypass project control stations and 9 surrounding permanent marks will form a test bed of 116 GPS-AHDD control points for the geoid model comparisons.

The GPS and levelling data collected as part of the preliminary planning activities for the proposed Toowoomba Bypass project and augmented by a post-processed GPS point positioning survey will constitute the principal source of control data for this study.

A combined least-squares adjustment of the GPS data will provide a single homogeneous network of ellipsoid heights facilitating the use of all 6,670 possible baselines in the geoid model analysis.

The gravimetric geoid heights that will be verified against the empirically derived geoid heights will be interpolated from the OSU91A, EGM96, EIGEN2/EGM96, UCPH2/EGM96 and PGM2000A global geoid models and the SBA Technique, RBA Technique, AUSGeoid93 and AUSGeoid98 geoid models of Australia. These geoid models were either freely available on the Internet or obtained by special request.

The two principal methods of land-based geoid model verification routinely used by other authors were identified. The absolute verification technique will be used to determine the absolute precision of each geoid model in relation to the GPS-AHDD control data. The relative verification technique will be used to determine the accuracy and precision of the gravimetric geoid gradients, as it is more representative of the way in which GPS surveys are used to convert GPS-derived ellipsoid heights to elevations on a local height datum such as the AHD.

It is important to reaffirm that the GPS and levelling data used in this study are not infallible and hence, cannot be totally relied upon as an unequivocal validation of gravimetric geoid models on land. As such, prior to conducting any statistical analysis of the geoid models, which is the crux of this study, it is necessary to describe how these data were obtained and to explain how the precision and accuracy estimates were assigned to the control data.

Chapter four will provide a description of how the GPS and levelling data were obtained and how the assessment was made of their accuracy in order to attach precision estimates to the empirical geoid heights.

CHAPTER 4

DATA ACQUISITION

4.1 Introduction

Chapter three described the research method that will guide this research. As stated, it is important to recognise that the GPS and levelling data used in this study are not infallible and hence, cannot be accepted as an unequivocal vindication of gravimetric geoid models on land. As such, prior to conducting any statistical analysis of the geoid models, which is the principal focus of this study, it is critical to emphasise that this chapter is necessary to describe how these data were obtained and to explain how the precision estimates were assigned to the control data to facilitate a statistically reliable assessment of the integrity of each geoid model.

Chapter four will be provide this appraisal by describing the data collection process and attaching an error estimate to these data based on the observation and adjustment techniques employed.

The ellipsoid height data will be described in terms of the GPS campaigns carried out by Main Roads and the author to coordinate the Toowoomba Bypass control stations, the adjustment technique adopted and the accuracy estimate of the resultant ellipsoid heights. An evaluation of the levelling data is then made comprising a description of the level traverse conducted by Main Roads to establish level control on the Toowoomba Bypass project control stations, the adjustment technique adopted and an accuracy classification. Completion of the appraisal of the GPS and levelling data will permit an assessment to be made of the accuracy of the empirically derived geoid heights that are used as the standard of comparison or ‘truth values’ for the geoid model comparisons presented in chapters 5 and 6 and discussed in chapter 7.

4.2 GPS Data

The acquisition and accuracy appraisal of the ellipsoid heights that form part of the empirical control data used in this study is described in detail below.

4.2.1 Data Acquisition

The GPS data utilised in this study was obtained from the original GPS control survey conducted by Main Roads to coordinate the Toowoomba Bypass control stations and a recent GPS point positioning survey conducted by the author to augment the baseline data.

4.2.1.1 GPS Baselines

The GPS campaign to coordinate the Toowoomba Bypass control network was carried out by Main Roads surveyors between October 1999 and March 2000. The Toowoomba Bypass control network was formed by the combination of GPS baselines observed as part of a major control network and a minor control network. The GPS baselines forming the major control network extend well beyond the proposed road corridor and were observed between several permanent marks identified to bring the survey onto the former national geodetic datum, AGD84, as required by Main Roads at the time of the survey, and the necessary Toowoomba Bypass control stations, as required to achieve good network geometry. The GPS baselines forming the minor control network were observed between each individual control station along the proposed road alignment and along side roads at proposed highway interchanges. The major control network and minor control network of GPS baselines forming the Toowoomba Bypass control network are shown in figure 4.1.

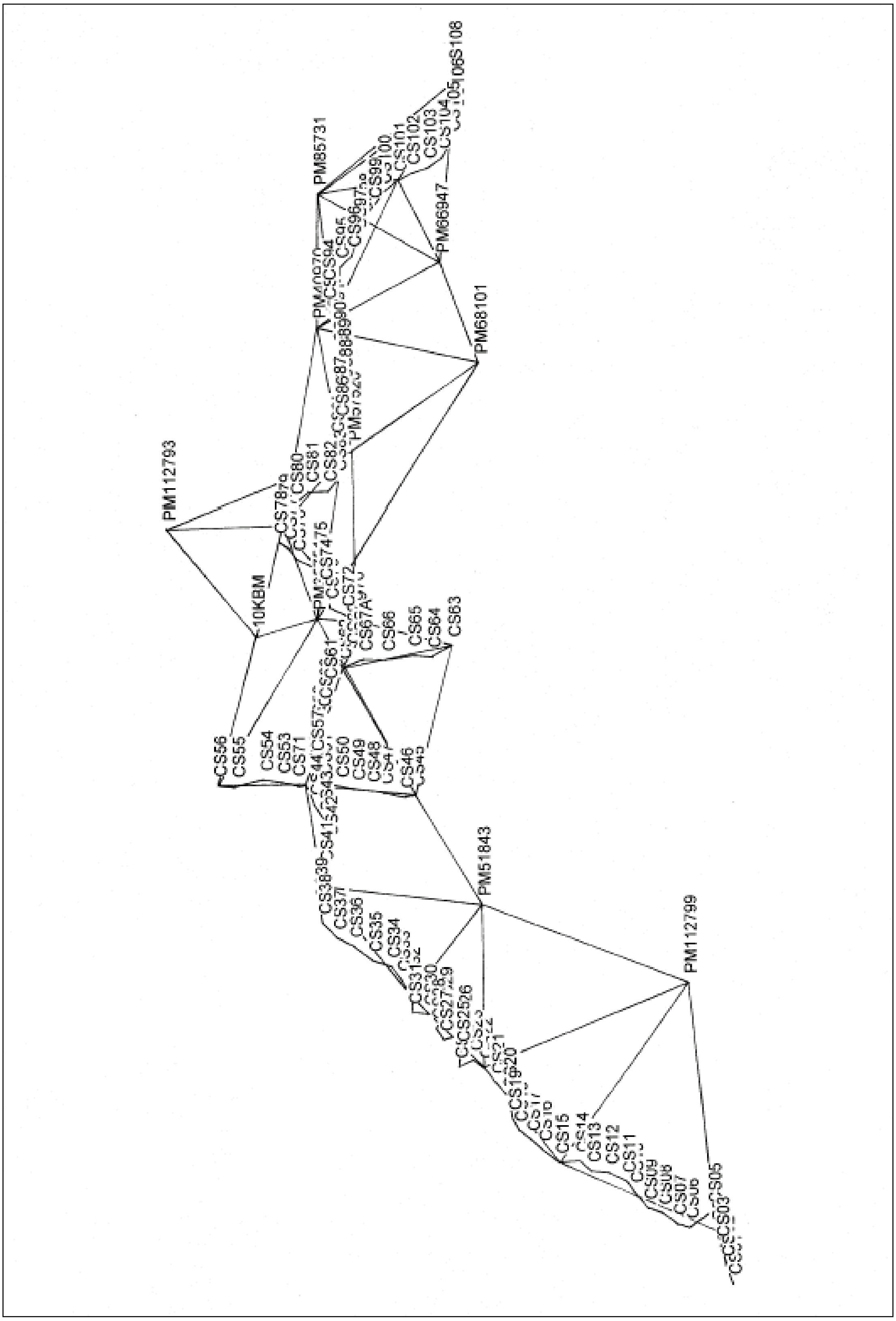

Figure 4.1 Toowoomba Bypass Control Network

(*Source:* GeoMap 2003)

The baselines forming the major control network were observed using three *Trimble 4700* dual-frequency carrier-phase observable GPS receivers in rapid static mode. The observation time at each control station varied between 30 minutes and 1 hour depending on satellite visibility. This was important because as identified by Featherstone and Alexander (1996, p.33) and noted in section 2.8.3 of chapter 2, all GPS baselines were required to have sufficient clean data to allow ambiguity resolution.

The baselines forming the minor control network traverse were observed using the same *Trimble 4700* GPS receivers in rapid static mode. Due to the lower accuracy requirement for these baselines the observation time at each control station was reduced to between 15 and 50 minutes, depending on satellite visibility. For example, at those control stations located on the Toowoomba range escarpment where a large section of the western sky was not visible, observations were generally longer and suffered more cycle slips. In addition, many control stations did not have independent observations, which further reduced their reliability. The consequence of these poorer quality observations will be further investigated in chapter 7.

4.2.1.2 Post-processed Point Positions

The GPS campaign to obtain discrete ellipsoid heights on several Toowoomba Bypass control stations was conducted by the author between March and June 2003. This was necessary to augment the available GPS baselines with accurate GDA94 point positions to facilitate an adjustment of the combined GPS data onto the national geodetic datum, GDA94, and to permit comparisons between empirical geoid heights and gravimetric geoid heights referenced to the same ellipsoid, WGS84 or its equivalent, GRS80. This was also important because as identified by Featherstone (2001a, pp.808-810) and noted in section 2.6 of chapter 2, absolute and relative verification of geoid models requires knowledge of GPS-derived ellipsoid heights relative to the same reference ellipsoid as used to compute the geoid models.

Point positions were initially observed at control stations CS1, CS70, CS107 and at the permanent mark PM35751 at Mt. Kynoch as shown in earlier figure 4.1. The GPS data was collected in static mode using two *Leica GPS System 500* dual-frequency carrier-phase observable GPS receivers. Each mark was occupied for 9 hours with data logged continuously at 30 second epochs. One of the *Leica GPS System 500* receivers used for this study is shown in figure 4.2.

Figure 4.2 Leica GPS System 500 Dual-frequency GPS Receiver
(*Source*: Author 2003)

Point positions were then observed at an additional 16 control stations along the proposed alignment. The control stations selected were CS4, CS9, CS25, CS33, CS40, CS52, CS68, CS72, CS73, CS76, CS77, CS88, CS90, CS97, CS101 and CS105 as shown in earlier figure 4.1. These control stations were chosen for their accessibility, satellite visibility and location along the proposed alignment such that a reasonably even distribution of point positions was achieved between the four control stations initially occupied. The GPS data was observed with the same *Leica GPS System 500* receivers, although the average occupation time for each mark was reduced to 6 hours of continuous data logged at 30 second epochs due to time restraints.

The GPS data collected at the twenty control stations was post-processed to obtain their point positions relative to the GRS80 ellipsoid. Leica's GPS processing software package, *SkiPro*, was used to convert the raw data files to Receiver Independent Exchange Standard (RINEX) for upload and processing by Geoscience Australia's AUSPOS Online GPS Processing facility. RINEX data is an ASCII format that provides a consistent data format for all geodetic GPS receivers and is the data format required by the AUSPOS facility.

The RINEX files output from *SkiPro* were uploaded to Geoscience Australia's AUSPOS Online GPS Processing facility at http://www.ga.gov.au/nmd/geodesy/sgc/wwwgps. The AUSPOS facility then utilised the International GPS Service (IGS) Final orbit product to compute the GDA94 coordinates of each point position, i.e., XYZ, $\phi\lambda h$, $ENhH_{(AUSGeoid98)}$, as noted in the AUSPOS Online GPS Processing Service reports in Appendix C.

The Main Roads observed GPS baselines described in earlier section 4.2.1.1, the post-processed point positions described above and the AUSPOS 'Solution Information', provided as part of the AUSPOS report to enable the user to verify the computed solution for each point, were then used in the adjustment of the Toowoomba Bypass control network; the details of which now follow.

4.2.2 Adjustment of the Toowoomba Bypass Control Network

The GPS data collected for this study was subject to a combined least-squares adjustment to provide a single homogeneous network of ellipsoid heights. The GPS baselines observed by Main Roads were combined with the twenty AUSPOS computed GDA94 point positions in a single network adjustment. This was necessary because as identified by Featherstone (2001a, p.810) and noted in section 2.6.2 of chapter 2, a single homogeneous network enables the use of all possible baselines between the control points, which in turn, provides a more thorough analysis of gravimetric geoid models through relative verification.

The combined least-squares adjustment of the GPS data was performed with the GPS baseline processing package *GeoMap v2.0*, utilising the least-squares adjustment module of the software. The adjustment methodology consisted of a minimally constrained adjustment and constrained adjustment of the GPS data. This was important as it is a recommended procedure in accordance with the best practice guidelines set out in SP1 for analysis using a least-squares adjustment (ICSM 2002b, p.B-24).

The adjustment procedure initially involved a minimally constrained adjustment to verify the internal consistency of the control network. As previously explained, the baselines observed by Main Roads were loaded into *GeoMap* to form a combined network featuring both the major control network baselines and minor control GPS traverse baselines as shown in earlier figure 4.1. The recommended best practice for a minimally constrained adjustment, described in SP1, was adopted and only one control point, PM35751, was used to constrain the adjustment. This point was selected for its approximate central location within the control network and its established standard of accuracy, i.e., 1^{st} Order horizontal and 4^{th} Order vertical. PM35751 was held fixed at its AUSPOS computed GDA94 point position and constrained by its associated 'Coordinate Precision' [XYZ in metres] obtained from the 'Solution Information' noted in AUSPOS report number 13471 listed in Appendix C.

The minimally constrained adjustment initially failed the statistical test used by *GeoMap* to verify the adjustment. The reason for this failure was determined to be that the error ellipses (σ) were generally too optimistic in their precision and hence, should be multiplied by a scalar to more realistically reflect the precision of the observations. The Differential VCV^{-1} Height Scaling Property for the matrices was then increased to 2.0 given that the vertical component is the most inaccurate with respect to GPS three-dimensional positioning. The minimally constrained adjustment subsequently passed the statistical test using this height scale factor.

The successful completion of the minimally constrained adjustment of the GPS baseline network permitted a constrained adjustment to be conducted. The recommended best practice for a constrained adjustment, described in SP1, was then adopted and all twenty AUSPOS computed point positions, described in earlier section 4.2.1.2, were used to constrain the adjustment. The control points were held fixed at their AUSPOS computed GDA94 coordinates and constrained by their associated ‘Coordinate Precision’ [XYZ in metres] obtained from the accompanying AUSPOS reports listed in Appendix C.

The constrained adjustment initially failed the statistical test using the AUSPOS computed coordinate precisions constraining each control point held fixed in the adjustment. A scale factor of 2.0 was then applied to all AUSPOS computed coordinate precisions, used to constrain their respective AUSPOS point positions, to permit the constrained adjustment to pass the statistical ratio test.

The constrained adjustment subsequently passed the statistical test using the minimum station constraint scale factor of 2.0. The least-squares adjustment report generated by *GeoMap* for the constrained adjustment of the Toowoomba Bypass control network is reproduced in Appendix D. Following the recommended best practice for the analysis of a least-squares adjustment, the information provided by the standard deviations of the adjusted control points, listed in the least-squares adjustment report generated by *GeoMap*, will be used to analyse the accuracy of the GPS-derived ellipsoid heights; the details of which now follow.

4.2.3 Estimated Accuracy of the Ellipsoid Heights

The accuracy of the GPS-derived ellipsoid heights was estimated from the results of the minimally and constrained adjustments described in section 4.2.2. This information was used to assign a level of precision to the ellipsoid heights, which in turn, was used to estimate the accuracy of the empirical geoid heights.

The variance for each GPS-derived ellipsoid height (σ_h^2) was obtained from the constrained least-squares adjustment report listed in Appendix D. The report contained a section titled ‘Adjusted Positions’ that lists the ‘Spheroidal Elevation Standard

Deviation', which was squared to give the variance for each GPS-derived ellipsoid height. Thus, the estimated average variance of the GPS-derived ellipsoid heights is 0.0001888 m^2 (σ_h = ±0.0134 m) and the estimated average variance at the 95% confidence level is 0.0003701 m^2 (σ_h = ±0.0262 m). Refer to Appendix E for the estimated variance of the ellipsoid height at each control point.

4.3 Levelling Data

Prior to validating the accuracy of the digitally levelled AHD Derived elevations used for this study, it is necessary to outline the process used to obtain the levelling data. The acquisition and accuracy appraisal of the levelling data that formed part of the empirical control data used in this study is described in detail below.

4.3.1 The Level Traverse

Main Roads surveyors carried out the levelling for the Toowoomba Bypass over a three-month period from approximately November 1999 to February 2000. In an effort to maintain consistency, accuracy and efficiency on the project the level traverse was conducted by a three-man survey crew using a *Zeiss DiNi 21* digital level and two 4 m telescopic fibreglass barcode-numeric staves with plumbing bubble attached.

The levelling methodology applied to the Toowoomba Bypass project was heavily influenced by the prevailing site conditions. The extreme terrain variations, densely vegetated escarpment area and length of the project posed challenges in terms of accessibility of marks, connection to known AHD marks and minimisation of error propagation. Consequently, the level traverse was conducted in an unconventional manner whereby each of the two level flights consisted of different control alignment traverses, interspersed with closed loops and side traverses. This was necessary as previously noted in section 4.2.1.1 and shown in earlier figure 4.1, the proposed alignment features several highway interchanges which required side traverses to connect to control stations and bench marks located along these adjoining roads.

However, as established in section 2.7 of chapter 2, Main Roads standards for establishing vertical control were maintained such that a misclose satisfying Australian 3rd Order levelling specifications was achieved.

4.3.2 Adjustment of the Toowoomba Bypass Level Traverse

The Toowoomba Bypass level traverse was subject to a full level correlation adjustment performed by the Geospatial Technologies Unit at Main Roads, Brisbane. Burton (2003, pers. comm., 20 Aug) indicated that it was extremely difficult to carry out an adjustment due to the complexity of the level run. Consequently, the original level traverse observed by Main Roads surveyors was appended to form one continuous level run consisting of two independent level flights from the start at CS108 (east) to the end at CS1 (west), overall approximately 68 km in length, and included as many known AHD and AHDD marks as possible. The longer level traverse compared to the proposed road corridor length was due to the appended level traverse forming a longer route to include all possible observed known marks.

The appended level traverse was subject to a full level correlation adjustment. Burton (2003, pers. comm., 20 Aug) stated that the resulting misclose was only 0.021 m over 68 km, clearly satisfying the equivalent 3rd Order levelling specification over this distance of 0.099 m, i.e., $12\sqrt{K}$ mm, where K is the length of the level traverse in kilometres (ICSM 2002b, Table 19, p.B-11). This was important because as established in section 2.7 of chapter 2, Main Roads require a level traverse conducted to establish vertical control on their transport infrastructure projects to achieve a misclose no greater than the maximum misclose permissible according to Australian 3rd Order levelling specifications set out in SP1. Correlations were then made to AHD or AHDD marks and the misclose distributed over each section, i.e., millimetres per change point (mm/CP), based on the misclose onto each benchmark for that particular section. The same procedure was applied to the side traverses and closed loops. Overall, the adjustment was only minor considering the complexity of the original level run. The details of the appended Toowoomba Bypass level traverse are listed in Appendix F.

The level correlation adjustment described above will be used to assign a precision estimate to the levelled heights; the details of which are described below.

4.3.3 Estimated Accuracy of the Levelling Data

The accuracy of the levelling data was estimated from the classification of the class and order of the level traverse, field techniques and misclose achieved. This information was then used to assign a level of precision to the levelling data, which in turn, was used to estimate the accuracy of the empirical geoid heights. The details of the accuracy appraisal of the levelling data are described below.

4.3.3.1 Class and Order

The Toowoomba Bypass level traverse was assigned a standard of accuracy according to the *ICSM Standards and Practices for Control Surveys (SP1) Ver. 1.5 May 2002*. Based on the appraisal of the level traverse according to the requirements set out for digital levelling under Part A – Standards of Accuracy, Section 3 – Vertical Control, Subsection 3.2 – Standards of Class and Order, it was determined that the Toowoomba Bypass level traverse was performed to Class D standard and the resulting AHDD levels were of 4th Order accuracy. This classification reflects the field methodology adopted and vertical datum control available to constrain the level traverse at the time of the survey.

A clarification regarding the assigned standard of Order for the level traverse must be made. As established in section 4.3.2, the appended level traverse achieved a misclose of 0.021 m over 68 km, clearly satisfying the equivalent 3rd Order standard over this distance of 0.099 m, i.e., $12\sqrt{K}$ mm (ICSM 2002b, Table 19, p.B-11). However, as the correlation adjustment utilised both 3rd Order standard and 4th Order standard AHD and AHDD benchmarks to constrain the level traverse and given that it was performed to Class D standard, then the maximum Order that can be assigned to the level traverse according to SP1 is 4th Order (ICSM 2002b, Table 5, p.A-14).

4.3.3.2 Estimation of Variance

Featherstone (2001, p.811) acknowledges that it is difficult to quantify the error present in AHD heights from a conventional levelling tolerance. Furthermore, the accuracy of the AHD heights becomes less important when considering that the main application of a geoid model is to derive elevations on a local vertical datum, such as the AHD, from GPS measurements. Therefore, the misclose onto each control station, as described in section 4.3.2 and listed in the level traverse correlation adjustment in Appendix F, will be adopted as the standard deviation of the AHDD height at each control point.

Due to the complexity of the level traverse, not all control stations and permanent marks forming the level control for this study appear in the appended level traverse and hence, only an estimate could be made of the misclose onto those marks not listed. This aside, the estimated average variance of the digitally levelled AHDD heights (σ_H^2) is 0.0001781 m^2 (±0.0127 m) and the estimated average variance at the 95% confidence level is 0.0003491 m^2 (±0.0249 m). Refer to Appendix E for the estimated variance of the AHDD height at each control point.

The estimated precision of the GPS-derived ellipsoid heights and the levelling derived AHD heights were used to estimate the precision of the empirical geoid heights that form the standard of comparison in the geoid model analysis presented in chapters 5 and 6. The details of the audit of the empirical geoid heights are described below.

4.4 Empirical Geoid Height Data

The GPS-derived ellipsoid heights and levelling derived AHD heights that were used to compute the empirical geoid heights have been appraised in sections 4.2 and 4.3. Prior to empirically validating the accuracy of the geoid models previously described in section 2.5 of chapter 2, it is necessary to describe the calculation and accuracy assessment of the empirical geoid heights that formed the standard of comparison for the geoid model analysis described in chapters 5 and 6; the details of each now follow.

4.4.1 Calculation of the Empirical Geoid Heights

The empirical geoid heights that form the standard of comparison for the verification of each geoid model in chapters 5 and 6 were computed by applying equation 2.4 at each discrete control point, i.e., $N_{CTRL} = h_{GPS} - H_{AHDD}$. The result is empirically derived separations between the GRS80 ellipsoid and the local vertical datum, i.e., the AHD, as opposed to separations between the GRS80 ellipsoid and the equipotential geoid (Featherstone *et al.* 2001, p.316). Thus, for reasons identified by Featherstone (2004, p.334) and noted in section 2.4 of chapter 2, the empirical geoid heights do not provide an unequivocal analysis of the data, theories and techniques used to compute the geoid models being verified. However, at present, the use of empirically derived geoid heights to validate gravimetric geoid models on land is the most practical method available.

The empirical geoid heights forming the standard of comparison in this study are listed in Appendix B and the estimation of their associated precision follows.

4.4.2 Estimated Accuracy of the Empirical Geoid Heights

The accuracy of the empirical geoid heights that will form the standard of comparison for the geoid model analysis described in chapters 5 and 6 was estimated by combining the estimated accuracies of the individual heighting components used to calculate the empirical geoid heights. That is, the errors in the GPS-derived ellipsoid heights combine additively with the errors in the levelling derived AHD heights and propagate into the empirical geoid heights by virtue of their calculation. Thus, at each discrete control point the estimated variance of the GPS-derived ellipsoid height and levelling derived AHD height, evaluated at the 95% confidence level, were summed to obtain the estimated variance of the resultant empirical geoid height at the 95% confidence level, i.e., $\sigma_N^2 = \sigma_h^2 + \sigma_H^2$.

Therefore, the estimated average variance of the empirical geoid heights (σ_N^2) forming the standard of comparison for the geoid model analysis in chapters 5 and 6 is

0.0003669 m^2 (±0.0189 m). Furthermore, the estimated average variance of the empirical geoid heights at the 95% confidence level is 0.0007191 m^2 (±0.0371 m). The calculation and accuracy assessment of the empirical geoid heights used for this study are shown in Appendix E.

4.5 Conclusion

This chapter has described the data acquisition process and estimated the precision of the existing control data. This was necessary as the GPS and levelling data contain their own errors budgets, which consequently propagate into the empirical geoid heights by virtue of their calculation. Thus, to facilitate statistically reliable comparisons between the empirical geoid heights and each geoid model, it was critical to qualify their precision.

Appraisal of the minimally constrained and constrained adjustments of the Toowoomba Bypass control network, performed to obtain a single homogenous network of ellipsoid heights, established that the estimated average variance of the ellipsoid heights is 0.0001888 m^2 (σ_h = ±0.0134 m) and evaluated at the 95% confidence level is 0.0003701 m^2 (σ_h = ±0.0262 m).

A similar analysis of the levelling derived AHD heights established that, following a level correlation adjustment, the misclose achieved clearly satisfied the Australian 3rd Order levelling specification however, validation against the *ICSM Standards and Practices for Control Surveys (SP1) v.1.5* (2002b) concluded that the Toowoomba Bypass level control only satisfies Class D, 4th Order standard. Adopting the misclose onto each control point as the observation standard deviation established that the estimated average variance of the levelling derived AHD heights (σ_H^2) is 0.0001781 m^2 (±0.0127 m) and evaluated at the 95% confidence level is 0.0003491 m^2 (±0.0249 m).

Propagation of the accuracy of the ellipsoid and levelling heights through the linear equation, i.e., $\sigma_N^2 = \sigma_h^2 + \sigma_H^2$, established that the estimated average variance of the empirically derived geoid heights (σ_N^2) forming the standard of comparison for the geoid model analysis in chapters 5 and 6 is 0.0003669 m^2 (±0.0189 m) and evaluated at the 95% confidence level is 0.0007191 m^2 (±0.0371 m).

Chapter five will provide a description of the absolute verification test schemes and present the results of the comparisons between each geoid model and the empirical geoid heights.

CHAPTER 5

RESULTS OF ABSOLUTE VERIFICATION

5.1 Introduction

Chapter four described the data acquisition process and provided an accuracy appraisal of each component of the control data to estimate the precision of the computed empirical geoid heights. As established in chapter two, a common technique used to evaluate the integrity of a gravimetric geoid model on land is by absolute verification against empirically derived geoid heights. The main application of this technique is that the absolute precision of the gravimetric geoid can be determined with respect to the reference ellipsoid.

Chapter five will provide this analysis by describing the absolute verification test schemes that will be used to compare the empirical geoid heights against gravimetric geoid heights interpolated from each geoid model and will present the results from these absolute verification schemes.

The test schemes developed to verify each gravimetric geoid model in an absolute sense, via comparisons with all 116 control points and over increasing AHD height, are described in terms of testing methodology and presentation of results. Following this, the numerical and graphical results obtained from the implementation of each absolute test scheme are presented.

5.2 Absolute Verification Test Schemes

Based on previous research reviewed in section 2.8 of chapter 2, the most practical absolute verification schemes that were identified and will be implemented in this study are:

- Comparison with all control points.
- Comparison over increasing AHD height.

These evaluation methods are expected to indicate the absolute precision of each gravimetric geoid model in relation to the reference ellipsoid. This translates to a determination of the variability in the absolute gravimetric geoid heights interpolated from each geoid model over the escarpment profile compared to the empirical geoid heights. The implication of these assessments from a practical perspective is that they will provide an indication of the suitability of each geoid model for the recovery of AHD heights in an absolute sense, as would be required when conducting a GPS point positioning survey, in areas of higher elevation such as on the Great Dividing Range escarpment at Toowoomba.

The application of each absolute verification scheme to this study is described in detail below.

5.2.1 Comparison with all 116 Control Points

This verification method will assess the accuracy and precision of the absolute fit of each geoid model to the 116 GPS-AHDD control points. The empirical N value (N_{CTRL}), determined via equation 2.4 at each control point, will be subtracted from the gravimetric N value (N_{GM}) interpolated at each control point using the geoid models described in section 2.5 of chapter 2, i.e., $\Delta N = N_{GM} - N_{CTRL}$. The result will be a residual geoid height difference at each control point.

Simple descriptive statistics will be computed to interpret the nature of the residual geoid height differences. The descriptive statistics that will be computed include values for the maximum, minimum, mean, standard deviation (STD) and root-mean-square (RMS). This form of analysis is recommended by other researchers (e.g. Featherstone & Alexander 1996; Johnston & Featherstone 1998; Vergos & Sideris 2001; Featherstone 2001a) who suggest that simple descriptive statistics can provide an indication of the suitability of a geoid model for converting GPS-derived ellipsoidal heights to elevations on the AHD.

The standard deviation of the absolute differences will be used as the principal measure of the precision of each geoid model in an absolute sense. Recalling the limitations of absolute verification described in section 2.6.1 of chapter 2, Featherstone (1999, p.143) cautioned relying on the computed mean and root-mean-square of the absolute differences as any gravimetric representation of the geoid is biased in scale due to an inexact knowledge of the Earth's mass distribution. Consequently, the only [partly] reliable estimate that can be made is of the precision of the gravimetric geoid model in relation to the reference ellipsoid.

The Z-statistic will be computed to identify any residual geoid height differences that lie outside three standard deviations from the mean, i.e., Z-score > 3.0, assuming a normal distribution. If the Z-score is greater than three standard deviations from the mean it will be flagged and the number of outliers totalled for further investigation in chapter 7. This method of data validation was also implemented in the studies by Featherstone and Guo (2001, p.81) and Featherstone (2001a, p.809) as described in section 2.8 of chapter 2, who suggest that where the differences between each geoid model and the control data are approximately normally distributed the Z-statistic can be used to identify any outliers.

Graphical comparisons between each geoid model and the empirical geoid heights will also be presented. The residual geoid height differences will be plotted against their respective approximate chainage along the escarpment profile. The plots are expected to reaffirm the conclusions drawn from the numerical comparisons with the 116 control points by illustrating the variation in the spread of the residual geoid height differences and thus, providing an indication of how parallel each geoid model is to the empirical geoid model in an absolute sense. In addition, the plots will also indicate the magnitude of the offset of each geoid model from the empirically derived geoid. The practical application of this will be to determine whether the variability in the absolute gravimetric geoid heights interpolated from each geoid model is small enough such that a 'block-shift' could be applied to the residual geoid heights to permit reliable GPS point positioning over the Great Dividing Range escarpment at Toowoomba.

5.2.2 Comparison over Increasing AHD Height

This verification method will assess the accuracy and precision of the absolute fit of each geoid model to the 116 GPS-AHDD control points over an increasing AHD height range. This verification test scheme will utilise the same residual geoid height differences featured in the evaluation described in section 5.2.1. Given that the lowest AHD height is 194.204 m at CS108 and comparisons have been previously described using all 116 control points, the comparisons over increasing AHD height will be commenced at all AHD heights greater than 200 m. This height range will then be increased at 100 m AHD height increments to greater than 600 m AHD. The result will be smaller subsets of control points. The total of each subset of control points is 107 points at greater than 200 m AHD, 93 points at greater than 300 m AHD, 86 points at greater than 400 m AHD, 57 points at greater than 500 m AHD and 5 points at greater than 600 m AHD.

Simple descriptive statistics will be computed to interpret the nature of the residual geoid height differences at each AHD height increment. The descriptive statistics that will be computed include values for the maximum, minimum, mean, standard deviation (STD), root-mean-square (RMS) and the number of outliers, i.e., Z-score > 3.

This evaluation follows the same verification technique used by Featherstone and Guo (2001, p.96) and described in section 2.8.1 of chapter 2, to assess geoid models in the mountainous regions of Australia. (*ibid.*) noted that this evaluation technique can provide an indication as to whether AUSGeoid98 has made any significant improvement over other geoid models when used to derive AHD heights from GPS measurements in areas of higher elevation. The extremely undulating terrain within the project area provides an ideal opportunity to assess the integrity of each geoid model for this fact and thus, it would be beneficial to conduct a similar evaluation to determine the most appropriate geoid model for use with GPS in the recovery of AHD heights in areas of higher elevation, such as found on the Great Dividing Range escarpment Toowoomba.

Graphical comparisons between each geoid model and the empirical geoid heights using all 116 control points will also be presented. The residual geoid height differences will be plotted against their respective AHD height and a linear trend line fitted to the data. The plots will illustrate the variation in the spread of the residual geoid height differences and thus, provide an indication of how parallel each geoid model is to the empirically derived geoid. In addition, it will also indicate the magnitude of the offset of each geoid model from the empirically derived geoid. This is expected to confirm the conclusions made from the comparisons with all 116 control points, described in section 5.2.1, regarding the suitability of each gravimetric geoid model for the conversion of GPS heights to elevations on the AHD.

The use of scatter plots to interpret the nature of the residual geoid height differences was also used by Featherstone and Guo (2001, Fig. 7, p.90) and described in section 2.8.1 of chapter 2, who suggest that it is informative to plot the absolute differences between the control data and each geoid model as a function of AHD to determine the improvements made by each model, if any, in the recovery of AHD heights from GPS measurements.

5.3 Results of Absolute Verification

The results of the absolute verification test schemes, described in section 5.2, involving comparisons using all 116 control points and over increasing AHD height, are presented below.

5.3.1 Results of Numerical Comparisons with all 116 Control Points

The descriptive statistics of the absolute comparisons between the 116 empirical geoid heights and each global geoid model and each bi-cubically and bi-linearly interpolated geoid model of Australia are shown in table 5.1 below.

Table 5.1
Descriptive Statistics of the *Absolute* Differences between the GPS-AHDD Control Data and each Global Geoid Model and Geoid Model of Australia (Bi-cubic and Bi-linear Interpolation)

	Toowoomba Bypass Control Network (116 points)						
Geoid Model	*Degree*	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*Outliers*
Raw data		42.936	42.335	42.674	0.172	42.674	0
OSU91A	360	-0.113	-0.688	-0.450	0.124	0.467	0
EGM96	360	-0.745	-1.377	-1.112	0.137	1.120	0
EIGEN2/EGM96	32/360	-0.129	-0.753	-0.488	0.135	0.506	0
UCPH2/EGM96	41/360	-0.111	-0.736	-0.474	0.136	0.493	0
PGM2000A	360	-0.077	-0.702	-0.439	0.136	0.459	0
SBA Technique (Bi-cubic)	360	-2.038	-2.379	-2.172	0.039	2.173	3 (2.59%)
RBA Technique (Bi-cubic)	360	-2.103	-2.444	-2.237	0.039	2.237	3 (2.59%)
AUSGeoid93 (Bi-cubic)	360	-0.336	-0.655	-0.477	0.057	0.481	1 (0.86%)
AUSGeoid98 (Bi-cubic)	360	-0.491	-0.802	-0.620	0.039	0.621	3 (2.59%)
SBA Technique (Bi-linear)	360	-2.032	-2.378	-2.172	0.041	2.172	3 (2.59%)
RBA Technique (Bi-linear)	360	-2.098	-2.443	-2.236	0.040	2.237	3 (2.59%)
AUSGeoid93 (Bi-linear)	360	-0.355	-0.678	-0.495	0.067	0.499	0
AUSGeoid98 (Bi-linear)	360	-0.487	-0.802	-0.620	0.041	0.621	3 (2.59%)

With reference to the descriptive statistics presented in table 5.1 above, an analysis and discussion of the comparisons between the 116 empirical geoid heights and each geoid model is offered in section 7.2.1 of chapter 7.

5.3.2 Results of Graphical Comparisons with all 116 Control Points

The scatter plots of the absolute comparisons between all 116 empirical geoid heights and each global geoid model and geoid model of Australia (bi-cubic interpolation) over the 46.2 km escarpment profile are shown in figure 5.1 below.

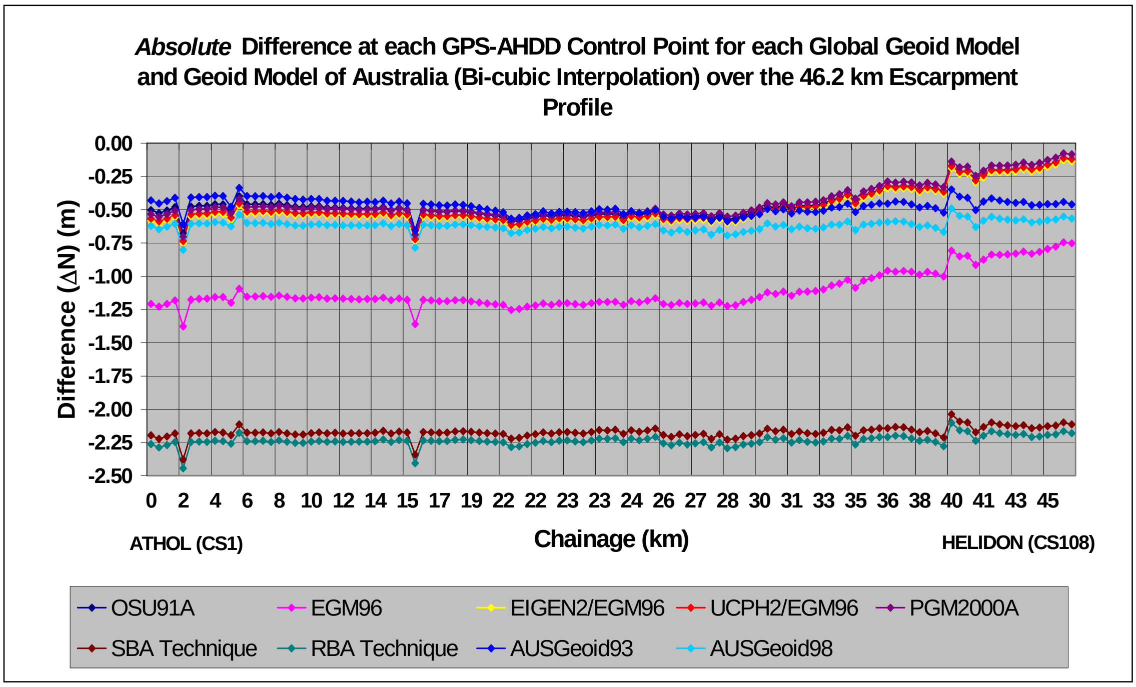

Figure 5.1 *Absolute* Difference at each GPS-AHDD Control Point for each Global Geoid Model and Geoid Model of Australia (Bi-cubic Interpolation) over the 46.2 km Escarpment Profile

The scatter plots of the absolute comparisons between all 116 empirical geoid heights and each geoid model of Australia (bi-linear interpolation) are shown in figure 5.2.

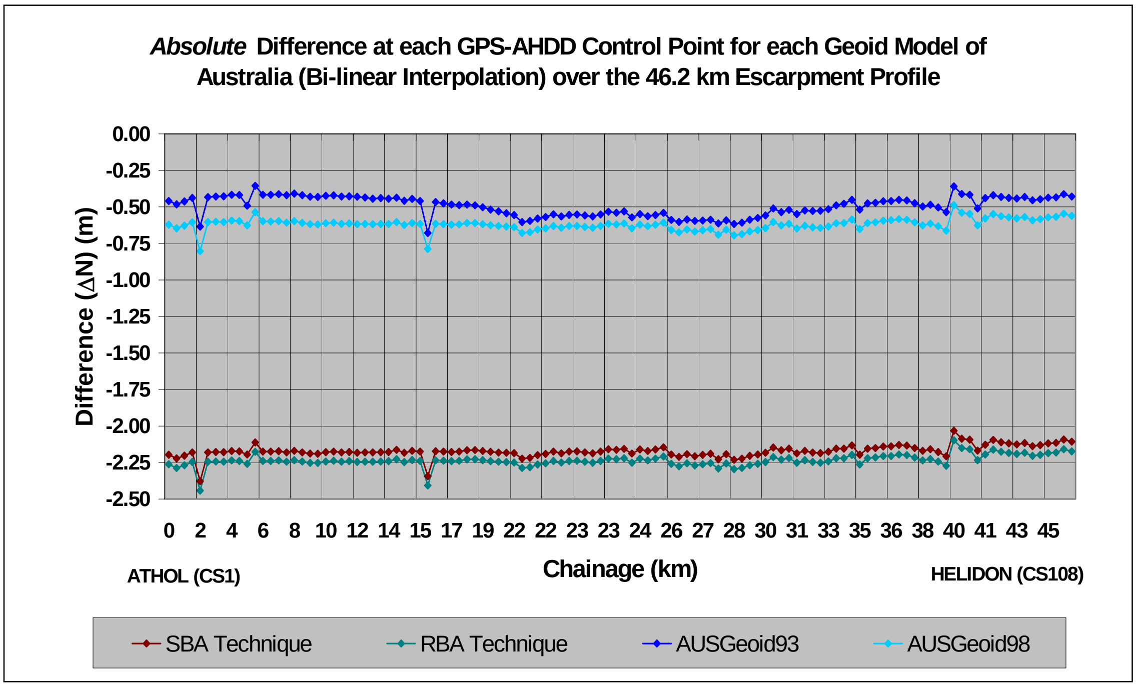

Figure 5.2 *Absolute* Difference at each GPS-AHDD Control Point for each Geoid Model of Australia (Bi-linear Interpolation) over the 46.2 km Escarpment Profile

With reference to the scatter plots of the absolute comparisons between all 116 empirical geoid heights and each geoid model shown in figures 5.1 and 5.2, an analysis and discussion of the comparisons is offered in section 7.2.2 of chapter 7.

5.3.3 Results of Numerical Comparisons over Increasing AHD Height

The descriptive statistics of the absolute comparisons between the subsets of empirical geoid heights and each geoid model over increasing AHD height are shown in table 5.2 as a type example and tables G.1 - G.12 in Appendix G.

Table 5.2
Descriptive Statistics of the *Absolute* Differences between the GPS-AHDD Control Data and OSU91A over Increasing AHD Height

AHD Height [m]	*No. of points*	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*Outliers*
> 200	*107*	-0.170	-0.688	-0.473	0.098	0.483	1 (0.93%)
> 300	*93*	-0.342	-0.688	-0.503	0.057	0.507	2 (2.15%)
> 400	*86*	-0.349	-0.688	-0.512	0.049	0.514	3 (3.49%)
> 500	*57*	-0.474	-0.688	-0.532	0.035	0.533	1 (1.75%)
> 600	*5*	-0.565	-0.688	-0.599	0.051	0.600	0

With reference to the descriptive statistics presented in table 5.2 and tables G.1 - G.12 in Appendix G, an analysis and discussion of the numerical comparisons between the subsets of empirical geoid heights and each geoid model over increasing AHD height is provided in section 7.2.3 of chapter 7.

5.3.4 Results of Graphical Comparisons over Increasing AHD Height

The plots of the absolute comparisons between all 116 empirical geoid heights and each global geoid model over increasing AHD height are shown in figure 5.3.

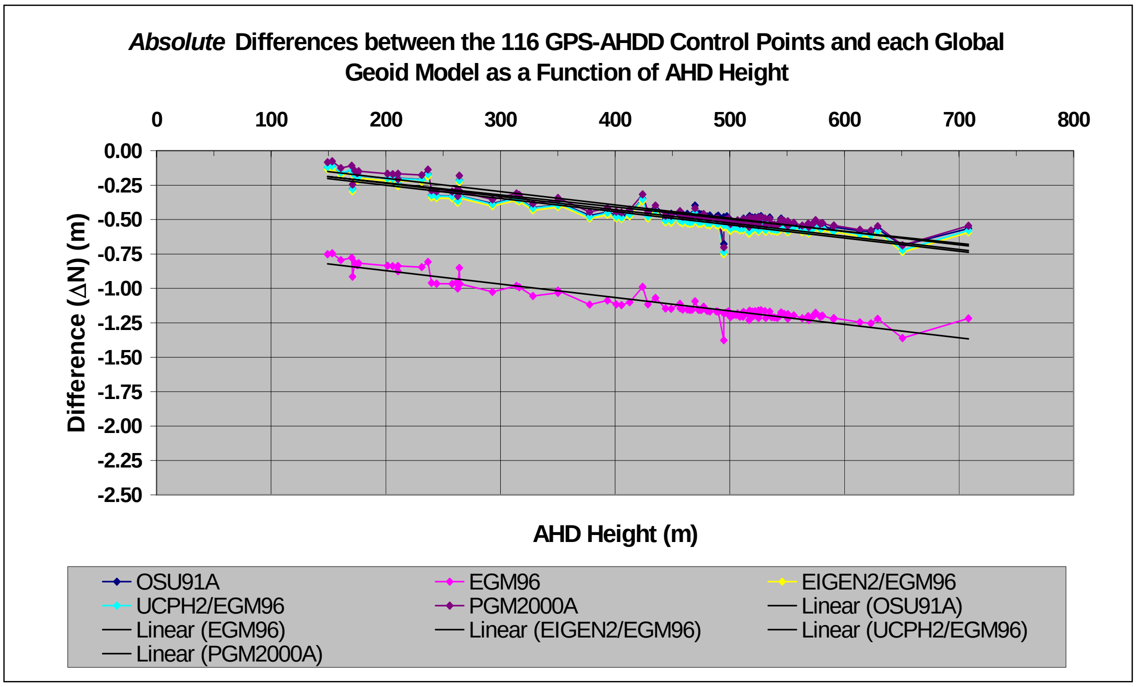

Figure 5.3 *Absolute* Differences between the 116 GPS-AHDD Control Points and each Global Geoid Model as a Function of AHD Height

The parameters of the least-squares linear regression of the differences for each global geoid model, as shown in figure 5.3, are summarised in table 5.3.

Table 5.3
Regression Coefficients of the *Absolute* Differences between the 116 GPS-AHDD Control Points and each Global Geoid Model as a Function of AHD Height

Model	*Gradient (m/m)*	*Intercept (m)*	*Correlation Coeff.*
OSU91A	-0.000880	-0.0565	-0.9461
EGM96	-0.000976	-0.6758	-0.9489
EIGEN/EGM96	-0.000957	-0.0605	-0.9486
UCPH2/EGM96	-0.000964	-0.0431	-0.9490
PGM2000A	-0.000963	-0.0084	-0.9489

The plots of the absolute comparisons between all 116 empirical geoid heights and each bi-cubically and bi-linearly interpolated geoid model of Australia over increasing AHD height are shown in figures 5.4 and 5.5.

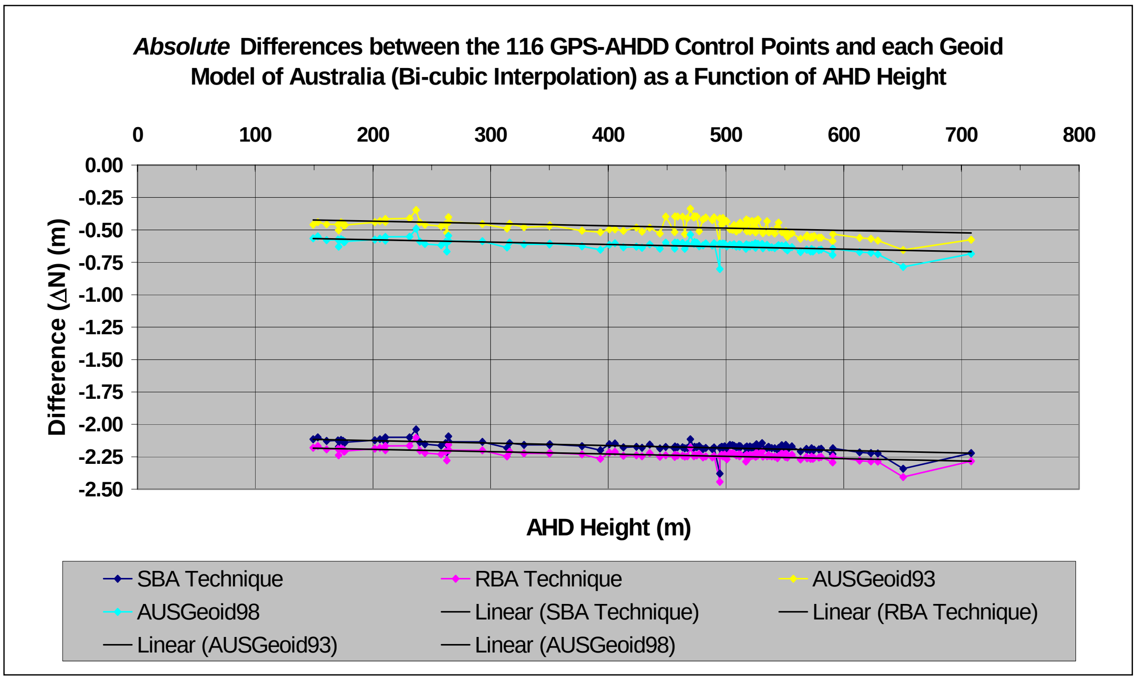

Figure 5.4 *Absolute* Differences between the 116 GPS-AHDD Control Points and the Geoid Models of Australia (Bi-cubic Interpolation) as a Function of AHD Height

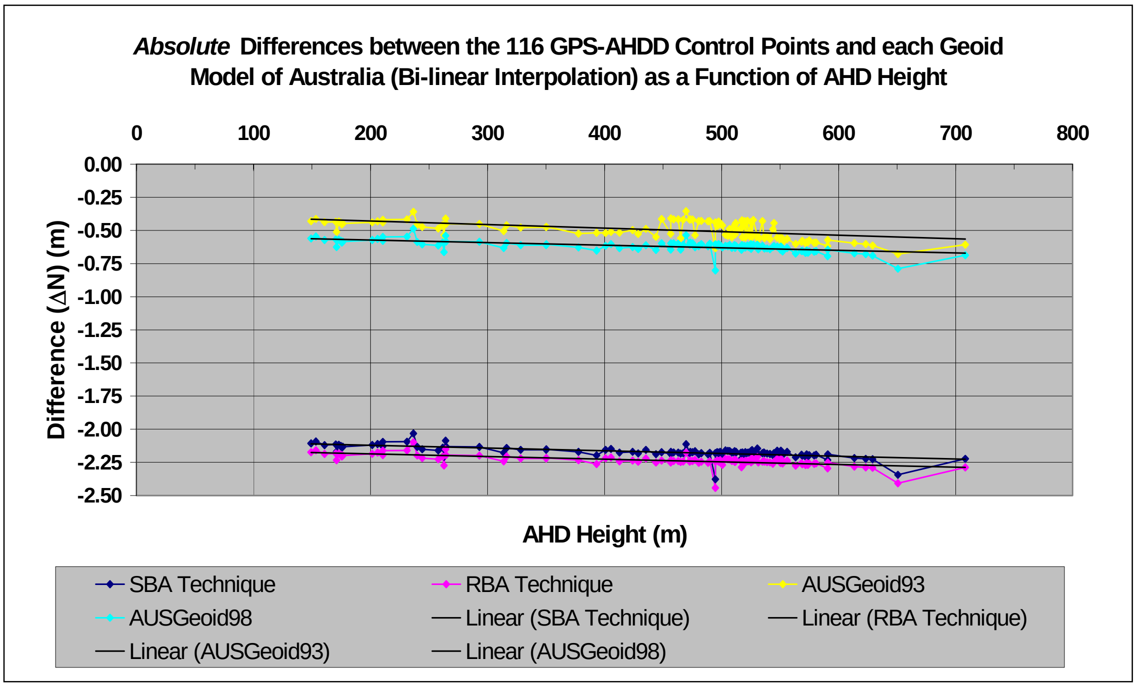

Figure 5.5 *Absolute* Differences between the 116 GPS-AHDD Control Points and the Geoid Models of Australia (Bi-linear Interpolation) as a Function of AHD Height

The parameters of the least-squares linear regression of the differences for each geoid model of Australia, as shown in figures 5.4 and 5.5, are summarised in table 5.4.

Table 5.4
Regression Coefficients of the *Absolute* Differences between the 116 GPS-AHDD Control Points and each Geoid Model of Australia as a Function of AHD Height

Model	*Interpolation Method*	*Gradient (m/m)*	*Intercept (m)*	*Correlation Coefficient*
SBA Technique	Bi-cubic	-0.000188	-2.0884	-0.6414
RBA Technique	Bi-cubic	-0.000181	-2.1556	-0.6256
AUSGeoid93	Bi-cubic	-0.000180	-0.3969	-0.4237
AUSGeoid98	Bi-cubic	-0.000181	-0.5392	-0.6150
SBA Technique	Bi-linear	-0.000207	-2.0797	-0.6790
RBA Technique	Bi-linear	-0.000200	-2.1469	-0.6652
AUSGeoid93	Bi-linear	-0.000268	-0.3749	-0.5362
AUSGeoid98	Bi-linear	-0.000196	-0.5321	-0.6436

With reference to the plots of the absolute comparisons between all 116 empirical geoid heights and each geoid model over increasing AHD height shown in figures 5.3 - 5.5 and the parameters of the least-squares linear regression of the differences for each geoid model, as summarised in tables 5.3 and 5.4, an analysis and discussion of the graphical comparisons between the empirical geoid heights and each geoid model over increasing AHD height is provided in section 7.2.4 of chapter 7.

5.4 Conclusion

This chapter has described the absolute verification test schemes used in this study and has presented the results from the absolute comparisons between the empirical geoid heights and gravimetric geoid heights interpolated from each geoid model. This was necessary to indicate the absolute precision of each gravimetric geoid model in relation to the reference ellipsoid.

From a practical perspective, these results are used to determine the suitability of each geoid model for the recovery of AHD heights in an absolute sense over areas of higher elevation such as found on the Toowoomba Bypass project. However, as stated earlier, an analysis and discussion of the implications of the absolute verification test schemes will be reserved for chapter 7.

Chapter six will provide a description of the relative verification test schemes and present the results of the relative comparisons between each geoid model and the empirical geoid heights.

CHAPTER 6

RESULTS OF RELATIVE VERIFICATION

6.1 Introduction

Chapter five developed the absolute verification test schemes and presented the results of their implementation. As established in chapter two, gravimetric geoid models are generally deficient in scale due to an inexact knowledge of the mass distribution of the Earth. This results in a less reliable assessment of the gravimetric geoid model from absolute verification. Thus, the most relevant appraisal of the integrity of gravimetric geoid models from the point-of-view of the GPS user is by relative verification.

Chapter six will provide this analysis by describing the relative verification schemes test that will be used to compare the empirical geoid gradients against gravimetric geoid gradients interpolated from each geoid model and will present the results from these relative verification schemes.

The test schemes developed to verify each gravimetric geoid model in a relative sense, via comparison of the misclose over the length of the minor control GPS traverse to the equivalent 3rd Order levelling specifications, comparison of the misclose over all possible baselines to the equivalent 3rd Order levelling specifications and comparison over increasing AHD height are described in terms of testing methodology and presentation of results. The numerical and graphical results from the relative verification of each geoid model are then presented.

6.2 Relative Verification Test Schemes

Featherstone *et al.* (2001, p.317) suggest that a more realistic evaluation that reflects the method in which gravimetric geoid models are used in Australia to convert GPS-derived ellipsoid height differences to AHD height differences is by relative comparisons.

The relative verification of the geoid models described in section 2.5 of chapter 2 will be achieved by using GPS-derived ellipsoid height differences, referenced to the same ellipsoid as used to compute each geoid model, and levelling derived AHD height differences to assess the accuracy and precision of the gravimetrically computed geoid gradients. Featherstone (2001a, p.810) notes that this verification method is less susceptible to the restrictions of absolute verification and, most importantly, any errors common to either end of a baseline are eliminated upon differencing.

The calculation of GPS-derived ellipsoid height differences and levelling derived AHD height differences, via equation 2.2 in chapter 2, will be conducted using the same control data as used for the absolute verification test schemes described section 5.2 of chapter 5. Thus, as established in section 3.3 of chapter 3, comparisons will be made between gravimetrically derived geoid gradients and empirically derived geoid gradients, both of which contain errors resulting in varying approximations of the true geoid-ellipsoid separation. However, given that the main application of a gravimetric geoid model is to convert GPS-derived ellipsoid heights to elevations on a local height datum, such as the AHD, this form of appraisal is beneficial to determine each geoid model's suitability for this purpose.

Based on previous studies reviewed in section 2.8 of chapter 2, the relative comparisons that will be conducted are:

- Comparison over the minor control GPS traverse.
- Comparison over all possible baselines.
- Comparison over increasing AHD height.

The comparison of the misclose over the length of the minor control GPS traverse is expected to indicate whether GPS, in conjunction with the geoid model being evaluated, can achieve an accuracy and precision equivalent to that obtained by conventional levelling over a test profile with respect to Australian 3rd Order levelling specifications and hence, be considered as a possible alternative to conventional levelling on the Great Dividing Range escarpment at Toowoomba.

The comparisons over all possible baselines in the control network are expected to provide a more thorough analysis of the accuracy and precision of the gravimetric geoid gradients interpolated from each geoid model. As described in section 2.6.2, this form of analysis is more informative to the GPS user as it will enable comparisons between AHD height differences derived from conventional levelling and AHD height differences derived from GPS in combination with each gravimetric geoid model. The geoid model that provides the most accurate conversion, as determined by the computed descriptive statistics, will be regarded as the superior model for use with GPS heighting over the Great Dividing Range escarpment at Toowoomba.

The comparisons over increasing AHD height are expected to indicate the accuracy and precision of each geoid model in areas of higher elevation. This comparison will also confirm whether additional terrain data used in the computation of the SBA Technique, the RBA Technique and AUSGeoid98 provides any statistically significant benefit, when compared to the results achieved by other models, in recovering AHD heights from GPS measurements in areas of higher elevation such as on the Great Dividing Range escarpment at Toowoomba.

As stated in section 3.3 of chapter 3, the comparisons and analysis will be performed using the mathematical, statistical and graphical suites of Microsoft Excel as this program offers the simplest method of handling the expected large quantity of data.

The application of each relative verification scheme to this study will now be described in detail.

6.2.1 Comparison over the Minor Control GPS Traverse

The most relevant analysis from a practical perspective is an evaluation that determines whether GPS heighting can achieve an equivalent accuracy and precision to that obtained by conventional levelling. This comparison is made by comparing the misclose, i.e., total height difference, over all 90 baselines forming the length of the minor control GPS traverse, described in section 4.2.1.1 of chapter 4, with respect to the equivalent Australian 3rd Order levelling specifications described in section 2.7 of chapter 2.

Specifically, the difference between the GPS-derived AHD height difference and the levelling derived AHD height difference will be determined over each leg of the minor control GPS traverse and summed to yield the total misclose for each geoid model, i.e., $\sum(\Delta H_{GPS} - \Delta H_{AHDD})$. The algebraic sum of the GPS-derived AHD height differences minus the levelling derived AHD height differences must be less than or equal to 0.082 m, which is the approximate equivalent maximum allowable misclose according to Australian 3rd Order levelling specifications over the length of the minor control GPS traverse, i.e., $12\sqrt{K}$ mm, where K is approximately 46.2 km. This evaluation method was also applied by Featherstone and Alexander (1996, p.31) and noted in section 2.8 of chapter 2, who suggest that if the equivalent Australian 3rd Order levelling specification is achieved, then GPS, in conjunction with the geoid model being verified, could be regarded as a possible alternative to conventional levelling in areas of undulating terrain.

The test profile will consist of 90 GPS baselines observed between each individual control station forming the minor control GPS traverse. The minor control GPS traverse consists of baselines observed from CS1 through to CS44, CS44 through to CS52, CS52 through to CS57, CS57 through to CS62, CS62 through to CS68, CS68 through to CS70, CS70 through to CS72 and CS72 through to CS108 as shown in figure 4.1 in chapter 4. The baseline length between corresponding control stations in the traverse will be adopted as the GDA94 ellipsoidal distance calculated between the latitude and longitude of each end of the baseline using Vincenty's Inverse formulae (ICSM 2002a, p.4-15). Consequently, the length of the minor control GPS traverse used for this evaluation is less than the length of the digital level traverse. However, the equivalent Australian 3rd Order levelling specification for this shorter distance will be applied.

The number of baselines exhibiting a relative height difference greater than the equivalent maximum allowable misclose according to Australian 3rd Order levelling specifications will also be determined. This will involve comparing the computed relative height difference over each leg of the minor control GPS traverse with the equivalent maximum allowable misclose according to the Australian 3rd Order levelling specification for that particular baseline length. The number of baselines with a misclose greater than the equivalent Australian 3rd Order levelling specification will then be totalled for each geoid model for further investigation in chapter 7.

This process was demonstrated by Featherstone (2001a, p.810) and described in section 2.8.2 of chapter 2, who noted that this provides a simple method of determining the number of baselines that exhibit relative height differences greater than the equivalent Australian 3rd Order levelling specifications. In addition, Featherstone and Alexander (1996, p.31) indicate that although a particular geoid model may satisfy the required Australian 3rd Order levelling specification over the whole traverse, it is generally not true over individual traverse legs. Thus, this inference will also be tested to provide an indication of the integrity of each geoid model over shorter baseline lengths as it is expected that the spatial resolution of each geoid model, combined with the errors noted in the control data, will affect their precision over the short baselines.

The ability of each geoid model to provide an acceptable misclose over the length of the minor control GPS traverse will also be examined graphically. Implementing the analysis used by Featherstone and Alexander (1996, Figs. 2-3, pp.32-33), the residual AHD Derived height differences for each baseline, i.e., $\Delta H_{GPS} - \Delta H_{AHDD}$, as computed using each geoid model in the numerical analysis described above, will be plotted over the entire traverse, where only the baseline length accumulates. Graphical comparisons will be made between the global geoid models, i.e., OSU91A, EGM96, EIGEN2/EGM96, UCPH2/EGM96 and PGM2000A and between the geoid models of Australia, i.e., the SBA Technique, the RBA Technique, AUSGeoid93 and AUSGeoid98. Featherstone and Alexander (1996, p.32) note that any residual height differences greater than the equivalent Australian 3rd Order levelling specification will appear as spikes on the plot and permit a visual examination of the trends exhibited by each geoid model over the test profile. The geoid model that displays residual height differences closest to zero over the length of the minor control GPS traverse will be considered the most suitable model for use with GPS heighting over the Great Dividing Range escarpment at Toowoomba.

6.2.2 Comparison over all 6,670 Possible Baselines

The relative verification scheme described in section 6.2.1 will be extended to include comparisons over all possible baselines in the Toowoomba Bypass control network. This evaluation method will assess the accuracy and reliability of each geoid model for the determination of AHD height by comparing the difference, i.e., misclose, between GPS-derived AHD height differences, calculated using each geoid model in equation 2.3 of chapter 2, and levelling derived AHD height differences, i.e., $\Delta H_{GPS} - \Delta H_{AHDD}$, over all possible baselines in the Toowoomba Bypass GPS control network. Featherstone and Alexander (1996, p.31) state that this is equivalent to comparing the relative accuracy and precision of geoid gradients computed using each gravimetric geoid model to geoid gradients derived empirically from the difference in GPS and levelling data.

Computing a single homogeneous network of ellipsoid heights facilitates the use of all possible baselines in the statistical analysis of each geoid model. As described in chapter 4, the ellipsoid height data was obtained from a combined least-squares adjustment of the network of baselines observed by Main Roads as part of the GPS campaign to coordinate control on the Toowoomba Bypass project and post-processed point positions observed by the author to augment the GPS data. The total number of possible baselines between n control points is given by $n(n-1)/2$, where for this study $n = 116$ and the total number of possible baselines equals 6,670.

Simple descriptive statistics will be computed to interpret the nature of the residual geoid height differences. Numerical analysis will involve computing values for the maximum, minimum, mean, standard deviation (STD) and root-mean-square (RMS) from the computed residuals, i.e., $\Delta H_{GPS} - \Delta H_{AHDD}$.

Reflecting the testing described in section 6.2.1, the number of baselines exhibiting a relative height difference outside the equivalent maximum allowable misclose according to Australian 3rd Order specifications will also be determined. This will be achieved by comparing the misclose between the GPS-derived AHD height difference and the levelling derived AHD height difference over each possible baseline, i.e., ΔH_{GPS} - ΔH_{AHDD}, against the equivalent maximum allowable misclose according to Australian 3rd Order levelling specifications identified in section 2.7 of chapter 2. The baseline length will be adopted as the GDA94 ellipsoidal distance calculated between the latitude and longitude of each end of the baseline using Vincenty's Inverse formulae (ICSM 2002a, p.4-15). The number of baselines exhibiting a misclose greater than the maximum allowable misclose according to Australian 3rd Order levelling specifications will then be tallied for each geoid model to provide an indication of the reliability of each model in recovering AHD heights from GPS measurements to a minimum of Australian 3rd Order levelling specifications over the Great Dividing Range escarpment at Toowoomba.

Also computed will be the mean difference over mean baseline length in parts per million, i.e., mm/km, for each geoid model. This will be achieved by dividing the mean relative geoid height difference by the mean baseline length determined from all 6,670 possible baselines in the control network. Featherstone (2001a, p.810) suggests that as GPS-derived AHD heights generally do not follow the square root of distance relationship applied to conventional levelling, this is a more informative appraisal of GPS heighting.

The graphical analysis to be conducted as part of the comparison of each geoid model over all possible baselines is adopted from the results presented by Featherstone (2001a, table 2, p.813), the details of which are described below.

The relative geoid height differences computed for each geoid model described above will be plotted according to their corresponding baseline length. As part of the analysis, the equivalent maximum allowable misclose according to Australian 3rd Order levelling specifications over each possible baseline will also be shown on the plot. Featherstone *et al.* (2001, Fig.5, p.327) and Featherstone (2001a, Fig.3, p.813) used this form of graphical analysis in their respective studies, indicating that this type of plot can illustrate whether the relative geoid height differences follow the traditional square root of distance rule applied to conventional levelling in Australia.

The negative relative geoid height differences associated with this comparison will be accounted for by plotting a line corresponding to the negative maximum allowable misclose according to Australian 3rd Order levelling specifications. Thus, the hypothesis implied is that the geoid model that achieves the most number of relative differences between these two curves will be deemed to provide the best overall relative fit to the control data and would be considered the most suitable geoid model for use with GPS heighting over the Great Dividing Range escarpment at Toowoomba.

As a supplementary assessment, the absolute values of the mean relative geoid height differences will be compared to the equivalent mean 3rd Order misclose over all possible baselines. The descriptive statistics, computed to interpret the nature of the relative geoid height differences for each geoid model described earlier, will be converted to absolute values to remove all negative numbers. The average relative differences for each geoid model will then be compared to the average maximum allowable misclose according to Australian 3rd Order levelling specifications over all 6,670 possible baselines in the control network. This will emphasise the integrity of each geoid model for deriving AHD heights using GPS given the expected small variation in the results between the SBA Technique, the RBA Technique and AUSGeoid98. Featherstone *et al.* (2001, p.327) employed this relative verification scheme noting that it was slightly more informative to GPS users to compare mean values when the differences between the geoid models being evaluated are less than the equivalent mean Australian 3rd Order levelling specification.

6.2.3 Comparison over Increasing AHD Height

The absolute verification scheme conducted over increasing AHD height described in chapter 5 will be extended over all possible baselines within each AHD height increment. Similarly, given that the lowest AHDD height is 194.204 m at CS108 and comparisons have been previously described using all 6,670 possible baselines, the relative height differences will be computed between all control points, in 100 m AHD height increments, with AHD heights greater than 200 m through to greater than 600 m.

The caveat placed on the comparison of the relative height differences over an increasing AHD height range is that the AHD height of the control points forming a baseline must be greater than the AHD height increment at which the baseline is being verified. For example, verification of each geoid model over AHD heights greater than 300 m will only be conducted using baselines between control points that have an AHD height of greater than 300 m, otherwise the control points and subsequent baseline will be omitted from the analysis. The result will be smaller subsets of baselines; the totals of each are 5,671 baselines greater than 200 m AHD, 4,278 baselines greater than 300 m AHD, 3,655 baselines greater than 400 m AHD, 1,596 baselines greater than 500 m AHD and 10 baselines greater than 600 m AHD. This method of analysis reflects the regional evaluations of AUSGeoid93 and AUSGeoid98 in areas of higher elevation in Australia conducted by Featherstone and Guo (2001, p.96), where only relative differences between points of higher elevation were utilised, while baselines spanning the entire continent were excluded.

Simple descriptive statistics will be computed to interpret the nature of the residual geoid height differences at each AHD height increment. Using the same computational procedures described in section 6.2.2, the descriptive statistics that will be computed for each AHD height range include values for the maximum, minimum, mean, standard deviation (STD), root-mean-square (RMS), number of outliers, i.e., Z-score > 3 and mean difference over mean baseline length in parts per million (mm/km).

6.3 Results of Relative Verification

The results from the relative verification test schemes described in section 6.2, involving comparisons over the minor control GPS traverse, over all possible baselines and over increasing AHD height are presented below.

6.3.1 Results of Graphical Comparisons over the Minor Control GPS Traverse

The difference between the GPS-derived AHD height difference (ΔH_{GPS}) and the levelling derived AHD height difference (ΔH_{AHDD}) over the length of the 46.2 km minor control GPS traverse for each global geoid model is presented in figure 6.1 below.

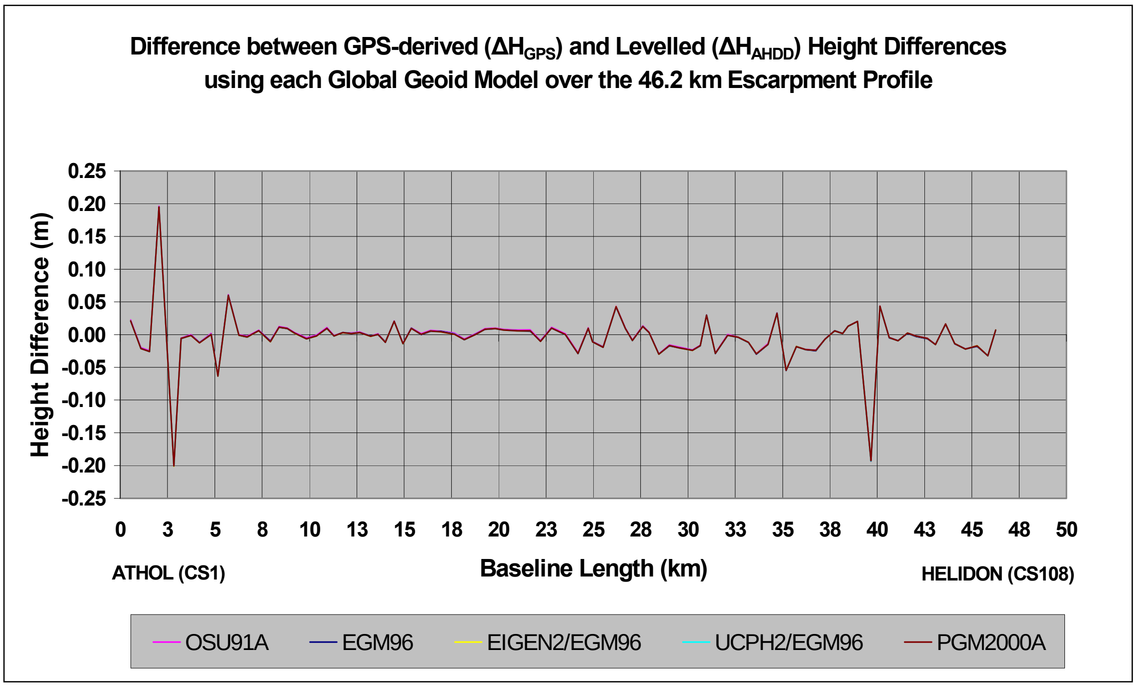

Figure 6.1 Difference between GPS-derived (ΔH_{GPS}) and Levelled (ΔH_{AHDD}) Height Differences over the 46.2 km Minor Control GPS Traverse (90 baselines) for each Global Geoid Model

The difference between the GPS-derived AHD height difference (ΔH_{GPS}) and the levelling derived AHD height difference (ΔH_{AHDD}) over the length of the 46.2 km minor control GPS traverse for each bi-cubically and bi-linearly interpolated geoid model of Australia are presented in figures 6.2 and 6.3.

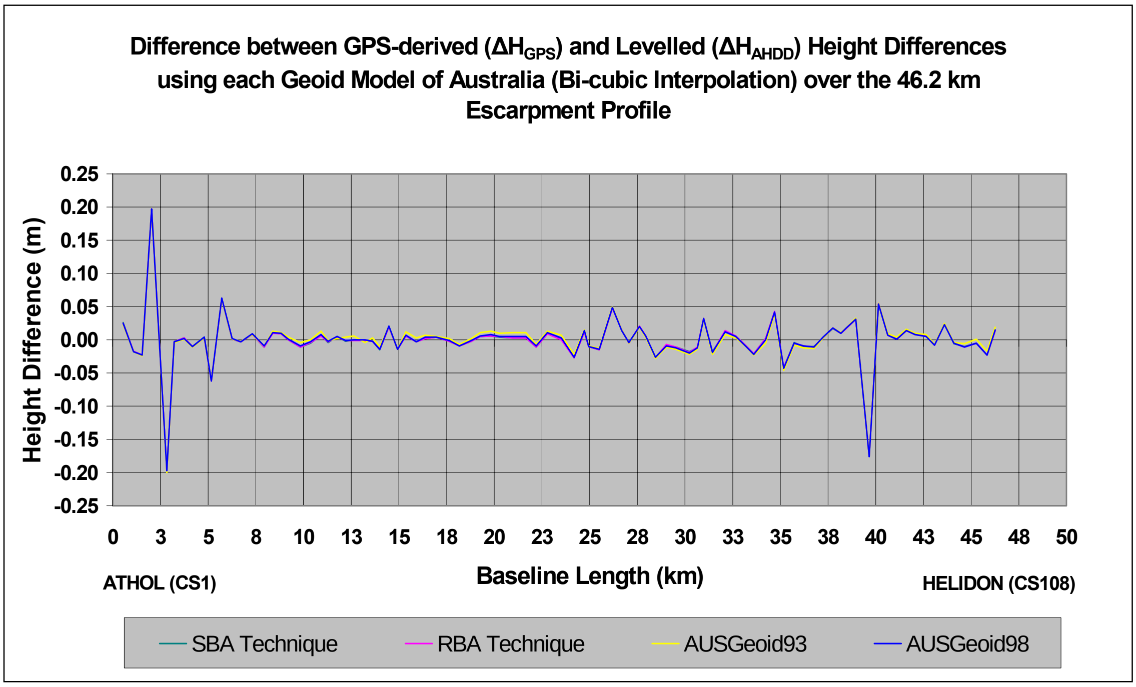

Figure 6.2 Difference between GPS-derived (ΔH_{GPS}) and Levelled (ΔH_{AHDD}) Height Differences over the 46.2 km Minor Control GPS Traverse (90 baselines) for each Geoid Model of Australia (Bi-cubic Interpolation)

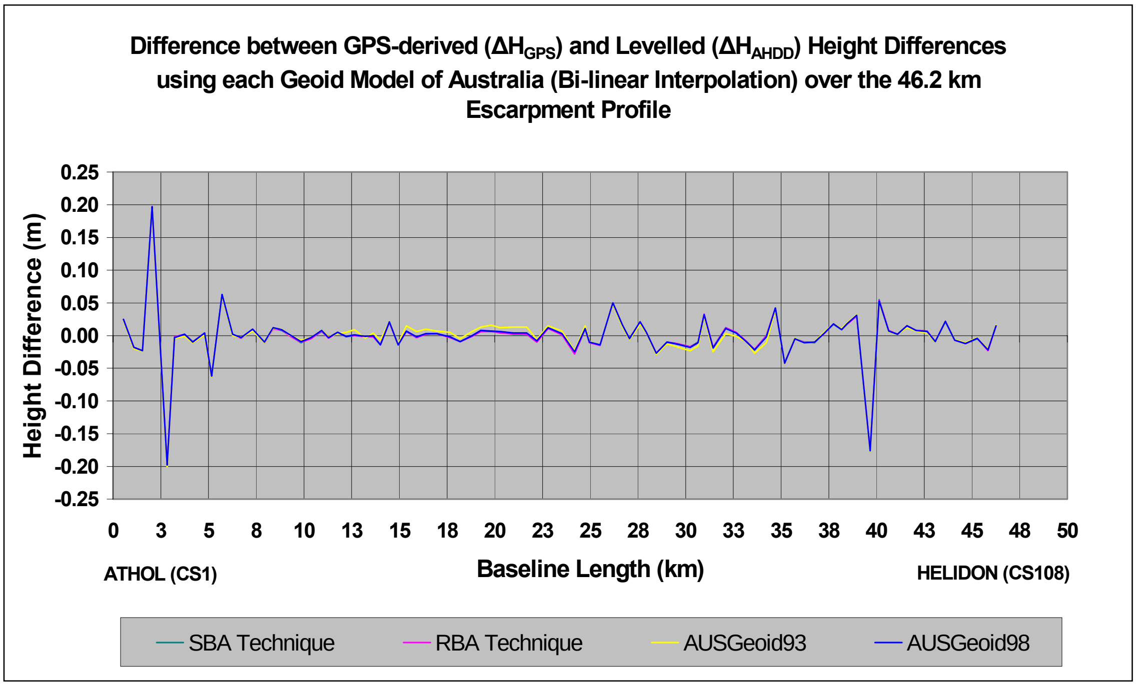

Figure 6.3 Difference between GPS-derived (ΔH_{GPS}) and Levelled (ΔH_{AHDD}) Height Differences over the 46.2 km Minor Control GPS Traverse (90 baselines) for each Geoid Model of Australia (Bi-linear Interpolation)

With reference to the relative difference over each individual baseline achieved using GPS in combination with each gravimetric geoid model over the length of the 46.2 km minor control GPS traverse displayed in figures 6.1 - 6.3 above, an analysis and discussion of the graphical comparisons is provided in section 7.3.1 of chapter 7.

6.3.2 Results of Numerical Comparisons over the Minor Control GPS Traverse

The total relative difference between the GPS-derived AHD height differences and the levelling derived AHD height differences compared to the equivalent Australian 3rd Order levelling specification over the length of the 46.2 km minor control GPS traverse for each global geoid model is shown in table 6.1.

Table 6.1
Total Misclose between GPS-derived Height Differences and Levelled Height Differences $\sum\{\Delta H_{GPS} - \Delta H_{AHDD}\}$ compared to Australian 3rd Order Levelling Specifications over the 46.2 km Minor Control GPS Traverse (90 baselines) for each Global Geoid Model

Model	*Misclose* [m]	*Total No. Baselines > 3rd Order*
OSU91A	-0.383	54
EGM96	-0.456	53
EIGEN2/EGM96	-0.448	54
UCPH2/EGM96	-0.449	54
PGM2000A	-0.449	53
3rd Order	0.082	

The total relative difference between the GPS-derived AHD height differences and the levelling derived AHD height differences compared to the equivalent Australian 3rd Order levelling specification over the length of the 46.2 km minor control GPS traverse for each geoid model of Australia is shown in table 6.2 below.

Table 6.2
Total Misclose between GPS-derived Height Differences and Levelled Height Differences $\sum\{\Delta H_{GPS} - \Delta H_{AHDD}\}$ compared to Australian 3rd Order Levelling Specifications over the 46.2 km Minor Control GPS Traverse (90 baselines) for each Geoid Model of Australia

Model	*Interpolation Method*	*Misclose* [m]	*Total No. Baselines > 3rd Order*
SBA Technique	Bi-cubic	-0.083	49
RBA Technique	Bi-cubic	-0.082	49
AUSGeoid93	Bi-cubic	0.030	53
AUSGeoid98	Bi-cubic	-0.055	49
SBA Technique	Bi-linear	-0.090	50
RBA Technique	Bi-linear	-0.088	51
AUSGeoid93	Bi-linear	-0.030	55
AUSGeoid98	Bi-linear	-0.060	50
3rd Order		0.082	

With reference to the total relative difference achieved using each geoid model noted in tables 6.1 and 6.2, an analysis and discussion of the numerical comparisons between the total relative difference achieved for each global geoid model and geoid model of Australia over the length of the 46.2 km minor control GPS traverse is provided in section 7.3.2 of chapter 7.

6.3.3 Results of Numerical Comparisons over all 6,670 Possible Baselines

The descriptive statistics of the relative differences between the empirical geoid gradients and gravimetric geoid gradients interpolated from each global geoid model over all 6,670 possible control baselines are shown in table 6.3.

Table 6.3
Descriptive Statistics of the *Relative* Differences (ΔH_{GPS} - ΔH_{AHDD}) between the Control Data and each Global Geoid Model over all 6,670 Possible Control Baselines

Model	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*No.>3rd Order*	*Mean ppm*
OSU91A	0.575	-0.564	-0.079	0.157	0.176	5161 (77.38%)	-6.70
EGM96	0.616	-0.632	-0.101	0.166	0.194	4750 (71.21%)	-8.63
EIGEN2/EGM96	0.607	-0.624	-0.099	0.163	0.191	4777 (71.62%)	-8.42
UCPH2/EGM96	0.611	-0.625	-0.099	0.165	0.192	4774 (71.57%)	-8.45
PGM2000A	0.610	-0.625	-0.099	0.164	0.192	4760 (71.36%)	-8.47

The descriptive statistics of the relative differences between the empirical geoid gradients and gravimetric geoid gradients from each bi-cubically and bi-linearly interpolated geoid model of Australia over all 6,670 possible control baselines are shown in table 6.4.

Table 6.4
Descriptive Statistics of the *Relative* Differences (ΔH_{GPS} - ΔH_{AHDD}), between the Control Data and each Geoid Model of Australia over all 6,670 Possible Control Baselines

Model	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*No.>3rd Order*	*Mean ppm*
SBA Technique [Bi-cubic]	0.304	-0.341	-0.016	0.053	0.055	2333 (34.98%)	-1.33
RBA Technique [Bi-cubic]	0.303	-0.341	-0.015	0.053	0.055	2284 (34.24%)	-1.28
AUSGeoid93 [Bi-cubic]	0.319	-0.272	0.020	0.078	0.080	4530 (67.92%)	1.74
AUSGeoid98 [Bi-cubic]	0.295	-0.311	-0.005	0.055	0.056	2614 (39.19%)	-0.43
SBA Technique [Bi-linear]	0.312	-0.346	-0.017	0.055	0.058	2519 (37.77%)	-1.43
RBA Technique [Bi-linear]	0.310	-0.345	-0.016	0.055	0.057	2460 (36.88%)	-1.37
AUSGeoid93 [Bi-linear]	0.323	-0.279	0.015	0.093	0.094	4741 (71.08%)	1.24
AUSGeoid98 [Bi-linear]	0.301	-0.315	-0.006	0.057	0.058	2757 (41.33%)	-0.51

With reference to the descriptive statistics of the relative differences for each gravimetric geoid model presented in tables 6.3 and 6.4 above, an analysis and discussion of the numerical comparisons of the misclose over all possible baselines for each gravimetric geoid model is provided in section 7.3.3 of chapter 7.

Converting the descriptive statistics summarised in table 6.3 to absolute values to remove negative numbers, the average relative difference for each global geoid model compared to the average allowable misclose according to the equivalent Australian 3rd Order levelling specifications over all 6,670 possible baselines is shown in table 6.5.

Table 6.5
Average *Relative* Difference between GPS-derived Height Differences and Levelled Height Differences (ΔH_{GPS} - ΔH_{AHDD}) compared to Australian 3rd Order Levelling Specifications over all 6,670 Possible Control Baselines for each Global Geoid Model

Model	*Average Relative Difference* [metre]
OSU91A	0.129
EGM96	0.140
EIGEN2/EGM96	0.137
UCPH2/EGM96	0.138
PGM2000A	0.138
3rd Order	0.039

Converting the descriptive statistics summarised in table 6.4 to absolute values to remove negative numbers, the average relative difference for each bi-cubically and bi-linearly interpolated geoid model of Australia compared to the average allowable misclose according to the equivalent Australian 3rd Order levelling specifications over all 6,670 possible baselines is shown in table 6.6.

Table 6.6
Average *Relative* Difference between GPS-derived Height Differences and Levelled Height Differences (ΔH_{GPS} - ΔH_{AHDD}) compared to Australian 3rd Order Levelling Specifications over all 6,670 Possible Control Baselines for each Geoid Model of Australia

Model	*Interpolation Method*	*Average Relative Difference* [metre]
SBA Technique	Bi-cubic	0.037
RBA Technique	Bi-cubic	0.037
AUSGeoid93	Bi-cubic	0.064
AUSGeoid98	Bi-cubic	0.040
SBA Technique	Bi-linear	0.039
RBA Technique	Bi-linear	0.039
AUSGeoid93	Bi-linear	0.076
AUSGeoid98	Bi-linear	0.042
3rd Order		0.039

With reference to the average relative difference for each gravimetric geoid model over all possible baselines presented in tables 6.5 and 6.6, an analysis and discussion of the comparisons is provided in section 7.3.3 of chapter 7.

6.3.4 Results of Graphical Comparisons over all 6,670 Possible Baselines

The scatter plots of the relative comparisons between the empirical geoid height differences and the gravimetric geoid height differences interpolated from each global geoid model over all 6,670 possible baselines are shown in figure 6.4 below as a type example and in figures H.1 - H.4 in Appendix H.

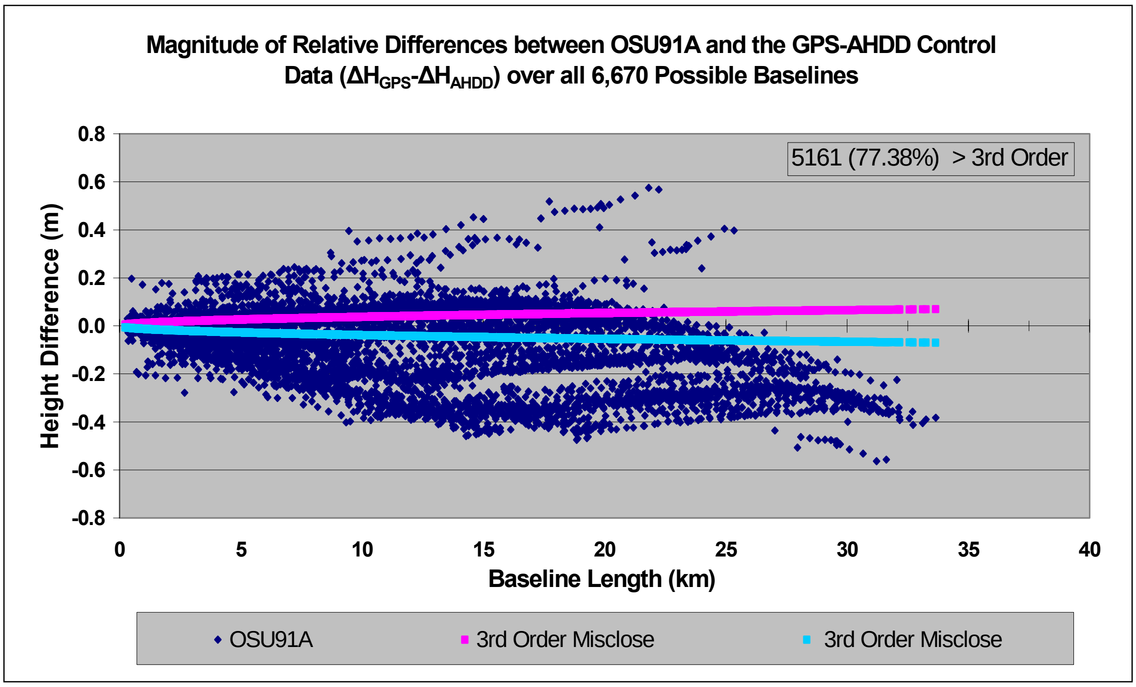

Figure 6.4 Magnitude of *Relative* Differences between OSU91A and the GPS-AHDD Control Data (ΔH_{GPS}-ΔH_{AHDD}) over all 6,670 Possible Baselines [Maximum allowable misclose under Australian 3rd Order levelling specifications also shown]

The scatter plots of the relative comparisons between the empirical geoid height differences and the gravimetric geoid height differences from each bi-cubically and bi-linearly interpolated geoid model of Australia over all 6,670 possible baselines are shown in figure 6.5 below as a type example and in figures H.5 - H.11 in Appendix H.

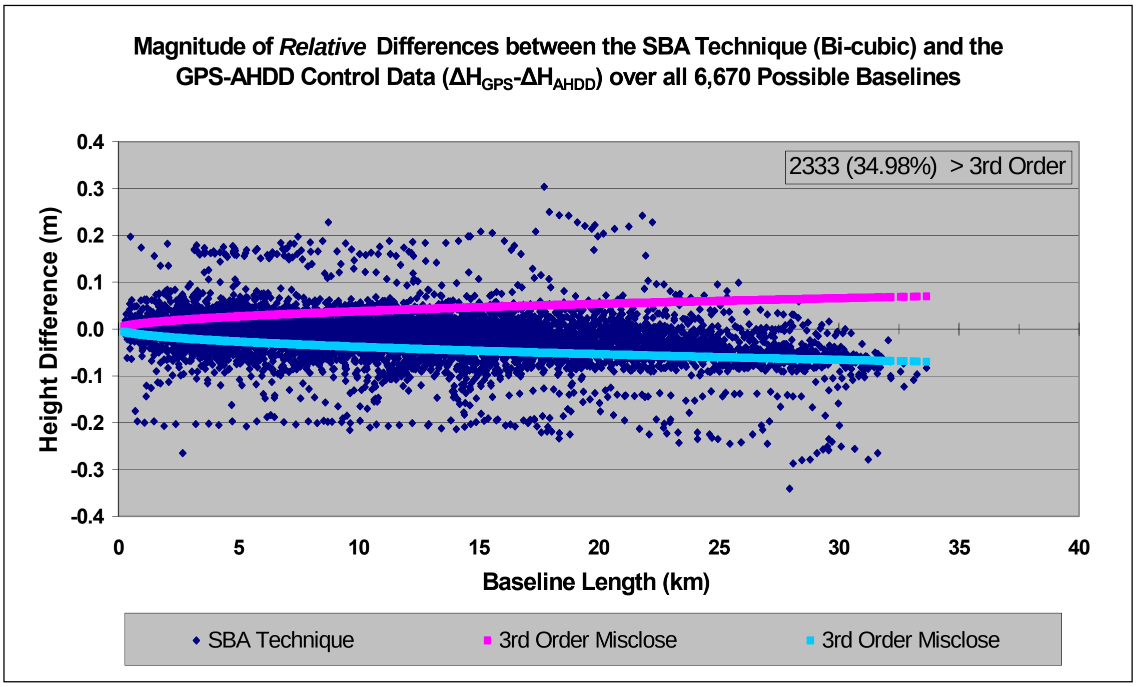

Figure 6.5 Magnitude of *Relative* Differences between the SBA Technique (Bi-cubic) and the GPS-AHDD Control Data (ΔH_{GPS}-ΔH_{AHDD}) over all 6,670 Possible Baselines [Maximum allowable misclose under Australian 3rd Order levelling specifications also shown]

With reference to the descriptive statistics of the relative differences for each gravimetric geoid model presented in tables 6.3 and 6.4 and the scatter plots displaying the magnitude of the relative differences over all possible baselines in figures 6.4, 6.5 and figures H.1 - H.11 in Appendix H, an analysis and discussion of the graphical comparisons of the misclose over all possible baselines for each gravimetric geoid model is provided in section 7.3.4 of chapter 7.

6.3.5 Results of Numerical Comparisons over Increasing AHD Height

The descriptive statistics of the relative comparisons between the empirical geoid height differences and the gravimetric geoid height differences interpolated from each geoid model over increasing AHD height are shown in table 6.7 below as a type example and tables I.1 - I.12 in Appendix I.

Table 6.7
Descriptive Statistics of the *Relative* Differences between the GPS-AHDD Control Data and OSU91A for Increasing AHD Height

AHD Height [m]	*No. of baselines*	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*Outliers*	*Mean ppm*
> 200	*5,671*	0.507	-0.518	0.048	0.130	0.139	26 (0.46%)	4.48
> 300	*4,278*	0.335	-0.346	0.001	0.081	0.081	17 (0.40%)	0.11
> 400	*3,655*	0.328	-0.339	-0.016	0.068	0.070	69 (1.89%)	-1.71
> 500	*1,596*	0.171	-0.214	-0.027	0.042	0.050	29 (1.82%)	-4.03
> 600	*10*	0.023	-0.123	-0.036	0.066	0.072	0	-7.65

With reference to the descriptive statistics of the relative differences for each gravimetric geoid model presented in table 6.7 and tables I.1 - I.12 in Appendix I, an analysis and discussion of the numerical comparisons of the misclose over increasing AHD height for each gravimetric geoid model is provided in section 7.3.5 of chapter 7.

6.4 Conclusion

This chapter has described the relative verification test schemes used to compare the empirical geoid gradients against gravimetric geoid gradients interpolated from each geoid model and has presented the results from these comparisons. This was necessary to indicate the relative accuracy and precision of the gravimetric geoid gradients in relation to the empirical geoid gradients as relative verification provides a more thorough and informative analysis of each gravimetric geoid model for the recovery of AHD height differences over areas of higher elevation such as found on the Toowoomba Bypass project.

As stated above, an analysis and discussion of the implications of the relative verification test schemes will be reserved for chapter 7.

Chapter seven will discuss the implications of the results of both the absolute and relative verification schemes in relation to work conducted by previous researchers' to determine the suitability of each geoid model in providing any reasonable alternative to conventional levelling on the Toowoomba Bypass project section of the Great Dividing Range escarpment at Toowoomba.

CHAPTER 7

DISCUSSION

7.1 Introduction

Chapter six developed the relative verification test schemes used to evaluate each geoid model and presented the results of their application. Prior to drawing any conclusions regarding the most appropriate geoid model for use with GPS heighting on the Toowoomba Bypass project, it is necessary to analyse the results from the absolute and relative verification test schemes, with respect to the errors in the control data, to determine if any statistically significant differences exist between the models and to explain how these results relate to previous studies upon which the test schemes are based.

Chapter seven will provide this transition by analysing the results of the absolute and relative verification tests schemes and discussing their significance in the context of results achieved by previous researchers to extend or modify existing theory and enable conclusions to be made regarding the suitability of each geoid model for use with GPS heighting over the Great Dividing Range escarpment at Toowoomba.

The absolute verification test schemes presented in chapter 5 are analysed and discussed based on the graphical and numerical comparisons made between each gravimetric geoid model and the empirical geoid model using all 116 control points and over increasing AHD height. This is expected to indicate which geoid model exhibits the smallest variation between adjacent N values over the escarpment profile and hence, would be the most suitable for use with GPS point positioning over the Great Dividing Range escarpment at Toowoomba. The more informative relative verification test schemes are then analysed and discussed based on the graphical and numerical comparisons made between the gravimetric geoid gradients and the empirical geoid gradients over the length of the minor control GPS traverse, over all 6,670 possible baselines and over increasing AHD height. This is expected to determine the most accurate and reliable geoid model for transferring AHD elevations over the Toowoomba range escarpment to a minimum of Australian 3rd Order levelling specifications.

7.2 Discussion of the Results of Absolute Verification

The absolute verification test schemes developed and presented in chapter 5 are analysed and discussed below in relation to previous research reviewed in chapter 2.

7.2.1 Numerical Comparisons with all 116 Control Points

The absolute accuracy and precision of each geoid model in relation to the reference ellipsoid can be determined from numerical comparisons using all control points in a GPS network. Thus, recalling the estimated average standard deviation of the empirical geoid heights at the 95% confidence level of ±0.0371 m, as established in chapter 4, the results from the numerical comparisons of each geoid model with all 116 control points in an absolute sense presented in section 5.3.1 of chapter 5 are discussed in detail below.

7.2.1.1 Global Geoid Models

Table 5.1 in chapter 5 shows the descriptive statistics of the absolute comparisons between all 116 empirical geoid heights and each global geoid model.

Based on the standard deviation obtained for each global geoid model, there is no statistically significant difference at the 95% confidence level. Absolute comparisons show that OSU91A provides a slight improvement on EGM96, EIGEN2/EGM96, UCPH2/EGM96 and PGM2000A by, on average, 0.012 m (8.8%) however, the difference between each model is inconclusive as their respective standard deviations are less than the error in the control data. Furthermore, no residual geoid height difference from any global model was greater than three standard deviations from the mean, i.e., Z-score > 3.0.

7.2.1.2 Geoid Models of Australia

Table 5.1 in chapter 5 shows the descriptive statistics of the absolute comparisons between all 116 empirical geoid heights and each bi-cubically and bi-linearly interpolated geoid model of Australia.

Appraisal of the standard deviation computed from the bi-cubic interpolation of each geoid model of Australia suggests that there is no statistically significant difference at the 95% confidence level between the results for each model. The SBA Technique, the RBA Technique and AUSGeoid98 yield equivalent standard deviations, while AUSGeoid93 is larger by 0.018 m. Conversely, AUSGeoid93 has only one outlier (0.86%), while the SBA Technique, the RBA Technique and AUSGeoid98 each have three outliers (2.59%).

Comparing the results for the bi-cubic interpolation of AUSGeoid93 and AUSGeoid98 with the results achieved by Featherstone and Guo (2001, table 4, p.86) and noted in section 2.8.1 of chapter 2, there is agreement with respect to AUSGeoid98 achieving a smaller standard deviation and the distribution of AUSGeoid93 being generally closer to zero. However, contrary to the findings of Featherstone and Guo (2001, table 2, p.85) and considering the errors in the control data, AUSGeoid93 provides a significant improvement in absolute fit to the control data compared to EGM96.

The results obtained for the SBA Technique and the RBA Technique agree with the conclusions made by Goos *et al.* (2003, table 4, p.109) and noted in section 2.8.4 of chapter 2.

Based on the standard deviation obtained from the bi-linear interpolation of each geoid model of Australia, there is no statistically significant difference at the 95% confidence level between the results for each model. Reflecting the results obtained for bi-cubic interpolation, the SBA Technique, the RBA Technique and AUSGeoid98 produce equivalent standard deviations, while AUSGeoid93 further reduces in precision to differ by 0.027 m. Similarly, AUSGeoid93 has no outliers, while the SBA Technique, the RBA Technique and AUSGeoid98 each have three outliers (2.59%). The results obtained for the bi-linear interpolation of AUSGeoid93 and AUSGeoid98 are consistent with the findings of Featherstone (2001a, table 1, p.812) and noted in section 2.8.2 of chapter 2.

Comparing the standard deviation computed for each geoid model of Australia using both bi-cubic and bi-linear interpolation, there is an insignificant variation between the results for the SBA Technique, the RBA Technique and AUSGeoid98. Moreover, the results suggest that overall AUSGeoid98 is the most statistically consistent model when considering the remaining computed statistics. In contrast, AUSGeoid93 displays the largest variation in standard deviation between interpolation techniques with a difference of 0.010 m.

The statistically insignificant variation between the results obtained for the SBA Technique, the RBA Technique and AUSGeoid98 is partly expected as the SBA gridding technique was used in the construction of AUSGeoid98 (Goos *et al.* 2003, p.93). Furthermore, the variation between the bi-cubic and bi-linear interpolation methods is consistent with the results reported by Featherstone (2001a, table 1, p.812) and noted in section 2.8.2 of chapter 2.

7.2.2 Graphical Comparisons with all 116 Control Points

The absolute accuracy and precision of each geoid model in relation to the reference ellipsoid can also be examined from graphical comparisons with all control points in a GPS network. Thus, recalling the estimated average standard deviation of the empirical geoid heights at the 95% confidence level of ±0.0371 m, as established in chapter 4, the results from the graphical comparisons of each geoid model with all 116 control points in an absolute sense presented in section 5.3.2 of chapter 5 are discussed in detail below.

7.2.2.1 Global Geoid Models

Figure 5.1 in chapter 5 shows the absolute difference between the geoid height interpolated from each global geoid model and the empirical geoid height at each GPS-AHDD control point plotted as a function of approximate chainage along the 46.2 km escarpment profile.

The plot for each global geoid model confirms the descriptive statistics presented in table 5.1 in chapter 5. The variation (max-min) among the absolute precision (standard deviation statistic) of each global geoid model is only 0.013 m and hence, each global model is similarly parallel to one another over the length of the escarpment profile. However, the average absolute precision of each global geoid model of 0.134 m reflects the variability in the N values interpolated from these models and, more importantly, indicates that the global geoid models are not parallel to the empirical geoid over the escarpment profile.

The variation among the absolute accuracy (mean statistic) for OSU91A, EIGEN/EGM96, UCPH2/EGM96 and PGM2000A is only 0.049 m and hence, these global geoid models are similarly offset from the empirical geoid. However, EGM96 exhibits the worst absolute accuracy, i.e., largest bias in scale, with an offset, on average, 0.649 m further from zero compared with the remaining global geoid models over the escarpment profile.

The practical implications of the absolute comparisons with all 116 control points are that it would be difficult to achieve reliable GPS point positioning over the Great Dividing Range escarpment at Toowoomba using any of the global geoid models tested in this study. The variation in the offset of each global geoid model from the empirical geoid over the escarpment profile would limit the effectiveness of any correction applied to the N values interpolated from each global geoid model to improve their GPS point positioning capability. An example of a common, simple correction is a 'block-shift', which is achieved via GPS observations at AHD benchmarks. However, the use of GPS point positioning to derive elevations on the AHD is not recommended in the best practice guidelines set out in SP1. Rather, positions should be established as part of a control network (ICSM 2002b, p.B-18).

7.2.2.2 Geoid Models of Australia

Figures 5.1 and 5.2 in chapter 5 show the absolute difference between the geoid height from the bi-cubic and bi-linear interpolation of each geoid model of Australia and the empirical geoid height at each GPS-AHDD control point over the 46.2 km escarpment profile. Figure 5.1 shows the global geoid models and the bi-cubic interpolation of each geoid model of Australia to display the relationship between the different geoid model solutions.

The plot for the bi-cubic interpolation of each geoid model of Australia confirms the descriptive statistics presented in table 5.1 in chapter 5. The variation among the absolute precision of each model resides solely in AUSGeoid93 (0.018 m) and hence, the SBA Technique, the RBA Technique and AUSGeoid98 are equally parallel over the length of the escarpment profile. Furthermore, with the exception of AUSGeoid93, the average absolute precision of the remaining bi-cubically interpolated geoid models of Australia of 0.039 m reflects the minimal variability in the geoid heights interpolated from these models and, more importantly, indicates that they are significantly more parallel to the empirical geoid than the global geoid models over the escarpment profile.

The variation among the absolute accuracy for each bi-cubically interpolated geoid model of Australia is 1.760 m. The residual geoid height differences from AUSGeoid93 are the closest to zero over the escarpment profile, while the residual geoid height differences from the RBA Technique are the furthest from zero due to reasons offered in chapter 2. Hence, these geoid models are not similarly offset from the empirical geoid over the escarpment profile.

The plot for the bi-linear interpolation of each geoid model of Australia confirms the descriptive statistics presented in table 5.1 in chapter 5. Reflecting the results displayed for bi-cubic interpolation, the variation among the absolute precision of each model resides solely in AUSGeoid93 (0.027 m) and hence, the SBA Technique, the RBA Technique and AUSGeoid98 are equally parallel over the length of the escarpment profile. Furthermore, with the exception of AUSGeoid93, the average absolute precision of the remaining bi-cubically interpolated geoid models of Australia of 0.041 m reflects the minimal variability in the geoid heights interpolated from these models and, more importantly, indicates that they are significantly more parallel to the empirical geoid than the global geoid models over the escarpment profile.

The variation among the absolute accuracy for each bi-linearly interpolated geoid model of Australia is 1.741 m. This reflects the deterioration in the absolute accuracy of AUSGeoid93 rather than in the absolute accuracy of any other model. Hence, these geoid models are not similarly offset from the empirical geoid over the escarpment profile.

Comparing the plots produced from the bi-cubic and bi-linear interpolation of each geoid model of Australia, there is an insignificant variation in the plots for the SBA Technique, the RBA Technique and AUSGeoid98. In addition, the plots suggest that overall AUSGeoid98 is the most statistically consistent model when considering the spread of the distribution for each model. Conversely, AUSGeoid93 displays the largest variation in absolute accuracy (0.018 m) and precision (0.010 m) between interpolation techniques. Thus, the graphical comparisons between the bi-cubic and bi-linear interpolation of each geoid model of Australia confirm that the bi-cubically interpolated geoid heights provide a superior statistical fit to the control data.

The practical implications of the absolute comparisons with all 116 control points are that it would not be possible to achieve reliable GPS point positioning over the Great Dividing Range escarpment at Toowoomba using the current versions of any of the geoid models of Australia. However, the minimal variation in the offset from the empirical geoid for the SBA Technique, the RBA Technique and AUSGeoid98 would permit a simple correction to be applied to the N values interpolated from these geoid models to significantly improve their GPS point positioning capability over the escarpment profile. As stated in section 7.2.2.1, a common, simple correction that could be applied is a ‘block-shift’, which is achieved via GPS observations at AHD benchmarks. Though, as mentioned earlier, the use of GPS point positioning to derive elevations on the AHD is not recommended in the best practice guidelines set out in SP1. Rather, positions should be established as part of a control network (ICSM SP1 2002b, p.B-18).

7.2.3 Numerical Comparisons over Increasing AHD Height

The results of the numerical and graphical comparisons of each geoid model with all 116 control points in an absolute sense were analysed and discussed in sections 7.2.1 and 7.2.2. To determine the absolute accuracy and reliability of each geoid model in areas of higher elevation, testing was conducted over an increasing AHD height range. Thus, recalling the estimated average standard deviation of the empirical geoid heights at the 95% confidence level of ±0.0371 m, as established in chapter 4, the numerical evaluations of each geoid model over increasing AHD height in an absolute sense presented in section 5.3.3 of chapter 5 are discussed in detail below.

7.2.3.1 Global Geoid Models

Table 5.2 in chapter 5 and tables G.1 - G.4 of Appendix G show the descriptive statistics of the absolute comparisons between the subsets of empirical geoid heights and each global geoid model over AHD elevations greater than 200 m through to greater than 600 m.

Based on the standard deviation obtained for each global geoid model at each AHD height increment, there is no statistically significant difference at the 95% confidence level between the absolute precisions of any model. Absolute comparisons indicate that OSU91A provides the best absolute fit to the control data for AHD heights greater than 200 m through to greater than 300 m, all global geoid models achieve an equivalent absolute precision for AHD heights greater than 400 m, EGM96, EIGEN2/EGM96, UCPH2/EGM96 and PGM2000A provide the best absolute precision for AHD heights greater than 500 m and OSU91A provides the best absolute precision for AHD heights greater than 600 m. However, the differences between the standard deviations are inconclusive given that they are less than the estimated average error in the control data (±0.0371 m). In addition, the standard deviations of each global geoid model improve over AHD heights greater than 200 m through to greater than 500 m, before deteriorating for AHD heights greater than 600 m. Furthermore, each global geoid model produced an equal number of outliers at each AHD height increment.

7.2.3.2 Geoid Models of Australia

Tables G.5 - G.12 in Appendix G show the descriptive statistics of the absolute comparisons between the subsets of empirical geoid heights and each bi-cubically and bi-linearly interpolated geoid model of Australia over AHD elevations greater than 200 m through to greater than 600 m.

Appraisal of the standard deviation produced for the bi-cubic interpolation of each geoid model of Australia at each AHD height increment suggests that there is no statistically significant difference at the 95% confidence level between the absolute precisions of any model. The SBA Technique, the RBA Technique and AUSGeoid98 achieve an equivalent standard deviation for AHD heights greater than 200 m through to greater than 500 m. However, for AHD heights greater than 600 m, the standard deviation of AUSGeoid98 is, on average, 0.007 m closer to zero than the SBA and RBA Techniques.

Assessment of the standard deviation computed for the bi-cubic interpolation of AUSGeoid93 indicates that it exhibits the largest variation in N values over most AHD height increments. The differences obtained were 0.021 m, 0.026 m, 0.027 m and 0.024 m for AHD heights greater than 200 m through to greater than 500 m. However, for AHD heights greater than 600 m, AUSGeoid93 gives a standard deviation closest to zero, while AUSGeoid98 differs by a further 0.010 m and the SBA and RBA Techniques by 0.017 m. In addition, the SBA Technique, the RBA Technique and AUSGeoid98 produce an equal number of outliers at each height increment, while AUSGeoid93 has the least number of outliers for AHD heights greater than 200 m through to greater than 500 m. For AHD heights greater than 600 m, there were no outliers produced by any model.

The standard deviations for the bi-cubic interpolation of each geoid model of Australia also display a similar trend to those obtained from the global geoid models. The standard deviations of the SBA Technique, the RBA Technique and AUSGeoid98 improve over AHD heights greater than 200 m through to greater than 500 m, before deteriorating for AHD heights greater than 600 m. Conversely, the standard deviation of AUSGeoid93 is statistically consistent for AHD heights greater than 200 m through to greater than 300 m, deteriorates for AHD heights greater than 400 m and improves for AHD heights greater than 600 m.

The results in tables G.5 - G.8 in Appendix G are consistent with the findings of Featherstone and Guo (2001, tables 10-11, p.96) and noted in section 2.8.1 of chapter 2. That is, despite the distribution of AUSGeoid93 being negatively skewed at each AHD height increment, it is closer to zero than any other model. Furthermore, the SBA Technique, the RBA Technique and AUSGeoid98 appear to have removed most of the positive bias seen in AUSGeoid93 over AHD heights greater than 200 m through to greater than 500 m.

Based on the standard deviation obtained for the bi-linear interpolation of each geoid model of Australia at each AHD height increment, there is no statistically significant difference at the 95% confidence level between the absolute precisions of any model. Reflecting the results obtained for bi-cubic interpolation, the SBA Technique, the RBA Technique and AUSGeoid98 produce equivalent standard deviations for AHD heights greater than 200 m through to greater than 500 m. However, for AHD heights greater than 600m, the standard deviation of AUSGeoid98 is, on average, 0.006m closer to zero than the SBA and RBA Techniques.

Appraisal of the standard deviation computed for the bi-linear interpolation of AUSGeoid93 indicates that it exhibits the largest variation in N values over most AHD height increments. The differences obtained were 0.028 m, 0.033 m, 0.035 m and

0.034 m for AHD heights greater than 200 m through to greater than 500 m, with the standard deviations for AHD heights greater than 300 m through to greater than 500 m slightly less than statistically significant at the 95% confidence level. However, for AHD heights greater than 600 m, AUSGeoid93 provides a standard deviation closest to zero, while AUSGeoid98 differs by a further 0.015 m and the SBA and RBA Techniques by 0.021 m. Furthermore, the SBA Technique, the RBA Technique and AUSGeoid98 produce an equal number of outliers at each height increment and no outliers for AHD heights greater than 600 m, while AUSGeoid93 produces no outliers at any AHD height increment

The standard deviations for the bi-linear interpolation of each geoid model of Australia also display a similar trend to those obtained from the global geoid models. The standard deviations of the SBA Technique, the RBA Technique and AUSGeoid98 improve over AHD heights greater than 200 m through to greater than 500 m, before deteriorating for AHD heights greater than 600 m. Alternatively, the standard deviation of AUSGeoid93 is statistically consistent for AHD heights greater than 200 m through to greater than 300 m, deteriorates for AHD heights greater than 400 m and improves for AHD heights greater than 600 m.

Comparing the standard deviations obtained for the bi-cubic interpolation of each geoid model of Australia to those obtained using bi-linear interpolation indicates that there is an insignificant variation among the results for the SBA Technique, the RBA Technique and AUSGeoid98. Moreover, the results at each AHD height increment suggest that overall AUSGeoid98 is the most statistically consistent model when considering the remaining computed statistics. On the other hand, AUSGeoid93 exhibits the largest variation in standard deviation with a +0.008 m difference from bi-cubic to bi-linear interpolation for AHD heights greater than 200 m through to greater than 400 m, +0.010 m for AHD heights greater than 500 m and –0.005 m for AHD heights greater than 600 m. This variation between interpolation techniques is consistent with conclusions made by Featherstone (2001a, p.812) and noted in section 2.8.2 of chapter 2.

7.2.4 Graphical Comparisons over Increasing AHD Height

The results of the numerical comparisons over an increasing AHD height range for each geoid model were discussed in section 7.2.3. Further to these comparisons, scatter plots of the absolute differences between the 116 GPS-AHDD control points and each geoid model were constructed to illustrate the accuracy and precision of each geoid model in areas of higher elevation. Thus, recalling the estimated average standard deviation of the empirical geoid heights at the 95% confidence level of ±0.0371 m, as established in chapter 4, the graphical evaluations of each geoid model over increasing AHD height in an absolute sense presented in section 5.3.4 of chapter 5 are discussed in detail below.

7.2.4.1 Global Geoid Models

Figure 5.3 in chapter 5 illustrates the absolute comparisons between all 116 empirical geoid heights and each global geoid model over AHD elevations greater than 200 m through to greater than 600 m. In addition, table 5.3 in chapter 5 shows the parameters of the least-squares linear regression line of the differences for each global geoid model.

From the results shown in figure 5.3 and table 5.3 in chapter 5, each global geoid model exhibits a similar variation of differences from the 116 GPS-AHDD control points over the entire AHD height range, as confirmed by their respective standard deviations listed in table 5.1. Figure 5.3 also shows that the absolute accuracy over the entire AHD height range between OSU91A, EIGEN2/EGM96, UCPH2/EGM96 and PGM2000A is reasonably equivalent, while EGM96 is offset, on average, a further 0.651 m as evidenced by their respective mean values noted in table 5.1. Furthermore, the absolute accuracy of each global geoid model deteriorates by a similar amount over increasing AHD height as determined from the minimal variation in the respective negative gradients of each model, i.e., max (EGM96) - min (OSU91A) = –0.000096 m/m.

From figure 5.3, each global geoid model exhibits a similar scatter of the absolute differences over the higher AHD elevations, i.e., >400 m - >600 m, as confirmed by the minimal variation in their respective correlation coefficients, i.e., max (EGM96) - min (OSU91A) = –0.0029. Inspection of the largest AHD elevation of 708.203 m at PM35751 at Mt. Kynoch shows the absolute difference for OSU91A, EIGEN2/EGM96, UCPH2/EGM96 and PGM2000A is, on average, –0.720 m and for EGM96 is –1.377 m. However, each model exhibits a similar offset from the linear regression line at this AHD height. Considering these differences together, the results in figure 5.3 and table 5.3 confirm the effect of the omission of terrain corrections in the global geoid models.

7.2.4.2 Geoid Models of Australia

Figures 5.4 and 5.5 in chapter 5 illustrate the absolute comparisons between all 116 empirical geoid heights and each bi-cubically and bi-linearly interpolated geoid model of Australia over AHD elevations greater than 200 m through to greater than 600 m. In addition, table 5.4 in chapter 5 shows the parameters of the least-squares linear regression line of the differences for each bi-cubically and bi-linearly interpolated geoid model of Australia.

From the results shown in figure 5.4 and table 5.4 in chapter 5, the bi-cubic interpolation of the SBA Technique, the RBA Technique and AUSGeoid98 exhibit a similar variation of differences from the 116 GPS-AHDD control points over the entire AHD height range, as confirmed by their respective standard deviations listed in table 5.1. In contrast, AUSGeoid93 displays the largest variation over the AHD height range, most notably between approximately 450 m and 600 m AHD, although the variation is not statistically significant. Figure 5.4 also shows that the absolute accuracy over the entire AHD height range varies among each model, with AUSGeoid93 providing the closet absolute fit to the control data, while AUSGeoid98 is, on average, offset a further 0.148 m from AUSGeoid93. The residual geoid height differences for the SBA Technique are, on average, offset a further 1.687 m and 1.551 m from AUSGeoid93 and AUSGeoid98 respectively, while the RBA Technique is, on average, offset a further 1.751 m and 1.615 m from AUSGeoid93 and AUSGeoid98 respectively. In addition, the absolute accuracy of each bi-cubically interpolated geoid model of Australia remains consistent over the increasing AHD height range as evidenced by the minimal variation in the respective negative gradients of each model, i.e., max (SBA Technique) - min (AUSGeoid93) = –0.000008 m/m.

From figure 5.4, the SBA Technique, the RBA Technique and AUSGeoid98 exhibit a similar scatter of the absolute differences over the higher AHD elevations, i.e., >400 m - >600 m, as confirmed by the minimal variation in their respective correlation coefficients, i.e., max (SBA Technique) - min (AUSGeoid98) = –0.0264. Conversely, AUSGeoid93 displays the largest scatter of absolute differences over the higher AHD elevations, as confirmed by its correlation coefficient of –0.4237. Comparing the absolute difference at the highest AHD elevation, i.e., 708.203 m at PM35751, reveals a variation from –0.576 m for AUSGeoid93 to –2.284 m for the RBA Technique. However, the SBA Technique, the RBA Technique and AUSGeoid98 only exhibit a small offset from the linear regression line at the highest AHD elevation, while AUSGeoid93 exhibits a large offset in comparison. Considering these differences together, the results in figure 5.4 and table 5.4 validate the inclusion of terrain corrections in the SBA Technique, the RBA Technique and AUSGeoid98, which is consistent with the findings of Featherstone and Guo (2001, p.89) and noted in section 2.8.1 of chapter 2.

From figure 5.5 and table 5.4 in chapter 5, the results obtained for the bi-linear interpolation of each geoid model of Australia reflect those obtained for bi-cubic interpolation. The SBA Technique, the RBA Technique and AUSGeoid98 show a similar variation of differences from the 116 GPS-AHDD control data over the entire AHD height range, which is confirmed by their respective standard deviations listed in table 5.1. On the contrary, AUSGeoid93 displays the largest variation over the AHD height range, most notably between approximately 450 m and 600 m AHD, although the variation is not statistically significant. Figure 5.5 also shows that the absolute accuracy over the entire AHD height range varies among each model, with AUSGeoid93 providing the closet absolute fit to the control data, while AUSGeoid98 is, on average, offset a further 0.127 m from AUSGeoid93. The residual geoid height differences for the SBA Technique are, on average, offset a further 1.677 m and 1.552 m from AUSGeoid93 and AUSGeoid98 respectively, while the RBA Technique is, on average, offset a further 1.741 m and 1.616 m from AUSGeoid93 and AUSGeoid98 respectively. Also noted is that the absolute accuracy of each bi-linearly interpolated geoid model of Australia remains consistent over the AHD height range as confirmed by the minimal variation in the respective negative gradients of each model, i.e., max (AUSGeoid93) - min (AUSGeoid98) = –0.000072 m/m.

From figure 5.5, the SBA Technique, the RBA Technique and AUSGeoid98 display a similar scatter of the absolute differences over the higher AHD elevations, i.e., >400 m - >600 m, as confirmed by the minimal variation in their respective correlation coefficients, i.e., max (SBA Technique) - min (AUSGeoid98) = –0.0354. Alternatively, AUSGeoid93 displays the largest scatter of absolute differences over the higher AHD elevations, as shown by its correlation coefficient of –0.5362. Comparing the absolute difference at the highest AHD elevation, i.e., 708.203 m at PM35751, reveals a variation from –0.608 m for AUSGeoid93 to –2.288 m for the RBA Technique. However, the SBA Technique, the RBA Technique and AUSGeoid98 only produce a minor offset from the linear regression line at the highest AHD elevation, while AUSGeoid93 produces a large offset in comparison. Considering these differences together, the results in figure 5.5 and table 5.4 validate the inclusion of terrain corrections in the SBA Technique, the RBA Technique and AUSGeoid98, which is consistent with the findings of Featherstone and Guo (2001, p.89) and noted in section 2.8.1 of chapter 2.

Comparing the scatter plots generated from the bi-cubic interpolation of each geoid model of Australia to those using bi-linear interpolation, there is an insignificant variation between the results obtained for the SBA Technique, the RBA Technique and AUSGeoid98. As determined from previous evaluations, the results suggest that overall AUSGeoid98 is the most statistically consistent model when considering the differences at each AHD height increment. Conversely, AUSGeoid93 displays the largest variation from bi-cubic to bi-linear interpolation with a difference in gradient of –0.000088 m/m and correlation coefficient of +0.1125, which is consistent with the findings of Featherstone (2001a, p.812) and noted in section 2.8.2 of chapter 2.

7.3 Discussion of the Results of Relative Verification

The relative verification test schemes developed and presented in chapter 6 are analysed and discussed below in relation to previous research reviewed in chapter 2.

7.3.1 Graphical Comparisons over the Minor Control GPS Traverse

As noted in chapter 6, the most relevant analysis from a practical perspective is an evaluation that determines whether GPS heighting can achieve an equivalent standard of accuracy to that obtained by conventional levelling. Thus, recalling the estimated average standard deviation of the empirical geoid heights at the 95% confidence level of ±0.0371 m, as established in chapter 4, the results of the graphical comparisons over the minor control GPS traverse for each geoid model presented in section 6.3.1 of chapter 6 are discussed below.

7.3.1.1 Global Geoid Models

Figure 6.1 in chapter 6 illustrates the difference between the GPS-derived AHD height differences (ΔH_{GPS}) and the levelling derived AHD height differences (ΔH_{AHDD}) over the length of the 46.2 km minor control GPS traverse for each global geoid model being investigated.

The residual height differences ($\Delta H_{GPS} - \Delta H_{AHDD}$) over an average of 54 (60%) of the 90 baselines for each global geoid model are greater than the equivalent maximum allowable height difference according to 3rd Order levelling specifications, i.e., $12\sqrt{K}$ mm, where K is the length of the particular baseline being compared. The baselines exhibiting the largest residual height difference are CS4 - CS5, CS5 - CS6 (approximately 1.5 - 2.8 km along the traverse) and CS94 - CS95 (approximately 38.9 - 39.7 km along the traverse), while smaller residual height differences occur over baselines CS57 through to CS108 (approximately 24 - 46 km along the traverse) as shown by the circled spikes in figure 7.1.

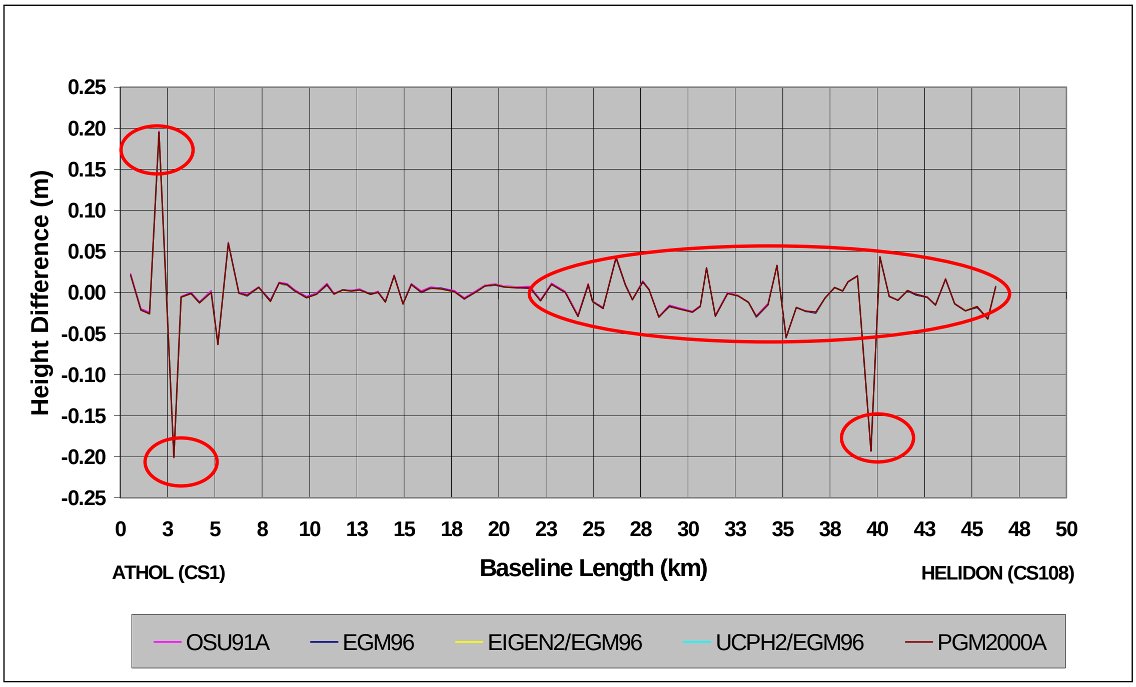

Figure 7.1 Residual height differences (ΔH_{GPS} - ΔH_{AHDD}) greater than the equivalent 3rd Order levelling specifications for the particular baseline over the 46.2 km Minor Control GPS Traverse (90 baselines) for each Global Geoid Model

Given that the combined least-squares adjustment of the GPS data was successful, as noted in chapter 4, the differences represented by the three large spikes that are greater than the equivalent 3rd Order levelling specification for the particular baseline length can possibly be attributed to errors in the AHD elevations at the corresponding control points. Similarly, the differences represented by the smaller spikes over the 24 - 46 km section of the minor control GPS traverse are possibly due to errors in the GPS data observed at these control points. As noted in chapter 4, these control points are situated on the densely vegetated, satellite visibility impeding range escarpment and consequently, it is probable that ambiguity resolution was not achieved for these observations as originally intended. The large number of discrepancies along the minor control GPS traverse, partly attributed to errors in the GPS or levelling data, or both, is consistent with the results reported by Featherstone and Alexander (1996, p.32) and noted in section 2.8.3 of chapter 2.

The large number of discrepancies over the escarpment profile can also be attributed to the individual baseline lengths. Compared to the baseline lengths used in the study by

Featherstone and Alexander (1996, p.31) and noted in section 2.8.3 of chapter 2, the longest GPS baseline observed for this evaluation was only 788 m, the shortest GPS baseline was 229 m and the average length was 514 m. Thus, the combination of the equivalent 3rd Order levelling specification and the associated error in the control data over the shorter baselines contributes to the total height difference for each global geoid model being greater than the required 3rd Order levelling specification over the 46.2 km escarpment profile.

The minimum resolution of the global geoid models being investigated is also likely to contribute to the large number of discrepancies over the escarpment profile. As noted in chapter 2, the resolution of the pre-computed grid of N values for the global geoid models varies from approximately 55 km for OSU91A, to approximately 27 km for EGM96. Thus, the length of the individual baselines used in this study are far less than the minimum resolution of the global geoid models being verified and consequently, any geoid heights interpolated at points less than the minimum resolution of the global geoid model being verified are likely to be biased due to the inability of the global geoid models to adequately define the geoid over the short wavelengths.

The insignificant variation between the plots of the residual geoid height differences for each global geoid model confirms their equivalent accuracy and precision over the length of the minor control GPS traverse. In addition, the global geoid models also exhibit equivalent long, medium and short wavelength trends over the escarpment profile confirming the findings of Featherstone and Alexander (1996, p.32), described in section 2.8.3 of chapter 2, in relation to the GEM-T2 and OSU91A global geoid models. Therefore, given the errors in the control data, the length of individual baselines forming the minor control GPS traverse and the resolution of each global geoid model tested, it is evident from a visual comparison of the residual height differences in figure 6.1 that each global geoid model is equally deficient over the entire wavelength spectrum and unable to transfer AHD elevations to an acceptable accuracy over the 46.2 km escarpment profile.

7.3.1.2 Geoid Models of Australia

Figures 6.2 and 6.3 in chapter 6 illustrate the difference between the GPS-derived AHD height differences (ΔH_{GPS}) and the levelling derived AHD height differences (ΔH_{AHDD}) over the length of the 46.2 km minor control GPS traverse for each bi-cubically and bi-linearly interpolated geoid model of Australia.

In terms of bi-cubic interpolation, the residual height differences over 49 (54.4%) of the 90 baselines for the SBA Technique, the RBA Technique and AUSGeoid98 and 53 (59%) of the 90 baselines for AUSGeoid93 are greater than the equivalent maximum allowable height difference according to 3rd Order levelling specifications, i.e., $12\sqrt{K}$ mm, where K is the length of the particular baseline being compared. In terms of bi-linear interpolation, the residual height differences over an average of 50 (55.6%) of the 90 baselines for the SBA Technique, the RBA Technique and AUSGeoid98 and 55 (61%) of the 90 baselines for AUSGeoid93 are greater than the equivalent maximum allowable height difference according to 3rd Order levelling specifications. Interestingly, the largest differences occur over the same baselines noted in the comparisons of the global geoid models, and shown in earlier figure 7.1, suggesting the presence of an error in the control data at these points.

The reasons for the discrepancies at several control points offered for each global geoid model are also valid in explaining the discrepancies associated with the geoid models of Australia, with the exception of the pre-computed grid resolution. As noted in chapter 2, the resolution of the pre-computed grid of N values for the geoid models of Australia varies from approximately 20 km for AUSGeoid93, to approximately 3.6 km for the SBA Technique, the RBA Technique and AUSGeoid98. However, the individual baseline lengths forming the minor control GPS traverse are still far less than the minimum resolution of each geoid model of Australia being verified and hence, the AHD elevations transferred over these short baseline lengths are also subject to the short wavelength deficiency, albeit reduced in magnitude, associated with each geoid model of Australia.

The insignificant variation between the plots of the residual geoid height differences for each bi-cubically and bi-linearly interpolated geoid model of Australia confirms their equivalent accuracy and precision over the length of the minor control GPS traverse. Moreover, the geoid models of Australia also exhibit improved long, medium and short wavelength trends over the escarpment profile when compared to the global geoid models, with each model, apart from AUSGeoid93, displaying the greatest improvement over the medium wavelengths. Thus, from a simple visual comparison of the residual geoid height differences, it is evident that GPS in conjunction with the bi-cubically and bi-linearly interpolated geoid models of Australia produce geoid height differences that are closer to zero over the length of the escarpment profile compared to those produced from GPS in conjunction with the global geoid models. This is consistent with the findings of Featherstone and Alexander (1996, p.32) and noted in section 2.8.3 of chapter 2.

The magnitude of the differences between the total height difference obtained when using GPS in conjunction with the bi-cubically and bi-linearly interpolated geoid models of Australia are difficult to ascertain from a visual comparison. Thus, the numerical comparisons that follow will quantify the results of the graphical comparisons using each interpolation method.

7.3.2 Numerical Comparisons over the Minor Control GPS Traverse

As noted in chapter 6, the most relevant analysis from a practical perspective is an evaluation that determines whether GPS heighting can achieve an equivalent standard of accuracy to that obtained by conventional levelling. Thus, recalling the estimated average standard deviation of the empirical geoid heights at the 95% confidence level of ±0.0371 m, as established in chapter 4, the results of the numerical comparisons over the minor control GPS traverse for each geoid model presented in section 6.3.2 of chapter 6 are discussed below.

7.3.2.1 Global Geoid Models

Table 6.1 in chapter 6 lists the total height difference (misclose) over the entire 46.2 km minor control GPS traverse for each global geoid model and the equivalent maximum allowable height difference according to 3rd Order levelling specifications.

Appraisal of the results show that GPS used in conjunction with each global geoid model does not achieve a total height difference that satisfies the equivalent 3rd Order levelling specification. Among the global geoid models, GPS combined with OSU91A gives a total height difference closest to zero, which is 0.073 m less than when combined with EGM96 and, on average, 0.066 m less than when combined with EIGEN2/EGM96, UCPH2/EGM96 and PGM2000A. These height differences are statistically significant to the order of approximately two standard deviations at the 95% confidence level. Furthermore, although different in magnitude, the results from this study appear to confirm the findings of Featherstone and Alexander (1996, pp.32-33).

Therefore, with respect to the errors in the control data and the previously discussed visual comparisons, the relative height differences obtained when using GPS in conjunction with each global geoid model are not of sufficient accuracy and precision to transfer AHD elevations over the entire 46.2 km Great Dividing Range escarpment profile at Toowoomba to a minimum of 3rd Order levelling specifications.

7.3.2.2 Geoid Models of Australia

Table 6.2 in chapter 6 lists the total height difference over the entire 46.2 km minor control GPS traverse for each bi-cubically and bi-linearly interpolated geoid model of Australia and the equivalent maximum allowable height difference according to 3rd Order levelling specifications.

Appraisal of the results indicate that GPS in conjunction with the bi-cubic interpolation of each geoid model of Australia and the bi-linear interpolation of AUSGeoid93 and AUSGeoid98 satisfy the equivalent 3rd Order levelling specification of 0.082 m over the

46.2 km minor control GPS traverse. This is consistent with the findings of Featherstone and Alexander (1996, p.32) and noted in section 2.8.3 of chapter 2.

The graphical comparisons made over the 90 individual baselines in the minor control GPS traverse for each geoid model of Australia can also be quantified. In terms of bi-cubic interpolation, the residual height differences over 41 (45.5%) baselines for the SBA Technique, the RBA Technique and AUSGeoid98 and 37 (41%) baselines for AUSGeoid93 satisfy the equivalent 3rd Order levelling specifications. In terms of bi-linear interpolation, the residual height differences over an average of 40 (44.4%) baselines for the SBA Technique, the RBA Technique and AUSGeoid98 and 35 (39%) baselines for AUSGeoid93 satisfy the equivalent 3rd Order levelling specifications. This is contrary to the findings of Featherstone and Alexander (1996, p.32) and noted in section 2.8.3 of chapter 2, who determined that GPS in conjunction with AUSGeoid93 was only capable of transferring AHD elevations over a long profile, typically greater than 10 km, to an equivalent 3rd Order levelling specification. However, these results are not a total vindication of this fact and hence, a more thorough analysis of the short wavelength integrity of each geoid model of Australia is provided by the evaluation using all possible baselines in following sections 7.3.3 and 7.3.4.

Appraisal of the results obtained using each interpolation technique indicates that there is no significant difference between the bi-cubic and bi-linear interpolations of the SBA Technique (–0.007 m), the RBA Technique (–0.006 m) or AUSGeoid98 (–0.005 m). In addition, the misclose achieved from GPS in conjunction with AUSGeoid98 is the most statistically stable between interpolation techniques. However, there is a statistically significant difference at the 95% confidence level between the total height differences obtained using each interpolation technique for AUSGeoid93, i.e., ±0.060 m, considering this geoid model provides the smallest height difference for both interpolation techniques. The variation in total height difference obtained when using GPS in conjunction with the bi-cubic and bi-linear interpolation of AUSGeoid93 appears to confirm the results obtained by Featherstone (2001a, p.812) and noted in section 2.8.2 of chapter 2.

With respect to the errors in the control data established in chapter 4, the length of the individual baselines and the resolution of each geoid model, it is evident that GPS in conjunction with each bi-cubically interpolated geoid model of Australia produces a total height difference closest to zero over the length of the escarpment profile. Furthermore, GPS in conjunction with AUSGeoid93 provides the smallest, though most statistically variable total height difference, while GPS in conjunction with AUSGeoid98 provides the most statistically consistent total height difference over the length of the minor control GPS traverse. However, this is not true over all individual baselines suggesting that a short wavelength bias remains in the geoid solution of each geoid model of Australia. Therefore, the results of the graphical and numerical comparisons between each geoid model of Australia indicates that the bi-cubic interpolation of AUSGeoid98 is the most suitable geoid model for use with GPS in transferring AHD elevations over the Great Dividing Range escarpment at Toowoomba to a minimum of Australian 3rd Order levelling specifications.

7.3.3 Numerical Comparisons over all 6,670 Possible Baselines

The implications of the relative comparisons over the minor control GPS traverse for each geoid model were discussed in sections 7.3.1 and 7.3.2. A more informative analysis of the accuracy and precision of each geoid model is an evaluation over all possible baselines. Thus, recalling the estimated average standard deviation of the empirical geoid heights at the 95% confidence level of ±0.0371 m, as established in chapter 4, the results of the relative verification of each geoid model over all 6,670 possible baselines presented in section 6.3.3 of chapter 6 are discussed in detail below.

7.3.3.1 Global Geoid Models

Table 6.3 in chapter 6 shows the descriptive statistics of the relative differences between the empirical geoid height differences and the gravimetric geoid height differences interpolated from each global geoid model over all 6,670 possible control baselines.

The results in table 6.3 supports the conclusions made from the results in table 5.1 in chapter 5. That is, no statistically significant difference at the 95% confidence level is evident between the results obtained for any global geoid model. Descriptive statistics, i.e., mean, standard deviation and RMS, from the relative comparisons are inconclusive, although the number of baselines greater than the equivalent 3rd Order levelling specification for the particular baseline length indicates that EGM96 provides the smallest relative precision of any global geoid model. Furthermore, there is an insignificant variation between the relative precisions of EGM96, EIGEN2/EGM96, UCPH2/EGM96 and PGM2000A.

The results obtained for OSU91A and EGM96 appear consistent with the conclusion made by Featherstone and Guo (2001, table 3, p.85) and noted in section 2.8.1 of chapter 2. Thus, as concluded from the descriptive statistics of the absolute comparisons in table 5.1 of chapter 5, the relative comparisons described above and with respect to the previously noted errors in the control data, this study highlights the spatial inconsistencies between the OSU91A and EGM96 global geoid models, most likely resulting from their different construction techniques and subsequent resolution.

The results in table 6.3 for EGM96, EIGEN2/EGM96, UCPH2/EGM96 and PGM2000A also reflect the results noted in table 5.1 of chapter 5. That is, the results are not as conclusive as those obtained by Amos and Featherstone (2003, table 3, p.13), who suggested that the EIGEN2/EGM96 geoid model provided a marginally improved, though statistically insignificant, fit to the control data used in their study. Given the minor variation in the accuracy and precision of each global geoid model, the only [partly] conclusive statistic available is the number of baselines exhibiting a relative height difference greater than the equivalent 3rd Order levelling specification. In this regard, EGM96 provides 10 fewer baselines greater than the equivalent maximum allowable Australian 3rd Order levelling specification compared to PGM2000A and, on average, 26 fewer compared to both EIGEN2/EGM96 and UCPH2/EGM96. Thus, the inconclusive results from this study are possibly attributed to the inability of the global geoid models to adequately differentiate the short wavelength component of the geoid.

Table 6.5 shows the average relative difference for each global geoid model compared to the equivalent average allowable relative difference according to 3rd Order levelling specifications over all 6,670 possible baselines. The values in table 6.5 were obtained by converting the descriptive statistics from table 6.3 in chapter 6 to absolute values to remove negative numbers.

The results in table 6.5 supports the conclusions reached from the results in table 6.3. That is, the average relative differences for each global geoid model are all greater than the equivalent average 3rd Order levelling specification. OSU91A provides the smallest average relative difference by, on average, 0.009 m less than any other global geoid model. However, the difference between each global geoid model is inconclusive given that it is less than the error in the control data. As previously concluded, there is no statistically significant variation between the results achieved for the EGM96, EIGEN2/EGM96, UCPH2/EGM96 and PGM2000A global geoid models when considering the errors in the control data.

7.3.3.2 Geoid Models of Australia

Table 6.4 in chapter 6 shows the descriptive statistics of the relative differences between the empirical geoid height differences and the gravimetric geoid height differences from each bi-cubically and bi-linearly interpolated geoid model of Australia over all 6,670 possible baselines.

The results for the bi-cubically interpolated geoid models of Australia supports the results obtained from the absolute comparisons in table 5.1 of chapter 5. That is, there is almost no difference between the SBA Technique and the RBA Technique, with the exception that the RBA Technique produces 49 (0.7%) fewer baselines with a relative height difference greater than the equivalent 3rd Order levelling specification for the particular baseline length. Furthermore, AUSGeoid98 provides a superior overall result, that whilst not statistically significantly different from either the SBA or RBA Technique, in terms of the short wavelength indicators provided by the mean, standard deviation and RMS statistics, its computed range (max-min) is, on average, 0.039 m less than either model, which is statistically significant at the 95% confidence level, its mean relative difference is approximately 0.010 m closer to zero, suggesting that it is the most accurate model and its mean difference over mean baseline length is approximately 0.86 ppm (67%) closer to zero. However, AUSGeoid98 does produce an average of 306 (4%) more baselines with a relative height difference greater than the equivalent 3rd Order levelling specification compared to the SBA and RBA Techniques, although this is not significant when considering the errors in the control data.

GPS used in conjunction with AUSGeoid93 gives the worst relative fit to the control data of any bi-cubically interpolated geoid model of Australia. The mean relative difference is approximately 0.025 m greater than AUSGeoid98 and approximately 0.035 m greater than the SBA and RBA Techniques, indicating that it is the most inaccurate model over the short wavelengths. The remaining statistics for AUSGeoid93 are similarly deficient with a standard deviation, on average, 0.024 m greater than that of any other geoid model of Australia, suggesting that it is also the least precise model over the short wavelengths. AUSGeoid93 also produces an average of 2069 more baselines exhibiting a relative height difference greater than the equivalent 3rd Order levelling specification and a mean difference over mean baseline length, on average, 2.61 ppm greater than that of any other geoid model of Australia.

The results in table 6.4 are consistent with the findings reported by Featherstone and Guo (2001, table 5, p.86) and noted in section 2.8.1 of chapter 2. In addition, the results in table 6.4 also support the conclusions made by Featherstone (2001a, table 2, p.813) and noted in section 2.8.2 of chapter 2. However, the results obtained for the short wavelength statistics of the mean and standard deviation for each geoid model of Australia are inconsistent with the conclusions made by Featherstone and Alexander (1996, table 2, p.33) and described in section 2.8.3 of chapter 2, who found that AUSGeoid91 and AUSGeoid93 did not provide any short wavelength improvement over the global geoid models tested. In contrast, the results noted in table 6.4 suggest there is a significant improvement in the short wavelength integrity of each bi-cubically interpolated geoid model of Australia over the global geoid models on the Great Dividing Range escarpment at Toowoomba to the order of approximately 2-3 standard deviations (±0.0742 m - ±0.1113 m) at the 95% confidence level.

The results from the bi-linearly interpolated geoid models of Australia reflect the results obtained using bi-cubic interpolation. That is, no statistically significant difference is evident between the SBA and RBA Techniques, with the exception that the RBA Technique produces 59 (0.9%) fewer baselines with a relative height difference greater than the equivalent 3rd Order levelling specification for the particular baseline length. AUSGeoid98 provides a superior overall relative fit, with the differences between the statistics from the SBA Technique, the RBA Technique and AUSGeoid98 indicating that each model exhibits an equivalent short wavelength precision, although AUSGeoid98 is slightly more accurate with a mean relative difference 0.010 m closer to zero.

GPS used in conjunction with AUSGeoid93 produces the worst relative fit to the control data of any bi-linearly interpolated geoid model of Australia. The mean relative difference improves slightly to be approximately 0.021 m greater than AUSGeoid98, although deteriorates to a statistically significant difference at the 95 % confidence level of 0.037 m greater than the SBA and RBA Techniques, indicating that it is the most inaccurate model over the short wavelengths. The remaining statistics for AUSGeoid93 are similarly deficient, with a statistically significant difference in standard deviation of, on average, 0.037 m greater than that of any other geoid model of Australia, suggesting that it is the least precise model over the short wavelengths. AUSGeoid93 also yields, on average, 2118 more baselines with a relative height difference greater than the equivalent 3rd Order levelling specification and a mean difference over mean baseline length, on average, 2.20 ppm greater than that of any other geoid model of Australia.

The results obtained for the bi-linear interpolation of AUSGeoid93 and AUSGeoid98 are consistent with the outcomes reported by Featherstone (2001a, table 2, p.813) and noted in section 2.8.2 of chapter 2.

Comparing the relative fit obtained for each geoid model of Australia using bi-cubic interpolation to that obtained using bi-linear interpolation, there is no statistically significant difference at the 95% confidence level between the results from either interpolation technique. Furthermore, there is an insignificant variation in the results for AUSGeoid98, the SBA Technique and the RBA Technique with AUSGeoid98 the most statistically consistent model overall when considering the remaining computed statistics. Conversely, AUSGeoid93 displays the largest variation between bi-cubic and bi-linear interpolation, with variations of –0.005 m in mean relative difference, 0.015 m in standard deviation, 0.014 m in RMS, 211 baselines greater than the equivalent 3rd Order levelling specification and –0.05 ppm in mean difference over mean baseline length.

Similar to the variation observed between the bi-cubic and bi-linear interpolation of AUSGeoid93 and AUSGeoid98 reported from the absolute comparisons of each model, the variation between each interpolation method associated with the relative comparisons is also consistent with the findings of Featherstone (2001a, p.812) and noted in section 2.8.2 of chapter 2.

Table 6.6 in chapter 6 shows the average relative difference for each bi-cubically and bi-linearly interpolated geoid model of Australia compared to the average allowable relative difference according to 3rd Order levelling specifications over all 6,670 possible baselines. The values in table 6.6 were obtained by converting the descriptive statistics from table 6.4 in chapter 6 to absolute values to remove any negative numbers.

The results in table 6.6 supports the conclusions reached from the results in table 6.4. That is, the SBA Technique, the RBA Technique and AUSGeoid98 exhibit equivalent average relative differences and hence, an equivalent accuracy over the short wavelengths, while AUSGeoid93 produces the largest average relative difference and is the least accurate geoid model of Australia. Interestingly, the results also suggest that the SBA and RBA Techniques provide a small, though statistically insignificant, improvement in short wavelength accuracy over AUSGeoid98, which contrasts the analysis of the results in table 6.4. However, the differences between the models from both tables are inconclusive as they are less than the errors in the control data. This aside, the average relative differences for the bi-cubic interpolation of the SBA Technique, the RBA Technique and AUSGeoid98 satisfy the equivalent average 3rd Order levelling specification, while AUSGeoid93 is greater than the equivalent average 3rd Order levelling specification by 0.025 m. This result is consistent with the findings noted by Featherstone *et al.* (2001, p.327), who indicated that AUSGeoid98 achieved a result slightly greater than the average allowable relative difference, which was far less than the result obtained from AUSGeoid93 and hence, provided an overall better fit to the control data in their study area.

In terms of bi-linear interpolation, the SBA and RBA Techniques provide an average relative difference equal to the equivalent average 3rd Order levelling specification, while AUSGeoid98 is marginally less accurate with an average relative difference 0.003 m greater than the equivalent 3rd Order levelling specification. In contrast, AUSGeoid93 gives a statistically significant average relative difference at the 95% confidence level of 0.037 m greater than the equivalent average 3rd Order levelling specification. Furthermore, the equivalent average relative differences obtained for the SBA Technique, the RBA Technique and AUSGeoid98 indicate that these models are equally accurate over the short wavelengths, while AUSGeoid93 is the least accurate geoid model of Australia.

Comparing the average relative differences obtained using bi-cubic interpolation to those obtained using bi-linear interpolation suggests that there is an insignificant difference in the results obtained for the SBA Technique and the RBA Technique. In contrast, AUSGeoid98 produces a minor variation of 0.002 m, while AUSGeoid93 produces the largest variation between interpolation techniques, with a difference of 0.012 m.

7.3.4 Graphical Comparisons over all 6,670 Possible Baselines

The implications of the numerical comparisons over all 6,670 possible baselines for each geoid model were discussed in section 7.3.3. The nature of the distribution of the relative differences over all possible baselines can also be analysed via the construction of scatter plots of the differences according to baseline length. Thus, recalling the estimated average standard deviation of the empirical geoid heights at the 95% confidence level of ±0.0371 m, as established in chapter 4, the results of the graphical comparisons of each geoid model over all 6,670 possible baselines presented in section 6.3.4 of chapter 6 are discussed in detail below.

7.3.4.1 Global Geoid Models

Figure 6.4 in chapter 6 and figures H.1 - H.4 in Appendix H show the distribution of the relative comparisons between the empirical geoid height differences and the gravimetric geoid height differences interpolated from each global geoid model over all 6,670 possible baselines.

The scatter plots presented in figure 6.4 of chapter 6 and figures H.1 - H.4 in Appendix H confirm the conclusions drawn from the results of the numerical comparisons over all possible baselines in table 6.3 of chapter 6. That is, when using GPS in conjunction with OSU91A, the relative height differences over 5,161 (77.38%) baselines are greater than the equivalent 3rd Order levelling specification for the particular baseline lengths. Similarly, when using GPS in conjunction with EGM96, EIGEN2/EGM96, UCPH2/EGM96 and PGM2000A the relative height differences over an average of 4,765 (71.44%) baselines are greater than the equivalent 3rd Order levelling specification. Furthermore, the relative height differences for each global geoid model exhibit a general negative trend over the entire baseline spectrum, as confirmed by the mean difference over mean baseline length for OSU91A of –6.70 ppm and an average for the remaining global geoid models of –8.49 ppm.

The scatter plots of the relative differences are consistent with the long, medium and short wavelength trends exhibited by each model in the evaluation over the escarpment profile described in sections 7.3.1.1 and 7.3.2.1. This result would appear to be inconsistent with the results obtained by Featherstone (2001a, p.813) and noted in section 2.8.2 of chapter 2. The combination of using shorter baseline lengths in this study and both positive and negative relative differences to highlight the true distribution, make it difficult to confirm or disprove this result based on the trends exhibited by the magnitude of the relative differences for the global geoid models being verified.

7.3.4.2 Geoid Models of Australia

Figure 6.5 in chapter 6 and figures H.5 - H.11 in Appendix H show the distribution of the relative comparisons between the empirical geoid height differences and the gravimetric geoid height differences from each bi-cubically and bi-linearly interpolated geoid model of Australia over all 6,670 possible baselines.

The scatter plots presented in figure 6.5 of chapter 6 and figures H.5 - H.11 in Appendix H confirm the conclusions drawn from the results of the numerical comparisons over all possible baselines in table 6.4. In terms of the bi-cubically interpolated geoid models of Australia, it is evident that the SBA and RBA Techniques remove most of the short, medium and long wavelength trend present in the global geoid models. However, a small negative medium and long wavelength trend remains in these models as confirmed by their respective relative mean differences of –0.016 m and –0.015 m and mean difference over mean baseline length values of –1.33 ppm and –1.28 ppm from table 6.4. The practical implication of these trends being that when using GPS in conjunction with the SBA Technique and the RBA Technique over the Great Dividing Range escarpment at Toowoomba, the relative height differences over an average of 2,309 (34.61%) of the 6,670 control baselines are greater than the equivalent 3rd Order levelling specification for the particular baseline lengths.

AUSGeoid98 also largely removes the short, medium and long wavelength trends present in each of the global geoid models. Similarly, a small negative medium and long wavelength trend remains in AUSGeoid98 as confirmed by its relative mean difference of –0.005 m and mean difference over mean baseline length value of –0.43 ppm from table 6.4. However, this trend is smaller in magnitude when compared to the residual trend remaining in the SBA and RBA Techniques. The practical implication of these trends being that when using GPS in conjunction with AUSGeoid98 over the Great Dividing Range escarpment at Toowoomba, the relative height differences over 2,614 (39.19%) of the 6,670 control baselines are greater than the equivalent 3rd Order levelling specification for the particular baseline lengths.

In contrast, AUSGeoid93 removes a small amount of the short wavelength trend exhibited by the global geoid models, converts the negative medium wavelength trend to a positive trend and removes most of the long wavelength trend. However, a small positive long wavelength trend remains in AUSGeoid93 as confirmed by its relative mean difference of +0.020 m and mean difference over mean baseline length value of +1.74 ppm from table 6.4. The practical implication of these trends being that when using GPS in conjunction with AUSGeoid93 over the Great Dividing Range escarpment at Toowoomba, the relative height differences over 4530 (67.92%) of the 6,670 control baselines are greater than the equivalent 3rd Order levelling specification for the particular baseline lengths.

The scatter plots of the relative differences from each bi-cubically interpolated geoid model of Australia are consistent with the long, medium and short wavelength trends exhibited by each model in the evaluation over the escarpment profile described in sections 7.3.1.2 and 7.3.2.2. The results also appear consistent with the findings made by Featherstone and Alexander (1996, pp.33-34) and noted in section 2.8.3 of chapter 2.

The scatter plots of the bi-linearly interpolated geoid models of Australia, presented in figures H.8 - H.11 in Appendix H, exhibit the same general trends as shown for bi-cubic interpolation, though slightly greater in magnitude. The practical implication of these trends being that when using GPS in conjunction with the SBA Technique and the RBA Technique over the Great Dividing Range escarpment at Toowoomba, the relative height differences over an average of 2,490 (37.32%) of the 6,670 control baselines are greater than the equivalent 3rd Order levelling specification for the particular baseline lengths. Similarly, when using GPS in conjunction with AUSGeoid98 over the Great Dividing Range escarpment at Toowoomba, the relative height differences over 2,757 (41.33%) of the 6,670 control baselines are greater than the equivalent 3rd Order levelling specification for the particular baseline lengths. Conversely, when using GPS in conjunction with AUSGeoid93 over the Great Dividing Range escarpment at Toowoomba, the relative height differences over 4,741 (71.08%) of the 6,670 control baselines are greater than the equivalent 3rd Order levelling specification for the particular baseline lengths.

Comparing the results between bi-cubic and bi-linear interpolation reveals that the bi-cubic interpolation of the SBA and RBA Technique provides, on average, 181 (2.71%) more baselines with a relative height difference that satisfies the equivalent 3rd Order levelling specification over the particular baseline length. In addition, the relative height differences are closest to zero over the short to medium baselines and trend toward the negative 3rd Order misclose limit over the longer baselines. The bi-cubic interpolation of AUSGeoid98 provides 143 (2.14%) more baselines with a relative height difference that satisfies the equivalent 3rd Order levelling specification over the particular baseline length. Furthermore, both interpolations of AUSGeoid98 display relative height differences closer to zero over the entire baseline spectrum and only a slightly greater variation over the short baselines compared to the SBA and RBA Techniques. On the contrary, AUSGeoid93 yields the greatest variation in distribution of any geoid model of Australia for both interpolation techniques. The positive and negative relative height differences are greater than the equivalent 3rd Order levelling specification over the short and medium baselines however, the differences reduce to satisfy the equivalent 3rd Order levelling specification over the longer baselines.

7.3.5 Numerical Comparisons over Increasing AHD Height

The implications of the graphical comparisons over all 6,670 possible baselines for each geoid model were discussed in section 7.3.4. To obtain a more informative analysis of the relative accuracy and reliability of each geoid model in areas of higher elevation, testing was conducted over an increasing AHD height range using all possible baselines. Thus, recalling the estimated average standard deviation of the empirical geoid heights at the 95% confidence level of ±0.0371 m, as established in chapter 4, the results of numerical comparisons of each geoid model over increasing AHD height using all 6,670 possible baselines presented in section 6.3.5 of chapter 6 are discussed in detail below.

7.3.5.1 Global Geoid Models

Table 6.7 in chapter 6 and tables I.1 - I.4 of Appendix I show the descriptive statistics of the relative comparisons between the empirical geoid height differences and the gravimetric geoid heights differences interpolated from each global geoid model over AHD elevations greater than 200 m through to greater than 600 m.

The results in table 6.7 and tables I.1 - I.4 confirm the results in table 5.2 and tables G.1 - G.4 in Appendix G. That is, contrary to the findings reported by Featherstone and Guo (2001, table 2, p.85) and noted in section 2.8.1 of chapter 2, it is apparent that OSU91A provides a small, though statistically insignificant, improvement in precision over any other global geoid model for AHD heights greater than 200 m to greater than 300 m. For AHD heights greater than 400 m to greater than 500 m EGM96, EIGEN2/EGM96, UCPH2/EGM96 and PGM2000A provide the smallest relative precision, while for AHD heights greater than 600 m, all models achieve a similar relative precision. However, the differences between each global geoid model at each AHD height increment are not statistically significant at the 95% confidence level considering the errors in the control data. As noted earlier, the reasons for this apparent difference in result can possibly be attributed to the local spatial inconsistencies between the OSU91A and EGM96 global geoid models, as demonstrated by this study, which are difficult to quantify using a nation-wide data set that can only expose general trends in each model.

The results obtained for EIGEN2/EGM96, UCPH2/EGM96 and PGM2000A also confirm the conclusion reached in sections 7.2.3.1 and 7.2.4.1. That is, no statistically significant difference is evident between the accuracy and precision of these global geoid models over the AHD height range. The results reported by Amos and Featherstone (2003, table 3, p.13) suggested that the EIGEN2/EGM96 global geoid model provided a marginally improved, though statistically insignificant, fit to the control data, where the control data consisted of the same set of 1,013 GPS-AHD control points as used by Featherstone and Guo (2001). Thus, the inconclusive results are most probably due to the inability of the global geoid models to adequately differentiate the short wavelength component of the geoid over the short baselines used in this study.

7.3.5.2 Geoid Models of Australia

Tables I.5 - I.12 in Appendix I show the descriptive statistics of the relative differences between the empirical geoid height differences and the gravimetric geoid height differences interpolated from each bi-cubically and bi-linearly interpolated geoid model of Australia over AHD elevations greater than 200 m through to greater than 600 m.

The results in tables I.5 - I.8 confirm the conclusions reached in tables G.5 - G.8 in Appendix G from the absolute comparisons. That is, no statistically significant difference at the 95 % confidence level is present between the bi-cubic interpolation of the SBA Technique, the RBA Technique and AUSGeoid98 at each AHD height increment. Similarly, descriptive statistics, i.e., mean, standard deviation and RMS, from the relative comparisons are also inconclusive. However, the range (max-min), number of outliers and mean difference over mean baseline length indicate that AUSGeoid98 provides a small, though statistically insignificant, improvement on the relative precision of the SBA Technique and the RBA Technique for AHD heights greater than 200 m through to greater than 600 m.

AUSGeoid93 provides the least precise relative fit of any bi-cubically interpolated geoid model of Australia with several statistically significant differences at the 95% confidence level over AHD heights greater than 200 m through to greater than 500 m. For AHD heights greater than 200 m, the mean relative difference is, on average, 0.038 m lower compared to the SBA and RBA Techniques. For AHD heights greater than 300 m, the mean relative difference is, on average, 0.047 m lower and the RMS is, on average, 0.037 m higher compared to the SBA and RBA Techniques. For AHD heights greater than 400 m, the mean relative difference is, on average, 0.052 m lower and the RMS is, on average, 0.039 m higher compared to the SBA and RBA Techniques, while the mean relative difference is 0.037 m lower compared to AUSGeoid98. For AHD heights greater than 500 m, the mean relative difference is, on average, 0.043 m lower compared to the SBA and RBA Techniques. However, for AHD heights greater than 600 m, AUSGeoid93 provides an average improvement of 0.017 m in relative precision compared to all other geoid models of Australia, although it is not statistically significant at the 95% confidence level.

The results in tables I.5 - I.8 are consistent with the conclusions made by Featherstone and Guo (2001, table 11, p.96) and noted in section 2.8.1 of chapter 2. The results achieved in this study at each AHD height increment reflect these results, except for AHD heights greater than 600 m where, as stated earlier, AUSGeoid93 provides a small, though statistically insignificant, improvement on all other models. This apparent improvement in relative fit to the control data over the higher elevations is most likely explained by the omission of terrain corrections for the systematically positive terrain effect in the construction of AUSGeoid93.

From tables I.9 - I.12 in Appendix I, the relative fit of each bi-linearly interpolated geoid model of Australia is similar in magnitude to that obtained using bi-cubic interpolation, with the exception of AUSGeoid93. That is, no statistically significant difference at the 95% confidence level is evident between the bi-linear interpolation of the SBA Technique, the RBA Technique or AUSGeoid98 at each AHD height increment. Furthermore, descriptive statistics, i.e., mean, standard deviation and RMS, from the relative comparisons are also inconclusive. However, the range (max-min), number of outliers and mean difference over mean baseline length indicate that AUSGeoid98 provides a small, though statistically insignificant, improvement on the precisions of the SBA and RBA Techniques for AHD heights greater than 200 m through to greater than 600 m.

AUSGeoid93 provides the least precise relative fit of any bi-linearly interpolated geoid model of Australia with several statistically significant differences at the 95% confidence level over AHD heights greater than 200 m through to greater than 500 m. For AHD heights greater than 200 m, the mean relative difference is, on average, 0.037 m lower, the standard deviation is, on average, 0.037 m higher and the RMS is, on average, 0.037 m higher compared to the results from the SBA and RBA Techniques. For AHD heights greater than 300 m, the mean relative difference is, on average, 0.049 m lower and the RMS is, on average, 0.049 m higher compared to the SBA and RBA Techniques. For AHD heights greater than 400m, the mean relative difference is, on average, 0.056 m lower and the RMS is, on average, 0.051 m higher compared to the SBA and RBA Techniques, while the mean relative difference is, on average, 0.041 m lower and the RMS is, on average, 0.047 m higher compared to AUSGeoid98. For AHD heights greater than 500 m, the mean relative difference is, on average, 0.051 m lower and the RMS is, on average, 0.049 m higher compared to the SBA and RBA Techniques, while the mean relative difference is, on average, 0.040 m lower and the RMS is, on average, 0.046 m higher compared to AUSGeoid98. However, for AHD heights greater than 600 m, AUSGeoid93 provides an average improvement of 0.026 m in relative precision compared to all other geoid models of Australia, although it is not statistically significant at the 95% confidence level.

Comparing the relative precision obtained for each geoid model of Australia using bi-cubic interpolation to that obtained using bi-linear interpolation indicates that there is an insignificant variation between the results for the SBA Technique, the RBA Technique and AUSGeoid98. In addition, the results also suggest that over the entire AHD height range, AUSGeoid98 is the most statistically consistent model when considering all the computed statistics. Furthermore, the relative precisions from each interpolation of these models improve and are superior for AHD heights greater than

200 m through to greater than 500 m, before deteriorating for AHD heights greater than 600 m.

AUSGeoid93 produces the largest variation in relative fit to the control data among each bi-cubically and bi-linearly interpolated geoid model of Australia over AHD heights greater than 200 m through to greater than 500 m. However, for AHD heights greater than 600 m, AUSGeoid93 provides the best relative fit of any geoid model of Australia, regardless of interpolation technique.

7.4 Conclusion

This chapter has analysed and discussed the results of the absolute and relative verification test schemes presented in chapters 5 and 6.

Absolute comparisons between the OSU91A, EGM96, EIGEN2/EGM96, UCPH2/EGM96 and PGM2000A global geoid models and all 116 empirical geoid heights and against subsets of the empirical geoid heights over AHD elevations greater than 200 m through to greater than 600 m concluded that, due to their poor absolute accuracy and precision, it would not be possible to achieve reliable GPS point positioning over the Great Dividing Range escarpment at Toowoomba using the current versions of these models. Furthermore, the variation in the offset of each global geoid model from the empirical geoid would hinder any correction applied to the N values interpolated from each global geoid model to improve their GPS point positioning capability.

Absolute comparisons between each bi-cubically and bi-linearly interpolated geoid model of Australia with all 116 empirical geoid heights and over AHD elevations greater than 200 m through to greater than 600 m concluded that, except for AUSGeoid93, the improved absolute precision of the SBA Technique, the RBA Technique and AUSGeoid98 would permit reliable GPS point positioning over the Great Dividing Range escarpment at Toowoomba. The small variation in the offset of these geoid models from the empirical geoid facilitates the application of a simple correction to the gravimetric N values interpolated from these geoid models. In practice, this is achieved by performing a 'block-shift' of the N values based on GPS observations at AHD benchmarks. However, GPS point positioning conducted to derive AHD elevations is not recommended in the best practice guidelines set out in SP1. Rather, positions should be established as part of a control network (ICSM SP1 2002b, p.B-18).

Relative comparisons of the OSU91A, EGM96, EIGEN2/EGM96, UCPH2/EGM96 and PGM2000A global geoid models with a 46.2 km GPS and levelling traverse over the Great Dividing Range escarpment at Toowoomba determined that, with respect to the errors in the control data, no GPS and global geoid model combination is able to satisfy the equivalent Australian 3rd Order levelling specification of 0.082 m when used to transfer AHD elevations over the entire length of the escarpment profile.

Relative comparisons of the geoid models of Australia with a 46.2 km GPS and levelling traverse over the Great Dividing Range escarpment at Toowoomba determined that, with respect to the errors in the control data, GPS combined with the bi-cubic interpolation of each geoid model of Australia and the bi-linear interpolation of AUSGeoid93 and AUSGeoid98 is able to satisfy the equivalent Australian 3rd Order levelling specification of 0.082 m when used to transfer AHD elevations over the entire length of the escarpment profile. However, this is not true over all baselines with discrepancies occurring over an average of 51 (56.7%) baselines for each model. Furthermore, GPS combined with AUSGeoid98 gives the smallest variation between interpolation techniques, GPS combined with AUSGeoid93 achieves the closest misclose to zero for each interpolation technique but the largest variation and GPS combined with bi-cubically interpolated geoid heights provides a smaller misclose.

Relative comparisons between each global geoid model over all 6,670 possible baselines and over AHD elevations greater than 200 m through to greater than 600 m established that the gravimetric geoid gradients interpolated from these models exhibit poor relative accuracy and precision compared to the empirical geoid gradients over the escarpment profile. Furthermore, the variation in the offset of the gravimetric geoid gradients over the escarpment profile suggests that when using relative GPS techniques over the Great Dividing Range escarpment at Toowoomba, it would be difficult to reliably transfer AHD elevations that satisfy the equivalent 3^{rd} Order levelling specification. This is confirmed by GPS in conjunction with OSU91A producing relative height differences over 5,161 (77.38%) baselines that are greater than the equivalent 3^{rd} Order levelling specification for the particular baseline lengths. Also confirming this conclusion is GPS in conjunction with EGM96, EIGEN2/EGM96, UCPH2/EGM96 and PGM2000A producing, on average, 4,765 (71.44%) baselines that are greater than the equivalent 3^{rd} Order levelling specification for the particular baseline lengths.

Relative comparisons between each bi-cubically and bi-linearly interpolated geoid model of Australia over all 6,670 possible baselines and over AHD elevations greater than 200 m through to greater than 600 m concluded that, except for AUSGeoid93, the gravimetric geoid gradients bi-cubically and bi-linearly interpolated from the SBA Technique, the RBA Technique and AUSGeoid98 yield an improved relative accuracy and precision compared to the global geoid models over the escarpment profile. Furthermore, the small variation in the offset of the bi-cubically interpolated gravimetric geoid gradients in relation to the empirical geoid gradients indicates that when using relative GPS techniques over the Great Dividing Range escarpment at Toowoomba, it would be possible to reliably transfer AHD elevations that satisfy the equivalent 3^{rd} Order levelling specification. This is confirmed by GPS in conjunction with the SBA and RBA Techniques and AUSGeoid98 producing relative height differences over an average of 4,361 (65.38%) and 4,056 (60.81%) baselines respectively that are less than the equivalent 3^{rd} Order levelling specification for the particular baseline lengths. In contrast, GPS used in conjunction with AUSGeoid93, which does not contain terrain corrections, only produces relative height differences over 2,140 (32.08%) baselines that are less than the equivalent 3^{rd} Order levelling specification for the particular baseline lengths, clearly not providing any significant improvement over the global geoid models.

Chapter eight will provide conclusions as to the suitability of each geoid model for use with GPS heighting over the over the Great Dividing Range escarpment at Toowoomba and propose recommendations and possible further research.

CHAPTER 8

CONCLUSIONS

8.1 Introduction

Chapter seven discussed the significance of the results from the absolute and relative verification of each geoid model in relation to the work conducted by previous researchers. As stated in chapter one, GPS in conjunction with conventional levelling is commonly used to coordinate engineering projects. However, the provision of vertical control on engineering projects located in undulating terrain can be resource intensive in regard to fieldwork requirements. Given that the main application of a gravimetric geoid model is for the conversion of GPS-derived ellipsoid heights to elevations on the AHD, the aim of this study was to assess the various commonly used and prototype gravimetric geoid models currently available for this purpose.

Chapter eight will respond to this aim by drawing conclusions regarding the accuracy and reliability of each geoid model verified and hence, their suitability for use with GPS heighting on the Great Dividing Range escarpment at Toowoomba.

Conclusions are drawn as to the most accurate and reliable geoid model for use with GPS heighting over the Great Dividing Range escarpment at Toowoomba based on the evaluations over the minor control GPS traverse, over the entire data set encompassing all 116 control points and all 6,670 possible baselines and over AHD elevations greater than 200 m through to greater than 600 m. Following this are suggestions for possible future research that flow from this study.

8.2 Conclusions

This study has used a variety of graphical and descriptive statistical techniques to compare the accuracy and reliability of the OSU91A, EGM96, EIGEN2/EGM96, UCPH2/EGM96 and PGM2000A global geoid models and the bi-cubic and bi-linear interpolation of the SBA Technique, the RBA Technique, AUSGeoid93 and AUSGeoid98 geoid models of Australia. Comparisons were made with 116 empirically derived geoid heights in an absolute and relative sense to determine the suitability of each geoid model for use with GPS heighting on the Great Dividing Range escarpment at Toowoomba. Analysis of the empirical geoid heights estimated their average standard deviation to be ±0.0371 m, elevated at the 95% confidence level.

Comparisons of each global geoid model with a 46.2 km GPS and levelling traverse, against 116 GPS-AHDD control points (6,670 possible baselines) and over AHD elevations greater than 200 m through to greater than 600 m lead to the conclusion that each global geoid model is equivalently inadequate for converting GPS-derived ellipsoid heights to elevations on the AHD over the Great Dividing Range escarpment at Toowoomba. This is attributed to errors residing in the control data and the inability of the global geoid models to adequately define the geoid over the short wavelengths as a consequence of the coarse resolution of their pre-computed geoid height grids.

Comparisons of each bi-cubically and bi-linearly interpolated geoid model of Australia with a 46.2 km GPS and levelling traverse, against 116 GPS-AHDD control points (6,670 possible baselines) and over AHD elevations greater than 200 m through to greater than 600 m lead to the conclusion that AUSGeoid98 is generally the superior model for converting GPS-derived ellipsoid heights to elevations on the AHD over the Great Dividing Range escarpment at Toowoomba. The equivalent absolute and relative precision achieved by the SBA Technique, the RBA Technique and AUSGeoid98 confirms the use of topographic data in the form of terrain corrections and satellite-altimeter-derived gravity data in their construction. To a lesser extent, the results partly endorse the computational theories and techniques used to compute AUSGeoid98 (i.e., the 1D-FFT and a modified kernel) and the SBA and RBA Techniques (i.e., the one 1D-FFT and an unmodified kernel) as opposed to those used for AUSGeoid93 (i.e., ring integration with an unmodified kernel).

The results obtained for each bi-cubically and bi-linearly interpolated geoid model of Australia from the absolute and relative verification test schemes lead to the conclusion that bi-cubically interpolated geoid heights provide a superior and more stable statistical fit to the control data. This is attributed to the grid spacing of each geoid model (i.e., SBA Technique, RBA Technique, AUSGeoid98 = 2’ x 2’; AUSGeoid93 = 10’ x 10’) as it is less reliable to bi-linearly interpolate from a coarse grid. This is confirmed by the stability of the descriptive statistics associated with the SBA Technique, the RBA Technique and AUSGeoid98 using both interpolation techniques and the variability in the result when using AUSGeoid93.

8.3 Further Research and Recommendations

This study has shown that the current national gravimetric geoid model, AUSGeoid98, provides a slight improvement in absolute and relative precision over the SBA and RBA Techniques and a reasonable improvement over AUSGeoid93 on the Great Dividing Range escarpment at Toowoomba. The evaluations determined that a small trend over the medium and long wavelengths remains in the AUSGeoid98 solution, although the extent to which this is true is difficult to ascertain considering the errors in the control data. Thus, any future release in the AUSGeoid series should aim to remove these trends by including additional topographic data to that featured in the current release of AUSGeoid98 and any subsequent testing should use improved GPS-AHD control data, if available.

The equivalent absolute and relative precision achieved by the SBA Technique, the RBA technique and AUSGeoid98 suggests further investigation is required to properly quantify the difference between these models. Recent testing conducted by Goos *et al.* (2003) compared AUSGeoid98, EGM96, the SBA Technique and the RBA Technique in an absolute sense with the same nation-wide control data set of 1,013 GPS-AHD control points as used in the study by Featherstone and Guo (2001) and found that the computational theories and data treatment used in the production of AUSGeoid98 provided a superior fit to the control data. Future evaluations of the SBA and RBA Techniques should be conducted in a relative sense using a more accurate, nation-wide control data set and subsequent to the inclusion of additional gravity data in areas to the north of Australia with currently poor data coverage, i.e., Indonesia and Papua New Guinea, as noted in the production of these models.

The equivalent absolute and relative precision of the global geoid models suggests each model is equally deficient over the short wavelengths. Recent investigations by Amos and Featherstone (2003) suggested that the EIGEN2/EGM96 hybrid global geoid model would be suitable for use in future Australia-New Zealand geoid solutions. Although inconclusive, results from this study suggest both EIGEN2/EGM96 and UCPH2/EGM96 would be suitable for this purpose.

8.4 Project Close

The aim of this project was to compare the accuracy and reliability of several geoid models against empirically derived geoid heights to determine the suitability of each geoid model for use with GPS heighting on the Great Dividing Range escarpment at Toowoomba. This project aim has been fully achieved through comparisons of the OSU91A, EGM96, EIGEN2/EGM96, UCPH2/EGM96 and PGM2000A global geoid models and the bi-cubic and bi-linear interpolation of the SBA Technique, the RBA Technique, AUSGeoid93 and AUSGeoid98 geoid models of Australia against 116 empirically derived geoid heights in an absolute and relative sense. The project was successful to the extent that the bi-cubically interpolated gravimetric geoid model of Australia, AUSGeoid98, was determined to be the superior model for converting GPS-derived ellipsoid heights to elevations on the AHD over the Great Dividing Range escarpment at Toowoomba to an acceptable accuracy and precision that satisfied the equivalent 3rd Order levelling specifications. In achieving the project aim, all project objectives were met.

In closing, it should be reaffirmed that empirical validation of gravimetric geoid models on land does not provide an unequivocal assessment of gravimetric geoid determination techniques due to the errors residing in the GPS and levelling data. However, at present land-based comparisons are the only practical means of verifying the integrity of gravimetric geoid models.

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APPENDIX A

PROJECT SPECIFICATION

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/2 *Research Project*
PROJECT SPECIFICATION

FOR: **Adam McDONALD**

TOPIC: WHICH GEOID MODEL SHOULD BE USED FOR GPS HEIGHTING ON THE TOOWOOMBA BYPASS PROJECT?

SUPERVISOR: Mr. Peter Gibbings

ENROLMENT: ENG 4111 – S1, E, 2004;
ENG 4112 – S2, E, 2004.

PROJECT AIM: The aim of this project is to compare the accuracy and reliability of several geoid models against empirically derived geoid heights to determine the suitability of each geoid model for use with GPS heighting on the Great Dividing Range escarpment at Toowoomba.

PROGRAMME: **Issue D, 11th September 2004**

1. To meet the objectives of ENG 4111/4112 Research Project.
2. Review existing literature to identify current methods used to assess gravimetric geoid models on land and any limitations associated with their application.
3. Identify and appraise the various commonly used and prototype gravimetric geoid models currently available to the GPS user for heighting purposes.
4. Investigate the geoid model test schemes used by other researchers and describe the results obtained in similar studies.
5. Design a suitable control network utilising Toowoomba Bypass control stations and suitable permanent marks and collect GPS and levelling data as appropriate.
6. Attach an error estimate to the GPS and levelling data following appropriate adjustments techniques.
7. Compare the accuracy and reliability of several geoid models over the test site using methods and test schemes determined from (2) and (4) above.
8. Determine whether GPS in conjunction with each geoid model tested can achieve an accuracy and precision equivalent to that obtained via conventional levelling on the Toowoomba Bypass project.
9. Assess whether any of the gravimetric geoid models tested are more suitable for GPS heighting than AUSGeoid98 on the Toowoomba Bypass project.

AGREED: ___________________ (student) _____________________(Supervisor)

APPENDIX B

LIST OF N VALUES INTERPOLATED AT EACH CONTROL POINT USING EACH GLOBAL GEOID MODEL AND GEOID MODEL OF AUSTRALIA

Title: N Values Interpolated at each Control Point using each Global Geoid Model and Geoid Model of Australia
Coordinate Source: Constrained Least-squares Adjustment of the Toowoomba Bypass Control Network: TB_Cntrl_Const_7.trc
Project Datum (ϕ,λ,h): GDA94 (GRS80 Ellipsoid)
Levelling Height Datum: AHD Derived
Units: h, H and N in metres

Toowoomba Bypass Control Data						Global Geoid Models				
	GDA94	GDA94	GDA94	AHDD	(h - H)	(OSU91A)	(EGM96)	(EIGEN2/EGM96)	(UCPH2/EGM96)	(PGM2000A)
Stn	ϕ	λ	h	H	N_{CTRL}	N	N	N	N	N
CS01	-27°37'10.3282"	151°46'11.2567"	561.530	519.195	42.335	41.832	41.127	41.751	41.768	41.802
CS02	-27°37'03.5082"	151°46'29.6524"	559.309	516.939	42.370	41.845	41.141	41.765	41.782	41.816
CS03	-27°36'58.8904"	151°46'48.9011"	543.069	500.708	42.361	41.856	41.153	41.777	41.794	41.828
CS04	-27°36'54.2756"	151°47'04.6151"	537.091	494.745	42.346	41.865	41.164	41.788	41.805	41.839
CS05	-27°36'51.4814"	151°47'22.5651"	537.290	494.739	42.551	41.874	41.174	41.798	41.815	41.849
CS06	-27°36'29.7017"	151°47'07.4785"	539.781	497.419	42.362	41.886	41.186	41.810	41.827	41.861
CS07	-27°36'17.6750"	151°47'11.4120"	532.261	489.893	42.368	41.897	41.198	41.822	41.838	41.872
CS08	-27°36'03.3919"	151°47'21.8075"	525.179	482.796	42.383	41.912	41.214	41.839	41.855	41.889
CS09	-27°35'50.0109"	151°47'27.2725"	515.638	473.254	42.384	41.925	41.227	41.852	41.868	41.902
CS10	-27°35'36.3844"	151°47'43.9767"	517.582	475.179	42.403	41.942	41.246	41.871	41.887	41.921
CS11	-27°35'29.2435"	151°47'54.4696"	512.105	469.755	42.350	41.951	41.256	41.881	41.897	41.931
CS12	-27°35'12.9486"	151°48'02.7136"	501.325	458.898	42.427	41.967	41.273	41.899	41.914	41.948
CS13	-27°34'55.2724"	151°48'05.1935"	505.405	462.963	42.442	41.982	41.289	41.915	41.930	41.964
CS14	-27°34'44.2145"	151°48'15.7257"	491.327	448.875	42.452	41.995	41.303	41.928	41.943	41.978
CS15	-27°34'24.5989"	151°48'14.4431"	515.237	472.763	42.474	42.010	41.319	41.944	41.959	41.993
CS16	-27°34'08.3845"	151°48'27.6936"	499.156	456.674	42.482	42.028	41.337	41.964	41.978	42.012
CS17	-27°33'56.9597"	151°48'37.9829"	509.674	467.167	42.507	42.041	41.351	41.977	41.991	42.026
CS18	-27°33'45.2533"	151°48'47.4965"	522.943	480.413	42.530	42.053	41.365	41.991	42.005	42.040
CS19	-27°33'39.0827"	151°48'59.5812"	530.887	488.345	42.542	42.062	41.375	42.001	42.015	42.050
CS20	-27°33'34.5905"	151°49'21.8834"	559.903	517.355	42.548	42.073	41.387	42.013	42.027	42.062
CS21	-27°33'23.0957"	151°49'36.2020"	569.708	527.147	42.561	42.087	41.402	42.028	42.042	42.077
CS22	-27°33'11.7623"	151°49'52.0072"	577.477	534.891	42.586	42.101	41.418	42.044	42.058	42.092
CS23	-27°33'01.9078"	151°49'59.4409"	564.673	522.078	42.595	42.111	41.429	42.055	42.069	42.103
CS24	-27°32'47.9193"	151°49'52.3910"	562.239	519.632	42.607	42.120	41.438	42.064	42.078	42.112
CS25	-27°32'50.0874"	151°50'08.6559"	568.313	525.700	42.613	42.124	41.442	42.068	42.082	42.117
CS26	-27°32'52.2169"	151°50'24.2065"	587.315	544.695	42.620	42.127	41.446	42.072	42.086	42.121
CS27	-27°32'33.9362"	151°50'19.4199"	560.579	517.948	42.631	42.140	41.459	42.086	42.099	42.134
CS28	-27°32'26.5307"	151°50'31.2571"	554.736	512.094	42.642	42.149	41.470	42.096	42.110	42.144

Toowoomba Bypass Control Data						Global Geoid Models				
	GDA94	GDA94	GDA94	AHDD	(h - H)	(OSU91A)	(EGM96)	(EIGEN2/EGM96)	(UCPH2/EGM96)	(PGM2000A)
Stn	ϕ	λ	***h***	**H**	N_{CTRL}	**N**	**N**	**N**	**N**	**N**
CS29	-27°32'34.0311"	151°50'42.3246"	567.686	525.058	42.628	42.147	41.467	42.094	42.107	42.142
CS30	-27°32'18.8114"	151°50'44.8713"	554.077	511.415	42.662	42.160	41.481	42.108	42.121	42.156
CS31	-27°32'04.0115"	151°50'46.6593"	541.540	498.879	42.661	42.172	41.494	42.121	42.134	42.169
CS32	-27°32'02.7790"	151°51'02.4241"	539.921	497.244	42.677	42.178	41.500	42.127	42.140	42.175
CS33	-27°31'53.3131"	151°51'18.8946"	538.979	496.288	42.691	42.190	41.514	42.141	42.154	42.189
CS34	-27°31'43.8138"	151°51'32.6810"	553.275	510.566	42.709	42.202	41.527	42.153	42.166	42.201
CS35	-27°31'26.2001"	151°51'38.7873"	559.255	516.525	42.730	42.217	41.543	42.170	42.183	42.218
CS36	-27°31'07.6930"	151°51'53.2994"	554.574	511.823	42.751	42.236	41.563	42.191	42.203	42.238
CS37	-27°30'52.2520"	151°52'01.6294"	553.818	511.059	42.759	42.251	41.579	42.206	42.218	42.254
CS38	-27°30'37.4246"	151°52'17.0749"	549.612	506.835	42.777	42.267	41.596	42.224	42.236	42.271
CS39	-27°30'34.3088"	151°52'33.6732"	555.118	512.325	42.793	42.274	41.604	42.231	42.243	42.279
CS40	-27°30'37.2142"	151°52'53.5679"	565.926	523.120	42.806	42.277	41.608	42.235	42.247	42.282
CS41	-27°30'39.5126"	151°53'09.7177"	554.345	511.529	42.816	42.279	41.611	42.238	42.250	42.285
CS42	-27°30'44.5909"	151°53'34.7582"	581.761	538.936	42.825	42.281	41.614	42.241	42.253	42.289
CS43	-27°30'39.5906"	151°53'59.4638"	568.023	525.181	42.842	42.291	41.626	42.252	42.265	42.300
CS44	-27°30'30.2789"	151°54'15.9270"	551.634	508.790	42.844	42.302	41.638	42.265	42.277	42.312
CS45	-27°32'08.5462"	151°54'22.6587"	665.982	623.169	42.813	42.225	41.560	42.185	42.199	42.234
CS46	-27°31'57.4408"	151°54'21.9303"	656.397	613.581	42.816	42.233	41.569	42.194	42.208	42.243
CS47	-27°31'37.7046"	151°54'25.7897"	611.819	569.004	42.815	42.250	41.586	42.211	42.225	42.260
CS48	-27°31'25.6373"	151°54'28.0552"	593.313	550.497	42.816	42.260	41.596	42.222	42.235	42.270
CS49	-27°31'11.0089"	151°54'30.5164"	584.240	541.416	42.824	42.272	41.609	42.235	42.248	42.283
CS50	-27°30'55.6052"	151°54'33.5103"	579.006	536.180	42.826	42.285	41.622	42.248	42.261	42.296
CS51	-27°30'39.0652"	151°54'35.7330"	563.208	520.369	42.839	42.299	41.636	42.263	42.275	42.310
CS52	-27°30'22.0670"	151°54'35.1341"	574.242	531.376	42.866	42.313	41.650	42.277	42.289	42.324
CS53	-27°29'58.9601"	151°54'37.5365"	560.749	517.876	42.873	42.332	41.670	42.297	42.308	42.344
CS54	-27°29'42.4343"	151°54'39.9677"	548.381	505.504	42.877	42.345	41.684	42.311	42.322	42.358
CS55	-27°29'15.5903"	151°54'34.3363"	546.157	503.260	42.897	42.366	41.704	42.332	42.343	42.378
CS56	-27°28'57.6956"	151°54'35.3756"	568.855	525.944	42.911	42.381	41.719	42.347	42.358	42.393
CS57	-27°30'31.2947"	151°54'59.4873"	633.631	590.766	42.865	42.310	41.649	42.275	42.288	42.323
CS58	-27°30'32.9978"	151°55'23.7233"	593.558	550.717	42.841	42.314	41.654	42.280	42.293	42.328
CS59	-27°30'38.4366"	151°55'42.4263"	598.818	555.967	42.851	42.313	41.655	42.280	42.293	42.328
CS60	-27°30'39.5227"	151°55'50.6836"	590.303	547.462	42.841	42.314	41.656	42.281	42.294	42.329
CS61	-27°30'44.8118"	151°56'09.9519"	573.502	530.680	42.822	42.313	41.656	42.282	42.295	42.330
CS62	-27°30'58.7015"	151°56'29.2737"	595.020	552.162	42.858	42.306	41.650	42.275	42.288	42.323

Toowoomba Bypass Control Data						Global Geoid Models				
	GDA94	GDA94	GDA94	AHDD	(h - H)	(OSU91A)	(EGM96)	(EIGEN2/EGM96)	(UCPH2/EGM96)	(PGM2000A)
Stn	ϕ	λ	h	H	N_{CTRL}	N	N	N	N	N
CS63	-27°32'44.8222"	151°56'49.9736"	623.627	580.859	42.768	42.224	41.570	42.193	42.208	42.243
CS64	-27°32'25.1688"	151°56'39.2697"	615.536	572.755	42.781	42.238	41.583	42.206	42.221	42.256
CS65	-27°32'06.3627"	151°56'41.1770"	621.873	579.070	42.803	42.253	41.598	42.222	42.236	42.272
CS66	-27°31'40.8491"	151°56'36.6400"	611.186	568.367	42.819	42.273	41.618	42.242	42.256	42.291
CS68	-27°31'07.1520"	151°56'44.5534"	606.112	563.248	42.864	42.301	41.647	42.271	42.285	42.320
CS69	-27°31'14.1902"	151°56'55.6876"	614.671	571.819	42.852	42.298	41.644	42.268	42.282	42.317
CS70	-27°31'11.4855"	151°57'15.5191"	671.932	629.061	42.871	42.303	41.650	42.274	42.288	42.323
CS71	-27°30'13.3759"	151°54'34.8327"	579.565	536.698	42.867	42.319	41.657	42.284	42.296	42.331
CS72	-27°31'02.4479"	151°57'21.4756"	633.456	590.573	42.883	42.311	41.659	42.283	42.297	42.332
CS73	-27°30'47.0741"	151°57'29.2206"	616.653	573.786	42.867	42.325	41.673	42.297	42.311	42.346
CS74	-27°30'41.1296"	151°57'48.5454"	617.758	574.899	42.859	42.332	41.682	42.306	42.319	42.354
CS75	-27°30'36.5345"	151°58'05.5310"	507.871	465.025	42.846	42.338	41.689	42.313	42.326	42.361
CS76	-27°30'15.6269"	151°58'17.0374"	520.127	477.286	42.841	42.356	41.708	42.332	42.345	42.380
CS77	-27°30'07.1644"	151°58'28.3748"	443.718	400.885	42.833	42.365	41.717	42.341	42.354	42.389
CS78	-27°29'58.0960"	151°58'34.3487"	486.845	443.974	42.871	42.373	41.725	42.349	42.362	42.398
CS79	-27°30'02.0921"	151°58'50.5561"	420.610	377.768	42.842	42.371	41.725	42.349	42.362	42.397
CS80	-27°30'13.6532"	151°59'10.5131"	471.535	428.700	42.835	42.364	41.719	42.343	42.356	42.391
CS81	-27°30'28.4653"	151°59'22.0126"	499.326	456.505	42.821	42.354	41.709	42.333	42.346	42.381
CS82	-27°30'46.3248"	151°59'22.6118"	455.558	412.763	42.795	42.339	41.695	42.318	42.332	42.367
CS83	-27°30'55.5731"	151°59'32.8562"	477.992	435.232	42.760	42.333	41.690	42.312	42.327	42.362
CS84	-27°30'59.8175"	151°59'54.5741"	371.128	328.383	42.745	42.332	41.690	42.312	42.327	42.362
CS85	-27°30'53.4880"	152°00'10.2399"	436.019	393.234	42.785	42.338	41.697	42.320	42.334	42.369
CS86	-27°30'58.2684"	152°00'26.9202"	392.872	350.143	42.729	42.337	41.696	42.318	42.332	42.368
CS87	-27°30'56.2399"	152°00'46.4687"	392.959	350.244	42.715	42.341	41.700	42.322	42.337	42.372
CS88	-27°31'01.6480"	152°01'03.3968"	358.981	316.291	42.690	42.338	41.698	42.320	42.334	42.370
CS89	-27°31'00.8103"	152°01'23.1105"	307.329	264.660	42.669	42.341	41.702	42.323	42.337	42.373
CS90	-27°30'56.8137"	152°01'40.0326"	282.615	239.948	42.667	42.346	41.707	42.328	42.342	42.377
CS91	-27°30'55.1646"	152°01'58.4615"	286.888	244.212	42.676	42.349	41.710	42.331	42.346	42.381
CS92	-27°30'51.3116"	152°02'13.0933"	300.526	257.844	42.682	42.353	41.714	42.335	42.350	42.385
CS93	-27°30'47.3381"	152°02'22.2957"	356.656	313.957	42.699	42.357	41.718	42.339	42.354	42.389
CS94	-27°30'46.8603"	152°02'40.5010"	305.454	262.733	42.721	42.359	41.720	42.341	42.356	42.391
CS95	-27°30'59.5517"	152°03'01.9373"	279.268	236.748	42.520	42.350	41.712	42.332	42.347	42.382
CS96	-27°31'11.3637"	152°03'12.9487"	306.704	264.149	42.555	42.341	41.704	42.324	42.339	42.374
CS97	-27°31'16.9521"	152°03'29.7463"	273.736	231.189	42.547	42.338	41.701	42.320	42.336	42.371

Toowoomba Bypass Control Data						Global Geoid Models				
	GDA94	GDA94	GDA94	AHDD	(h - H)	(OSU91A)	(EGM96)	(EIGEN2/EGM96)	(UCPH2/EGM96)	(PGM2000A)
Stn	**ϕ**	**λ**	***h***	**H**	**N_{CTRL}**	**N**	**N**	**N**	**N**	**N**
CS98	-27°31'22.6710"	152°03'45.5413"	253.166	210.632	42.534	42.334	41.697	42.316	42.332	42.367
CS99	-27°31'31.7738"	152°04'00.4854"	248.536	206.006	42.530	42.327	41.691	42.310	42.326	42.361
CS100	-27°31'41.1558"	152°04'13.8580"	244.063	201.542	42.521	42.320	41.685	42.303	42.319	42.354
CS101	-27°31'56.2560"	152°04'26.5645"	217.212	174.708	42.504	42.308	41.674	42.292	42.308	42.343
CS102	-27°32'09.0671"	152°04'33.0801"	215.398	172.919	42.479	42.298	41.664	42.282	42.299	42.333
CS103	-27°32'25.4512"	152°04'38.9416"	218.008	175.525	42.483	42.286	41.652	42.269	42.286	42.321
CS104	-27°32'39.0469"	152°04'48.2614"	218.750	176.291	42.459	42.275	41.642	42.259	42.276	42.311
CS105	-27°32'48.4139"	152°05'05.5583"	203.158	160.728	42.430	42.268	41.635	42.252	42.269	42.304
CS106	-27°32'52.7006"	152°05'27.7184"	212.717	170.307	42.410	42.265	41.633	42.249	42.267	42.301
CS107	-27°32'49.8069"	152°05'48.0136"	195.653	153.273	42.380	42.267	41.635	42.251	42.269	42.303
CS108	-27°32'51.1624"	152°06'03.3038"	191.590	149.204	42.386	42.266	41.634	42.250	42.268	42.302
PM35751	-27°30'34.7743"	151°57'18.4195"	751.101	708.203	42.898	42.333	41.680	42.305	42.318	42.353
PM40970	-27°30'36.6897"	152°02'03.5264"	466.669	423.956	42.713	42.364	41.725	42.346	42.360	42.396
PM66947	-27°32'36.4499"	152°03'05.2715"	253.129	210.615	42.514	42.273	41.638	42.256	42.273	42.308
PM85731	-27°30'38.4820"	152°04'13.8654"	213.646	170.998	42.648	42.370	41.733	42.352	42.367	42.403
PM68101	-27°33'12.5407"	152°01'26.8412"	304.223	261.665	42.558	42.236	41.599	42.219	42.235	42.270
PM51843	-27°33'11.5512"	151°52'33.1649"	693.476	650.640	42.836	42.148	41.475	42.100	42.114	42.149
PM57526	-27°31'09.5767"	152°00'02.2281"	335.771	293.062	42.709	42.325	41.683	42.305	42.320	42.355
PM112793	-27°28'10.5208"	151°58'47.8521"	448.507	405.571	42.936	42.462	41.814	42.440	42.451	42.486
PM112799	-27°36'30.0339"	151°51'12.7222"	586.242	543.758	42.484	41.967	41.285	41.907	41.925	41.959

	Geoid Models of Australia							
	(SBA Tech)	(RBA Tech)	(AUSGeoid93)	(AUSGeoid98)	(SBA Tech)	(RBA Tech)	(AUSGeoid93)	(AUSGeoid98)
	(Bi-cubic Interpolation)				(Bi-linear Interpolation)			
Stn	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
CS01	40.138	40.073	41.905	41.714	40.138	40.073	41.876	41.714
CS02	40.147	40.083	41.917	41.724	40.148	40.083	41.888	41.724
CS03	40.156	40.091	41.926	41.733	40.157	40.092	41.899	41.733
CS04	40.164	40.099	41.935	41.741	40.165	40.100	41.908	41.741
CS05	40.172	40.107	41.943	41.749	40.173	40.108	41.917	41.749
CS06	40.180	40.115	41.954	41.757	40.181	40.117	41.929	41.758
CS07	40.189	40.124	41.964	41.766	40.190	40.125	41.939	41.767
CS08	40.201	40.136	41.978	41.779	40.203	40.138	41.955	41.780
CS09	40.212	40.147	41.990	41.790	40.213	40.149	41.967	41.791
CS10	40.227	40.163	42.006	41.805	40.229	40.164	41.985	41.806
CS11	40.236	40.172	42.014	41.814	40.237	40.173	41.995	41.815
CS12	40.251	40.187	42.029	41.828	40.252	40.188	42.011	41.829
CS13	40.265	40.201	42.043	41.841	40.266	40.202	42.026	41.842
CS14	40.278	40.214	42.055	41.854	40.279	40.216	42.039	41.855
CS15	40.292	40.228	42.069	41.867	40.293	40.229	42.054	41.867
CS16	40.311	40.247	42.086	41.884	40.312	40.248	42.073	41.885
CS17	40.325	40.262	42.098	41.898	40.326	40.263	42.087	41.898
CS18	40.339	40.276	42.110	41.911	40.341	40.277	42.100	41.912
CS19	40.351	40.288	42.118	41.922	40.352	40.289	42.111	41.922
CS20	40.368	40.305	42.128	41.937	40.369	40.305	42.124	41.937
CS21	40.386	40.322	42.141	41.953	40.386	40.323	42.140	41.953
CS22	40.404	40.341	42.153	41.970	40.405	40.341	42.157	41.970
CS23	40.417	40.353	42.163	41.981	40.417	40.354	42.168	41.982
CS24	40.424	40.361	42.173	41.988	40.424	40.361	42.177	41.989
CS25	40.432	40.368	42.175	41.995	40.432	40.368	42.178	41.996
CS26	40.439	40.376	42.176	42.002	40.439	40.375	42.176	42.002
CS27	40.451	40.388	42.191	42.013	40.451	40.388	42.191	42.014
CS28	40.464	40.401	42.199	42.026	40.464	40.401	42.198	42.025

	Geoid Models of Australia							
	(SBA Tech)	(RBA Tech)	(AUSGeoid93)	(AUSGeoid98)	(SBA Tech)	(RBA Tech)	(AUSGeoid93)	(AUSGeoid98)
	(Bi-cubic Interpolation)				(Bi-linear Interpolation)			
Stn	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
CS29	40.465	40.401	42.195	42.026	40.464	40.401	42.191	42.025
CS30	40.479	40.416	42.209	42.039	40.478	40.415	42.204	42.038
CS31	40.492	40.429	42.222	42.052	40.491	40.428	42.216	42.051
CS32	40.502	40.439	42.226	42.061	40.501	40.438	42.217	42.060
CS33	40.519	40.456	42.237	42.078	40.518	40.455	42.225	42.076
CS34	40.535	40.472	42.248	42.092	40.534	40.471	42.233	42.091
CS35	40.552	40.489	42.264	42.109	40.552	40.489	42.247	42.109
CS36	40.575	40.512	42.283	42.131	40.576	40.513	42.263	42.132
CS37	40.592	40.529	42.298	42.148	40.593	40.530	42.276	42.149
CS38	40.612	40.549	42.314	42.167	40.612	40.549	42.288	42.167
CS39	40.623	40.560	42.319	42.177	40.622	40.559	42.291	42.175
CS40	40.630	40.567	42.319	42.182	40.629	40.565	42.288	42.181
CS41	40.636	40.572	42.319	42.187	40.634	40.571	42.286	42.185
CS42	40.642	40.578	42.317	42.191	40.641	40.577	42.282	42.190
CS43	40.656	40.592	42.323	42.203	40.656	40.592	42.286	42.203
CS44	40.669	40.605	42.332	42.214	40.668	40.604	42.294	42.213
CS45	40.592	40.528	42.245	42.137	40.589	40.525	42.210	42.135
CS46	40.600	40.536	42.255	42.145	40.598	40.534	42.220	42.143
CS47	40.617	40.553	42.272	42.162	40.615	40.551	42.236	42.160
CS48	40.628	40.564	42.283	42.172	40.625	40.561	42.247	42.170
CS49	40.640	40.576	42.296	42.184	40.637	40.574	42.259	42.182
CS50	40.653	40.590	42.310	42.197	40.651	40.587	42.272	42.195
CS51	40.668	40.604	42.325	42.211	40.665	40.601	42.287	42.209
CS52	40.682	40.618	42.341	42.225	40.679	40.615	42.301	42.223
CS53	40.702	40.638	42.362	42.245	40.698	40.634	42.321	42.242
CS54	40.717	40.654	42.377	42.260	40.714	40.650	42.337	42.257
CS55	40.740	40.676	42.402	42.283	40.737	40.673	42.364	42.281
CS56	40.757	40.693	42.419	42.300	40.754	40.690	42.381	42.298
CS57	40.680	40.617	42.333	42.221	40.676	40.613	42.293	42.219
CS58	40.683	40.620	42.331	42.223	40.680	40.617	42.292	42.220
CS59	40.681	40.618	42.326	42.219	40.680	40.616	42.287	42.219
CS60	40.681	40.618	42.325	42.219	40.680	40.617	42.286	42.219
CS61	40.677	40.614	42.319	42.214	40.676	40.613	42.281	42.214
CS62	40.665	40.602	42.305	42.201	40.662	40.599	42.269	42.200

	Geoid Models of Australia							
	(SBA Tech)	(RBA Tech)	(AUSGeoid93)	(AUSGeoid98)	(SBA Tech)	(RBA Tech)	(AUSGeoid93)	(AUSGeoid98)
	(Bi-cubic Interpolation)				(Bi-linear Interpolation)			
Stn	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
CS63	40.581	40.517	42.208	42.116	40.575	40.511	42.177	42.112
CS64	40.596	40.533	42.227	42.133	40.591	40.527	42.194	42.129
CS65	40.610	40.547	42.244	42.147	40.605	40.541	42.210	42.143
CS66	40.630	40.567	42.267	42.167	40.626	40.563	42.233	42.164
CS68	40.656	40.593	42.296	42.193	40.653	40.589	42.262	42.190
CS69	40.649	40.586	42.289	42.185	40.645	40.582	42.256	42.183
CS70	40.648	40.584	42.289	42.184	40.644	40.580	42.258	42.181
CS71	40.689	40.625	42.349	42.232	40.686	40.622	42.309	42.230
CS72	40.654	40.590	42.297	42.190	40.651	40.587	42.266	42.188
CS73	40.664	40.601	42.309	42.200	40.662	40.598	42.279	42.199
CS74	40.664	40.600	42.312	42.201	40.664	40.600	42.284	42.201
CS75	40.662	40.598	42.313	42.200	40.663	40.599	42.288	42.201
CS76	40.675	40.612	42.330	42.215	40.675	40.611	42.306	42.214
CS77	40.679	40.615	42.336	42.219	40.677	40.614	42.314	42.217
CS78	40.685	40.621	42.343	42.225	40.683	40.619	42.322	42.223
CS79	40.674	40.611	42.336	42.215	40.672	40.608	42.318	42.213
CS80	40.655	40.590	42.321	42.196	40.653	40.589	42.308	42.195
CS81	40.635	40.570	42.304	42.177	40.635	40.570	42.295	42.177
CS82	40.618	40.553	42.288	42.161	40.618	40.553	42.279	42.161
CS83	40.604	40.539	42.276	42.148	40.605	40.539	42.271	42.148
CS84	40.587	40.522	42.266	42.133	40.590	40.524	42.267	42.135
CS85	40.585	40.519	42.267	42.131	40.588	40.522	42.267	42.133
CS86	40.571	40.505	42.257	42.118	40.573	40.508	42.253	42.119
CS87	40.561	40.496	42.251	42.109	40.564	40.499	42.243	42.110
CS88	40.546	40.480	42.238	42.093	40.549	40.484	42.229	42.096
CS89	40.535	40.470	42.230	42.083	40.539	40.473	42.218	42.085
CS90	40.530	40.465	42.225	42.077	40.533	40.468	42.211	42.080
CS91	40.522	40.456	42.216	42.068	40.525	40.459	42.202	42.071
CS92	40.518	40.452	42.211	42.064	40.522	40.456	42.197	42.068
CS93	40.517	40.452	42.210	42.063	40.521	40.456	42.195	42.067
CS94	40.508	40.443	42.199	42.054	40.513	40.448	42.185	42.058
CS95	40.482	40.417	42.173	42.029	40.488	40.422	42.161	42.033
CS96	40.463	40.397	42.153	42.010	40.468	40.403	42.144	42.015
CS97	40.448	40.382	42.136	41.995	40.453	40.387	42.130	42.000

	Geoid Models of Australia							
	(SBA Tech)	(RBA Tech)	(AUSGeoid93)	(AUSGeoid98)	(SBA Tech)	(RBA Tech)	(AUSGeoid93)	(AUSGeoid98)
	(Bi-cubic Interpolation)				(Bi-linear Interpolation)			
Stn	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
CS98	40.434	40.368	42.119	41.981	40.438	40.372	42.115	41.985
CS99	40.416	40.350	42.099	41.963	40.419	40.353	42.099	41.966
CS100	40.399	40.333	42.080	41.946	40.402	40.336	42.083	41.949
CS101	40.376	40.310	42.055	41.924	40.378	40.312	42.062	41.926
CS102	40.359	40.293	42.037	41.907	40.362	40.296	42.047	41.910
CS103	40.339	40.273	42.016	41.888	40.345	40.278	42.029	41.892
CS104	40.321	40.254	41.996	41.869	40.327	40.261	42.011	41.875
CS105	40.302	40.236	41.973	41.851	40.310	40.244	41.993	41.858
CS106	40.287	40.221	41.952	41.836	40.295	40.228	41.976	41.842
CS107	40.280	40.214	41.939	41.829	40.287	40.221	41.967	41.834
CS108	40.272	40.206	41.926	41.820	40.279	40.212	41.957	41.825
PM35751	40.677	40.614	42.322	42.213	40.674	40.610	42.290	42.211
PM40970	40.540	40.475	42.231	42.084	40.543	40.477	42.216	42.087
PM66947	40.380	40.314	42.075	41.932	40.385	40.319	42.074	41.936
PM85731	40.475	40.410	42.145	42.018	40.479	40.414	42.138	42.022
PM68101	40.414	40.348	42.103	41.966	40.418	40.352	42.099	41.968
PM51843	40.494	40.430	42.181	42.050	40.492	40.428	42.158	42.048
PM57526	40.573	40.508	42.255	42.121	40.576	40.511	42.257	42.123
PM112793	40.789	40.725	42.440	42.334	40.788	40.723	42.426	42.332
PM112799	40.289	40.224	42.006	41.859	40.289	40.224	41.993	41.858

APPENDIX C

AUSPOS ONLINE GPS PROCESSING REPORTS FOR 20 POST-PROCESSED POINT POSITIONS

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AUSPOS Online GPS Processing Report

Space Geodesy Analysis Centre
The National Mapping Division (NMD), Geoscience Australia

April 22, 2003

This document is a report of the GPS data processing undertaken by the AUSPOS Online GPS Processing Service. The AUSPOS Online GPS Processing Service uses International GPS Service (IGS) products (final, rapid, ultra-rapid depending on availability) including Precise Orbits, Earth Orientation, Coordinate Solutions (IGS-SSC) to compute precise coordinates in ITRF anywhere on Earth. The Service is designed to process only dual frequency GPS phase data.

The AUSPOS Online GPS Processing Service is a free service and you are encouraged to use it for your projects. However, you may not charge others for this service. Geoscience Australia does not warrant that this service a) is error free; b) meets the customer's requirements. Geoscience Australia shall not be liable to the customer in respect of any loss, damage or injury (including consequential loss, damage or injury) however caused, which may arise directly or indirectly in respect of this service.

An overview of the GPS processing strategy is attached to this report. Please direct email correspondence to geodesy@auslig.gov.au

AUSPOS Project Manager

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The National Mapping Division
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Job number: #13471; User: `solicitor@lawsystems.com.au` AUSPOS version 1.01.23

1 User and IGS GPS Data

All antenna heights refer to the vertical distance from the Ground Mark to the Antennna Reference Point (ARP).

User File	Antenna Type	Antenna Height (m)	Start Time	End Time
Psm30860.03o	LEIAT502	1.4780	2003-03-28 00:00:00	2003-03-28 08:13:00
Cs100870.03o	LEIAT502	1.2490	2003-03-28 21:18:59	2003-03-29 07:21:00
Cs700880.03o	LEIAT502	1.1780	2003-03-29 08:39:00	2003-03-29 15:20:00
Cs000880.03o	LEIAT502	1.2180	2003-03-29 21:17:59	2003-03-30 07:31:59

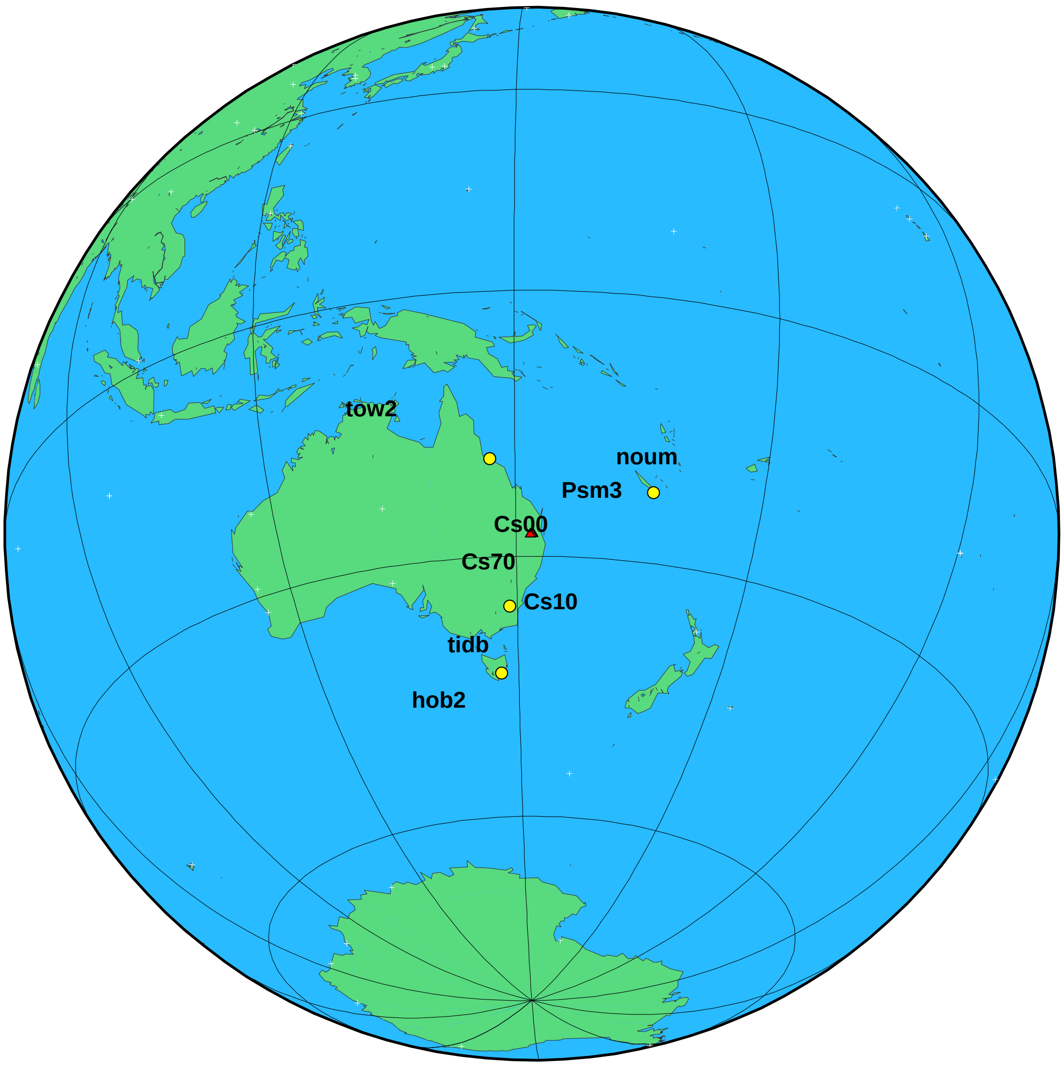

Figure 1: Global View – submitted GPS station(s) and nearby IGS GPS stations used in the processing; triangle(s) represent submitted user data; circle(s) represent the nearest available IGS stations.

2 Processing Summary

Date	IGS Data	User Data	Orbit Type
2003-03-28	tidb tow2 noum	Cs10 Psm3	IGS Final
2003-03-29	tidb tow2 hob2	Cs00 Cs70 Cs10	IGS Final
2003-03-30	tidb tow2 noum	Cs00	IGS Final

3 Computed Coordinates, GDA94

For Australian users Geocentric Datum of Australia (GDA94, ITRF92@1994.0) coordinates are provided. GDA94 coordinates are determined from ITRF coordinates by an Geoscience Australia (GA) derived coordinate transformation process. GA transformation parameters between ITRF and GDA94 are re-computed weekly, incorporating the latest available tectonic motions (determined from the GA GPS network). GA recommends that users within Australia use GDA94 coordinates. All coordinates refer to the Ground Mark. For general/technical information on GDA94 see www.auslig.gov.au/geodesy/datums/gda.htm and www.anzlic.org.au/icsm/gdatm/

3.1 Cartesian, GDA94

	X(m)	Y(m)	Z(m)	
tidb	-4460996.067	2682557.136	-3674443.861	GDA94
tow2	-5054582.664	3275504.564	-2091539.890	GDA94
noum	-5739971.530	1387563.771	-2402123.709	GDA94
Cs10	-5001320.221	2648434.841	-2932196.041	GDA94
Psm3	-4996892.145	2661917.813	-2928766.640	GDA94
hob2	-3950071.284	2522415.222	-4311638.525	GDA94
Cs00	-4983143.356	2675321.460	-2939473.611	GDA94
Cs70	-4996331.896	2661709.579	-2929732.348	GDA94

3.2 Geodetic, GRS80 Ellipsoid, GDA94

The height above the Geoid is computed using the GPS Ellipsoidal height and subtracting a Geoid-Ellipsoid separation. Geoid-Ellipsoidal separations are computed using a bilinear interpolation of the AUSGeoid98 grid. The height above the Geoid is only provided for sites within the AUSGeoid98 extents. For information on AUSGeoid98 see www.auslig.gov.au/geodesy/ausgeoid/geoid.htm

	Latitude(DMS)	Longitude(DMS)	Ellipsoidal Height(m)	Above-Geoid Height(m)	
tidb	-35-23 -57.1560	148 58 47.9845	665.427	646.141	GDA94
tow2	-19-16 -9.4282	147 3 20.4654	88.219	30.130	GDA94
noum	-22-16 -11.4785	166 24 36.7158	83.161		GDA94
Cs10	-27-32 -49.8068	152 5 48.0145	195.663	153.829	GDA94
Psm3	-27-30 -34.7742	151 57 18.4197	751.143	708.931	GDA94
hob2	-42-48 -16.9852	147 26 19.4356	41.144	44.450	GDA94
Cs00	-27-37 -10.3284	151 46 11.2554	561.553	519.840	GDA94
Cs70	-27-31 -11.4855	151 57 15.5185	671.911	629.730	GDA94

3.3 MGA Grid, GRS80 Ellipsoid, GDA94

	East(M)	North(M)	Zone	Ellipsoidal Height(m)	Above-Geoid Height(m)	
tidb	679807.859	6080884.476	55	665.427	646.141	GDA94
tow2	505851.331	7869375.316	55	88.219	30.130	GDA94
noum	645295.439	7536625.658	58	83.161		GDA94
Cs10	410811.742	6952633.269	56	195.663	153.829	GDA94
Psm3	396799.842	6956678.546	56	751.143	708.931	GDA94
hob2	535873.398	5260777.227	55	41.144	44.450	GDA94
Cs00	378615.435	6944338.257	56	561.553	519.840	GDA94
Cs70	396729.768	6955548.206	56	671.911	629.730	GDA94

4 Computed Coordinates, ITRF2000

All computed coordinates are based on the IGS realisation of the ITRF2000 reference frame, provided by the IGS cumulative solution. All the given ITRF2000 coordinates refer to a mean epoch of the site observation data. All coordinates refer to the Ground Mark.

4.1 Cartesian, ITRF2000

	X(m)	Y(m)	Z(m)	ITRF2000 @
tidb	-4460996.369	2682557.088	-3674443.425	2003/03/29
tow2	-5054582.903	3275504.371	-2091539.393	2003/03/29
noum	-5739971.670	1387563.573	-2402123.293	2003/03/29
Cs10	-5001320.473	2648434.712	-2932195.582	2003/03/29
Cs10	0.032 m	0.005 m	0.017 m	RMS
Psm3	-4996892.398	2661917.684	-2928766.180	2003/03/28
hob2	-3950071.619	2522415.248	-4311638.125	2003/03/29
Cs00	-4983143.611	2675321.332	-2939473.151	2003/03/30
Cs00	0.006 m	0.006 m	0.019 m	RMS
Cs70	-4996332.149	2661709.450	-2929731.887	2003/03/29

4.2 Geodetic, GRS80 Ellipsoid, ITRF2000

The height above the Geoid is computed using the GPS Ellipsoidal height and subtracting a Geoid-Ellipsoid separation. Geoid-Ellipsoidal separations, in this section, are computed using a spherical harmonic synthesis of the global EGM96 geoid. More information on the EGM96 geoid can be found at www.nima.mil/GandG/wgsegm/egm96.html

	Latitude(DMS)	Longitude(DMS)	Ellipsoidal Height(m)	Above-Geoid Height(m)	
tidb	-35-23 -57.1401	148 58 47.9923	665.366	646.203	
tow2	-19-16 -9.4119	147 3 20.4754	88.145	30.098	
noum	-22-16 -11.4649	166 24 36.7237	83.086	23.416	
Cs10	-27-32 -49.7911	152 5 48.0230	195.595	153.960	
Cs10	0.001 m	0.010 m	0.035 m		RMS
Psm3	-27-30 -34.7585	151 57 18.4282	751.074	709.394	
hob2	-42-48 -16.9691	147 26 19.4425	41.089	44.599	
Cs00	-27-37 -10.3127	151 46 11.2639	561.485	520.358	
Cs00	0.018 m	0.008 m	0.006 m		RMS
Cs70	-27-31 -11.4698	151 57 15.5270	671.843	630.193	

5 Solution Information

To validate your solution you should check the :-

i. Antenna Reference Point (ARP) to Ground Mark records;

ii. Apriori Coordinate Updates (valid range is 0.000 - 15.000 m);

iii. Coordinate Precision (valid range is 0.001 - 0.025 m);

iv. Root Mean Square (RMS) (valid range is 0.0005 - 0.0250 m); and

v. % Observations Deleted (valid range is 0 - 25) %;

5.1 ARP to Ground Mark, per day

All heights refer to the vertical distance from the Ground Mark to the Antenna Reference Point (ARP). The Antenna Offsets refer to the vertical distance from the ARP to the L1 phase centre.

	Height(m)	Antenna Offsets(m)			
Station	Up	East	North	Up	yyyy/mm/dd
Cs10	1.2490	0.0020	0.0003	0.0618	2003/03/28
Psm3	1.4780	0.0020	0.0003	0.0618	2003/03/28
Cs00	1.2180	0.0020	0.0003	0.0618	2003/03/29
Cs70	1.1780	0.0020	0.0003	0.0618	2003/03/29
Cs10	1.2490	0.0020	0.0003	0.0618	2003/03/29
Cs00	1.2180	0.0020	0.0003	0.0618	2003/03/30

5.2 Apriori Coordinate Updates - Cartesian, per day

	dX(m)	dY(m)	dZ(m)	yyyy/mm/dd
Cs10	0.023	-0.003	0.011	2003/03/28
Cs10	0.019	-0.018	0.016	2003/03/29
Psm3	0.013	-0.034	0.020	2003/03/28
Cs00	-0.007	-0.009	-0.012	2003/03/29
Cs00	0.008	-0.012	0.008	2003/03/30
Cs70	0.022	0.068	0.000	2003/03/29

5.3 Coordinate Precision - Cartesian, per day

1 Sigma	sX(m)	sY(m)	sZ(m)	yyyy/mm/dd
Cs10	0.030	0.024	0.020	2003/03/28
Cs10	0.010	0.010	0.007	2003/03/29
Psm3	0.010	0.007	0.007	2003/03/28
Cs00	0.024	0.024	0.017	2003/03/29
Cs00	0.009	0.009	0.005	2003/03/30
Cs70	0.010	0.010	0.007	2003/03/29

5.4 Coordinate Value - Cartesian, ITRF2000, per day

	X(m)	Y(m)	Z(m)	ITRF2000 @
Cs10	-5001320.518	2648434.720	-2932195.606	2003/03/28
Cs10	-5001320.468	2648434.711	-2932195.579	2003/03/29
Psm3	-4996892.398	2661917.684	-2928766.180	2003/03/28
Cs00	-4983143.602	2675321.340	-2939473.177	2003/03/29
Cs00	-4983143.612	2675321.331	-2939473.149	2003/03/30
Cs70	-4996332.149	2661709.450	-2929731.887	2003/03/29

5.5 Geodetic, GRS80 Ellipsoid, ITRF2000, per day

	Latitude(DMS)	Longitude(DMS)	Ellipsoidal Height(m)	
Cs10	-27-32 -49.7911	152 5 48.0235	195.644	2003/03/28
Cs10	-27-32 -49.7911	152 5 48.0230	195.589	2003/03/29
Psm3	-27-30 -34.7585	151 57 18.4282	751.074	2003/03/28
Cs00	-27-37 -10.3135	151 46 11.2635	561.493	2003/03/29
Cs00	-27-37 -10.3127	151 46 11.2639	561.484	2003/03/30
Cs70	-27-31 -11.4698	151 57 15.5270	671.843	2003/03/29

5.6 RMS, Observations, Deletions per day

Data	RMS (m)	# Observations	% Obs. Deleted	Date
tidb	0.0071	24127	5 %	2003-03-28
tow2	0.0063	21850	2 %	2003-03-28
noum	0.0066	18707	3 %	2003-03-28
Cs10	0.0062	2037	0 %	2003-03-28
Psm3	0.0071	10443	1 %	2003-03-28
tidb	0.0066	31122	2 %	2003-03-29
hob2	0.0065	27245	4 %	2003-03-29
tow2	0.0067	25448	7 %	2003-03-29
Cs00	0.0051	2970	0 %	2003-03-29
Cs10	0.0081	8976	7 %	2003-03-29
Cs70	0.0073	9145	9 %	2003-03-29
tidb	0.0091	5074	0 %	2003-03-30
tow2	0.0087	4939	0 %	2003-03-30
noum	0.0093	4723	0 %	2003-03-30
Cs00	0.0090	14736	0 %	2003-03-30

A GPS Computation Standards

A.1 Measurement Modelling

Observable	Ionosphere corrected L1 double difference carrier phase, Psuedo-range only used for receiver clock estimation, Elevation cut-off 15^o, Sampling rate 30 seconds, Weighting 1.0cm for double difference, elevation dependent 1/sin(E).
Troposphere	Hopfield, Niell mapping function
Preprocessing	Receiver clocks estimated using pseudo-range information
Satellite center of mass correction	Block II x,y,z: 0.2794, 0.0000, 1.0259 m Block IIA x,y,z: 0.2794, 0.0000, 1.2053 m
Satellite Antenna Phase centre calibration	Not applied
Ground Antenna phase centre calibrations	Elevation-dependent phase centre corrections are applied according to the model IGS01, the NGS antenna calibrations are used when the antenna used is not a recognised IGS type. The corrections are given relative to the Dorne Margolin T antenna.
Atmospheric Drag	Jachhia Model
Centre of Mass Correction / Attitude	Nil

A.2 Orbit Modelling

Earth's Gravitational (Static) Potential Model	EGM96 - degree and order 12
Solid Earth Tides (Dynamic) Potential	Love Model
Ocean Tide (Dynamic) Potential	Christodoulidis
Third Body Perturbations	Sun, Moon and Planets Values for physical constants - AU, Moon/Earth mass ratio, GM(moon, sun and planets) from JPL DE403 Planetary Ephemeris.
Direct Solar Radiation Pressure	Rock

A.3 Station Position Modelling and Reference Frame

Precession	IAU76/IERS96
Nutation	IAU80/IERS96 (including epsilon and psi corrections)
Sine terms added to accumulated precession and nutation in Right Ascension	As in IERS TN 21, p. 21
Geodesic Nutation	As in IERS TN 21, P. 37
Polar Motion	IGS Earth Orientation Parameters (Ultra-rapid, Rapid, Final) - apriori
Earth Rotation (UT1)	IGS Earth Orientation Parameters (Ultra-rapid, Rapid, Final) - apriori
Daily and Sub-daily tidal corrections to X, Y and UT1	Applied (IERS2000)
Plate Motion	IGS Cumulative SSC
Planetary and Lunar Ephemeris	JPL DE403
Station Displacement - Solid Earth Tide Loading	Williamson and Diamante (1972) + Wahr (1980) for the frequency dependent elastic response of the Earth's fluid interior.
Station Displacement - Ocean Tide Loading	not applied
Station Displacement - Pole Tide	applied
Station Displacement - Atmosphere Loading	not applied
Reference Frame	IGS Cumulative SSC

AUSPOS Online GPS Processing Report

Space Geodesy Analysis Centre
The National Mapping Division (NMD), Geoscience Australia

June 6, 2003

This document is a report of the GPS data processing undertaken by the AUSPOS Online GPS Processing Service. The AUSPOS Online GPS Processing Service uses International GPS Service (IGS) products (final, rapid, ultra-rapid depending on availability) including Precise Orbits, Earth Orientation, Coordinate Solutions (IGS-SSC) to compute precise coordinates in ITRF anywhere on Earth. The Service is designed to process only dual frequency GPS phase data.

The AUSPOS Online GPS Processing Service is a free service and you are encouraged to use it for your projects. However, you may not charge others for this service. Geoscience Australia does not warrant that this service a) is error free; b) meets the customer's requirements. Geoscience Australia shall not be liable to the customer in respect of any loss, damage or injury (including consequential loss, damage or injury) however caused, which may arise directly or indirectly in respect of this service.

An overview of the GPS processing strategy is attached to this report. Please direct email correspondence to geodesy@auslig.gov.au

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Job number: #14099; User: `solicitor@lawsystems.com.au` AUSPOS version 1.01.23

1 User and IGS GPS Data

All antenna heights refer to the vertical distance from the Ground Mark to the Antennna Reference Point (ARP).

User File	Antenna Type	Antenna Height (m)	Start Time	End Time
Cs721220.03o	LEIAT502	1.2480	2003-05-02 20:49:59	2003-05-03 03:50:59
Cs681220.03o	LEIAT502	1.2460	2003-05-02 21:24:00	2003-05-03 03:30:00
Cs771230.03o	LEIAT502	1.2340	2003-05-03 04:24:59	2003-05-03 11:14:00
Cs761230.03o	LEIAT502	1.2460	2003-05-03 04:51:59	2003-05-03 10:57:00
Cs881230.03o	LEIAT502	1.2330	2003-05-03 20:52:00	2003-05-04 02:58:00
Cs901230.03o	LEIAT502	1.2240	2003-05-03 21:08:00	2003-05-04 03:14:00
C1051240.03o	LEIAT502	1.1830	2003-05-04 03:39:00	2003-05-04 10:15:00

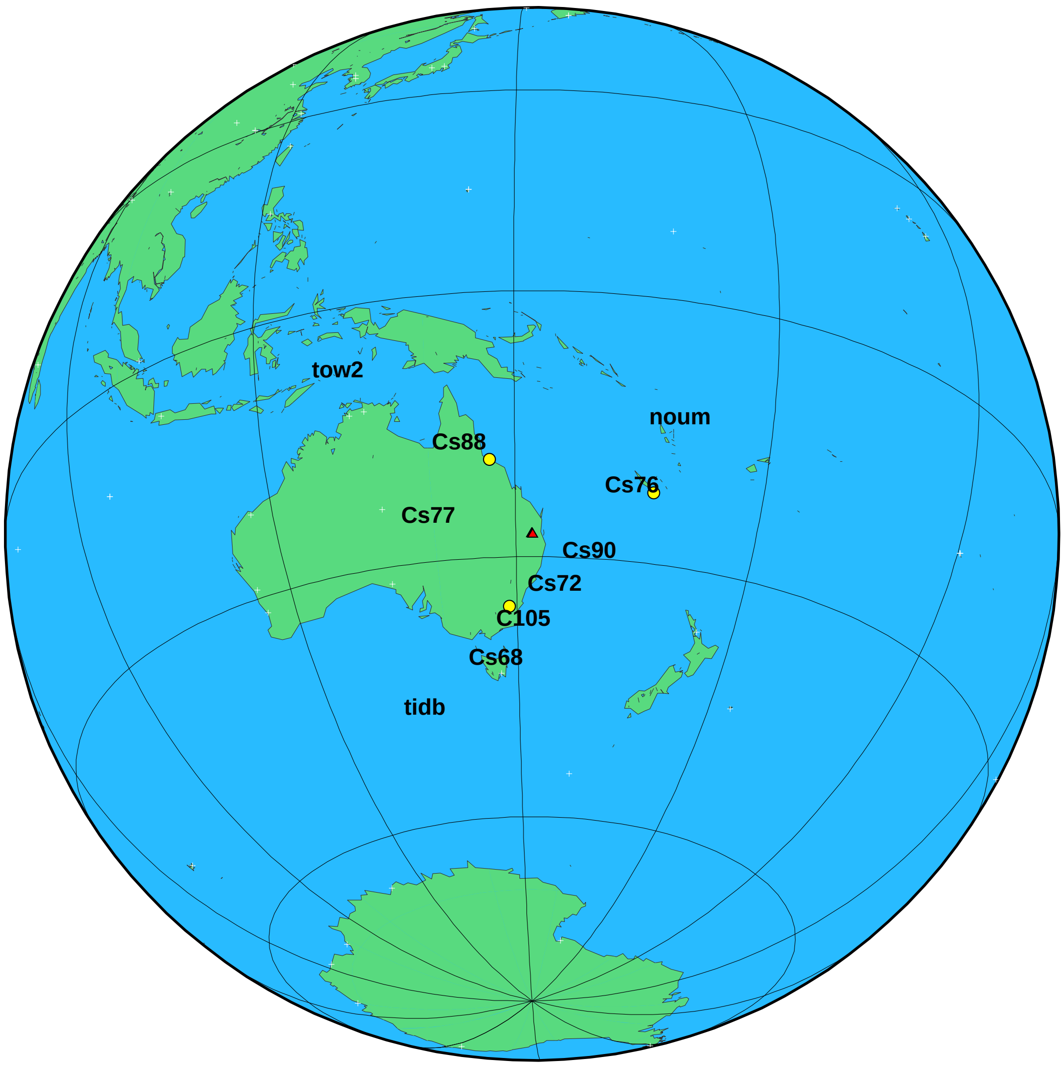

Figure 1: Global View – submitted GPS station(s) and nearby IGS GPS stations used in the processing; triangle(s) represent submitted user data; circle(s) represent the nearest available IGS stations.

2 Processing Summary

Date	IGS Data	User Data	Orbit Type
2003-05-02	tidb tow2 noum	Cs68 Cs72	IGS Final
2003-05-03	tidb tow2 noum	Cs76 Cs77 Cs88 Cs90 Cs72 Cs68	IGS Final
2003-05-04	tidb tow2 noum	C105 Cs88 Cs90	IGS Final

3 Computed Coordinates, GDA94

For Australian users Geocentric Datum of Australia (GDA94, ITRF92@1994.0) coordinates are provided. GDA94 coordinates are determined from ITRF coordinates by an Geoscience Australia (GA) derived coordinate transformation process. GA transformation parameters between ITRF and GDA94 are re-computed weekly, incorporating the latest available tectonic motions (determined from the GA GPS network). GA recommends that users within Australia use GDA94 coordinates. All coordinates refer to the Ground Mark. For general/technical information on GDA94 see www.auslig.gov.au/geodesy/datums/gda.htm and www.anzlic.org.au/icsm/gdatm/

3.1 Cartesian, GDA94

	X(m)	Y(m)	Z(m)	
tidb	-4460996.067	2682557.136	-3674443.861	GDA94
tow2	-5054582.664	3275504.564	-2091539.890	GDA94
noum	-5739971.529	1387563.770	-2402123.709	GDA94
Cs68	-4995935.183	2662461.168	-2929583.619	GDA94
Cs72	-4996492.120	2661609.661	-2929467.848	GDA94
Cs76	-4997707.829	2660529.309	-2928137.127	GDA94
Cs77	-4997900.480	2660279.262	-2927870.765	GDA94
Cs88	-4999147.929	2656123.506	-2929319.177	GDA94
Cs90	-4999620.510	2655236.016	-2929151.898	GDA94
C105	-5000798.345	2649476.622	-2932161.476	GDA94

3.2 Geodetic, GRS80 Ellipsoid, GDA94

The height above the Geoid is computed using the GPS Ellipsoidal height and subtracting a Geoid-Ellipsoid separation. Geoid-Ellipsoidal separations are computed using a bilinear interpolation of the AUSGeoid98 grid. The height above the Geoid is only provided for sites within the AUSGeoid98 extents. For information on AUSGeoid98 see www.auslig.gov.au/geodesy/ausgeoid/geoid.htm

	Latitude(DMS)	Longitude(DMS)	Ellipsoidal Height(m)	Above-Geoid Height(m)	
tidb	-35-23 -57.1560	148 58 47.9845	665.427	646.142	GDA94
tow2	-19-16 -9.4282	147 3 20.4654	88.219	30.130	GDA94
noum	-22-16 -11.4785	166 24 36.7158	83.160		GDA94
Cs68	-27-31 -7.1510	151 56 44.5536	606.131	563.941	GDA94
Cs72	-27-31 -2.4482	151 57 21.4763	633.452	591.264	GDA94
Cs76	-27-30 -15.6267	151 58 17.0364	520.100	477.885	GDA94
Cs77	-27-30 -7.1632	151 58 28.3755	443.718	401.501	GDA94
Cs88	-27-31 -1.6478	152 1 3.3969	358.958	316.862	GDA94
Cs90	-27-30 -56.8132	152 1 40.0326	282.571	240.491	GDA94
C105	-27-32 -48.4137	152 5 5.5578	203.131	161.273	GDA94

3.3 MGA Grid, GRS80 Ellipsoid, GDA94

	East(M)	North(M)	Zone	Ellipsoidal Height(m)	Above-Geoid Height(m)	
tidb	679807.859	6080884.476	55	665.427	646.142	GDA94
tow2	505851.331	7869375.316	55	88.219	30.130	GDA94
noum	645295.440	7536625.658	58	83.160		GDA94
Cs68	395879.124	6955674.391	56	606.131	563.941	GDA94
Cs72	396890.876	6955827.676	56	633.452	591.264	GDA94
Cs76	398403.227	6957281.187	56	520.100	477.885	GDA94
Cs77	398712.199	6957544.195	56	443.718	401.501	GDA94
Cs88	402979.075	6955902.053	56	358.958	316.862	GDA94

Cs90	403983.005	6956058.744	56	282.571	240.491	GDA94
C105	409646.958	6952667.587	56	203.131	161.273	GDA94

4 Computed Coordinates, ITRF2000

All computed coordinates are based on the IGS realisation of the ITRF2000 reference frame, provided by the IGS cumulative solution. All the given ITRF2000 coordinates refer to a mean epoch of the site observation data. All coordinates refer to the Ground Mark.

4.1 Cartesian, ITRF2000

	X(m)	Y(m)	Z(m)	ITRF2000 @
tidb	-4460996.373	2682557.088	-3674443.421	2003/05/03
tow2	-5054582.906	3275504.370	-2091539.388	2003/05/03
noum	-5739971.672	1387563.571	-2402123.289	2003/05/03
Cs68	-4995935.439	2662461.039	-2929583.155	2003/05/03
Cs68	0.010 m	0.016 m	0.002 m	RMS
Cs72	-4996492.376	2661609.531	-2929467.384	2003/05/03
Cs72	0.035 m	0.019 m	0.026 m	RMS
Cs76	-4997708.085	2660529.179	-2928136.662	2003/05/03
Cs77	-4997900.736	2660279.132	-2927870.301	2003/05/03
Cs88	-4999148.185	2656123.376	-2929318.713	2003/05/04
Cs88	0.023 m	0.015 m	0.004 m	RMS
Cs90	-4999620.766	2655235.886	-2929151.433	2003/05/04
Cs90	0.008 m	0.014 m	0.003 m	RMS
C105	-5000798.601	2649476.492	-2932161.012	2003/05/04

4.2 Geodetic, GRS80 Ellipsoid, ITRF2000

The height above the Geoid is computed using the GPS Ellipsoidal height and subtracting a Geoid-Ellipsoid separation. Geoid-Ellipsoidal separations, in this section, are computed using a spherical harmonic synthesis of the global EGM96 geoid. More information on the EGM96 geoid can be found at www.nima.mil/GandG/wgsegm/egm96.html

	Latitude(DMS)	Longitude(DMS)	Ellipsoidal Height(m)	Above-Geoid Height(m)	
tidb	-35-23 -57.1399	148 58 47.9924	665.366	646.203	
tow2	-19-16 -9.4117	147 3 20.4755	88.146	30.099	
noum	-22-16 -11.4648	166 24 36.7238	83.086	23.416	
Cs68	-27-31 -7.1352	151 56 44.5621	606.063	564.416	
Cs68	0.009 m	0.009 m	0.013 m		RMS
Cs72	-27-31 -2.4324	151 57 21.4848	633.384	591.725	
Cs72	0.005 m	0.001 m	0.047 m		RMS
Cs76	-27-30 -15.6108	151 58 17.0450	520.031	478.323	
Cs77	-27-30 -7.1474	151 58 28.3841	443.650	401.933	
Cs88	-27-31 -1.6320	152 1 3.4054	358.889	317.191	
Cs88	0.009 m	0.004 m	0.026 m		RMS
Cs90	-27-30 -56.7973	152 1 40.0411	282.503	240.796	
Cs90	0.004 m	0.009 m	0.013 m		RMS
C105	-27-32 -48.3979	152 5 5.5663	203.062	161.427	

5 Solution Information

To validate your solution you should check the :-

i. Antenna Reference Point (ARP) to Ground Mark records;

ii. Apriori Coordinate Updates (valid range is 0.000 - 15.000 m);

iii. Coordinate Precision (valid range is 0.001 - 0.025 m);

iv. Root Mean Square (RMS) (valid range is 0.0005 - 0.0250 m); and

v. % Observations Deleted (valid range is 0 - 25) %;

5.1 ARP to Ground Mark, per day

All heights refer to the vertical distance from the Ground Mark to the Antenna Reference Point (ARP). The Antenna Offsets refer to the vertical distance from the ARP to the L1 phase centre.

	Height(m)	Antenna Offsets(m)			
Station	Up	East	North	Up	yyyy/mm/dd
Cs68	1.2460	0.0020	0.0003	0.0618	2003/05/02
Cs72	1.2480	0.0020	0.0003	0.0618	2003/05/02
Cs76	1.2460	0.0020	0.0003	0.0618	2003/05/03
Cs77	1.2340	0.0020	0.0003	0.0618	2003/05/03
Cs88	1.2330	0.0020	0.0003	0.0618	2003/05/03
Cs90	1.2240	0.0020	0.0003	0.0618	2003/05/03
Cs72	1.2480	0.0020	0.0003	0.0618	2003/05/03
Cs68	1.2460	0.0020	0.0003	0.0618	2003/05/03
C105	1.1830	0.0020	0.0003	0.0618	2003/05/04
Cs88	1.2330	0.0020	0.0003	0.0618	2003/05/04
Cs90	1.2240	0.0020	0.0003	0.0618	2003/05/04

5.2 Apriori Coordinate Updates - Cartesian, per day

	dX(m)	dY(m)	dZ(m)	yyyy/mm/dd
Cs68	-0.054	0.053	-0.046	2003/05/02
Cs68	0.041	-0.073	0.065	2003/05/03
Cs72	0.058	-0.091	0.033	2003/05/02
Cs72	-0.081	0.039	-0.057	2003/05/03
Cs76	0.081	0.035	0.012	2003/05/03
Cs77	0.032	0.022	0.006	2003/05/03
Cs88	0.237	-0.216	0.158	2003/05/03
Cs88	0.016	-0.020	0.002	2003/05/04
Cs90	-0.087	0.088	-0.044	2003/05/03
Cs90	0.010	-0.038	0.015	2003/05/04
C105	0.024	-0.012	0.008	2003/05/04

5.3 Coordinate Precision - Cartesian, per day

1 Sigma	sX(m)	sY(m)	sZ(m)	yyyy/mm/dd
Cs68	0.019	0.019	0.012	2003/05/02
Cs68	0.028	0.020	0.016	2003/05/03
Cs72	0.012	0.012	0.009	2003/05/02
Cs72	0.032	0.028	0.016	2003/05/03
Cs76	0.020	0.012	0.008	2003/05/03
Cs77	0.016	0.008	0.008	2003/05/03
Cs88	0.016	0.016	0.012	2003/05/03
Cs88	0.010	0.014	0.007	2003/05/04
Cs90	0.020	0.020	0.012	2003/05/03
Cs90	0.010	0.010	0.007	2003/05/04
C105	0.010	0.007	0.007	2003/05/04

5.4 Coordinate Value - Cartesian, ITRF2000, per day

	X(m)	Y(m)	Z(m)	ITRF2000 @
Cs68	-4995935.444	2662461.053	-2929583.153	2003/05/02
Cs68	-4995935.426	2662461.022	-2929583.157	2003/05/03
Cs72	-4996492.369	2661609.526	-2929467.372	2003/05/02
Cs72	-4996492.426	2661609.557	-2929467.418	2003/05/03
Cs76	-4997708.085	2660529.179	-2928136.662	2003/05/03
Cs77	-4997900.736	2660279.132	-2927870.301	2003/05/03
Cs88	-4999148.215	2656123.393	-2929318.718	2003/05/03
Cs88	-4999148.172	2656123.364	-2929318.711	2003/05/04
Cs90	-4999620.776	2655235.905	-2929151.437	2003/05/03
Cs90	-4999620.763	2655235.881	-2929151.432	2003/05/04
C105	-5000798.601	2649476.492	-2932161.012	2003/05/04

5.5 Geodetic, GRS80 Ellipsoid, ITRF2000, per day

```
                                                    Ellipsoidal
        Latitude(DMS)    Longitude(DMS)     Height(m)
Cs68   -27-31   -7.1350  151 56  44.5617       606.073 2003/05/02
Cs68   -27-31   -7.1355  151 56  44.5624       606.048 2003/05/03
Cs72   -27-31   -2.4322  151 57  21.4849       633.370 2003/05/02
Cs72   -27-31   -2.4325  151 57  21.4849       633.449 2003/05/03
Cs76   -27-30 -15.6108  151 58  17.0450       520.031 2003/05/03
Cs77   -27-30   -7.1474  151 58  28.3841       443.650 2003/05/03
Cs88   -27-31   -1.6316  152  1   3.4054       358.922 2003/05/03
Cs88   -27-31   -1.6322  152  1   3.4056       358.873 2003/05/04
Cs90   -27-30 -56.7972  152  1  40.0407       282.520 2003/05/03
Cs90   -27-30 -56.7974  152  1  40.0412       282.498 2003/05/04
C105   -27-32 -48.3979  152  5   5.5663       203.062 2003/05/04
```

5.6 RMS, Observations, Deletions per day

Data	RMS (m)	# Observations	% Obs. Deleted	Date
tidb	0.0059	23500	6 %	2003-05-02
tow2	0.0056	24711	7 %	2003-05-02
noum	0.0064	15757	6 %	2003-05-02
Cs68	0.0082	3695	17 %	2003-05-02
Cs72	0.0077	5743	12 %	2003-05-02
tidb	0.0071	32240	5 %	2003-05-03
tow2	0.0065	32197	6 %	2003-05-03
noum	0.0082	23009	11 %	2003-05-03
Cs68	0.0087	3437	33 %	2003-05-03
Cs72	0.0092	3653	54 %	2003-05-03
Cs76	0.0106	5993	19 %	2003-05-03
Cs77	0.0108	10296	14 %	2003-05-03
Cs88	0.0078	7388	7 %	2003-05-03
Cs90	0.0077	5211	1 %	2003-05-03
tidb	0.0063	29485	3 %	2003-05-04
tow2	0.0065	29752	2 %	2003-05-04
noum	0.0071	22099	5 %	2003-05-04
C105	0.0084	8042	2 %	2003-05-04
Cs88	0.0071	7322	3 %	2003-05-04
Cs90	0.0072	10240	9 %	2003-05-04

WARNING: This solution has MAJOR modelling problems associated with the submitted GPS data. Please consider this solution as INVALID. If you would like more information on this solution you can contact the National Mapping Division at geodesy@auslig.gov.au but to help us please quote your processing job number.

A GPS Computation Standards

A.1 Measurement Modelling

Observable	Ionosphere corrected L1 double difference carrier phase, Psuedo-range only used for receiver clock estimation, Elevation cut-off 15^o, Sampling rate 30 seconds, Weighting 1.0cm for double difference, elevation dependent 1/sin(E).
Troposphere	Hopfield, Niell mapping function
Preprocessing	Receiver clocks estimated using pseudo-range information
Satellite center of mass correction	Block II x,y,z: 0.2794, 0.0000, 1.0259 m Block IIA x,y,z: 0.2794, 0.0000, 1.2053 m
Satellite Antenna Phase centre calibration	Not applied
Ground Antenna phase centre calibrations	Elevation-dependent phase centre corrections are applied according to the model IGS01, the NGS antenna calibrations are used when the antenna used is not a recognised IGS type. The corrections are given relative to the Dorne Margolin T antenna.
Atmospheric Drag	Jachhia Model
Centre of Mass Correction / Attitude	Nil

A.2 Orbit Modelling

Earth's Gravitational (Static) Potential Model	EGM96 - degree and order 12
Solid Earth Tides (Dynamic) Potential	Love Model
Ocean Tide (Dynamic) Potential	Christodoulidis
Third Body Perturbations	Sun, Moon and Planets Values for physical constants - AU, Moon/Earth mass ratio, GM(moon, sun and planets) from JPL DE403 Planetary Ephemeris.
Direct Solar Radiation Pressure	Rock

A.3 Station Position Modelling and Reference Frame

Precession	IAU76/IERS96
Nutation	IAU80/IERS96 (including epsilon and psi corrections)
Sine terms added to accumulated precession and nutation in Right Ascension	As in IERS TN 21, p. 21
Geodesic Nutation	As in IERS TN 21, P. 37
Polar Motion	IGS Earth Orientation Parameters (Ultra-rapid, Rapid, Final) - apriori
Earth Rotation (UT1)	IGS Earth Orientation Parameters (Ultra-rapid, Rapid, Final) - apriori
Daily and Sub-daily tidal corrections to X, Y and UT1	Applied (IERS2000)
Plate Motion	IGS Cumulative SSC
Planetary and Lunar Ephemeris	JPL DE403
Station Displacement - Solid Earth Tide Loading	Williamson and Diamante (1972) + Wahr (1980) for the frequency dependent elastic response of the Earth's fluid interior.
Station Displacement - Ocean Tide Loading	not applied
Station Displacement - Pole Tide	applied
Station Displacement - Atmosphere Loading	not applied
Reference Frame	IGS Cumulative SSC

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AUSPOS Online GPS Processing Report

Space Geodesy Analysis Centre
The National Mapping Division (NMD), Geoscience Australia

June 6, 2003

This document is a report of the GPS data processing undertaken by the AUSPOS Online GPS Processing Service. The AUSPOS Online GPS Processing Service uses International GPS Service (IGS) products (final, rapid, ultra-rapid depending on availability) including Precise Orbits, Earth Orientation, Coordinate Solutions (IGS-SSC) to compute precise coordinates in ITRF anywhere on Earth. The Service is designed to process only dual frequency GPS phase data.

The AUSPOS Online GPS Processing Service is a free service and you are encouraged to use it for your projects. However, you may not charge others for this service. Geoscience Australia does not warrant that this service a) is error free; b) meets the customer's requirements. Geoscience Australia shall not be liable to the customer in respect of any loss, damage or injury (including consequential loss, damage or injury) however caused, which may arise directly or indirectly in respect of this service.

An overview of the GPS processing strategy is attached to this report. Please direct email correspondence to geodesy@auslig.gov.au

AUSPOS Project Manager

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The National Mapping Division
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The National Mapping Division Home Page: www.auslig.gov.au

Job number: #14100; User: `solicitor@lawsystems.com.au` AUSPOS version 1.01.23

1 User and IGS GPS Data

All antenna heights refer to the vertical distance from the Ground Mark to the Antennna Reference Point (ARP).

User File	Antenna Type	Antenna Height (m)	Start Time	End Time
C1011240.03o	LEIAT502	1.2310	2003-05-04 03:59:00	2003-05-04 10:02:59
Cs971240.03o	LEIAT502	1.2610	2003-05-04 10:40:59	2003-05-04 16:47:00
Cs731240.03o	LEIAT502	1.2530	2003-05-04 20:36:00	2003-05-05 02:42:00
Cs521240.03o	LEIAT502	1.2010	2003-05-04 21:01:59	2003-05-05 03:08:00
Cs401250.03o	LEIAT502	1.2040	2003-05-05 04:27:00	2003-05-05 10:37:59
Cs331250.03o	LEIAT502	1.3320	2003-05-05 07:28:59	2003-05-05 13:35:59
Cs251250.03o	LEIAT502	1.2050	2003-05-05 11:01:59	2003-05-05 17:08:00

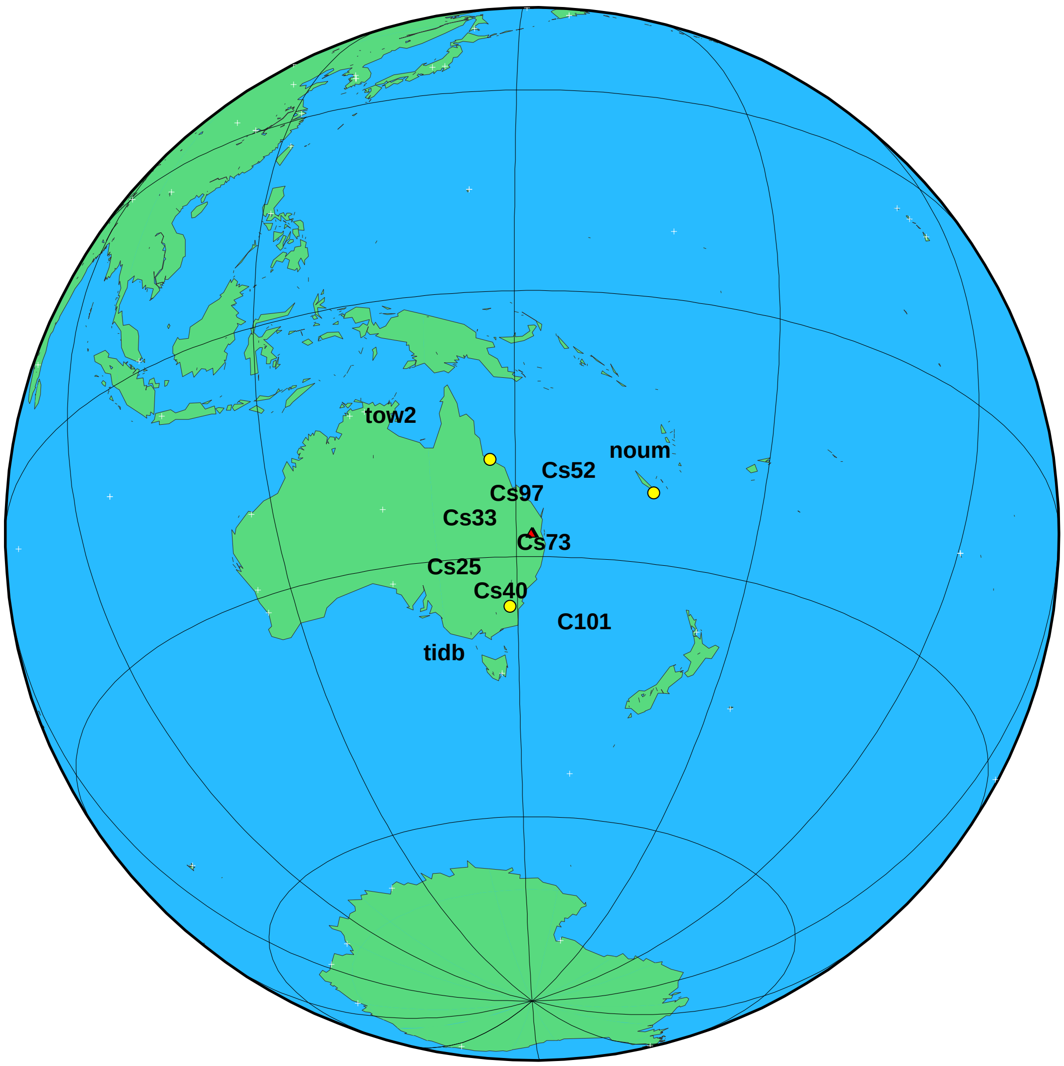

Figure 1: Global View – submitted GPS station(s) and nearby IGS GPS stations used in the processing; triangle(s) represent submitted user data; circle(s) represent the nearest available IGS stations.

2 Processing Summary

Date	IGS Data	User Data	Orbit Type
2003-05-04	tidb tow2 noum	C101 Cs52 Cs73 Cs97	IGS Final
2003-05-05	tidb tow2 noum	Cs25 Cs33 Cs40 Cs73 Cs52	IGS Final

3 Computed Coordinates, GDA94

For Australian users Geocentric Datum of Australia (GDA94, ITRF92@1994.0) coordinates are provided. GDA94 coordinates are determined from ITRF coordinates by an Geoscience Australia (GA) derived coordinate transformation process. GA transformation parameters between ITRF and GDA94 are re-computed weekly, incorporating the latest available tectonic motions (determined from the GA GPS network). GA recommends that users within Australia use GDA94 coordinates. All coordinates refer to the Ground Mark. For general/technical information on GDA94 see www.auslig.gov.au/geodesy/datums/gda.htm and www.anzlic.org.au/icsm/gdatm/

3.1 Cartesian, GDA94

	X(m)	Y(m)	Z(m)	
tidb	-4460996.067	2682557.136	-3674443.861	GDA94
tow2	-5054582.663	3275504.564	-2091539.890	GDA94
noum	-5739971.529	1387563.771	-2402123.708	GDA94
C101	-5000964.318	2650775.456	-2930744.377	GDA94
Cs52	-4994804.322	2665883.894	-2928337.987	GDA94
Cs73	-4996771.878	2661517.825	-2929040.349	GDA94
Cs97	-5000772.227	2652438.416	-2929697.616	GDA94
Cs25	-4989494.820	2671338.077	-2932376.032	GDA94
Cs33	-4991093.787	2670007.755	-2930812.785	GDA94
Cs40	-4993294.533	2668238.058	-2928747.707	GDA94

3.2 Geodetic, GRS80 Ellipsoid, GDA94

The height above the Geoid is computed using the GPS Ellipsoidal height and subtracting a Geoid-Ellipsoid separation. Geoid-Ellipsoidal separations are computed using a bilinear interpolation of the AUSGeoid98 grid. The height above the Geoid is only provided for sites within the AUSGeoid98 extents. For information on AUSGeoid98 see www.auslig.gov.au/geodesy/ausgeoid/geoid.htm

	Latitude(DMS)	Longitude(DMS)	Ellipsoidal Height(m)	Above-Geoid Height(m)	
tidb	-35-23 -57.1560	148 58 47.9845	665.427	646.141	GDA94
tow2	-19-16 -9.4282	147 3 20.4654	88.219	30.130	GDA94
noum	-22-16 -11.4785	166 24 36.7158	83.160		GDA94
C101	-27-31 -56.2558	152 4 26.5646	217.220	175.294	GDA94
Cs52	-27-30 -22.0667	151 54 35.1337	574.278	532.055	GDA94
Cs73	-27-30 -47.0744	151 57 29.2214	616.647	574.448	GDA94
Cs97	-27-31 -16.9520	152 3 29.7473	273.774	231.775	GDA94
Cs25	-27-32 -50.0870	151 50 8.6558	568.313	526.317	GDA94
Cs33	-27-31 -53.3132	151 51 18.8948	538.981	496.905	GDA94
Cs40	-27-30 -37.2141	151 52 53.5673	565.929	523.748	GDA94

3.3 MGA Grid, GRS80 Ellipsoid, GDA94

	East(M)	North(M)	Zone	Ellipsoidal Height(m)	Above-Geoid Height(m)	
tidb	679807.859	6080884.476	55	665.427	646.141	GDA94
tow2	505851.330	7869375.316	55	88.219	30.130	GDA94
noum	645295.440	7536625.659	58	83.160		GDA94
C101	408565.488	6954264.598	56	217.220	175.294	GDA94
Cs52	392316.296	6957031.017	56	574.278	532.055	GDA94
Cs73	397099.388	6956302.541	56	616.647	574.448	GDA94
Cs97	406997.748	6955462.279	56	273.774	231.775	GDA94
Cs25	385047.355	6952409.628	56	568.313	526.317	GDA94
Cs33	386957.753	6954174.646	56	538.981	496.905	GDA94
Cs40	389533.693	6956540.091	56	565.929	523.748	GDA94

4 Computed Coordinates, ITRF2000

All computed coordinates are based on the IGS realisation of the ITRF2000 reference frame, provided by the IGS cumulative solution. All the given ITRF2000 coordinates refer to a mean epoch of the site observation data. All coordinates refer to the Ground Mark.

4.1 Cartesian, ITRF2000

	X(m)	Y(m)	Z(m)	ITRF2000 @	
tidb	-4460996.373	2682557.088	-3674443.421	2003/05/05	
tow2	-5054582.906	3275504.370	-2091539.388	2003/05/05	
noum	-5739971.672	1387563.571	-2402123.289	2003/05/05	
C101	-5000964.574	2650775.326	-2930743.913	2003/05/04	
Cs52	-4994804.579	2665883.764	-2928337.522	2003/05/05	
Cs52	0.015 m	0.007 m	0.013 m		RMS
Cs73	-4996772.135	2661517.696	-2929039.884	2003/05/05	
Cs73	0.009 m	0.007 m	0.010 m		RMS
Cs97	-5000772.483	2652438.286	-2929697.152	2003/05/04	
Cs25	-4989495.078	2671337.948	-2932375.567	2003/05/05	
Cs33	-4991094.044	2670007.626	-2930812.320	2003/05/05	
Cs40	-4993294.790	2668237.929	-2928747.242	2003/05/05	

4.2 Geodetic, GRS80 Ellipsoid, ITRF2000

The height above the Geoid is computed using the GPS Ellipsoidal height and subtracting a Geoid-Ellipsoid separation. Geoid-Ellipsoidal separations, in this section, are computed using a spherical harmonic synthesis of the global EGM96 geoid. More information on the EGM96 geoid can be found at www.nima.mil/GandG/wgsegm/egm96.html

	Latitude(DMS)	Longitude(DMS)	Ellipsoidal Height(m)	Above-Geoid Height(m)	
tidb	-35-23 -57.1399	148 58 47.9924	665.366	646.203	
tow2	-19-16 -9.4117	147 3 20.4755	88.146	30.099	
noum	-22-16 -11.4648	166 24 36.7238	83.085	23.415	
C101	-27-31 -56.2399	152 4 26.5731	217.152	175.478	
Cs52	-27-30 -22.0508	151 54 35.1422	574.210	532.560	
Cs52	0.004 m	0.003 m	0.020 m		RMS
Cs73	-27-30 -47.0585	151 57 29.2299	616.579	574.906	
Cs73	0.004 m	0.003 m	0.014 m		RMS
Cs97	-27-31 -16.9361	152 3 29.7558	273.706	232.005	
Cs25	-27-32 -50.0711	151 50 8.6644	568.245	526.803	
Cs33	-27-31 -53.2973	151 51 18.9034	538.913	497.399	
Cs40	-27-30 -37.1982	151 52 53.5758	565.861	524.253	

5 Solution Information

To validate your solution you should check the :-

i. Antenna Reference Point (ARP) to Ground Mark records;

ii. Apriori Coordinate Updates (valid range is 0.000 - 15.000 m);

iii. Coordinate Precision (valid range is 0.001 - 0.025 m);

iv. Root Mean Square (RMS) (valid range is 0.0005 - 0.0250 m); and

v. % Observations Deleted (valid range is 0 - 25) %;

5.1 ARP to Ground Mark, per day

All heights refer to the vertical distance from the Ground Mark to the Antenna Reference Point (ARP). The Antenna Offsets refer to the vertical distance from the ARP to the L1 phase centre.

	Height(m)	Antenna Offsets(m)			
Station	Up	East	North	Up	yyyy/mm/dd
C101	1.2310	0.0020	0.0003	0.0618	2003/05/04
Cs52	1.2010	0.0020	0.0003	0.0618	2003/05/04
Cs73	1.2530	0.0020	0.0003	0.0618	2003/05/04
Cs97	1.2610	0.0020	0.0003	0.0618	2003/05/04
Cs25	1.2050	0.0020	0.0003	0.0618	2003/05/05
Cs33	1.3320	0.0020	0.0003	0.0618	2003/05/05
Cs40	1.2040	0.0020	0.0003	0.0618	2003/05/05
Cs73	1.2530	0.0020	0.0003	0.0618	2003/05/05
Cs52	1.2010	0.0020	0.0003	0.0618	2003/05/05

5.2 Apriori Coordinate Updates - Cartesian, per day

	dX(m)	dY(m)	dZ(m)	yyyy/mm/dd
C101	-0.016	0.007	-0.011	2003/05/04
Cs52	-0.061	0.057	-0.033	2003/05/04
Cs52	-0.059	0.096	-0.035	2003/05/05
Cs73	0.065	-0.004	0.034	2003/05/04
Cs73	-0.084	0.007	-0.021	2003/05/05
Cs97	0.003	0.003	0.004	2003/05/04
Cs25	0.038	-0.021	0.017	2003/05/05
Cs33	0.020	-0.004	0.006	2003/05/05
Cs40	0.050	0.009	0.026	2003/05/05

5.3 Coordinate Precision - Cartesian, per day

1 Sigma	sX(m)	sY(m)	sZ(m)	yyyy/mm/dd
C101	0.011	0.007	0.007	2003/05/04
Cs52	0.018	0.014	0.011	2003/05/04
Cs52	0.011	0.015	0.007	2003/05/05
Cs73	0.014	0.011	0.007	2003/05/04
Cs73	0.015	0.019	0.011	2003/05/05
Cs97	0.014	0.007	0.007	2003/05/04
Cs25	0.011	0.007	0.004	2003/05/05
Cs33	0.007	0.011	0.004	2003/05/05
Cs40	0.011	0.007	0.007	2003/05/05

5.4 Coordinate Value - Cartesian, ITRF2000, per day

	X(m)	Y(m)	Z(m)	ITRF2000 @
C101	-5000964.574	2650775.326	-2930743.913	2003/05/04
Cs52	-4994804.560	2665883.757	-2928337.506	2003/05/04
Cs52	-4994804.587	2665883.771	-2928337.530	2003/05/05
Cs73	-4996772.127	2661517.692	-2929039.879	2003/05/04
Cs73	-4996772.144	2661517.705	-2929039.897	2003/05/05
Cs97	-5000772.483	2652438.286	-2929697.152	2003/05/04
Cs25	-4989495.078	2671337.948	-2932375.567	2003/05/05
Cs33	-4991094.044	2670007.626	-2930812.320	2003/05/05
Cs40	-4993294.790	2668237.929	-2928747.242	2003/05/05

5.5 Geodetic, GRS80 Ellipsoid, ITRF2000, per day

	Latitude(DMS)	Longitude(DMS)	Ellipsoidal Height(m)	
C101	-27-31 -56.2399	152 4 26.5731	217.152	2003/05/04
Cs52	-27-30 -22.0507	151 54 35.1421	574.185	2003/05/04
Cs52	-27-30 -22.0509	151 54 35.1421	574.223	2003/05/05
Cs73	-27-30 -47.0585	151 57 29.2299	616.569	2003/05/04
Cs73	-27-30 -47.0587	151 57 29.2298	616.596	2003/05/05
Cs97	-27-31 -16.9361	152 3 29.7558	273.706	2003/05/04
Cs25	-27-32 -50.0711	151 50 8.6644	568.245	2003/05/05
Cs33	-27-31 -53.2973	151 51 18.9034	538.913	2003/05/05

```
Cs40  -27-30 -37.1982  151 52  53.5758      565.861 2003/05/05
```

5.6 RMS, Observations, Deletions per day

Data	RMS (m)	# Observations	% Obs. Deleted	Date
tidb	0.0063	29418	3 %	2003-05-04
tow2	0.0067	31154	3 %	2003-05-04
noum	0.0071	25045	3 %	2003-05-04
C101	0.0073	6801	5 %	2003-05-04
Cs52	0.0084	5452	2 %	2003-05-04
Cs73	0.0085	7967	3 %	2003-05-04
Cs97	0.0069	10539	1 %	2003-05-04
tidb	0.0067	37763	5 %	2003-05-05
tow2	0.0071	38361	3 %	2003-05-05
noum	0.0080	30783	7 %	2003-05-05
Cs25	0.0080	16236	10 %	2003-05-05
Cs33	0.0077	13037	0 %	2003-05-05
Cs40	0.0060	7915	0 %	2003-05-05
Cs52	0.0088	8023	25 %	2003-05-05
Cs73	0.0089	5514	18 %	2003-05-05

A GPS Computation Standards

A.1 Measurement Modelling

Observable	Ionosphere corrected L1 double difference carrier phase, Psuedo-range only used for receiver clock estimation, Elevation cut-off 15^o, Sampling rate 30 seconds, Weighting 1.0cm for double difference, elevation dependent 1/sin(E).
Troposphere	Hopfield, Niell mapping function
Preprocessing	Receiver clocks estimated using pseudo-range information
Satellite center of mass correction	Block II x,y,z: 0.2794, 0.0000, 1.0259 m Block IIA x,y,z: 0.2794, 0.0000, 1.2053 m
Satellite Antenna Phase centre calibration	Not applied
Ground Antenna phase centre calibrations	Elevation-dependent phase centre corrections are applied according to the model IGS01, the NGS antenna calibrations are used when the antenna used is not a recognised IGS type. The corrections are given relative to the Dorne Margolin T antenna.
Atmospheric Drag	Jachhia Model
Centre of Mass Correction / Attitude	Nil

A.2 Orbit Modelling

Earth's Gravitational (Static) Potential Model	EGM96 - degree and order 12
Solid Earth Tides (Dynamic) Potential	Love Model
Ocean Tide (Dynamic) Potential	Christodoulidis
Third Body Perturbations	Sun, Moon and Planets Values for physical constants - AU, Moon/Earth mass ratio, GM(moon, sun and planets) from JPL DE403 Planetary Ephemeris.
Direct Solar Radiation Pressure	Rock

A.3 Station Position Modelling and Reference Frame

Precession	IAU76/IERS96
Nutation	IAU80/IERS96 (including epsilon and psi corrections)
Sine terms added to accumulated precession and nutation in Right Ascension	As in IERS TN 21, p. 21
Geodesic Nutation	As in IERS TN 21, P. 37
Polar Motion	IGS Earth Orientation Parameters (Ultra-rapid, Rapid, Final) - apriori
Earth Rotation (UT1)	IGS Earth Orientation Parameters (Ultra-rapid, Rapid, Final) - apriori
Daily and Sub-daily tidal corrections to X, Y and UT1	Applied (IERS2000)
Plate Motion	IGS Cumulative SSC
Planetary and Lunar Ephemeris	JPL DE403
Station Displacement - Solid Earth Tide Loading	Williamson and Diamante (1972) + Wahr (1980) for the frequency dependent elastic response of the Earth's fluid interior.
Station Displacement - Ocean Tide Loading	not applied
Station Displacement - Pole Tide	applied
Station Displacement - Atmosphere Loading	not applied
Reference Frame	IGS Cumulative SSC

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The National Mapping Division (NMD), Geoscience Australia

June 5, 2003

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An overview of the GPS processing strategy is attached to this report. Please direct email correspondence to geodesy@auslig.gov.au

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Job number: #14101; User: `solicitor@lawsystems.com.au` AUSPOS version 1.01.23

1 User and IGS GPS Data

All antenna heights refer to the vertical distance from the Ground Mark to the Antennna Reference Point (ARP).

User File	Antenna Type	Antenna Height (m)	Start Time	End Time
Cs041270.03o	LEIAT502	1.1930	2003-05-07 06:36:00	2003-05-07 14:19:00
Cs091270.03o	LEIAT502	1.2150	2003-05-07 06:56:00	2003-05-07 13:57:00

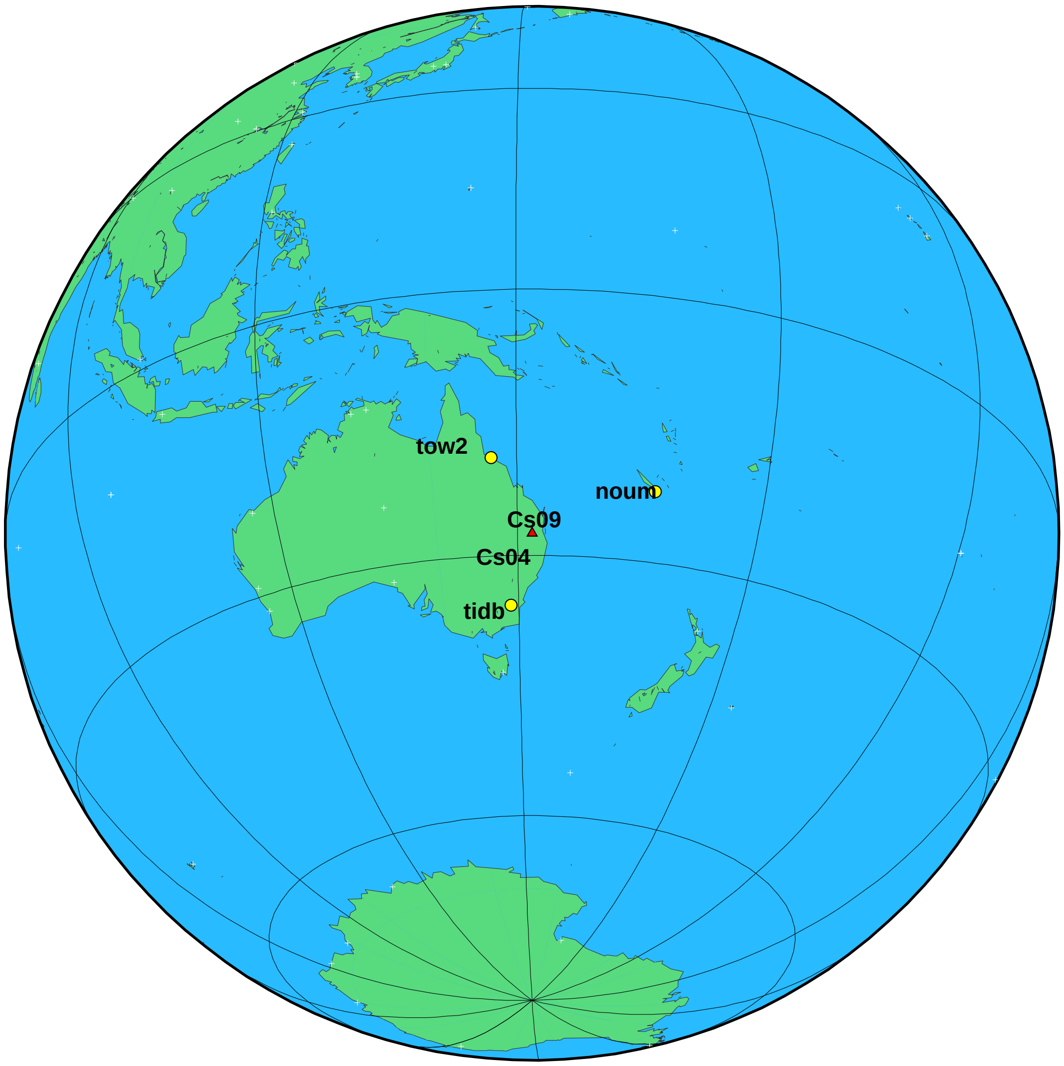

Figure 1: Global View – submitted GPS station(s) and nearby IGS GPS stations used in the processing; triangle(s) represent submitted user data; circle(s) represent the nearest available IGS stations.

2 Processing Summary

Date	IGS Data	User Data	Orbit Type
2003-05-07	tidb tow2 noum	Cs04 Cs09	IGS Final

3 Computed Coordinates, GDA94

For Australian users Geocentric Datum of Australia (GDA94, ITRF92@1994.0) coordinates are provided. GDA94 coordinates are determined from ITRF coordinates by an Geoscience Australia (GA) derived coordinate transformation process. GA transformation parameters between ITRF and GDA94 are re-computed weekly, incorporating the latest available tectonic motions (determined from the GA GPS network). GA recommends that users within Australia use GDA94 coordinates. All coordinates refer to the Ground Mark. For general/technical information on GDA94 see www.auslig.gov.au/geodesy/datums/gda.htm and www.anzlic.org.au/icsm/gdatm/

3.1 Cartesian, GDA94

	X(m)	Y(m)	Z(m)	
tidb	-4460996.066	2682557.136	-3674443.861	GDA94
tow2	-5054582.663	3275504.564	-2091539.890	GDA94
noum	-5739971.529	1387563.771	-2402123.708	GDA94
Cs04	-4984018.035	2674130.305	-2939024.418	GDA94
Cs09	-4985102.847	2674007.185	-2937261.365	GDA94

3.2 Geodetic, GRS80 Ellipsoid, GDA94

The height above the Geoid is computed using the GPS Ellipsoidal height and subtracting a Geoid-Ellipsoid separation. Geoid-Ellipsoidal separations are computed using a bilinear interpolation of the AUSGeoid98 grid. The height above the Geoid is only provided for sites within the AUSGeoid98 extents. For information on AUSGeoid98 see www.auslig.gov.au/geodesy/ausgeoid/geoid.htm

	Latitude(DMS)	Longitude(DMS)	Ellipsoidal Height(m)	Above-Geoid Height(m)	
tidb	-35-23 -57.1560	148 58 47.9845	665.427	646.141	GDA94
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Cs04	-27-36 -54.2762	151 47 4.6153	537.088	495.346	GDA94
Cs09	-27-35 -50.0110	151 47 27.2718	515.636	473.845	GDA94

3.3 MGA Grid, GRS80 Ellipsoid, GDA94

	East(M)	North(M)	Zone	Ellipsoidal Height(m)	Above-Geoid Height(m)	
tidb	679807.859	6080884.476	55	665.427	646.141	GDA94
tow2	505851.330	7869375.316	55	88.219	30.130	GDA94
noum	645295.439	7536625.659	58	83.160		GDA94
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4 Computed Coordinates, ITRF2000

All computed coordinates are based on the IGS realisation of the ITRF2000 reference frame, provided by the IGS cumulative solution. All the given ITRF2000 coordinates refer to a mean epoch of the site observation data. All coordinates refer to the Ground Mark.

4.1 Cartesian, ITRF2000

	X(m)	Y(m)	Z(m)	ITRF2000 @
tidb	-4460996.373	2682557.088	-3674443.421	2003/05/07
tow2	-5054582.906	3275504.370	-2091539.387	2003/05/07
noum	-5739971.672	1387563.571	-2402123.288	2003/05/07
Cs04	-4984018.293	2674130.176	-2939023.953	2003/05/07
Cs09	-4985103.105	2674007.056	-2937260.900	2003/05/07

4.2 Geodetic, GRS80 Ellipsoid, ITRF2000

The height above the Geoid is computed using the GPS Ellipsoidal height and subtracting a Geoid-Ellipsoid separation. Geoid-Ellipsoidal separations, in this section, are computed using a spherical harmonic synthesis of the global EGM96 geoid. More information on the EGM96 geoid can be found at
www.nima.mil/GandG/wgsegm/egm96.html

```
                                          Ellipsoidal  Above-Geoid
        Latitude(DMS)    Longitude(DMS)     Height(m)    Height(m)
tidb   -35-23 -57.1399  148 58  47.9924      665.366      646.203
tow2   -19-16  -9.4117  147  3  20.4755       88.145       30.098
noum   -22-16 -11.4647  166 24  36.7238       83.085       23.415
Cs04   -27-36 -54.2603  151 47   4.6238      537.020      495.856
Cs09   -27-35 -49.9951  151 47  27.2804      515.568      474.340
```

5 Solution Information

To validate your solution you should check the :-

i. Antenna Reference Point (ARP) to Ground Mark records;

ii. Apriori Coordinate Updates (valid range is 0.000 - 15.000 m);

iii. Coordinate Precision (valid range is 0.001 - 0.025 m);

iv. Root Mean Square (RMS) (valid range is 0.0005 - 0.0250 m); and

v. % Observations Deleted (valid range is 0 - 25) %;

5.1 ARP to Ground Mark, per day

All heights refer to the vertical distance from the Ground Mark to the Antenna Reference Point (ARP). The Antenna Offsets refer to the vertical distance from the ARP to the L1 phase centre.

```
           Height(m)          Antenna Offsets(m)
Station    Up            East      North     Up     yyyy/mm/dd
Cs04       1.1930        0.0020    0.0003    0.0618 2003/05/07
Cs09       1.2150        0.0020    0.0003    0.0618 2003/05/07
```

5.2 Apriori Coordinate Updates - Cartesian, per day

```
                dX(m)          dY(m)          dZ(m) yyyy/mm/dd
Cs04           -0.003         -0.024          0.000 2003/05/07
Cs09            0.019         -0.006          0.010 2003/05/07
```

5.3 Coordinate Precision - Cartesian, per day

```
1 Sigma         sX(m)          sY(m)          sZ(m) yyyy/mm/dd
Cs04            0.007          0.003          0.003 2003/05/07
Cs09            0.007          0.007          0.003 2003/05/07
```

5.4 RMS, Observations, Deletions per day

Data	RMS (m)	# Observations	% Obs. Deleted	Date
tidb	0.0058	28349	2 %	2003-05-07
tow2	0.0064	37220	2 %	2003-05-07
noum	0.0074	24589	2 %	2003-05-07
Cs04	0.0065	22139	0 %	2003-05-07
Cs09	0.0064	15835	0 %	2003-05-07

A GPS Computation Standards

A.1 Measurement Modelling

Observable	Ionosphere corrected L1 double difference carrier phase, Psuedo-range only used for receiver clock estimation, Elevation cut-off 15^o, Sampling rate 30 seconds, Weighting 1.0cm for double difference, elevation dependent 1/sin(E).
Troposphere	Hopfield, Niell mapping function
Preprocessing	Receiver clocks estimated using pseudo-range information
Satellite center of mass correction	Block II x,y,z: 0.2794, 0.0000, 1.0259 m Block IIA x,y,z: 0.2794, 0.0000, 1.2053 m
Satellite Antenna Phase centre calibration	Not applied
Ground Antenna phase centre calibrations	Elevation-dependent phase centre corrections are applied according to the model IGS01, the NGS antenna calibrations are used when the antenna used is not a recognised IGS type. The corrections are given relative to the Dorne Margolin T antenna.
Atmospheric Drag	Jachhia Model
Centre of Mass Correction / Attitude	Nil

A.2 Orbit Modelling

Earth's Gravitational (Static) Potential Model	EGM96 - degree and order 12
Solid Earth Tides (Dynamic) Potential	Love Model
Ocean Tide (Dynamic) Potential	Christodoulidis
Third Body Perturbations	Sun, Moon and Planets Values for physical constants - AU, Moon/Earth mass ratio, GM(moon, sun and planets) from JPL DE403 Planetary Ephemeris.
Direct Solar Radiation Pressure	Rock

A.3 Station Position Modelling and Reference Frame

Precession	IAU76/IERS96
Nutation	IAU80/IERS96 (including epsilon and psi corrections)
Sine terms added to accumulated precession and nutation in Right Ascension	As in IERS TN 21, p. 21
Geodesic Nutation	As in IERS TN 21, P. 37
Polar Motion	IGS Earth Orientation Parameters (Ultra-rapid, Rapid, Final) - apriori
Earth Rotation (UT1)	IGS Earth Orientation Parameters (Ultra-rapid, Rapid, Final) - apriori
Daily and Sub-daily tidal corrections to X, Y and UT1	Applied (IERS2000)
Plate Motion	IGS Cumulative SSC
Planetary and Lunar Ephemeris	JPL DE403
Station Displacement - Solid Earth Tide Loading	Williamson and Diamante (1972) + Wahr (1980) for the frequency dependent elastic response of the Earth's fluid interior.
Station Displacement - Ocean Tide Loading	not applied
Station Displacement - Pole Tide	applied
Station Displacement - Atmosphere Loading	not applied
Reference Frame	IGS Cumulative SSC

APPENDIX D

LEAST-SQUARES ADJUSTMENT REPORT FOR THE CONSTRAINED ADJUSTMENT OF THE TOOWOOMBA BYPASS CONTROL NETWORK: TB_Cntrl_Const_7.trc

```
Project Datum is :- GDA94
Mike Stoodley Demo Version


Geomap Adjustment for Project :- TB_Cntrl_Adjustment
===========================================

Run Name                      :- TB_Cntrl_Const_7
Trace is in file              :- TB_Cntrl_Const_7
Run started                   :- Monday, December, 01, 2003 at 18:40:09


The following settings were used for this run:-

Run mode                                :- Adjustment
Maximum Iterations                      :- 6
Convergance Limit                       :- 1.0000 mm
(C - O) / Stand Dev                     :-    100000.000
Coordinates written to file are         :- Geodetic
Coordinate corrections are    listed for each iteration
Input data is    written to the trace file
Elevation adjustment mode               :- Spheroidal Heights only
Geoid Spheroid corrections are applied to :- No Observations
Weighting model                         :- Use Instrument SD always
External standard deviations were  not  applied


 Input stations:-
================
```

Label	Long Name	Latitude	Longitude	Sph Hgt	Geoid Hgt	N	Class	Cons.	Lat Cons.	Long Cons.	Geoid Cons	Sph Cons
PM40970	40970	S27°30'36.674380	E152° 2' 3.566029	466.043			A:C	Uncons				
CS92	CS92	S27°30'51.296277	E152° 2'13.132762	299.895			A:D	Uncons				
CS79	CS79	S27°30' 2.076509	E151°58'50.595642	419.930			A:D	Uncons				
CS75	CS75	S27°30'36.518944	E151°58' 5.570833	507.184			A:D	Uncons				
PM35751	35751	S27°30'34.774164	E151°57'18.419670	751.143			A:D	Cons	0.020000	0.014000		0.014000
10KBM	10KBM	S27°29'35.666116	E151°57' 1.137451	705.625			A:C	Uncons				
PM112793	112793	S27°28'10.505462	E151°58'47.891150	447.837			A:E	Uncons				
PM66947	66947	S27°32'36.434357	E152° 3' 5.310930	252.523			A:C	Uncons				
PM112799	PSM12799	S27°36'30.019430	E151°51'12.758939	585.617			A:D	Uncons				
CS15	CS000015	S27°34'24.584195	E151°48'14.479835	514.674			A:D	Uncons				
PM85731	85731	S27°30'38.466829	E152° 4'13.904986	213.040			A:C	Uncons				
CS84	CS84	S27°30'59.802571	E151°59'54.613685	370.500			A:D	Uncons				
PM68101	68101	S27°33'12.525853	E152° 1'26.880866	303.573			A:C	Uncons				
CS101	CS101	S27°31'56.255807	E152° 4'26.564593	217.220			A:D	Cons	0.022000	0.014000		0.014000
CS107	CS107	S27°32'49.806744	E152° 5'48.014555	195.663			A:D	Cons	0.040000	0.034000		0.027000
PM51843	PSM51843	S27°33'11.536360	E151°52'33.202259	692.848			A:C	Uncons				
CS32	CS000032	S27°32' 2.764064	E151°51' 2.461347	539.296			A:D	Uncons				
CS108	CS108	S27°32'51.147008	E152° 6' 3.342935	190.984			A:D	Uncons				
CS22	CS000022	S27°33'11.747465	E151°49'52.044512	576.860			A:D	Uncons				
CS40	CS000040	S27°30'37.214053	E151°52'53.567255	565.929			A:D	Cons	0.022000	0.014000		0.014000
CS45	CS000045	S27°32' 8.531513	E151°54'22.696180	665.326			A:D	Uncons				

CS62	CS000062	S27°30'58.687067	E151°56'29.311575	594.349	A:D	Uncons			
CS63	CS000063	S27°32'44.808019	E151°56'50.011349	622.948	A:D	Uncons			
CS04	CS000004	S27°36'54.276231	E151°47' 4.615263	537.088	A:D	Cons	0.014000	0.006000	0.006000
CS70	CS70	S27°31'11.485506	E151°57'15.518495	671.911	A:D	Cons	0.020000	0.020000	0.014000
CS56	CS56	S27°28'57.680828	E151°54'35.414667	568.148	A:D	Uncons			
PM57526	57526	S27°31' 9.561694	E152° 0' 2.266702	335.093	A:C	Uncons			
CS52	CS000052	S27°30'22.066701	E151°54'35.133683	574.278	A:D	Cons	0.029000	0.029000	0.018000
CS05	CS000005	S27°36'51.467126	E151°47'22.601324	536.671	A:D	Uncons			
CS06	CS000006	S27°36'29.687292	E151°47' 7.514729	539.163	A:D	Uncons			
CS07	CS000007	S27°36'17.660525	E151°47'11.448314	531.642	A:D	Uncons			
CS08	CS000008	S27°36' 3.377442	E151°47'21.843804	524.560	A:D	Uncons			
CS09	CS000009	S27°35'50.011028	E151°47'27.271799	515.636	A:D	Cons	0.014000	0.014000	0.006000
CS10	CS000010	S27°35'36.369807	E151°47'44.012968	516.959	A:D	Uncons			
CS11	CS000011	S27°35'29.228915	E151°47'54.505869	511.478	A:D	Uncons			
CS12	CS000012	S27°35'12.933956	E151°48' 2.749832	500.694	A:D	Uncons			
CS01	CS000001	S27°37'10.328460	E151°46'11.255369	561.553	A:D	Cons	0.033000	0.033000	0.022000
CS02	CS000002	S27°37' 3.494194	E151°46'29.688712	558.708	A:D	Uncons			
CS03	CS000003	S27°36'58.876375	E151°46'48.937404	542.477	A:D	Uncons			
CS14	CS000014	S27°34'44.199992	E151°48'15.761984	490.754	A:D	Uncons			
CS13	CS000013	S27°34'55.257956	E151°48' 5.229859	504.836	A:D	Uncons			
CS16	CS000016	S27°34' 8.369830	E151°48'27.730306	498.587	A:D	Uncons			
CS17	CS000017	S27°33'56.944991	E151°48'38.019671	509.102	A:D	Uncons			
CS18	CS000018	S27°33'45.238621	E151°48'47.533234	522.366	A:D	Uncons			
CS21	CS000021	S27°33'23.319465	E151°49'36.329268	559.164	A:D	Uncons			
CS23	CS000023	S27°33' 2.131633	E151°49'59.568238	554.120	A:D	Uncons			
CS20	CS000020	S27°33'34.814270	E151°49'22.010752	549.364	A:D	Uncons			
CS24	CS000024	S27°32'48.143042	E151°49'52.518372	551.682	A:D	Uncons			
CS19	CS000019	S27°33'39.306517	E151°48'59.708484	520.355	A:D	Uncons			
CS33	CS000033	S27°31'53.313223	E151°51'18.894818	538.981	A:D	Cons	0.014000	0.022000	0.008000
CS31	CS000031	S27°32' 3.996572	E151°50'46.696638	540.939	A:D	Uncons			
CS30	CS000030	S27°32'18.796543	E151°50'44.908619	553.480	A:D	Uncons			
CS29	CS000029	S27°32'34.016212	E151°50'42.361839	567.093	A:D	Uncons			
CS28	CS000028	S27°32'26.515923	E151°50'31.294321	554.147	A:D	Uncons			
CS27	CS000027	S27°32'33.921465	E151°50'19.457151	559.994	A:D	Uncons			
CS26	CS000026	S27°32'52.202160	E151°50'24.243752	586.734	A:D	Uncons			
CS25	CS000025	S27°32'50.086976	E151°50' 8.655772	568.313	A:D	Cons	0.022000	0.014000	0.008000
CS106	CS106	S27°32'52.685258	E152° 5'27.757614	212.123	A:D	Uncons			
CS36	CS000036	S27°31' 7.637193	E151°51'53.091729	553.623	A:D	Uncons			
CS37	CS000037	S27°30'52.196198	E151°52' 1.421697	552.865	A:D	Uncons			
CS105	CS105	S27°32'48.413722	E152° 5' 5.557773	203.131	A:D	Cons	0.020000	0.014000	0.014000
CS35	CS000035	S27°31'26.144333	E151°51'38.579626	558.306	A:D	Uncons			
CS104	CS104	S27°32'39.031467	E152° 4'48.300588	218.165	A:D	Uncons			
CS34	CS000034	S27°31'43.758075	E151°51'32.473284	552.328	A:D	Uncons			
CS103	CS103	S27°32'25.435709	E152° 4'38.980865	217.419	A:D	Uncons			
CS102	CS102	S27°32' 9.051540	E152° 4'33.119380	214.805	A:D	Uncons			
CS53	CS000053	S27°29'58.944740	E151°54'37.574859	560.109	A:D	Uncons			
CS54	CS000054	S27°29'42.419064	E151°54'40.006044	547.745	A:D	Uncons			
CS71	CS000071	S27°30'13.360549	E151°54'34.870962	578.922	A:D	Uncons			
CS100	CS100	S27°31'41.140201	E152° 4'13.897365	243.476	A:D	Uncons			
CS51	CS000051	S27°30'39.049834	E151°54'35.771424	562.562	A:D	Uncons			
CS98	CS98	S27°31'22.655702	E152° 3'45.581143	252.599	A:D	Uncons			

CS97	CS97	S27°31'16.951982	E152° 3'29.747263	273.774	A:D	Cons	0.028000	0.014000	0.014000
CS44	CS000044	S27°30'30.263478	E151°54'15.965390	550.991	A:D	Uncons			
CS99	CS99	S27°31'31.758333	E152° 4' 0.525061	247.961	A:D	Uncons			
CS43	CS000043	S27°30'39.575157	E151°53'59.502180	567.382	A:D	Uncons			
CS55	CS000055	S27°29'15.575058	E151°54'34.374643	545.525	A:D	Uncons			
CS42	CS000042	S27°30'44.575401	E151°53'34.796622	581.123	A:D	Uncons			
CS41	CS000041	S27°30'39.497055	E151°53' 9.756262	553.709	A:D	Uncons			
CS39	CS000039	S27°30'34.293342	E151°52'33.711753	554.487	A:D	Uncons			
CS38	CS000038	S27°30'37.409058	E151°52'17.113489	548.982	A:D	Uncons			
CS46	CS000046	S27°31'57.734810	E151°54'21.507296	664.181	A:D	Uncons			
CS47	CS000047	S27°31'37.998663	E151°54'25.366640	619.603	A:D	Uncons			
CS48	CS000048	S27°31'25.931315	E151°54'27.632053	601.096	A:D	Uncons			
CS49	CS000049	S27°31'11.302943	E151°54'30.093100	592.023	A:D	Uncons			
CS50	CS000050	S27°30'55.899216	E151°54'33.086985	586.788	A:D	Uncons			
CS58	CS000058	S27°30'33.268569	E151°55'23.684135	586.465	A:D	Uncons			
CS59	CS000059	S27°30'38.707566	E151°55'42.387310	591.735	A:D	Uncons			
CS60	CS000060	S27°30'39.793841	E151°55'50.644680	583.228	A:D	Uncons			
CS57	CS000057	S27°30'31.565364	E151°54'59.447976	626.524	A:D	Uncons			
CS61	CS000061	S27°30'45.083100	E151°56' 9.913135	566.437	A:D	Uncons			
CS67	CS000067	S27°31'19.308621	E151°56'37.526379	595.512	A:D	Uncons			
CS68	CS000068	S27°31' 7.151039	E151°56'44.553553	606.131	A:D	Cons	0.047000	0.039000	0.028000
CS66	CS000066	S27°31'41.120712	E151°56'36.601342	604.132	A:D	Uncons			
CS65	CS000065	S27°32' 6.634167	E151°56'41.138253	614.820	A:D	Uncons			
CS64	CS000064	S27°32'25.440248	E151°56'39.230939	608.483	A:D	Uncons			
CS69	CS000069	S27°31'14.175412	E151°56'55.725897	613.977	A:D	Uncons			
CS91	CS91	S27°30'55.149133	E152° 1'58.500892	286.220	A:D	Uncons			
CS93	CS93	S27°30'47.322534	E152° 2'22.334654	355.956	A:D	Uncons			
CS94	CS94	S27°30'46.844582	E152° 2'40.539643	304.725	A:D	Uncons			
CS95	CS95	S27°30'59.535913	E152° 3' 1.977685	278.685	A:D	Uncons			
CS96	CS96	S27°31'11.347758	E152° 3'12.988897	306.094	A:D	Uncons			
CS90	CS90	S27°30'56.813174	E152° 1'40.032591	282.571	A:D	Cons	0.030000	0.030000	0.019000
CS89	CS89	S27°31' 0.794827	E152° 1'23.149995	306.670	A:D	Uncons			
CS88	CS88	S27°31' 1.647859	E152° 1' 3.396896	358.958	A:D	Cons	0.026000	0.030000	0.019000
CS83	CS83	S27°30'55.558259	E151°59'32.894710	477.318	A:D	Uncons			
CS82	CS82	S27°30'46.310010	E151°59'22.650322	454.877	A:D	Uncons			
CS81	CS81	S27°30'28.450619	E151°59'22.051214	498.637	A:D	Uncons			
CS80	CS80	S27°30'13.638598	E151°59'10.551791	470.838	A:D	Uncons			
CS85	CS85	S27°30'53.473261	E152° 0'10.278285	435.363	A:D	Uncons			
CS87	CS87	S27°30'56.224760	E152° 0'46.507510	392.279	A:D	Uncons			
CS72	CS72	S27°31' 2.448214	E151°57'21.476296	633.452	A:D	Cons	0.044000	0.040000	0.025000
CS73	CS73	S27°30'47.074394	E151°57'29.221347	616.647	A:D	Cons	0.029000	0.030000	0.018000
CS74	CS74	S27°30'41.114370	E151°57'48.583537	617.064	A:D	Uncons			
CS76	CS76	S27°30'15.626669	E151°58'17.036458	520.100	A:D	Cons	0.040000	0.024000	0.016000
CS77	CS77	S27°30' 7.163247	E151°58'28.375522	443.718	A:D	Cons	0.032000	0.016000	0.016000
CS78	CS78	S27°29'58.080525	E151°58'34.387249	486.140	A:D	Uncons			
CS86	CS86	S27°30'58.253231	E152° 0'26.959083	392.185	A:D	Uncons			
CS67A	CS00067A	S27°31'19.148346	E151°56'37.064148	603.822	A:D	Uncons			

Standardised residual scaler is 0.767

Iteration Number 0
========================

```
Listing of input Observations:-
===============================


From PM40970 To CS92ddX       190.670 dY      -398.512 dZ      -322.453  SSE/SST RS
Input VCV (cm^2)
    0.0255107    -0.0075941     0.0205721
   -0.0075941     0.0070261    -0.0052103
    0.0205721    -0.0052103     0.0327676
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -14621.897 dLong      9566.732 dHt      -166.148
Used VCV (cm^2)
    0.0427317    -0.0041005    -0.0238201
   -0.0041005     0.0404214    -0.0275219
   -0.0238201    -0.0275219     1.0542538
=================================================

From CS79 To CS75dX       944.611 dY       897.234 dZ      -980.703  SSE/SST RS
Input VCV (cm^2)
    0.0529258    -0.0215765     0.0252004
   -0.0215765     0.0211556    -0.0091886
    0.0252004    -0.0091886     0.0244001
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -34442.435 dLong    -45024.809 dHt        87.254
Used VCV (cm^2)
    0.0606478    -0.0096893    -0.0648179
   -0.0096893     0.0619839    -0.0986352
   -0.0648179    -0.0986352     2.6534004
=================================================

From CS75 To PM35751dX       395.373 dY      1254.509 dZ       -64.264  SSE/SST RS
Input VCV (cm^2)
    0.0563726    -0.0146655     0.0272409
   -0.0146655     0.0185921    -0.0017647
    0.0272409    -0.0017647     0.0346248
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      1760.480 dLong    -47111.574 dHt       243.192
Used VCV (cm^2)
    0.0618667    -0.0169092    -0.0363141
```

```
   -0.0169092     0.0634383    -0.0273352
   -0.0363141    -0.0273352     1.8321521
=================================================

From CS79 To 10KBMdX       857.226 dY      2947.708 dZ       589.262  SSE/SST RS
Input VCV (cm^2)
    0.1449145    -0.0793283     0.0692879
   -0.0793283     0.0746042    -0.0422388
    0.0692879    -0.0422388     0.0518507
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     26410.393 dLong   -109458.191 dHt       285.695
Used VCV (cm^2)
    0.0774343     0.0003025    -0.2141876
    0.0003025     0.0954198    -0.3512434
   -0.2141876    -0.3512434     6.8820993
=================================================

From 10KBM To PM112793dX     -2243.487 dY     -2125.904 dZ      2444.701  SSE/SST RS
Input VCV (cm^2)
    0.1252966    -0.0674558     0.0584937
   -0.0674558     0.0641551    -0.0353860
    0.0584937    -0.0353860     0.0439098
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     85160.653 dLong    106753.699 dHt      -257.788
Used VCV (cm^2)
    0.0989835    -0.0000888    -0.3031900
   -0.0000888     0.1278300    -0.4961084
   -0.3031900    -0.4961084     9.6785081
=================================================

From PM40970 To PM66947dX       877.832 dY     -2384.225 dZ     -3170.531  SSE/SST RS
Input VCV (cm^2)
    0.2143378    -0.0742071     0.0880784
   -0.0742071     0.0686282    -0.0346958
    0.0880784    -0.0346958     0.0666305
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat   -119759.977 dLong     61744.901 dHt      -213.520
Used VCV (cm^2)
    0.1182441    -0.0159434    -0.2968949
```

```
   -0.0159434     0.1663723    -0.3897802
   -0.2968949    -0.3897802     9.3471279
=================================================

From PM112799 To CS15dX       787.352 dY      5125.176 dZ      3455.129  SSE/SST RS
Input VCV (cm^2)
    0.7970340    -0.2441470     0.1923695
   -0.2441470     0.1459599    -0.0713689
    0.1923695    -0.0713689     0.1029228
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    125435.235 dLong   -178279.104 dHt       -70.943
Used VCV (cm^2)
    0.2246036    -0.0050560    -0.5022279
   -0.0050560     0.2602266    -0.9925611
   -0.5022279    -0.9925611    19.2473199
=================================================

From PM40970 To PM85731dX     -1455.844 dY     -3277.278 dZ        67.927  SSE/SST RS
Input VCV (cm^2)
    0.0991711    -0.0417092     0.0525302
   -0.0417092     0.0425405    -0.0182243
    0.0525302    -0.0182243     0.0828888
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     -1792.449 dLong    130338.957 dHt      -253.003
Used VCV (cm^2)
    0.1397965    -0.0345854    -0.1273611
   -0.0345854     0.1354274    -0.2886623
   -0.1273611    -0.2886623     7.1059656
=================================================

From CS84 To PM68101dX       532.034 dY     -3149.964 dZ     -3591.865  SSE/SST RS
Input VCV (cm^2)
    0.3043537    -0.2280159     0.1741906
   -0.2280159     0.2232189    -0.1502526
    0.1741906    -0.1502526     0.1570950
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat   -132723.283 dLong     92267.181 dHt       -66.927
Used VCV (cm^2)
    0.1130706     0.0234107    -0.4137685
```

```
    0.0234107     0.1291110    -0.8533933
   -0.4137685    -0.8533933    14.0502823
=================================================

From PM35751 To PM68101dX      -869.800 dY     -7259.084 dZ     -4100.087  SSE/SST RS
Input VCV (cm^2)
    0.0754421    -0.0369879     0.0317792
   -0.0369879     0.0400004    -0.0217309
    0.0317792    -0.0217309     0.0332237
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat   -157766.540 dLong    248422.088 dHt      -446.870
Used VCV (cm^2)
    0.3662376     0.0246294    -0.8487335
    0.0246294     0.4572334    -1.6637480
   -0.8487335    -1.6637480    31.4651803
=================================================

From PM85731 To CS101dX       811.370 dY      -824.547 dZ     -2124.781  SSE/SST RS
Input VCV (cm^2)
    0.0270976    -0.0123746     0.0087850
   -0.0123746     0.0097032    -0.0053860
    0.0087850    -0.0053860     0.0070885
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -77773.767 dLong     12699.197 dHt         3.587
Used VCV (cm^2)
    0.0770478     0.0054861    -0.1056378
    0.0054861     0.0740562    -0.2550183
   -0.1056378    -0.2550183     4.5467825
=================================================

From PM85731 To PM66947dX      2333.671 dY       893.051 dZ     -3238.469  SSE/SST RS
Input VCV (cm^2)
    0.0285549    -0.0119780     0.0129469
   -0.0119780     0.0120453    -0.0047128
    0.0129469    -0.0047128     0.0185111
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat   -117967.776 dLong    -68593.910 dHt        39.491
Used VCV (cm^2)
    0.1665417    -0.0394387    -0.1489012
```

```
   -0.0394387     0.1598176    -0.3650050
   -0.1489012    -0.3650050     8.6699066
=================================================

From PM66947 To CS101dX     -1522.297 dY     -1717.606 dZ      1113.687  SSE/SST RS
Input VCV (cm^2)
    0.0155180    -0.0053228     0.0104072
   -0.0053228     0.0052731    -0.0029726
    0.0104072    -0.0029726     0.0172992
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     40193.876 dLong     81293.261 dHt       -35.911
Used VCV (cm^2)
    0.0913696    -0.0214748    -0.0990870
   -0.0214748     0.0979808    -0.1529930
   -0.0990870    -0.1529930     4.3745064
=================================================

From PM85731 To CS107dX       455.484 dY     -3165.141 dZ     -3576.452  SSE/SST RS
Input VCV (cm^2)
    0.0318263    -0.0130405     0.0096967
   -0.0130405     0.0103986    -0.0043656
    0.0096967    -0.0043656     0.0084721
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat   -131324.967 dLong     94148.195 dHt       -17.971
Used VCV (cm^2)
    0.1870112    -0.0221832    -0.2316996
   -0.0221832     0.1778537    -0.6055998
   -0.2316996    -0.6055998    11.8605268
=================================================

From PM51843 To CS32dX       430.934 dY      2593.121 dZ      1948.148  SSE/SST RS
Input VCV (cm^2)
    0.1147674    -0.0619923     0.0806661
   -0.0619923     0.0735071    -0.0461786
    0.0806661    -0.0461786     0.0978417
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     68772.296 dLong    -90740.913 dHt      -153.552
Used VCV (cm^2)
    0.0908393    -0.0118525    -0.2104635
```

```
   -0.0118525     0.1149379    -0.3040934
   -0.2104635    -0.3040934     6.9485813
=================================================

From CS79 To PM35751dX      1339.978 dY      2151.752 dZ     -1044.973  SSE/SST RS
Input VCV (cm^2)
    0.0679051    -0.0137231     0.0965236
   -0.0137231     0.0138887    -0.0147480
    0.0965236    -0.0147480     0.2124980
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -32681.989 dLong    -92136.552 dHt       330.457
Used VCV (cm^2)
    0.0816295    -0.0328244    -0.1757088
   -0.0328244     0.1238159    -0.0945483
   -0.1757088    -0.0945483     4.8642613
=================================================

From CS79 To PM112793dX     -1386.254 dY       821.778 dZ      3033.977  SSE/SST RS
Input VCV (cm^2)
    0.0398290    -0.0089003     0.0340642
   -0.0089003     0.0157691     0.0022780
    0.0340642     0.0022780     0.0661309
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    111571.143 dLong     -2703.774 dHt        27.885
Used VCV (cm^2)
    0.1387403    -0.0821270    -0.1483665
   -0.0821270     0.1797871    -0.0029259
   -0.1483665    -0.0029259     5.7727415
=================================================

From PM40970 To PM68101dX      2557.959 dY      -218.571 dZ     -4179.163  SSE/SST RS
Input VCV (cm^2)
    0.0672791    -0.0309489     0.0265431
   -0.0309489     0.0291730    -0.0093262
    0.0265431    -0.0093262     0.0250664
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat   -155850.882 dLong    -36685.131 dHt      -162.439
Used VCV (cm^2)
    0.1935515    -0.0618225    -0.2425383
```

```
   -0.0618225     0.1889599    -0.5202958
   -0.2425383    -0.5202958    12.1965196
=================================================

From CS107 To CS108dX      -176.073 dY      -381.466 dZ       -35.114  SSE/SST RS
Input VCV (cm^2)
    0.2150102    -0.0641995     0.0877724
   -0.0641995     0.0517222    -0.0253193
    0.0877724    -0.0253193     0.1091522
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     -1355.450 dLong     15290.211 dHt        -4.065
Used VCV (cm^2)
    0.0432208    -0.0026305    -0.0134245
   -0.0026305     0.0374935    -0.0275313
   -0.0134245    -0.0275313     0.9035713
=================================================

From PM35751 To CS70dX       560.193 dY      -208.229 dZ      -965.725  SSE/SST RS
Input VCV (cm^2)
    0.1163289    -0.0636917     0.0475516
   -0.0636917     0.0686350    -0.0457886
    0.0475516    -0.0457886     0.0824725
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -36711.056 dLong     -2900.387 dHt       -79.177
Used VCV (cm^2)
    0.0548764     0.0040573    -0.0291722
    0.0040573     0.0469953    -0.0970213
   -0.0291722    -0.0970213     1.8091153
=================================================

From CS92 To CS101dX      -835.124 dY     -3703.318 dZ     -1734.409  SSE/SST RS
Input VCV (cm^2)
    0.1005402    -0.0500199     0.0334627
   -0.0500199     0.0396348    -0.0157774
    0.0334627    -0.0157774     0.0196682
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -64944.835 dLong    133471.219 dHt       -83.283
Used VCV (cm^2)
    0.1222059    -0.0199042    -0.2700309
```

```
   -0.0199042     0.1283605    -0.5314687
   -0.2700309    -0.5314687    10.4112933
=================================================

From PM51843 To CS22dX      2179.178 dY      3848.915 dZ        47.891  SSE/SST RS
Input VCV (cm^2)
    0.1612508    -0.0582642     0.0697330
   -0.0582642     0.0594159    -0.0439055
    0.0697330    -0.0439055     0.0820383
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      -211.105 dLong   -161157.747 dHt      -115.988
Used VCV (cm^2)
    0.1429078     0.0247044    -0.3067035
    0.0247044     0.1906634    -0.5262692
   -0.3067035    -0.5262692    10.4035036
=================================================

From CS84 To PM112793dX     -1324.424 dY      2779.148 dZ      4587.177  SSE/SST RS
Input VCV (cm^2)
    0.9736675    -0.5284625     0.3927250
   -0.5284625     0.5510766    -0.2211897
    0.3927250    -0.2211897     0.3111406
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    169296.896 dLong    -66721.754 dHt        77.388
Used VCV (cm^2)
    0.1852912    -0.0272435    -0.4254897
   -0.0272435     0.2153613    -0.7682560
   -0.4254897    -0.7682560    15.8022315
=================================================

From PM51843 To PM112799dX      3619.055 dY       567.007 dZ     -5366.166  SSE/SST RS
Input VCV (cm^2)
    0.1282827    -0.0665542     0.0788522
   -0.0665542     0.0822777    -0.0669034
    0.0788522    -0.0669034     0.1193292
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat   -198482.805 dLong    -80442.986 dHt      -107.222
Used VCV (cm^2)
    0.2272816     0.0524640    -0.6046112
```

```
    0.0524640     0.3135783    -1.0994411
   -0.6046112    -1.0994411    20.3570767
=================================================

From PM51843 To CS40dX     -2101.070 dY       488.013 dZ      4272.056  SSE/SST RS
Input VCV (cm^2)
    0.3428231    -0.0976785     0.1074953
   -0.0976785     0.0627288    -0.0413962
    0.1074953    -0.0413962     0.0706610
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    154337.277 dLong     20403.044 dHt      -127.552
Used VCV (cm^2)
    0.1447464     0.0088132    -0.3720841
    0.0088132     0.1916219    -0.6198734
   -0.3720841    -0.6198734    12.3834728
=================================================

From CS107 To CS101dX       355.904 dY      2340.583 dZ      1451.670  SSE/SST RS
Input VCV (cm^2)
    0.2775696    -0.1439499     0.1709454
   -0.1439499     0.0855389    -0.0904276
    0.1709454    -0.0904276     0.1212664
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     53550.881 dLong    -81448.987 dHt        21.540
Used VCV (cm^2)
    0.0519540     0.0093293    -0.2144633
    0.0093293     0.0622040    -0.3835148
   -0.2144633    -0.3835148     6.4885907
=================================================

From PM112799 To PM51843dX     -3619.037 dY      -567.013 dZ      5366.176  SSE/SST RS
Input VCV (cm^2)
    0.1988314    -0.1033630     0.1800381
   -0.1033630     0.1001079    -0.1019386
    0.1800381    -0.1019386     0.2337477
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    198482.824 dLong     80442.861 dHt       107.201
Used VCV (cm^2)
    0.1659849    -0.0090107    -0.7557289
```

```
   -0.0090107     0.2695741    -1.0880064
   -0.7557289    -1.0880064    22.1768970
=================================================

From CS107 To PM66947dX      1878.186 dY      4058.186 dZ       337.987  SSE/SST RS
Input VCV (cm^2)
    0.2054483    -0.0543886     0.1590792
   -0.0543886     0.0473175    -0.0354205
    0.1590792    -0.0354205     0.2437620
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     13357.268 dLong   -162741.905 dHt        57.459
Used VCV (cm^2)
    0.1538356    -0.0534497    -0.3000852
   -0.0534497     0.2072579    -0.3293177
   -0.3000852    -0.3293177    10.2804330
=================================================

From PM51843 To CS45dX     -2185.172 dY     -2239.023 dZ      1732.451  SSE/SST RS
Input VCV (cm^2)
    0.4577918    -0.1520641     0.1030098
   -0.1520641     0.0946200    -0.0417290
    0.1030098    -0.0417290     0.0544688
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     63004.847 dLong    109493.921 dHt       -27.522
Used VCV (cm^2)
    0.1130415    -0.0011711    -0.1902948
   -0.0011711     0.1174487    -0.4097268
   -0.1902948    -0.4097268     7.8364317
=================================================

From CS56 To PM35751dX     -1031.094 dY     -4522.572 dZ     -2735.054  SSE/SST RS
Input VCV (cm^2)
    0.1165704    -0.0668094     0.0507073
   -0.0668094     0.0725598    -0.0491319
    0.0507073    -0.0491319     0.0880354
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -97078.821 dLong    163044.453 dHt       182.247
Used VCV (cm^2)
    0.2231160     0.0342866    -0.2684073
```

```
    0.0342866     0.2054525    -0.8775334
   -0.2684073    -0.8775334    14.3352465
=================================================

From PM35751 To CS45dX      3513.472 dY      3593.212 dZ     -2520.692  SSE/SST RS
Input VCV (cm^2)
    0.3089029    -0.1416423     0.0922456
   -0.1416423     0.1385179    -0.0734902
    0.0922456    -0.0734902     0.1189558
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -93772.394 dLong   -175760.973 dHt       -85.145
Used VCV (cm^2)
    0.2462550     0.0306037    -0.2756643
    0.0306037     0.2355811    -0.8787821
   -0.2756643    -0.8787821    14.9880396
=================================================

From PM112799 To CS22dX     -1439.863 dY      3281.901 dZ      5414.052  SSE/SST RS
Input VCV (cm^2)
    0.1953347    -0.1213775     0.0734603
   -0.1213775     0.1745722    -0.0635938
    0.0734603    -0.0635938     0.0714489
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    198271.331 dLong    -80714.741 dHt        -8.777
Used VCV (cm^2)
    0.2538892     0.0090054    -0.5222492
    0.0090054     0.3078665    -1.0114353
   -0.5222492    -1.0114353    19.9006378
=================================================

From CS45 To CS62dX     -2456.608 dY     -2627.892 dZ      1939.529  SSE/SST RS
Input VCV (cm^2)
    0.2221268    -0.1064246     0.0888900
   -0.1064246     0.1162462    -0.0595820
    0.0888900    -0.0595820     0.0903039
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     69844.788 dLong    126615.247 dHt       -70.992
Used VCV (cm^2)
    0.1331654     0.0057996    -0.2465672
```

```
    0.0057996     0.1552508    -0.4757274
   -0.2465672    -0.4757274     9.3519517
=================================================

From CS45 To CS63dX     -1413.579 dY     -3827.479 dZ      -970.587  SSE/SST RS
Input VCV (cm^2)
    0.2290626    -0.1304717     0.0789955
   -0.1304717     0.1159045    -0.0444027
    0.0789955    -0.0444027     0.0452604
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -36276.164 dLong    147315.022 dHt       -42.393
Used VCV (cm^2)
    0.1148690    -0.0133891    -0.2935950
   -0.0133891     0.1265165    -0.5531567
   -0.2935950    -0.5531567    10.6833842
=================================================

From PM112799 To CS04dX      3556.369 dY      5813.283 dZ      -638.482  SSE/SST RS
Input VCV (cm^2)
    0.1089154    -0.0505945     0.0480042
   -0.0505945     0.0694249    -0.0347992
    0.0480042    -0.0347992     0.0477992
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -24241.634 dLong   -248106.873 dHt       -49.160
Used VCV (cm^2)
    0.2431987     0.0266232    -0.7022608
    0.0266232     0.3777556    -1.0209208
   -0.7022608    -1.0209208    21.7560655
=================================================

From PM35751 To CS62dX      1056.823 dY       965.333 dZ      -581.154  SSE/SST RS
Input VCV (cm^2)
    0.0694934    -0.0237132     0.0283524
   -0.0237132     0.0378156    -0.0166774
    0.0283524    -0.0166774     0.0280019
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -23926.746 dLong    -49145.465 dHt      -156.103
Used VCV (cm^2)
    0.0570882     0.0008844    -0.0758326
```

```
    0.0008844     0.0705159    -0.0828642
   -0.0758326    -0.0828642     2.3702803
=================================================

From CS70 To CS63dX      1539.628 dY       -25.997 dZ     -2525.574  SSE/SST RS
Input VCV (cm^2)
    0.1782597    -0.1318522     0.1704334
   -0.1318522     0.1122290    -0.1380359
    0.1704334    -0.1380359     0.1831793
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -93336.827 dLong    -25545.648 dHt       -48.278
Used VCV (cm^2)
    0.0485775     0.0184868    -0.2507735
    0.0184868     0.0656092    -0.4364762
   -0.2507735    -0.4364762     7.2007725
=================================================

From PM35751 To CS70dX       560.177 dY      -208.220 dZ      -965.749  SSE/SST RS
Input VCV (cm^2)
    0.1979732    -0.0807795     0.0777983
   -0.0807795     0.0764608    -0.0220963
    0.0777983    -0.0220963     0.0722147
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -36711.464 dLong     -2900.400 dHt       -79.151
Used VCV (cm^2)
    0.0544949    -0.0093485    -0.0324572
   -0.0093485     0.0493504    -0.0596868
   -0.0324572    -0.0596868     1.7808876
=================================================

From PM35751 To 10KBMdX      -482.741 dY       795.949 dZ      1634.252  SSE/SST RS
Input VCV (cm^2)
    0.5036305    -0.2843864     0.2374681
   -0.2843864     0.2085355    -0.1361054
    0.2374681    -0.1361054     0.1467848
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     59092.638 dLong    -17321.599 dHt       -44.781
Used VCV (cm^2)
    0.0495539     0.0015348    -0.1124313
```

```
    0.0015348     0.0513134    -0.2000502
   -0.1124313    -0.2000502     3.7134704
=================================================

From PM40970 To CS79dX      2087.809 dY      4888.733 dZ       965.911  SSE/SST RS
Input VCV (cm^2)
    0.0624543    -0.0568928     0.0622680
   -0.0568928     0.0675792    -0.0627352
    0.0622680    -0.0627352     0.0758636
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     34597.454 dLong   -192970.239 dHt       -46.066
Used VCV (cm^2)
    0.0921447     0.0336528    -0.6225148
    0.0336528     0.1504707    -1.0470619
   -0.6225148    -1.0470619    17.7614582
=================================================

From PM85731 To CS92dX      1646.532 dY      2878.747 dZ      -390.372  SSE/SST RS
Input VCV (cm^2)
    0.0763745    -0.0632013     0.0389169
   -0.0632013     0.0664095    -0.0373169
    0.0389169    -0.0373169     0.0285726
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -12829.597 dLong   -120771.946 dHt        86.830
Used VCV (cm^2)
    0.0704081     0.0176316    -0.2528921
    0.0176316     0.0815717    -0.4932417
   -0.2528921    -0.4932417     8.1278728
=================================================

From PM40970 To CS84dX      2025.957 dY      2931.369 dZ      -587.286  SSE/SST RS
Input VCV (cm^2)
    0.0480395    -0.0133281     0.0180567
   -0.0133281     0.0141974    -0.0147224
    0.0180567    -0.0147224     0.0289583
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -23127.862 dLong   -128952.088 dHt       -95.552
Used VCV (cm^2)
    0.1193416     0.0493224    -0.2173449
```

```
    0.0493224     0.1621063    -0.4056621
   -0.2173449    -0.4056621     7.2052588
=================================================

From PM35751 To CS84dX     -1401.803 dY     -4109.124 dZ      -508.207  SSE/SST RS
Input VCV (cm^2)
    0.2153850    -0.0716784     0.0789183
   -0.0716784     0.0509773    -0.0407329
    0.0789183    -0.0407329     0.0724969
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -25043.277 dLong    156154.495 dHt      -379.976
Used VCV (cm^2)
    0.1362777     0.0241868    -0.2954409
    0.0241868     0.1645517    -0.5891458
   -0.2954409    -0.5891458    10.6402652
=================================================

From CS84 To CS79dX        61.859 dY      1957.356 dZ      1553.204  SSE/SST RS
Input VCV (cm^2)
    0.4174939    -0.1299649     0.5259723
   -0.1299649     0.0606678    -0.1744263
    0.5259723    -0.1744263     0.7304085
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     57725.378 dLong    -64018.000 dHt        49.474
Used VCV (cm^2)
    0.0479186     0.0049877    -0.2007201
    0.0049877     0.0700917    -0.2817214
   -0.2007201    -0.2817214     5.4354676
=================================================

From PM66947 To PM68101dX      1680.115 dY      2165.673 dZ     -1008.632  SSE/SST RS
Input VCV (cm^2)
    0.6687443    -0.3017197     0.1540197
   -0.3017197     0.1519069    -0.0707687
    0.1540197    -0.0707687     0.0435571
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -36090.611 dLong    -98430.442 dHt        51.097
Used VCV (cm^2)
    0.0574621     0.0092075    -0.2163906
```

```
    0.0092075     0.0630838    -0.4156481
   -0.2163906    -0.4156481     6.9237499
=================================================

From 10KBM To CS56dX      1513.838 dY      3726.582 dZ      1100.807  SSE/SST RS
Input VCV (cm^2)
    0.1956709    -0.0787495     0.0758256
   -0.0787495     0.0674668    -0.0314294
    0.0758256    -0.0314294     0.0525904
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     37985.983 dLong   -145721.594 dHt      -137.486
Used VCV (cm^2)
    0.1220066    -0.0198539    -0.2947943
   -0.0198539     0.1536386    -0.4484524
   -0.2947943    -0.4484524    10.0137483
=================================================

From PM85731 To CS108dX       279.410 dY     -3546.611 dZ     -3611.574  SSE/SST RS
Input VCV (cm^2)
    0.7726763    -0.2020225     0.1810422
   -0.2020225     0.1360897    -0.0524687
    0.1810422    -0.0524687     0.1788722
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat   -132680.687 dLong    109438.584 dHt       -22.033
Used VCV (cm^2)
    0.2367305    -0.0365233    -0.1763353
   -0.0365233     0.2240681    -0.5420595
   -0.1763353    -0.5420595    11.8361894
=================================================

From CS70 To PM57526dX     -1910.378 dY     -4166.254 dZ       207.424  SSE/SST RS
Input VCV (cm^2)
    4.9379882    -2.0606809     1.9309835
   -2.0606809     0.8989363    -0.7877923
    1.9309835    -0.7877923     0.8894701
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      1908.528 dLong    166708.907 dHt      -336.154
Used VCV (cm^2)
    0.0791716     0.0164942    -0.4434259
```

```
    0.0164942     0.0917356    -0.8643892
   -0.4434259    -0.8643892    14.0074024
=================================================

From PM57526 To PM68101dX       480.395 dY     -2884.591 dZ     -3341.788  SSE/SST RS
Input VCV (cm^2)
    2.5776819    -1.0705167     1.0092793
   -1.0705167     0.4646621    -0.4100212
    1.0092793    -0.4100212     0.4636169
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat   -122964.129 dLong     84613.063 dHt       -31.542
Used VCV (cm^2)
    0.0760908     0.0158816    -0.4205433
    0.0158816     0.0884951    -0.8215071
   -0.4205433    -0.8215071    13.3024334
=================================================

From CS04 To CS15dX     -2768.906 dY      -688.175 dZ      4093.641  SSE/SST RS
Input VCV (cm^2)
    0.1459750    -0.0642031     0.0445237
   -0.0642031     0.0493992    -0.0268689
    0.0445237    -0.0268689     0.0360686
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    149675.800 dLong     69828.058 dHt       -21.913
Used VCV (cm^2)
    0.1734240     0.0164927    -0.3056856
    0.0164927     0.1735202    -0.7651911
   -0.3056856    -0.7651911    13.3176730
=================================================

From CS15 To CS22dX     -2227.262 dY     -1843.240 dZ      1958.895  SSE/SST RS
Input VCV (cm^2)
    0.0865615    -0.0499355     0.0376575
   -0.0499355     0.0539701    -0.0345814
    0.0376575    -0.0345814     0.0514823
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     72836.158 dLong     97564.043 dHt        62.231
Used VCV (cm^2)
    0.1163051     0.0177864    -0.1639833
```

```
    0.0177864     0.1139365    -0.4363221
   -0.1639833    -0.4363221     7.4470859
=================================================

From CS40 To CS52dX     -1509.773 dY     -2354.158 dZ       409.717  SSE/SST RS
Input VCV (cm^2)
    0.2961714    -0.1663699     0.1336148
   -0.1663699     0.1195077    -0.0771248
    0.1336148    -0.0771248     0.0781063
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     15147.117 dLong    101565.923 dHt         8.341
Used VCV (cm^2)
    0.0607188     0.0043945    -0.2012237
    0.0043945     0.0693550    -0.3588220
   -0.2012237    -0.3588220     6.4019391
=================================================

From CS52 To CS62dX     -1031.012 dY     -3000.683 dZ     -1009.819  SSE/SST RS
Input VCV (cm^2)
    0.0540950    -0.0424573     0.0207860
   -0.0424573     0.0599232    -0.0261789
    0.0207860    -0.0261789     0.0578232
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -36633.916 dLong    114138.693 dHt        20.804
Used VCV (cm^2)
    0.1472544     0.0001769    -0.0388905
    0.0001769     0.1053803    -0.3777283
   -0.0388905    -0.3777283     6.2710807
=================================================

From CS52 To CS56dX     -1056.723 dY       556.492 dZ      2306.403  SSE/SST RS
Input VCV (cm^2)
    0.1805574    -0.0730625     0.0767214
   -0.0730625     0.0644163    -0.0417267
    0.0767214    -0.0417267     0.0689777
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     84371.327 dLong       241.452 dHt        -5.386
Used VCV (cm^2)
    0.0766408     0.0036675    -0.1421551
```

```
    0.0036675     0.0889296    -0.2444003
   -0.1421551    -0.2444003     4.9536404
=================================================

From CS40 To CS32dX      2532.006 dY      2105.102 dZ     -2323.886  SSE/SST RS
Input VCV (cm^2)
    0.1739751    -0.0845974     0.0697287
   -0.0845974     0.0798958    -0.0278727
    0.0697287    -0.0278727     0.0623325
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -85564.419 dLong   -111143.808 dHt       -26.015
Used VCV (cm^2)
    0.1424010    -0.0387798    -0.1937877
   -0.0387798     0.1392427    -0.3999050
   -0.1937877    -0.3999050     9.1322533
=================================================

From CS32 To CS22dX      1748.247 dY      1255.795 dZ     -1900.243  SSE/SST RS
Input VCV (cm^2)
    0.2380677    -0.0462452     0.2788427
   -0.0462452     0.0527508    -0.0406306
    0.2788427    -0.0406306     0.5385455
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -68983.034 dLong    -70416.877 dHt        37.556
Used VCV (cm^2)
    0.0881737    -0.0359802    -0.1818523
   -0.0359802     0.1353058    -0.0843590
   -0.1818523    -0.0843590     5.0618060
=================================================

From CS52 To CS45dX      1425.641 dY      -372.853 dZ     -2949.326  SSE/SST RS
Input VCV (cm^2)
    0.7593179    -0.4099940     0.3850562
   -0.4099940     0.2598898    -0.2124928
    0.3850562    -0.2124928     0.2369784
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat   -106479.078 dLong    -12475.335 dHt        91.724
Used VCV (cm^2)
    0.0618967     0.0097104    -0.2650702
```

```
    0.0097104     0.0740276    -0.4813193
   -0.2650702    -0.4813193     8.2204346
=================================================

From CS63 To CS62dX     -1043.020 dY      1199.585 dZ      2910.110  SSE/SST RS
Input VCV (cm^2)
    0.1468097    -0.0422447     0.1056172
   -0.0422447     0.0547210    -0.0210102
    0.1056172    -0.0210102     0.2142704
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    106120.619 dLong    -20699.876 dHt       -28.603
Used VCV (cm^2)
    0.1278946    -0.0400438    -0.1377400
   -0.0400438     0.1518222    -0.1461611
   -0.1377400    -0.1461611     5.8792261
=================================================

From PM112799 To CS04dX      3556.367 dY      5813.302 dZ      -638.499  SSE/SST RS
Input VCV (cm^2)
    0.0828261    -0.0639445     0.0646109
   -0.0639445     0.0662375    -0.0600490
    0.0646109    -0.0600490     0.0781248
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -24241.987 dLong   -248107.459 dHt       -49.143
Used VCV (cm^2)
    0.1679763     0.0571147    -0.7850999
    0.0571147     0.2178061    -1.5549275
   -0.7850999    -1.5549275    25.5873667
=================================================

From CS04 To CS05dX      -267.986 dY      -414.810 dZ        76.126  SSE/SST RS
Input VCV (cm^2)
    0.0340832    -0.0143712     0.0181715
   -0.0143712     0.0169038    -0.0144852
    0.0181715    -0.0144852     0.0273107
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      2794.214 dLong     17950.045 dHt         0.199
Used VCV (cm^2)
    0.0414454     0.0027407    -0.0237807
```

```
    0.0027407     0.0388770    -0.0423647
   -0.0237807    -0.0423647     1.0313733
=================================================

From CS05 To CS06dX       -80.194 dY       512.509 dZ       592.958  SSE/SST RS
Input VCV (cm^2)
    0.0908803    -0.0385565     0.0361479
   -0.0385565     0.0329479    -0.0211921
    0.0361479    -0.0211921     0.0308510
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     21779.834 dLong    -15086.594 dHt         2.492
Used VCV (cm^2)
    0.0437603     0.0016554    -0.0344292
    0.0016554     0.0410105    -0.0641669
   -0.0344292    -0.0641669     1.4290224
=================================================

From CS06 To CS07dX      -196.307 dY       -17.097 dZ       331.567  SSE/SST RS
Input VCV (cm^2)
    0.1797630    -0.0561043     0.0438897
   -0.0561043     0.0327781    -0.0152049
    0.0438897    -0.0152049     0.0227313
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     12026.767 dLong      3933.585 dHt        -7.521
Used VCV (cm^2)
    0.0402992    -0.0007573    -0.0180397
   -0.0007573     0.0347050    -0.0359123
   -0.0180397    -0.0359123     0.9512935
=================================================

From CS07 To CS08dX      -308.767 dY      -157.881 dZ       392.926  SSE/SST RS
Input VCV (cm^2)
    0.0710847    -0.0197320     0.0262258
   -0.0197320     0.0131736    -0.0103202
    0.0262258    -0.0103202     0.0191973
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     14283.082 dLong     10395.489 dHt        -7.082
Used VCV (cm^2)
    0.0403879     0.0010123    -0.0277023
```

```
    0.0010123     0.0382958    -0.0424731
   -0.0277023    -0.0424731     1.0968670
=================================================

From CS08 To CS09dX      -231.568 dY       -45.868 dZ       369.470  SSE/SST RS
Input VCV (cm^2)
    0.0121205    -0.0053253     0.0057882
   -0.0053253     0.0064324    -0.0033830
    0.0057882    -0.0033830     0.0071905
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     13381.076 dLong      5465.088 dHt        -9.541
Used VCV (cm^2)
    0.0417246    -0.0005268    -0.0189953
   -0.0005268     0.0377911    -0.0322699
   -0.0189953    -0.0322699     0.9522325
=================================================

From CS09 To CS10dX      -389.290 dY      -311.073 dZ       370.861  SSE/SST RS
Input VCV (cm^2)
    0.0198011    -0.0119176     0.0056217
   -0.0119176     0.0144515    -0.0052365
    0.0056217    -0.0052365     0.0083825
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     13626.559 dLong     16704.076 dHt         1.939
Used VCV (cm^2)
    0.0476989     0.0002146    -0.0107653
    0.0002146     0.0384141    -0.0501560
   -0.0107653    -0.0501560     1.1091030
=================================================

From CS10 To CS11dX      -221.458 dY      -207.799 dZ       197.361  SSE/SST RS
Input VCV (cm^2)
    0.0217281    -0.0121024     0.0096953
   -0.0121024     0.0126958    -0.0090747
    0.0096953    -0.0090747     0.0164644
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      7140.893 dLong     10492.902 dHt        -5.480
Used VCV (cm^2)
    0.0416557     0.0016264    -0.0126543
```

```
    0.0016264     0.0344648    -0.0399731
   -0.0126543    -0.0399731     0.8966970
=================================================

From CS11 To CS12dX      -303.168 dY       -94.009 dZ       449.576  SSE/SST RS
Input VCV (cm^2)
    0.0859020    -0.0439687     0.0343413
   -0.0439687     0.0512442    -0.0263528
    0.0343413    -0.0263528     0.0394896
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     16294.958 dLong      8243.963 dHt       -10.784
Used VCV (cm^2)
    0.0430563     0.0009680    -0.0210066
    0.0009680     0.0383137    -0.0449354
   -0.0210066    -0.0449354     1.0861905
=================================================

From CS01 To CS02dX      -322.607 dY      -399.330 dZ       187.050  SSE/SST RS
Input VCV (cm^2)
    0.1137292    -0.0714191     0.0599973
   -0.0714191     0.0948057    -0.0444766
    0.0599973    -0.0444766     0.0685628
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      6819.946 dLong     18395.751 dHt        -2.213
Used VCV (cm^2)
    0.0420248    -0.0007141    -0.0233139
   -0.0007141     0.0376960    -0.0424634
   -0.0233139    -0.0424634     1.1093277
=================================================

From CS02 To CS03dX      -294.995 dY      -440.711 dZ       133.483  SSE/SST RS
Input VCV (cm^2)
    0.2350658    -0.2098102     0.0908070
   -0.2098102     0.2819610    -0.0966715
    0.0908070    -0.0966715     0.0707603
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      4617.819 dLong     19248.692 dHt       -16.231
Used VCV (cm^2)
    0.0410484     0.0007205    -0.0237608
```

```
    0.0007205     0.0348948    -0.0539294
   -0.0237608    -0.0539294     1.1707012
=================================================

From CS03 To CS04dX      -257.103 dY      -351.060 dZ       128.644  SSE/SST RS
Input VCV (cm^2)
    0.0294132    -0.0153331     0.0137816
   -0.0153331     0.0203736    -0.0111440
    0.0137816    -0.0111440     0.0152750
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      4614.737 dLong     15714.126 dHt        -5.971
Used VCV (cm^2)
    0.0406157     0.0012583    -0.0228721
    0.0012583     0.0375832    -0.0383682
   -0.0228721    -0.0383682     0.9987547
=================================================

From CS14 To CS13dX       264.407 dY       186.040 dZ      -308.242  SSE/SST RS
Input VCV (cm^2)
    0.0236882    -0.0156678     0.0097421
   -0.0156678     0.0223384    -0.0083338
    0.0097421    -0.0083338     0.0104623
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -11057.964 dLong    -10532.125 dHt        14.082
Used VCV (cm^2)
    0.0417449    -0.0001628    -0.0180974
   -0.0001628     0.0364161    -0.0378722
   -0.0180974    -0.0378722     0.9841786
=================================================

From CS13 To CS12dX       257.387 dY       -60.824 dZ      -480.401  SSE/SST RS
Input VCV (cm^2)
    0.0713724    -0.0506798     0.0287692
   -0.0506798     0.0697179    -0.0275587
    0.0287692    -0.0275587     0.0272755
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -17676.247 dLong     -2479.835 dHt        -4.075
Used VCV (cm^2)
    0.0419093     0.0008621    -0.0232316
```

```
    0.0008621     0.0370507    -0.0481732
   -0.0232316    -0.0481732     1.1238705
=================================================

From CS15 To CS16dX      -362.784 dY      -217.949 dZ       449.900  SSE/SST RS
Input VCV (cm^2)
    0.0260942    -0.0075044     0.0115144
   -0.0075044     0.0077796    -0.0055859
    0.0115144    -0.0055859     0.0122777
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     16214.365 dLong     13250.471 dHt       -16.086
Used VCV (cm^2)
    0.0425963     0.0010894    -0.0299021
    0.0010894     0.0426529    -0.0394558
   -0.0299021    -0.0394558     1.1360081
=================================================

From CS16 To CS17dX      -285.019 dY      -167.493 dZ       306.904  SSE/SST RS
Input VCV (cm^2)
    0.0308884    -0.0185407     0.0087551
   -0.0185407     0.0223858    -0.0082088
    0.0087551    -0.0082088     0.0131530
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     11424.840 dLong     10289.365 dHt        10.514
Used VCV (cm^2)
    0.0448194     0.0002332    -0.0086412
    0.0002332     0.0360116    -0.0403666
   -0.0086412    -0.0403666     0.9381700
=================================================

From CS17 To CS18dX      -280.630 dY      -145.717 dZ       313.324  SSE/SST RS
Input VCV (cm^2)
    0.0542283    -0.0307927     0.0244581
   -0.0307927     0.0324312    -0.0231413
    0.0244581    -0.0231413     0.0415334
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     11706.369 dLong      9513.563 dHt        13.264
Used VCV (cm^2)
    0.0426601     0.0018286    -0.0143298
```

```
    0.0018286     0.0353714    -0.0453048
   -0.0143298    -0.0453048     0.9800888
=================================================

From CS14 To CS15dX      -248.417 dY       173.099 dZ       524.179  SSE/SST RS
Input VCV (cm^2)
    0.0227679    -0.0035858     0.0127246
   -0.0035858     0.0030156    -0.0029390
    0.0127246    -0.0029390     0.0179467
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     19615.712 dLong     -1282.682 dHt        23.905
Used VCV (cm^2)
    0.0438138    -0.0015873    -0.0273329
   -0.0015873     0.0446391    -0.0263096
   -0.0273329    -0.0263096     1.0632376
=================================================

From CS21 To CS22dX      -353.068 dY      -302.828 dZ       305.718  SSE/SST RS
Input VCV (cm^2)
    0.0367224    -0.0131684     0.0062459
   -0.0131684     0.0087936    -0.0030939
    0.0062459    -0.0030939     0.0058442
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     11333.338 dLong     15805.203 dHt         7.765
Used VCV (cm^2)
    0.0471754    -0.0006937    -0.0075525
   -0.0006937     0.0368488    -0.0461082
   -0.0075525    -0.0461082     1.0394364
=================================================

From CS22 To CS23dX      -209.972 dY      -118.929 dZ       274.881  SSE/SST RS
Input VCV (cm^2)
    0.0450734    -0.0132219     0.0151840
   -0.0132219     0.0081990    -0.0059563
    0.0151840    -0.0059563     0.0102380
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      9854.494 dLong      7433.767 dHt       -12.808
Used VCV (cm^2)
    0.0391151     0.0006618    -0.0212336
```

```
    0.0006618     0.0352144    -0.0359585
   -0.0212336    -0.0359585     0.9379148
=================================================

From CS21 To CS20dX       337.457 dY       264.890 dZ      -309.174  SSE/SST RS
Input VCV (cm^2)
    0.0609060    -0.0361480     0.0255307
   -0.0361480     0.0392376    -0.0237332
    0.0255307    -0.0237332     0.0401158
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -11494.805 dLong    -14318.517 dHt        -9.800
Used VCV (cm^2)
    0.0440406     0.0014230    -0.0151585
    0.0014230     0.0363333    -0.0496298
   -0.0151585    -0.0496298     1.0637550
=================================================

From CS23 To CS24dX       -82.359 dY       263.522 dZ       382.926  SSE/SST RS
Input VCV (cm^2)
    0.0297226    -0.0073888     0.0118194
   -0.0073888     0.0064141    -0.0049519
    0.0118194    -0.0049519     0.0106323
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     13988.592 dLong     -7049.866 dHt        -2.438
Used VCV (cm^2)
    0.0405007     0.0011379    -0.0261120
    0.0011379     0.0396883    -0.0337226
   -0.0261120    -0.0337226     0.9950769
=================================================

From CS20 To CS19dX       368.021 dY       496.978 dZ      -109.174  SSE/SST RS
Input VCV (cm^2)
    0.5519168    -0.5103710     0.2278723
   -0.5103710     0.5267329    -0.2197688
    0.2278723    -0.2197688     0.1141915
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     -4492.247 dLong    -22302.268 dHt       -29.010
Used VCV (cm^2)
    0.0370692     0.0020290    -0.0381746
```

```
    0.0020290     0.0326029    -0.0719388
   -0.0381746    -0.0719388     1.4085920
=================================================

From CS19 To CS18dX       240.268 dY       247.389 dZ      -164.721  SSE/SST RS
Input VCV (cm^2)
    0.0428954    -0.0186709     0.0198222
   -0.0186709     0.0178928    -0.0125652
    0.0198222    -0.0125652     0.0152355
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     -6170.545 dLong    -12084.660 dHt        -7.940
Used VCV (cm^2)
    0.0376650     0.0018337    -0.0267775
    0.0018337     0.0356680    -0.0387163
   -0.0267775    -0.0387163     0.9812537
=================================================

From CS32 To CS33dX      -331.247 dY      -335.386 dZ       258.834  SSE/SST RS
Input VCV (cm^2)
    0.0408772    -0.0211933     0.0236946
   -0.0211933     0.0266379    -0.0216434
    0.0236946    -0.0216434     0.0372731
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      9465.968 dLong     16470.540 dHt        -0.947
Used VCV (cm^2)
    0.0417241     0.0027619    -0.0247225
    0.0027619     0.0385732    -0.0470893
   -0.0247225    -0.0470893     1.0873239
=================================================

From CS31 To CS30dX       199.055 dY       -50.877 dZ      -409.785  SSE/SST RS
Input VCV (cm^2)
    0.0252659    -0.0131614     0.0119486
   -0.0131614     0.0175703    -0.0095528
    0.0119486    -0.0095528     0.0130559
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -14799.972 dLong     -1788.019 dHt        12.541
Used VCV (cm^2)
    0.0405281     0.0012093    -0.0235607
```

```
    0.0012093     0.0376907    -0.0384427
   -0.0235607    -0.0384427     1.0044389
=================================================

From CS30 To CS29dX       213.333 dY       -34.908 dZ      -421.723  SSE/SST RS
Input VCV (cm^2)
    0.0367120    -0.0125932     0.0151441
   -0.0125932     0.0171612    -0.0085365
    0.0151441    -0.0085365     0.0142591
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -15219.669 dLong     -2546.780 dHt        13.613
Used VCV (cm^2)
    0.0408410     0.0004499    -0.0258009
    0.0004499     0.0403923    -0.0303066
   -0.0258009    -0.0303066     0.9805996
=================================================

From CS29 To CS28dX        59.299 dY       312.715 dZ       210.709  SSE/SST RS
Input VCV (cm^2)
    0.0318870    -0.0090395     0.0108511
   -0.0090395     0.0148219    -0.0053672
    0.0108511    -0.0053672     0.0118237
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      7500.289 dLong    -11067.518 dHt       -12.946
Used VCV (cm^2)
    0.0418226    -0.0004430    -0.0182495
   -0.0004430     0.0402045    -0.0203194
   -0.0182495    -0.0203194     0.8332082
=================================================

From CS28 To CS27dX       241.652 dY       239.064 dZ      -204.840  SSE/SST RS
Input VCV (cm^2)
    0.1309568    -0.0939653     0.1256006
   -0.0939653     0.0789382    -0.1007556
    0.1256006    -0.1007556     0.1401228
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     -7405.542 dLong    -11837.170 dHt         5.847
Used VCV (cm^2)
    0.0353258     0.0023852    -0.0307256
```

```
    0.0023852     0.0313727    -0.0538530
   -0.0307256    -0.0538530     1.1104016
=================================================

From CS27 To CS26dX       146.551 dY      -227.424 dZ      -511.328  SSE/SST RS
Input VCV (cm^2)
    0.0280983    -0.0082027     0.0286038
   -0.0082027     0.0058413    -0.0107394
    0.0286038    -0.0107394     0.0438467
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -18280.695 dLong      4786.601 dHt        26.741
Used VCV (cm^2)
    0.0390176     0.0004756    -0.0356601
    0.0004756     0.0392709    -0.0439377
   -0.0356601    -0.0439377     1.1917455
=================================================

From CS26 To CS25dX       189.504 dY       382.532 dZ        66.908  SSE/SST RS
Input VCV (cm^2)
    0.0180482    -0.0038512     0.0129633
   -0.0038512     0.0037059    -0.0018998
    0.0129633    -0.0018998     0.0160312
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      2129.488 dLong    -15550.639 dHt       -18.998
Used VCV (cm^2)
    0.0411010    -0.0049981    -0.0227958
   -0.0049981     0.0401904    -0.0145895
   -0.0227958    -0.0145895     0.9180874
=================================================

From CS107 To CS108dX      -176.073 dY      -381.466 dZ       -35.114  SSE/SST RS
Input VCV (cm^2)
    0.2150102    -0.0641995     0.0877724
   -0.0641995     0.0517222    -0.0253193
    0.0877724    -0.0253193     0.1091522
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     -1355.450 dLong     15290.211 dHt        -4.065
Used VCV (cm^2)
    0.0432208    -0.0026305    -0.0134245
```

```
   -0.0026305     0.0374935    -0.0275313
   -0.0134245    -0.0275313     0.9035713
=================================================

From CS25 To CS24dX       188.195 dY       405.468 dZ        61.984  SSE/SST RS
Input VCV (cm^2)
    0.0187960    -0.0065218     0.0128933
   -0.0065218     0.0056857    -0.0037193
    0.0128933    -0.0037193     0.0146270
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      2168.142 dLong    -16264.951 dHt        -6.069
Used VCV (cm^2)
    0.0404769    -0.0034995    -0.0231526
   -0.0034995     0.0374575    -0.0277333
   -0.0231526    -0.0277333     0.9987139
=================================================

From CS107 To CS106dX       283.640 dY       479.888 dZ       -86.872  SSE/SST RS
Input VCV (cm^2)
    0.0598688    -0.0186373     0.0273302
   -0.0186373     0.0163190    -0.0078789
    0.0273302    -0.0078789     0.0382779
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     -2893.701 dLong    -20295.110 dHt        17.074
Used VCV (cm^2)
    0.0454929    -0.0034972    -0.0160033
   -0.0034972     0.0401106    -0.0317654
   -0.0160033    -0.0317654     1.0339487
=================================================

From CS36 To CS37dX      -300.871 dY       -98.377 dZ       421.910  SSE/SST RS
Input VCV (cm^2)
    0.1109944    -0.0609270     0.0489826
   -0.0609270     0.0627239    -0.0449179
    0.0489826    -0.0449179     0.0812550
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     15440.995 dLong      8329.968 dHt        -0.758
Used VCV (cm^2)
    0.0437346     0.0020495    -0.0162503
```

```
    0.0020495     0.0365226    -0.0504526
   -0.0162503    -0.0504526     1.0640558
=================================================

From CS106 To CS105dX       238.169 dY       561.879 dZ       121.411  SSE/SST RS
Input VCV (cm^2)
    0.2680923    -0.1066565     0.0764823
   -0.1066565     0.0820197    -0.0314176
    0.0764823    -0.0314176     0.0609424
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      4286.759 dLong    -22160.082 dHt        -9.548
Used VCV (cm^2)
    0.0453179    -0.0022601    -0.0178928
   -0.0022601     0.0381813    -0.0463705
   -0.0178928    -0.0463705     1.1588084
=================================================

From CS36 To CS35dX       416.306 dY       229.026 dZ      -507.413  SSE/SST RS
Input VCV (cm^2)
    0.0565691    -0.0347438     0.0253088
   -0.0347438     0.0395003    -0.0255331
    0.0253088    -0.0255331     0.0463590
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -18507.140 dLong    -14512.104 dHt         4.683
Used VCV (cm^2)
    0.0469102     0.0020219    -0.0176389
    0.0020219     0.0387428    -0.0613629
   -0.0176389    -0.0613629     1.2407055
=================================================

From CS105 To CS104dX        92.162 dY       488.256 dZ       248.443  SSE/SST RS
Input VCV (cm^2)
    0.7385323    -0.2731164     0.2088276
   -0.2731164     0.2135977    -0.0854708
    0.2088276    -0.0854708     0.1664760
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      9367.033 dLong    -17296.944 dHt        15.590
Used VCV (cm^2)
    0.0441936    -0.0016880    -0.0175392
```

```
   -0.0016880     0.0379295    -0.0414266
   -0.0175392    -0.0414266     1.0778892
=================================================

From CS35 To CS34dX       304.680 dY        27.086 dZ      -478.074  SSE/SST RS
Input VCV (cm^2)
    0.0629359    -0.0378869     0.0194599
   -0.0378869     0.0469059    -0.0170192
    0.0194599    -0.0170192     0.0272991
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -17613.742 dLong     -6106.341 dHt        -5.978
Used VCV (cm^2)
    0.0461788    -0.0000814    -0.0120279
   -0.0000814     0.0378053    -0.0458763
   -0.0120279    -0.0458763     1.0606130
=================================================

From CS104 To CS103dX       -50.667 dY       316.257 dZ       371.422  SSE/SST RS
Input VCV (cm^2)
    0.1131939    -0.0608515     0.0387994
   -0.0608515     0.0485864    -0.0264538
    0.0387994    -0.0264538     0.0266082
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     13595.758 dLong     -9319.723 dHt        -0.745
Used VCV (cm^2)
    0.0400558     0.0015313    -0.0235078
    0.0015313     0.0342781    -0.0530480
   -0.0235078    -0.0530480     1.1121240
=================================================

From CS34 To CS33dX       308.810 dY       263.876 dZ      -252.705  SSE/SST RS
Input VCV (cm^2)
    0.0152333    -0.0051964     0.0068410
   -0.0051964     0.0056260    -0.0036024
    0.0068410    -0.0036024     0.0076601
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     -9499.284 dLong    -13786.419 dHt       -14.294
Used VCV (cm^2)
    0.0414622     0.0004349    -0.0231469
```

```
    0.0004349     0.0392785    -0.0339615
   -0.0231469    -0.0339615     0.9920709
=================================================

From CS103 To CS102dX      -128.663 dY       250.218 dZ       448.409  SSE/SST RS
Input VCV (cm^2)
    0.2919657    -0.1918672     0.1185507
   -0.1918672     0.1744711    -0.0951638
    0.1185507    -0.0951638     0.0835150
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     16384.169 dLong     -5861.485 dHt        -2.614
Used VCV (cm^2)
    0.0393302     0.0018871    -0.0274965
    0.0018871     0.0340611    -0.0583493
   -0.0274965    -0.0583493     1.1878559
=================================================

From CS53 To CS54dX      -228.963 dY        46.551 dZ       456.960  SSE/SST RS
Input VCV (cm^2)
    0.0116647    -0.0052677     0.0063374
   -0.0052677     0.0063711    -0.0052983
    0.0063374    -0.0052983     0.0097059
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     16525.676 dLong      2431.185 dHt       -12.364
Used VCV (cm^2)
    0.0415990     0.0027433    -0.0241573
    0.0027433     0.0388537    -0.0439090
   -0.0241573    -0.0439090     1.0474990
=================================================

From CS102 To CS101dX       -78.763 dY       244.099 dZ       348.852  SSE/SST RS
Input VCV (cm^2)
    0.0275050    -0.0179020     0.0106631
   -0.0179020     0.0185758    -0.0103921
    0.0106631    -0.0103921     0.0102103
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     12811.190 dLong     -6515.608 dHt         1.811
Used VCV (cm^2)
    0.0402373     0.0024606    -0.0200988
```

```
    0.0024606     0.0342161    -0.0497988
   -0.0200988    -0.0497988     1.0255293
=================================================

From CS53 To CS71dX       201.011 dY       -23.153 dZ      -402.312  SSE/SST RS
Input VCV (cm^2)
    0.0930063    -0.0573401     0.0640104
   -0.0573401     0.0701193    -0.0517019
    0.0640104    -0.0517019     0.0905516
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -14415.809 dLong     -2703.897 dHt        18.813
Used VCV (cm^2)
    0.0400547     0.0007034    -0.0230672
    0.0007034     0.0359268    -0.0418316
   -0.0230672    -0.0418316     1.0277469
=================================================

From CS101 To CS100dX       -47.562 dY       419.853 dZ       399.769  SSE/SST RS
Input VCV (cm^2)
    0.0295444    -0.0200981     0.0163673
   -0.0200981     0.0197186    -0.0138038
    0.0163673    -0.0138038     0.0170756
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     15100.149 dLong    -12706.406 dHt        26.860
Used VCV (cm^2)
    0.0404762     0.0017457    -0.0275955
    0.0017457     0.0349907    -0.0605798
   -0.0275955    -0.0605798     1.2333988
=================================================

From CS71 To CS52dX       109.276 dY       -67.702 dZ      -234.844  SSE/SST RS
Input VCV (cm^2)
    0.0739540    -0.0521546     0.0265291
   -0.0521546     0.0760757    -0.0237288
    0.0265291    -0.0237288     0.0268457
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     -8691.060 dLong       301.398 dHt        -5.326
Used VCV (cm^2)
    0.0401162    -0.0002621    -0.0126935
```

```
   -0.0002621     0.0338932    -0.0295131
   -0.0126935    -0.0295131     0.8091027
=================================================

From CS52 To CS51dX       214.109 dY      -132.915 dZ      -459.013  SSE/SST RS
Input VCV (cm^2)
    0.1734874    -0.1562239     0.0629275
   -0.1562239     0.2137727    -0.0671977
    0.0629275    -0.0671977     0.0472298
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -16998.225 dLong       599.064 dHt       -11.033
Used VCV (cm^2)
    0.0410130     0.0005585    -0.0227507
    0.0005585     0.0347587    -0.0520096
   -0.0227507    -0.0520096     1.1362976
=================================================

From CS98 To CS97dX       115.109 dY       429.605 dZ       146.608  SSE/SST RS
Input VCV (cm^2)
    0.0210377    -0.0085036     0.0079070
   -0.0085036     0.0098049    -0.0012700
    0.0079070    -0.0012700     0.0122020
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      5718.812 dLong    -15794.829 dHt        20.577
Used VCV (cm^2)
    0.0465212    -0.0056902    -0.0066112
   -0.0056902     0.0385472    -0.0217609
   -0.0066112    -0.0217609     0.8922531
=================================================

From CS52 To CS44dX       368.947 dY       400.668 dZ      -213.774  SSE/SST RS
Input VCV (cm^2)
    0.0360738    -0.0184338     0.0160328
   -0.0184338     0.0254750    -0.0130056
    0.0160328    -0.0130056     0.0173721
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     -8211.870 dLong    -19206.970 dHt       -22.605
Used VCV (cm^2)
    0.0421660     0.0014848    -0.0273053
```

```
    0.0014848     0.0401359    -0.0445204
   -0.0273053    -0.0445204     1.1289475
=================================================

From CS98 To CS99dX       -74.090 dY      -424.906 dZ      -246.342  SSE/SST RS
Input VCV (cm^2)
    0.0490264    -0.0093107     0.0619960
   -0.0093107     0.0054464    -0.0114140
    0.0619960    -0.0114140     0.1010363
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     -9102.631 dLong     14943.917 dHt        -4.638
Used VCV (cm^2)
    0.0386358    -0.0029273    -0.0328554
   -0.0029273     0.0394833    -0.0280429
   -0.0328554    -0.0280429     1.0697460
=================================================

From CS44 To CS43dX       316.799 dY       343.111 dZ      -261.809  SSE/SST RS
Input VCV (cm^2)
    0.0212207    -0.0106532     0.0098733
   -0.0106532     0.0142451    -0.0076732
    0.0098733    -0.0076732     0.0105853
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     -9311.679 dLong    -16463.210 dHt        16.392
Used VCV (cm^2)
    0.0413018     0.0013075    -0.0264657
    0.0013075     0.0391850    -0.0418644
   -0.0264657    -0.0418644     1.0820940
=================================================

From CS54 To CS55dX      -261.998 dY       315.069 dZ       734.067  SSE/SST RS
Input VCV (cm^2)
    0.0921129    -0.0475969     0.0343631
   -0.0475969     0.0373914    -0.0211220
    0.0343631    -0.0211220     0.0233511
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     26844.006 dLong     -5631.401 dHt        -2.220
Used VCV (cm^2)
    0.0430892     0.0013895    -0.0379321
```

```
    0.0013895     0.0386066    -0.0771555
   -0.0379321    -0.0771555     1.5720355
=================================================

From CS55 To CS56dX      -255.488 dY       104.019 dZ       478.208  SSE/SST RS
Input VCV (cm^2)
    0.1043905    -0.0347308     0.0228576
   -0.0347308     0.0210465    -0.0088273
    0.0228576    -0.0088273     0.0121141
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     17894.605 dLong      1039.318 dHt        22.701
Used VCV (cm^2)
    0.0427845    -0.0006209    -0.0205598
   -0.0006209     0.0366241    -0.0466629
   -0.0205598    -0.0466629     1.1179832
=================================================

From CS43 To CS42dX       371.402 dY       570.399 dZ      -142.867  SSE/SST RS
Input VCV (cm^2)
    0.0358601    -0.0122344     0.0148172
   -0.0122344     0.0176910    -0.0083924
    0.0148172    -0.0083924     0.0145141
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     -5000.244 dLong    -24705.558 dHt        13.741
Used VCV (cm^2)
    0.0436699     0.0003848    -0.0335029
    0.0003848     0.0453475    -0.0384643
   -0.0335029    -0.0384643     1.2030334
=================================================

From CS42 To CS41dX       281.584 dY       628.789 dZ       151.315  SSE/SST RS
Input VCV (cm^2)
    0.0590180    -0.0144269     0.0166337
   -0.0144269     0.0192271    -0.0073046
    0.0166337    -0.0073046     0.0156528
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      5078.345 dLong    -25040.360 dHt       -27.414
Used VCV (cm^2)
    0.0464353    -0.0002671    -0.0272341
```

```
   -0.0002671     0.0471036    -0.0329141
   -0.0272341    -0.0329141     1.1409771
=================================================

From CS41 To CS40dX       171.011 dY       411.206 dZ        57.401  SSE/SST RS
Input VCV (cm^2)
    0.1377462    -0.1004312     0.1347828
   -0.1004312     0.0840558    -0.1080922
    0.1347828    -0.1080922     0.1500360
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      2298.365 dLong    -16149.765 dHt        11.584
Used VCV (cm^2)
    0.0353381     0.0025146    -0.0334572
    0.0025146     0.0315901    -0.0584278
   -0.0334572    -0.0584278     1.1807232
=================================================

From CS40 To CS39dX       229.400 dY       496.559 dZ        84.316  SSE/SST RS
Input VCV (cm^2)
    0.0169320    -0.0041449     0.0146581
   -0.0041449     0.0033527    -0.0046021
    0.0146581    -0.0046021     0.0213073
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      2905.349 dLong    -19894.744 dHt       -10.806
Used VCV (cm^2)
    0.0401850    -0.0009022    -0.0323303
   -0.0009022     0.0408695    -0.0336616
   -0.0323303    -0.0336616     1.1057838
=================================================

From CS39 To CS38dX       258.147 dY       378.598 dZ       -82.526  SSE/SST RS
Input VCV (cm^2)
    0.0160276    -0.0032951     0.0115579
   -0.0032951     0.0032165    -0.0016535
    0.0115579    -0.0016535     0.0144225
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     -3115.716 dLong    -16598.264 dHt        -5.505
Used VCV (cm^2)
    0.0414693    -0.0052057    -0.0241437
```

```
   -0.0052057     0.0410788    -0.0147049
   -0.0241437    -0.0147049     0.9456900
=================================================

From CS38 To CS37dX       382.531 dY       276.205 dZ      -406.768  SSE/SST RS
Input VCV (cm^2)
    0.0225876    -0.0077257     0.0151899
   -0.0077257     0.0066178    -0.0043817
    0.0151899    -0.0043817     0.0168679
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -14827.439 dLong    -15445.562 dHt         4.208
Used VCV (cm^2)
    0.0422144    -0.0042396    -0.0292538
   -0.0042396     0.0402119    -0.0351366
   -0.0292538    -0.0351366     1.1876767
=================================================

From CS46 To CS45dX       122.507 dY       -88.059 dZ      -307.582  SSE/SST RS
Input VCV (cm^2)
    0.0279872    -0.0163685     0.0127282
   -0.0163685     0.0176829    -0.0123336
    0.0127282    -0.0123336     0.0221138
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -11105.432 dLong       728.555 dHt         9.585
Used VCV (cm^2)
    0.0414433     0.0015107    -0.0121435
    0.0015107     0.0341385    -0.0391743
   -0.0121435    -0.0391743     0.8783499
=================================================

From CS46 To CS47dX      -262.739 dY        20.193 dZ       559.371  SSE/SST RS
Input VCV (cm^2)
    0.0469734    -0.0277175     0.0147324
   -0.0277175     0.0326950    -0.0138118
    0.0147324    -0.0138118     0.0238308
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     19736.148 dLong      3859.344 dHt       -44.578
Used VCV (cm^2)
    0.0473907     0.0005505    -0.0115430
```

```
    0.0005505     0.0383354    -0.0511672
   -0.0115430    -0.0511672     1.1105718
=================================================

From CS47 To CS48dX      -166.250 dY        18.267 dZ       337.985  SSE/SST RS
Input VCV (cm^2)
    0.0274404    -0.0163603     0.0097145
   -0.0163603     0.0205868    -0.0076261
    0.0097145    -0.0076261     0.0130809
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     12067.348 dLong      2265.413 dHt       -18.508
Used VCV (cm^2)
    0.0427380    -0.0005159    -0.0109002
   -0.0005159     0.0353683    -0.0340065
   -0.0109002    -0.0340065     0.8820997
=================================================

From CS48 To CS49dX      -208.279 dY        34.610 dZ       403.551  SSE/SST RS
Input VCV (cm^2)
    0.0253263    -0.0098158     0.0124809
   -0.0098158     0.0117681    -0.0070539
    0.0124809    -0.0070539     0.0154096
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     14628.372 dLong      2461.047 dHt        -9.073
Used VCV (cm^2)
    0.0414288    -0.0000046    -0.0216634
   -0.0000046     0.0387508    -0.0324449
   -0.0216634    -0.0324449     0.9668601
=================================================

From CS49 To CS50dX      -227.873 dY        28.486 dZ       422.960  SSE/SST RS
Input VCV (cm^2)
    0.0630313    -0.0166776     0.0251890
   -0.0166776     0.0127903    -0.0103373
    0.0251890    -0.0103373     0.0208895
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     15403.727 dLong      2993.885 dHt        -5.235
Used VCV (cm^2)
    0.0401074     0.0011662    -0.0270239
```

```
    0.0011662     0.0388138    -0.0373731
   -0.0270239    -0.0373731     1.0288313
=================================================

From CS50 To CS51dX      -223.866 dY        50.337 dZ       458.878  SSE/SST RS
Input VCV (cm^2)
    0.2109946    -0.0611364     0.0755995
   -0.0611364     0.0385789    -0.0298604
    0.0755995    -0.0298604     0.0530379
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     16539.995 dLong      2222.600 dHt       -15.799
Used VCV (cm^2)
    0.0402145     0.0009902    -0.0270787
    0.0009902     0.0374531    -0.0440441
   -0.0270787    -0.0440441     1.0948008
=================================================

From CS58 To CS59dX      -177.482 dY      -487.156 dZ      -150.936  SSE/SST RS
Input VCV (cm^2)
    0.0579524    -0.0241636     0.0290196
   -0.0241636     0.0423094    -0.0276126
    0.0290196    -0.0276126     0.0403922
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     -5438.997 dLong     18703.175 dHt         5.270
Used VCV (cm^2)
    0.0414332     0.0034339    -0.0288324
    0.0034339     0.0419885    -0.0389992
   -0.0288324    -0.0389992     1.0444711
=================================================

From CS59 To CS60dX       -86.362 dY      -210.804 dZ       -25.729  SSE/SST RS
Input VCV (cm^2)
    0.0676614    -0.0289200     0.0297659
   -0.0289200     0.0388492    -0.0205922
    0.0297659    -0.0205922     0.0298813
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     -1086.275 dLong      8257.370 dHt        -8.507
Used VCV (cm^2)
    0.0383500     0.0007682    -0.0177006
```

```
    0.0007682     0.0352715    -0.0247332
   -0.0177006    -0.0247332     0.7738602
=================================================

From CS58 To CS57dX       260.417 dY       615.057 dZ        28.000  SSE/SST RS
Input VCV (cm^2)
    0.0990769    -0.0281982     0.0980418
   -0.0281982     0.0207910    -0.0375882
    0.0980418    -0.0375882     0.1513518
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      1703.205 dLong    -24236.159 dHt        40.060
Used VCV (cm^2)
    0.0398699     0.0008312    -0.0399024
    0.0008312     0.0412868    -0.0485025
   -0.0399024    -0.0485025     1.2907975
=================================================

From CS60 To CS61dX      -169.322 dY      -509.069 dZ      -136.654  SSE/SST RS
Input VCV (cm^2)
    0.0961303    -0.0695241     0.0414999
   -0.0695241     0.0945142    -0.0384292
    0.0414999    -0.0384292     0.0381792
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     -5289.259 dLong     19268.455 dHt       -16.791
Used VCV (cm^2)
    0.0414115     0.0006442    -0.0250329
    0.0006442     0.0369167    -0.0489642
   -0.0250329    -0.0489642     1.1423934
=================================================

From CS57 To CS52dX       245.451 dY       626.711 dZ       279.394  SSE/SST RS
Input VCV (cm^2)
    0.0318693    -0.0058374     0.0226447
   -0.0058374     0.0060122    -0.0026992
    0.0226447    -0.0026992     0.0285869
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      9227.961 dLong    -24353.465 dHt       -59.402
Used VCV (cm^2)
    0.0450947    -0.0076814    -0.0333603
```

```
   -0.0076814     0.0478602    -0.0165426
   -0.0333603    -0.0165426     1.1950325
=================================================

From CS61 To CS62dX       -92.012 dY      -551.921 dZ      -389.167  SSE/SST RS
Input VCV (cm^2)
    1.5822954    -1.3606383     0.7469997
   -1.3606383     1.8318045    -0.6227432
    0.7469997    -0.6227432     0.7578991
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -13889.844 dLong     19321.940 dHt        21.530
Used VCV (cm^2)
    0.0442474    -0.0021410    -0.0233399
   -0.0021410     0.0369126    -0.0561427
   -0.0233399    -0.0561427     1.2957120
=================================================

From CS62 To CS67dX       142.314 dY      -333.718 dZ      -558.668  SSE/SST RS
Input VCV (cm^2)
    0.0197961    -0.0111674     0.0163020
   -0.0111674     0.0119480    -0.0106792
    0.0163020    -0.0106792     0.0217692
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -20335.677 dLong      8291.304 dHt         7.545
Used VCV (cm^2)
    0.0406519     0.0000983    -0.0349083
    0.0000983     0.0385854    -0.0546431
   -0.0349083    -0.0546431     1.3128888
=================================================

From CS62 To CS68dX       -99.862 dY      -421.989 dZ      -235.832  SSE/SST RS
Input VCV (cm^2)
    0.0583360    -0.0321653     0.0574577
   -0.0321653     0.0298973    -0.0295983
    0.0574577    -0.0295983     0.0743026
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     -8450.412 dLong     15279.728 dHt        11.091
Used VCV (cm^2)
    0.0383587    -0.0015612    -0.0297736
```

```
   -0.0015612     0.0352872    -0.0428494
   -0.0297736    -0.0428494     1.1334694
=================================================

From CS67 To CS66dX       279.036 dY      -119.951 dZ      -599.443  SSE/SST RS
Input VCV (cm^2)
    0.0285636    -0.0150028     0.0164172
   -0.0150028     0.0191115    -0.0154508
    0.0164172    -0.0154508     0.0262803
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -21812.091 dLong      -925.037 dHt         8.620
Used VCV (cm^2)
    0.0433908     0.0034230    -0.0289104
    0.0034230     0.0408298    -0.0562348
   -0.0289104    -0.0562348     1.2370457
=================================================

From CS66 To CS65dX       253.461 dY      -276.168 dZ      -701.405  SSE/SST RS
Input VCV (cm^2)
    0.8674153    -0.3273647     0.2503720
   -0.3273647     0.2238581    -0.1014638
    0.2503720    -0.1014638     0.1570219
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -25513.455 dLong      4536.910 dHt        10.688
Used VCV (cm^2)
    0.0454541    -0.0016194    -0.0290860
   -0.0016194     0.0400572    -0.0609864
   -0.0290860    -0.0609864     1.4234146
=================================================

From CS65 To CS64dX       265.781 dY       -82.341 dZ      -510.409  SSE/SST RS
Input VCV (cm^2)
    0.2349645    -0.0737502     0.0579824
   -0.0737502     0.0430354    -0.0202035
    0.0579824    -0.0202035     0.0299917
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -18806.081 dLong     -1907.314 dHt        -6.337
Used VCV (cm^2)
    0.0422984    -0.0009150    -0.0240002
```

```
   -0.0009150     0.0372114    -0.0474531
   -0.0240002    -0.0474531     1.1649379
=================================================

From CS64 To CS63dX       102.429 dY      -387.401 dZ      -540.180  SSE/SST RS
Input VCV (cm^2)
    0.1315216    -0.0369498     0.0347718
   -0.0369498     0.0230480    -0.0125004
    0.0347718    -0.0125004     0.0201197
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -19653.269 dLong     10703.804 dHt         8.091
Used VCV (cm^2)
    0.0431985    -0.0000197    -0.0288290
   -0.0000197     0.0401006    -0.0506732
   -0.0288290    -0.0506732     1.2529189
=================================================

From CS70 To CS69dX       334.709 dY       438.391 dZ       -47.388  SSE/SST RS
Input VCV (cm^2)
    0.1069428    -0.0674315     0.0405763
   -0.0674315     0.0823081    -0.0269335
    0.0405763    -0.0269335     0.0487693
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     -2704.907 dLong    -19831.574 dHt       -57.262
Used VCV (cm^2)
    0.0450209    -0.0020669    -0.0142480
   -0.0020669     0.0371586    -0.0421569
   -0.0142480    -0.0421569     1.0704058
=================================================

From CS69 To CS68dX        62.067 dY       313.194 dZ       196.099  SSE/SST RS
Input VCV (cm^2)
    0.6057122    -0.1429030     0.2367556
   -0.1429030     0.1404529    -0.1040679
    0.2367556    -0.1040679     0.2268083
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      7038.001 dLong    -11134.314 dHt        -8.560
Used VCV (cm^2)
    0.0398445     0.0011871    -0.0226821
```

```
    0.0011871     0.0387899    -0.0276902
   -0.0226821    -0.0276902     0.8820023
=================================================

From CS31 To CS32dX      -218.303 dY      -373.839 dZ        34.393  SSE/SST RS
Input VCV (cm^2)
    0.0111548    -0.0067842     0.0048981
   -0.0067842     0.0077032    -0.0049377
    0.0048981    -0.0049377     0.0089692
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      1232.473 dLong     15764.776 dHt        -1.623
Used VCV (cm^2)
    0.0430882     0.0014584    -0.0124518
    0.0014584     0.0352897    -0.0437692
   -0.0124518    -0.0437692     0.9571409
=================================================

From CS92 To CS91dX       247.381 dY       323.321 dZ       -98.892  SSE/SST RS
Input VCV (cm^2)
    0.0290665    -0.0116655     0.0116762
   -0.0116655     0.0139934    -0.0020697
    0.0116762    -0.0020697     0.0212011
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     -3852.943 dLong    -14631.710 dHt       -13.629
Used VCV (cm^2)
    0.0458646    -0.0049886    -0.0057091
   -0.0049886     0.0379876    -0.0202721
   -0.0057091    -0.0202721     0.8417705
=================================================

From CS92 To CS93dX      -212.283 dY      -173.247 dZ        82.566  SSE/SST RS
Input VCV (cm^2)
    0.0585846    -0.0115954     0.0794565
   -0.0115954     0.0093764    -0.0140639
    0.0794565    -0.0140639     0.1550761
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      3973.655 dLong      9202.052 dHt        56.108
Used VCV (cm^2)
    0.0381731    -0.0030313    -0.0223741
```

```
   -0.0030313     0.0371873    -0.0153290
   -0.0223741    -0.0153290     0.8199884
=================================================

From CS93 To CS94dX      -200.118 dY      -459.456 dZ        36.715  SSE/SST RS
Input VCV (cm^2)
    0.7405974    -0.0975062     0.8235156
   -0.0975062     0.0484269    -0.1052568
    0.8235156    -0.1052568     1.1221889
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat       477.952 dLong     18204.989 dHt       -51.231
Used VCV (cm^2)
    0.0384272    -0.0034549    -0.0349166
   -0.0034549     0.0407111    -0.0237062
   -0.0349166    -0.0237062     1.0636958
=================================================

From CS95 To CS96dX       -14.703 dY      -334.294 dZ      -335.125  SSE/SST RS
Input VCV (cm^2)
    0.2057826    -0.1312903     0.1094526
   -0.1312903     0.1292072    -0.0917111
    0.1094526    -0.0917111     0.1237883
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -11811.846 dLong     11011.212 dHt        27.409
Used VCV (cm^2)
    0.0402091     0.0015954    -0.0223364
    0.0015954     0.0343943    -0.0510896
   -0.0223364    -0.0510896     1.0821468
=================================================

From CS91 To CS90dX       261.267 dY       433.934 dZ       -43.055  SSE/SST RS
Input VCV (cm^2)
    0.0876557    -0.0389739     0.0304071
   -0.0389739     0.0430096    -0.0051232
    0.0304071    -0.0051232     0.0412587
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     -1649.200 dLong    -18428.881 dHt        -4.262
Used VCV (cm^2)
    0.0471899    -0.0062676    -0.0063714
```

```
   -0.0062676     0.0383197    -0.0249421
   -0.0063714    -0.0249421     0.9425112
=================================================

From CS90 To CS89dX       248.692 dY       393.780 dZ      -120.522  SSE/SST RS
Input VCV (cm^2)
    0.6184885    -0.3430183     0.2902277
   -0.3430183     0.2313710    -0.1645062
    0.2902277    -0.1645062     0.1654546
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     -3996.495 dLong    -16922.015 dHt        24.712
Used VCV (cm^2)
    0.0366763     0.0010067    -0.0316921
    0.0010067     0.0324208    -0.0562020
   -0.0316921    -0.0562020     1.1898791
=================================================

From CS89 To CS88dX       223.902 dY       493.703 dZ       -46.732  SSE/SST RS
Input VCV (cm^2)
    0.8434768    -0.4655729     0.3933478
   -0.4655729     0.3016186    -0.2220269
    0.3933478    -0.2220269     0.2149367
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      -837.673 dLong    -19713.636 dHt        51.650
Used VCV (cm^2)
    0.0365368     0.0014073    -0.0354703
    0.0014073     0.0325870    -0.0628326
   -0.0354703    -0.0628326     1.2853700
=================================================

From CS84 To CS83dX       142.909 dY       599.109 dZ        66.508  SSE/SST RS
Input VCV (cm^2)
    0.1566045    -0.0616496     0.1086954
   -0.0616496     0.0537203    -0.0520883
    0.1086954    -0.0520883     0.1491482
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      4244.359 dLong    -21717.875 dHt       106.855
Used VCV (cm^2)
    0.0419686    -0.0003652    -0.0289324
```

```
   -0.0003652     0.0392301    -0.0468805
   -0.0289324    -0.0468805     1.2015668
=================================================

From CS04 To CS01dX       874.679 dY      1191.103 dZ      -449.195  SSE/SST RS
Input VCV (cm^2)
    0.2014762    -0.0670641     0.0812727
   -0.0670641     0.1109121    -0.0457355
    0.0812727    -0.0457355     0.0819478
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -16052.648 dLong    -53358.196 dHt        24.444
Used VCV (cm^2)
    0.0580846    -0.0003518    -0.0727500
   -0.0003518     0.0713116    -0.0770469
   -0.0727500    -0.0770469     2.3410945
=================================================

From CS83 To CS82dX        33.498 dY       300.654 dZ       262.859  SSE/SST RS
Input VCV (cm^2)
    0.0468632    -0.0125164     0.0402028
   -0.0125164     0.0118666    -0.0115875
    0.0402028    -0.0115875     0.0717426
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      9248.248 dLong    -10244.388 dHt       -22.441
Used VCV (cm^2)
    0.0407759    -0.0022229    -0.0208424
   -0.0022229     0.0385383    -0.0231386
   -0.0208424    -0.0231386     0.9042458
=================================================

From CS82 To CS81dX      -250.741 dY       152.006 dZ       467.394  SSE/SST RS
Input VCV (cm^2)
    0.0991552    -0.0508078     0.0471321
   -0.0508078     0.0410397    -0.0268410
    0.0471321    -0.0268410     0.0354263
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     17859.391 dLong      -599.109 dHt        43.760
Used VCV (cm^2)
    0.0394326     0.0003414    -0.0296393
```

```
    0.0003414     0.0354293    -0.0526619
   -0.0296393    -0.0526619     1.1993938
=================================================

From CS81 To CS80dX       -15.900 dY       365.985 dZ       417.262  SSE/SST RS
Input VCV (cm^2)
    0.1421117    -0.0496967     0.0513294
   -0.0496967     0.0522212    -0.0294694
    0.0513294    -0.0294694     0.0535767
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     14812.021 dLong    -11499.423 dHt       -27.799
Used VCV (cm^2)
    0.0430187     0.0010099    -0.0233277
    0.0010099     0.0403400    -0.0400322
   -0.0233277    -0.0400322     1.0628020
=================================================

From CS84 To CS85dX      -332.146 dY      -310.351 dZ       142.814  SSE/SST RS
Input VCV (cm^2)
    2.0563645    -1.5066978     0.7592316
   -1.5066978     1.2294596    -0.5919193
    0.7592316    -0.5919193     0.3492265
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      6329.356 dLong     15665.700 dHt        64.900
Used VCV (cm^2)
    0.0364889     0.0019260    -0.0312637
    0.0019260     0.0315583    -0.0603028
   -0.0312637    -0.0603028     1.1996117
=================================================

From CS87 To CS88dX      -123.480 dY      -460.500 dZ      -131.951  SSE/SST RS
Input VCV (cm^2)
    0.0571379    -0.0185600     0.0442676
   -0.0185600     0.0189676    -0.0116156
    0.0442676    -0.0116156     0.0767150
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     -5408.124 dLong     16928.041 dHt       -33.971
Used VCV (cm^2)
    0.0429928    -0.0040885    -0.0195719
```

```
   -0.0040885     0.0395551    -0.0248611
   -0.0195719    -0.0248611     0.9829461
=================================================

From CS70 To CS72dX      -160.195 dY       -99.889 dZ       264.524  SSE/SST RS
Input VCV (cm^2)
    0.0745720    -0.0361673     0.0256473
   -0.0361673     0.0482300    -0.0008803
    0.0256473    -0.0008803     0.0661908
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      9037.808 dLong      5956.331 dHt       -38.481
Used VCV (cm^2)
    0.0461129    -0.0051161     0.0010914
   -0.0051161     0.0360870    -0.0169958
    0.0010914    -0.0169958     0.7367894
=================================================

From CS72 To CS73dX      -279.753 dY       -91.834 dZ       427.509  SSE/SST RS
Input VCV (cm^2)
    0.3105264    -0.0525258     0.4054507
   -0.0525258     0.0386961    -0.0598541
    0.4054507    -0.0598541     0.7206819
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     15374.023 dLong      7744.958 dHt       -16.812
Used VCV (cm^2)
    0.0398271    -0.0045588    -0.0324457
   -0.0045588     0.0417622    -0.0195328
   -0.0324457    -0.0195328     1.0464080
=================================================

From CS73 To CS74dX      -324.804 dY      -427.965 dZ       161.802  SSE/SST RS
Input VCV (cm^2)
    0.1878636    -0.0584093     0.1792553
   -0.0584093     0.0323608    -0.0565088
    0.1792553    -0.0565088     0.2084240
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      5944.712 dLong     19324.788 dHt         1.092
Used VCV (cm^2)
    0.0377441    -0.0007725    -0.0363020
```

```
   -0.0007725     0.0365870    -0.0475769
   -0.0363020    -0.0475769     1.2285132
=================================================

From CS74 To CS75dX      -190.760 dY      -426.614 dZ       176.228  SSE/SST RS
Input VCV (cm^2)
    0.3019615    -0.2239957     0.1326172
   -0.2239957     0.2126008    -0.1108446
    0.1326172    -0.1108446     0.0844494
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      4595.270 dLong     16985.656 dHt      -109.899
Used VCV (cm^2)
    0.0378823     0.0016299    -0.0294924
    0.0016299     0.0330147    -0.0574147
   -0.0294924    -0.0574147     1.1853606
=================================================

From CS75 To CS76dX      -420.412 dY      -133.981 dZ       565.184  SSE/SST RS
Input VCV (cm^2)
    0.2942675    -0.1036372     0.0982047
   -0.1036372     0.0866727    -0.0328927
    0.0982047    -0.0328927     0.1257879
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     20907.558 dLong     11506.454 dHt        12.265
Used VCV (cm^2)
    0.0493766    -0.0038799    -0.0138539
   -0.0038799     0.0414393    -0.0429153
   -0.0138539    -0.0429153     1.1904400
=================================================

From CS76 To CS77dX      -192.597 dY      -250.028 dZ       266.352  SSE/SST RS
Input VCV (cm^2)
    0.2048901    -0.0422204     0.1149564
   -0.0422204     0.0242255    -0.0229229
    0.1149564    -0.0229229     0.1139678
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      8462.591 dLong     11337.544 dHt       -76.412
Used VCV (cm^2)
    0.0401047    -0.0024905    -0.0225327
```

```
   -0.0024905     0.0374905    -0.0266976
   -0.0225327    -0.0266976     0.9497861
=================================================

From CS77 To CS78dX      -224.602 dY       -66.221 dZ       227.700  SSE/SST RS
Input VCV (cm^2)
    1.2633113    -0.5740358     0.8283878
   -0.5740358     0.3093239    -0.3846831
    0.8283878    -0.3846831     0.6194092
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      9068.427 dLong      5974.058 dHt        43.122
Used VCV (cm^2)
    0.0354594     0.0010597    -0.0268852
    0.0010597     0.0310240    -0.0460887
   -0.0268852    -0.0460887     1.0169400
=================================================

From CS78 To CS79dX      -107.006 dY      -447.029 dZ       -78.524  SSE/SST RS
Input VCV (cm^2)
    0.2245789    -0.1138738     0.0882692
   -0.1138738     0.1028369    -0.0463501
    0.0882692    -0.0463501     0.0621473
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     -3995.973 dLong     16207.660 dHt       -66.239
Used VCV (cm^2)
    0.0401626    -0.0010736    -0.0230459
   -0.0010736     0.0353869    -0.0411304
   -0.0230459    -0.0411304     1.0571398
=================================================

From CS79 To CS80dX      -152.116 dY      -539.581 dZ      -339.189  SSE/SST RS
Input VCV (cm^2)
    0.1261783    -0.0574037     0.0514839
   -0.0574037     0.0530282    -0.0380328
    0.0514839    -0.0380328     0.0694206
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -11561.083 dLong     19956.933 dHt        50.933
Used VCV (cm^2)
    0.0448721     0.0021777    -0.0219168
```

```
    0.0021777     0.0390535    -0.0569430
   -0.0219168    -0.0569430     1.2075218
=================================================

From CS100 To CS99dX        50.458 dY       388.599 dZ       254.032  SSE/SST RS
Input VCV (cm^2)
    0.0848974    -0.0158069     0.1064980
   -0.0158069     0.0089383    -0.0192993
    0.1064980    -0.0192993     0.1705092
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      9381.916 dLong    -13372.321 dHt         4.481
Used VCV (cm^2)
    0.0383217    -0.0027427    -0.0318025
   -0.0027427     0.0388890    -0.0273342
   -0.0318025    -0.0273342     1.0406542
=================================================

From CS94 To CS95dX       -95.802 dY      -615.188 dZ      -334.366  SSE/SST RS
Input VCV (cm^2)
   12.0265988    -2.3895874     6.7113866
   -2.3895874     0.5413577    -1.3524503
    6.7113866    -1.3524503     3.8129581
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -12691.282 dLong     21436.165 dHt       -26.223
Used VCV (cm^2)
    0.0354090     0.0023829    -0.0487171
    0.0023829     0.0336218    -0.0794550
   -0.0487171    -0.0794550     1.5554153
=================================================

From CS96 To CS97dX      -119.954 dY      -458.200 dZ      -137.314  SSE/SST RS
Input VCV (cm^2)
    0.2053633    -0.2182151     0.1529075
   -0.2182151     0.3245925    -0.2402729
    0.1529075    -0.2402729     0.2774905
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat     -5588.415 dLong     16797.426 dHt       -32.995
Used VCV (cm^2)
    0.0406110     0.0031231    -0.0215452
```

```
    0.0031231     0.0337931    -0.0582606
   -0.0215452    -0.0582606     1.1126409
=================================================

From CS86 To CS85dX       121.077 dY       454.102 dZ       110.580  SSE/SST RS
Input VCV (cm^2)
    0.2418350    -0.2930622     0.2718643
   -0.2930622     0.4592333    -0.4787914
    0.2718643    -0.4787914     0.6586551
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      4780.384 dLong    -16680.173 dHt        43.138
Used VCV (cm^2)
    0.0395318     0.0037068    -0.0235914
    0.0037068     0.0329776    -0.0607610
   -0.0235914    -0.0607610     1.1299050
=================================================

From CS86 To CS87dX      -277.342 dY      -460.182 dZ        55.334  SSE/SST RS
Input VCV (cm^2)
    0.1269886    -0.0822238     0.1378078
   -0.0822238     0.1095996    -0.1592963
    0.1378078    -0.1592963     0.3499369
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat      2028.428 dLong     19548.372 dHt         0.095
Used VCV (cm^2)
    0.0402320     0.0043232    -0.0284190
    0.0043232     0.0374696    -0.0545932
   -0.0284190    -0.0545932     1.1356332
=================================================

From CS62 To CS67AdX       149.395 dY      -320.777 dZ      -562.996  SSE/SST RS
Input VCV (cm^2)
    0.0581868    -0.0479321     0.0463300
   -0.0479321     0.0527818    -0.0462194
    0.0463300    -0.0462194     0.0589587
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -20462.766 dLong      7753.862 dHt         9.400
Used VCV (cm^2)
    0.0395772     0.0026152    -0.0349132
```

```
    0.0026152     0.0350349    -0.0706623
   -0.0349132    -0.0706623     1.3848031
=================================================

From CS67A To CS66dX       271.948 dY      -132.889 dZ      -595.109  SSE/SST RS
Input VCV (cm^2)
    0.1390537    -0.1135095     0.1132469
   -0.1135095     0.1221291    -0.1109978
    0.1132469    -0.1109978     0.1433242
Rescaling using SSE/SST RS properties
Rescaleing to   5.0 mm   5.0 ppm
Scalers:-   1.0   1.0   2.0 Centering:-   0.0   0.0
---------------------
Baseline as used:-
dLat    -21684.674 dLong      -387.537 dHt         6.768
Used VCV (cm^2)
    0.0393299     0.0026750    -0.0356816
    0.0026750     0.0349075    -0.0714747
   -0.0356816    -0.0714747     1.3959765
=================================================
Time to form Normal Equations 00:00:00

Time to Solve Normal Equations 00:00:00



Coordinate corrections for iteration 0
=========================================
Station        Lat    Long     Elev
PM40970       -0.471  0.588  0.626
CS92          -0.472  0.586  0.631
CS79          -0.480  0.587  0.680
CS75          -0.478  0.591  0.687
PM35751       -0.003  0.002 -0.042
10KBM         -0.477  0.587  0.691
PM112793      -0.472  0.580  0.670
PM66947       -0.477  0.586  0.606
PM112799      -0.445  0.548  0.625
CS15          -0.452  0.548  0.564
PM85731       -0.468  0.589  0.606
CS84          -0.458  0.588  0.628
PM68101       -0.456  0.591  0.650
CS101         -0.005  0.001 -0.008
CS107         -0.006  0.014 -0.010
PM51843       -0.458  0.555  0.628
CS32          -0.461  0.554  0.625
CS108         -0.474  0.582  0.605
CS22          -0.458  0.556  0.616
CS40          -0.005 -0.010 -0.003
CS45          -0.452  0.557  0.655
CS62          -0.443  0.563  0.671
```

CS63	-0.436	0.562	0.679
CS04	0.020	0.002	0.003
CS70	0.002	-0.010	0.021
CS56	-0.456	0.579	0.706
PM57526	-0.463	0.574	0.678
CS52	-0.009	-0.006	-0.036
CS05	-0.441	0.540	0.619
CS06	-0.442	0.540	0.619
CS07	-0.444	0.541	0.619
CS08	-0.446	0.541	0.619
CS09	0.004	-0.011	0.002
CS10	-0.449	0.541	0.623
CS11	-0.450	0.540	0.627
CS12	-0.452	0.539	0.631
CS01	0.008	-0.020	-0.023
CS02	-0.432	0.541	0.601
CS03	-0.430	0.542	0.592
CS14	-0.447	0.541	0.573
CS13	-0.446	0.542	0.569
CS16	-0.452	0.547	0.569
CS17	-0.451	0.547	0.573
CS18	-0.451	0.547	0.577
CS21	6.888	1.895	10.543
CS23	6.888	1.895	10.552
CS20	6.888	1.895	10.539
CS24	6.888	1.895	10.557
CS19	6.888	1.895	10.533
CS33	0.004	0.003	-0.002
CS31	-0.459	0.555	0.601
CS30	-0.458	0.555	0.597
CS29	-0.457	0.554	0.593
CS28	-0.456	0.554	0.590
CS27	-0.455	0.554	0.585
CS26	-0.454	0.554	0.580
CS25	-0.013	-0.002	-0.000
CS106	-0.474	0.583	0.594
CS36	-1.717	-3.087	0.951
CS37	-1.717	-3.086	0.953
CS105	-0.006	-0.008	0.027
CS35	-1.716	-3.088	0.949
CS104	-0.476	0.583	0.586
CS34	-1.716	-3.088	0.947
CS103	-0.478	0.584	0.589
CS102	-0.479	0.584	0.592
CS53	-0.471	0.569	0.640
CS54	-0.470	0.569	0.637
CS71	-0.473	0.569	0.644
CS100	-0.479	0.586	0.587
CS51	-0.474	0.570	0.646
CS98	-0.472	0.592	0.567
CS97	-0.005	0.015	-0.038

CS44	-0.475	0.570	0.644
CS99	-0.475	0.589	0.575
CS43	-0.476	0.571	0.641
CS55	-0.469	0.569	0.632
CS42	-0.476	0.572	0.639
CS41	-0.477	0.573	0.636
CS39	-0.477	0.573	0.631
CS38	-0.477	0.573	0.630
CS46	9.051	-6.289	-7.784
CS47	9.050	-6.290	-7.784
CS48	9.050	-6.290	-7.783
CS49	9.050	-6.291	-7.782
CS50	9.050	-6.291	-7.782
CS58	8.336	-0.582	7.093
CS59	8.341	-0.580	7.083
CS60	8.345	-0.578	7.075
CS57	8.330	-0.584	7.106
CS61	8.351	-0.576	7.065
CS67	8.358	-0.575	7.053
CS68	-0.030	0.003	-0.019
CS66	8.360	-0.575	7.054
CS65	8.357	-0.576	7.053
CS64	8.354	-0.577	7.053
CS69	-0.454	0.569	0.695
CS91	-0.475	0.585	0.668
CS93	-0.479	0.579	0.700
CS94	-0.484	0.574	0.729
CS95	-0.487	0.601	0.583
CS96	-0.490	0.598	0.610
CS90	-0.017	-0.000	0.044
CS89	-0.475	0.586	0.659
CS88	-0.003	0.001	0.023
CS83	-0.455	0.572	0.675
CS82	-0.454	0.573	0.681
CS81	-0.452	0.574	0.689
CS80	-0.451	0.574	0.697
CS85	-0.455	0.570	0.657
CS87	-0.466	0.577	0.680
CS72	0.010	0.011	0.004
CS73	0.010	0.011	0.006
CS74	-0.467	0.567	0.694
CS76	-0.008	-0.013	0.027
CS77	-0.035	0.011	0.000
CS78	-0.478	0.573	0.705
CS86	-0.466	0.577	0.687
CS67A	-0.492	0.544	0.597

Time to Update Station Positions 00:00:00

Iteration Number 1

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Time to form Normal Equations 00:00:00

Time to Solve Normal Equations 00:00:00

Coordinate corrections for iteration 1
===

Station	Lat	Long	Elev
PM40970	-0.000	0.000	-0.000
CS92	0.000	-0.000	0.000
CS79	-0.000	0.000	0.000
CS75	0.000	0.000	0.000
PM35751	0.000	0.000	0.000
10KBM	0.000	0.000	-0.000
PM112793	0.000	-0.000	-0.000
PM66947	-0.000	0.000	-0.000
PM112799	0.000	-0.000	0.000
CS15	-0.000	-0.000	-0.000
PM85731	0.000	-0.000	-0.000
CS84	-0.000	-0.000	0.000
PM68101	-0.000	-0.000	-0.000
CS101	-0.000	0.000	-0.000
CS107	0.000	0.000	0.000
PM51843	-0.000	0.000	0.000
CS32	0.000	0.000	0.000
CS108	-0.000	-0.000	0.000
CS22	-0.000	-0.000	0.000
CS40	0.000	0.000	-0.000
CS45	-0.000	0.000	-0.000
CS62	0.000	-0.000	0.000
CS63	0.000	0.000	-0.000
CS04	0.000	0.000	-0.000
CS70	0.000	-0.000	0.000
CS56	0.000	0.000	0.000
PM57526	0.000	-0.000	-0.000
CS52	0.000	0.000	-0.000
CS05	0.000	0.000	0.000
CS06	0.000	-0.000	0.000
CS07	-0.000	0.000	0.000
CS08	-0.000	-0.000	0.000
CS09	-0.000	0.000	-0.000
CS10	-0.000	0.000	0.000
CS11	0.000	0.000	0.000
CS12	0.000	0.000	-0.000
CS01	-0.000	-0.000	-0.000
CS02	-0.000	0.000	0.000
CS03	-0.000	-0.000	0.000
CS14	-0.000	-0.000	-0.000
CS13	-0.000	-0.000	0.000

CS16	-0.000	0.000	-0.000
CS17	-0.000	0.000	-0.000
CS18	0.000	0.000	0.000
CS21	-0.000	0.000	0.000
CS23	-0.000	0.000	-0.000
CS20	-0.000	0.000	0.000
CS24	-0.000	-0.000	0.000
CS19	-0.000	0.000	-0.000
CS33	0.000	-0.000	0.000
CS31	0.000	-0.000	0.000
CS30	-0.000	0.000	0.000
CS29	-0.000	-0.000	0.000
CS28	0.000	0.000	-0.000
CS27	0.000	-0.000	-0.000
CS26	0.000	0.000	-0.000
CS25	-0.000	0.000	-0.000
CS106	-0.000	-0.000	-0.000
CS36	0.000	-0.000	0.000
CS37	0.000	0.000	-0.000
CS105	-0.000	-0.000	-0.000
CS35	0.000	0.000	0.000
CS104	-0.000	-0.000	-0.000
CS34	0.000	-0.000	-0.000
CS103	0.000	-0.000	-0.000
CS102	-0.000	-0.000	-0.000
CS53	-0.000	-0.000	-0.000
CS54	0.000	-0.000	0.000
CS71	0.000	0.000	-0.000
CS100	0.000	-0.000	0.000
CS51	-0.000	-0.000	-0.000
CS98	-0.000	0.000	-0.000
CS97	0.000	-0.000	0.000
CS44	0.000	0.000	0.000
CS99	-0.000	-0.000	0.000
CS43	0.000	0.000	0.000
CS55	-0.000	0.000	-0.000
CS42	-0.000	-0.000	-0.000
CS41	0.000	-0.000	-0.000
CS39	0.000	0.000	-0.000
CS38	0.000	-0.000	-0.000
CS46	0.000	0.000	-0.000
CS47	0.000	-0.000	-0.000
CS48	0.000	0.000	-0.000
CS49	-0.000	-0.000	-0.000
CS50	-0.000	-0.000	-0.000
CS58	-0.000	-0.000	-0.000
CS59	0.000	-0.000	-0.000
CS60	0.000	-0.000	-0.000
CS57	0.000	-0.000	-0.000
CS61	-0.000	0.000	0.000
CS67	-0.000	-0.000	-0.000

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CS68          -0.000 -0.000 -0.000
CS66          -0.000 -0.000 -0.000
CS65          -0.000 -0.000 -0.000
CS64          -0.000  0.000 -0.000
CS69           0.000  0.000  0.000
CS91          -0.000 -0.000  0.000
CS93           0.000  0.000 -0.000
CS94          -0.000 -0.000  0.000
CS95           0.000 -0.000  0.000
CS96           0.000  0.000 -0.000
CS90           0.000 -0.000  0.000
CS89          -0.000  0.000  0.000
CS88          -0.000 -0.000  0.000
CS83           0.000  0.000  0.000
CS82           0.000  0.000 -0.000
CS81          -0.000  0.000  0.000
CS80          -0.000 -0.000 -0.000
CS85          -0.000  0.000 -0.000
CS87           0.000 -0.000 -0.000
CS72          -0.000  0.000 -0.000
CS73           0.000  0.000  0.000
CS74          -0.000  0.000  0.000
CS76           0.000 -0.000  0.000
CS77           0.000 -0.000  0.000
CS78          -0.000  0.000 -0.000
CS86           0.000 -0.000 -0.000
CS67A         -0.000  0.000 -0.000

Time to Update Station Positions 00:00:00

Time to Invert Normal Equations 00:00:01


Time to complete adjustment run 00:00:01

Observations Summary
====================

Number of GPS Baselines         :-   169
Number of Elevation Differences :-     0
Number of Geoidal Distances     :-     0
Number of Spheroidal Distances  :-     0
Number of Ground Mark Distances :-     0
Number of Azimuths              :-     0
Number of Constraint Stations   :-    20

Variance Test
=============

Number of Observations :-   567
Number of Unkowns      :-   357
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Degrees of Freedom :- 210
Minimum :-1007600.423 (cm^2)
Variance Ratio :- 1.291
Variance ratio should be between 0.732 and 1.318

Adjustment satisfies the Variance Ratio Test!

Adjusted Positions
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Station	Latitude	Longitude	Spheroidal Elevation	Error Ellipse(M) Semi Major Axis	Semi Minor Axis	Orient	Spheroidal Elevation Std Dev
PM40970	S27°30'36.6897"	152° 2' 3.5264"	466.669	0.0080	0.0066	357.6	0.0125
CS92	S27°30'51.3116"	152° 2' 13.0933"	300.526	0.0084	0.0067	357.0	0.0116
CS79	S27°30' 2.0921"	151°58' 50.5561"	420.610	0.0075	0.0061	355.0	0.0103
CS75	S27°30'36.5345"	151°58' 5.5310"	507.871	0.0080	0.0064	351.5	0.0094
PM35751	S27°30'34.7743"	151°57' 18.4195"	751.101	0.0070	0.0056	356.9	0.0076
10KBM	S27°29'35.6816"	151°57' 1.0979"	706.316	0.0081	0.0069	356.9	0.0149
PM112793	S27°28'10.5208"	151°58' 47.8521"	448.507	0.0098	0.0082	336.2	0.0192
PM66947	S27°32'36.4499"	152° 3' 5.2715"	253.129	0.0086	0.0069	354.4	0.0147
PM112799	S27°36'30.0339"	151°51' 12.7222"	586.242	0.0088	0.0075	8.3	0.0204
CS15	S27°34'24.5989"	151°48' 14.4431"	515.237	0.0091	0.0073	1.1	0.0152
PM85731	S27°30'38.4820"	152° 4' 13.8654"	213.646	0.0087	0.0069	357.3	0.0140
CS84	S27°30'59.8175"	151°59' 54.5741"	371.128	0.0078	0.0066	1.5	0.0126
PM68101	S27°33'12.5407"	152° 1' 26.8412"	304.223	0.0084	0.0070	0.9	0.0186
CS101	S27°31'56.2560"	152° 4' 26.5645"	217.212	0.0084	0.0064	356.1	0.0094
CS107	S27°32'49.8069"	152° 5' 48.0136"	195.653	0.0089	0.0070	354.6	0.0123
PM51843	S27°33'11.5512"	151°52' 33.1649"	693.476	0.0079	0.0069	1.7	0.0155
CS32	S27°32' 2.7790"	151°51' 2.4241"	539.921	0.0079	0.0069	343.4	0.0100
CS108	S27°32'51.1624"	152° 6' 3.3038"	191.590	0.0098	0.0077	353.6	0.0137
CS22	S27°33'11.7623"	151°49' 52.0072"	577.477	0.0083	0.0070	356.2	0.0124
CS40	S27°30'37.2142"	151°52' 53.5679"	565.926	0.0078	0.0064	353.8	0.0100
CS45	S27°32' 8.5462"	151°54' 22.6587"	665.982	0.0078	0.0066	359.9	0.0145
CS62	S27°30'58.7015"	151°56' 29.2737"	595.020	0.0077	0.0064	356.9	0.0105
CS63	S27°32'44.8222"	151°56' 49.9736"	623.627	0.0082	0.0070	360.0	0.0154
CS04	S27°36'54.2756"	151°47' 4.6151"	537.091	0.0083	0.0050	359.5	0.0056
CS70	S27°31'11.4855"	151°57' 15.5191"	671.932	0.0073	0.0059	355.7	0.0079
CS56	S27°28'57.6956"	151°54' 35.3756"	568.855	0.0087	0.0075	358.5	0.0159
PM57526	S27°31' 9.5767"	152° 0' 2.2281"	335.771	0.0094	0.0081	15.7	0.0282
CS52	S27°30'22.0670"	151°54' 35.1341"	574.242	0.0075	0.0062	356.6	0.0104
CS05	S27°36'51.4814"	151°47' 22.5651"	537.290	0.0095	0.0069	1.4	0.0103
CS06	S27°36'29.7017"	151°47' 7.4785"	539.781	0.0103	0.0079	1.5	0.0123
CS07	S27°36'17.6750"	151°47' 11.4120"	532.261	0.0105	0.0084	0.7	0.0121
CS08	S27°36' 3.3919"	151°47' 21.8075"	525.179	0.0103	0.0085	359.9	0.0101
CS09	S27°35'50.0109"	151°47' 27.2725"	515.638	0.0097	0.0082	359.0	0.0057
CS10	S27°35'36.3844"	151°47' 43.9767"	517.582	0.0107	0.0089	359.6	0.0111
CS11	S27°35'29.2435"	151°47' 54.4696"	512.105	0.0111	0.0092	0.1	0.0134
CS12	S27°35'12.9486"	151°48' 2.7136"	501.325	0.0112	0.0092	0.1	0.0151
CS01	S27°37'10.3282"	151°46' 11.2567"	561.530	0.0100	0.0074	359.3	0.0112

CS02	S27°37' 3.5082" 151°46' 29.6524"	559.309	0.0104	0.0075	359.9	0.0119
CS03	S27°36'58.8904" 151°46' 48.9011"	543.069	0.0098	0.0069	0.3	0.0103
CS14	S27°34'44.2145" 151°48' 15.7257"	491.327	0.0103	0.0085	359.6	0.0159
CS13	S27°34'55.2724" 151°48' 5.1935"	505.405	0.0109	0.0090	359.8	0.0159
CS16	S27°34' 8.3845" 151°48' 27.6936"	499.156	0.0104	0.0086	1.1	0.0170
CS17	S27°33'56.9597" 151°48' 37.9829"	509.674	0.0113	0.0092	0.7	0.0178
CS18	S27°33'45.2533" 151°48' 47.4965"	522.943	0.0116	0.0094	0.8	0.0181
CS21	S27°33'23.0957" 151°49' 36.2020"	569.708	0.0101	0.0083	357.4	0.0151
CS23	S27°33' 1.9078" 151°49' 59.4409"	564.673	0.0096	0.0078	357.9	0.0123
CS20	S27°33'34.5905" 151°49' 21.8834"	559.903	0.0111	0.0090	359.3	0.0168
CS24	S27°32'47.9193" 151°49' 52.3910"	562.239	0.0103	0.0083	358.1	0.0109
CS19	S27°33'39.0827" 151°48' 59.5812"	530.887	0.0115	0.0094	0.4	0.0179
CS33	S27°31'53.3131" 151°51' 18.8946"	538.979	0.0084	0.0079	342.3	0.0072
CS31	S27°32' 4.0115" 151°50' 46.6593"	541.540	0.0096	0.0082	354.5	0.0127
CS30	S27°32'18.8114" 151°50' 44.8713"	554.077	0.0107	0.0090	357.3	0.0142
CS29	S27°32'34.0311" 151°50' 42.3246"	567.686	0.0113	0.0095	358.0	0.0148
CS28	S27°32'26.5307" 151°50' 31.2571"	554.736	0.0116	0.0096	358.0	0.0147
CS27	S27°32'33.9362" 151°50' 19.4199"	560.579	0.0116	0.0095	357.4	0.0137
CS26	S27°32'52.2169" 151°50' 24.2065"	587.315	0.0112	0.0090	356.1	0.0112
CS25	S27°32'50.0874" 151°50' 8.6559"	568.313	0.0105	0.0082	357.6	0.0074
CS106	S27°32'52.7006" 152° 5' 27.7184"	212.717	0.0100	0.0078	354.7	0.0124
CS36	S27°31' 7.6930" 151°51' 53.2994"	554.574	0.0110	0.0096	355.5	0.0151
CS37	S27°30'52.2520" 151°52' 1.6294"	553.818	0.0109	0.0094	353.1	0.0153
CS105	S27°32'48.4139" 152° 5' 5.5583"	203.158	0.0101	0.0077	356.3	0.0107
CS35	S27°31'26.2001" 151°51' 38.7873"	559.255	0.0107	0.0094	355.3	0.0137
CS104	S27°32'39.0469" 152° 4' 48.2614"	218.750	0.0106	0.0082	357.6	0.0128
CS34	S27°31'43.8138" 151°51' 32.6810"	553.275	0.0098	0.0089	353.0	0.0114
CS103	S27°32'25.4512" 152° 4' 38.9416"	218.008	0.0105	0.0082	359.0	0.0133
CS102	S27°32' 9.0671" 152° 4' 33.0801"	215.398	0.0098	0.0076	359.0	0.0122
CS53	S27°29'58.9601" 151°54' 37.5365"	560.749	0.0101	0.0084	359.0	0.0153
CS54	S27°29'42.4343" 151°54' 39.9677"	548.381	0.0103	0.0086	359.6	0.0165
CS71	S27°30'13.3759" 151°54' 34.8327"	579.565	0.0092	0.0076	357.7	0.0132
CS100	S27°31'41.1558" 152° 4' 13.8580"	244.063	0.0099	0.0076	358.2	0.0124
CS51	S27°30'39.0652" 151°54' 35.7330"	563.208	0.0093	0.0077	358.8	0.0139
CS98	S27°31'22.6710" 152° 3' 45.5413"	253.166	0.0112	0.0085	356.2	0.0126
CS97	S27°31'16.9521" 152° 3' 29.7463"	273.736	0.0112	0.0082	357.3	0.0110
CS44	S27°30'30.2789" 151°54' 15.9270"	551.634	0.0092	0.0077	359.6	0.0132
CS99	S27°31'31.7738" 152° 4' 0.4854"	248.536	0.0107	0.0083	356.6	0.0132
CS43	S27°30'39.5906" 151°53' 59.4638"	568.023	0.0099	0.0084	360.0	0.0144
CS55	S27°29'15.5903" 151°54' 34.3363"	546.157	0.0099	0.0084	358.8	0.0168
CS42	S27°30'44.5909" 151°53' 34.7582"	581.761	0.0099	0.0084	359.3	0.0144
CS41	S27°30'39.5126" 151°53' 9.7177"	554.345	0.0091	0.0076	359.0	0.0131
CS39	S27°30'34.3088" 151°52' 33.6732"	555.118	0.0094	0.0080	354.5	0.0131
CS38	S27°30'37.4246" 151°52' 17.0749"	549.612	0.0104	0.0089	352.1	0.0145
CS46	S27°31'57.4408" 151°54' 21.9303"	656.397	0.0095	0.0079	1.6	0.0159
CS47	S27°31'37.7046" 151°54' 25.7897"	611.819	0.0106	0.0088	1.1	0.0169
CS48	S27°31'25.6373" 151°54' 28.0552"	593.313	0.0110	0.0092	0.6	0.0171
CS49	S27°31'11.0089" 151°54' 30.5164"	584.240	0.0109	0.0091	0.5	0.0168
CS50	S27°30'55.6052" 151°54' 33.5103"	579.006	0.0104	0.0087	0.0	0.0159
CS58	S27°30'32.9978" 151°55' 23.7233"	593.558	0.0101	0.0087	353.8	0.0153
CS59	S27°30'38.4366" 151°55' 42.4263"	598.818	0.0104	0.0089	356.7	0.0156

CS60	S27°30'39.5227"	151°55' 50.6836"	590.303	0.0102	0.0086	356.9	0.0153
CS57	S27°30'31.2947"	151°54' 59.4873"	633.631	0.0094	0.0080	348.7	0.0137
CS61	S27°30'44.8118"	151°56' 9.9519"	573.502	0.0094	0.0078	355.6	0.0139
CS67	S27°31'19.0371"	151°56' 37.5650"	602.565	0.0091	0.0077	359.3	0.0140
CS68	S27°31' 7.1520"	151°56' 44.5534"	606.112	0.0087	0.0071	355.8	0.0111
CS66	S27°31'40.8491"	151°56' 36.6400"	611.186	0.0092	0.0077	0.8	0.0144
CS65	S27°32' 6.3627"	151°56' 41.1770"	621.873	0.0098	0.0082	359.7	0.0162
CS64	S27°32'25.1688"	151°56' 39.2697"	615.536	0.0095	0.0080	359.9	0.0164
CS69	S27°31'14.1902"	151°56' 55.6876"	614.671	0.0087	0.0071	355.7	0.0109
CS91	S27°30'55.1646"	152° 1' 58.4615"	286.888	0.0097	0.0078	353.7	0.0123
CS93	S27°30'47.3381"	152° 2' 22.2957"	356.656	0.0098	0.0079	355.7	0.0134
CS94	S27°30'46.8603"	152° 2' 40.5010"	305.454	0.0108	0.0086	356.0	0.0146
CS95	S27°30'59.5517"	152° 3' 1.9373"	279.268	0.0112	0.0088	357.6	0.0147
CS96	S27°31'11.3637"	152° 3' 12.9487"	306.704	0.0114	0.0087	358.1	0.0136
CS90	S27°30'56.8137"	152° 1' 40.0326"	282.615	0.0101	0.0083	353.4	0.0117
CS89	S27°31' 0.8103"	152° 1' 23.1105"	307.329	0.0104	0.0087	356.0	0.0130
CS88	S27°31' 1.6480"	152° 1' 3.3968"	358.981	0.0104	0.0088	357.4	0.0124
CS83	S27°30'55.5731"	151°59' 32.8562"	477.992	0.0094	0.0079	359.7	0.0147
CS82	S27°30'46.3248"	151°59' 22.6118"	455.558	0.0101	0.0084	358.9	0.0154
CS81	S27°30'28.4653"	151°59' 22.0126"	499.326	0.0101	0.0084	359.6	0.0151
CS80	S27°30'13.6532"	151°59' 10.5131"	471.535	0.0094	0.0077	359.6	0.0137
CS85	S27°30'53.4880"	152° 0' 10.2399"	436.019	0.0092	0.0077	2.2	0.0143
CS87	S27°30'56.2399"	152° 0' 46.4687"	392.959	0.0104	0.0087	0.6	0.0140
CS72	S27°31' 2.4479"	151°57' 21.4756"	633.456	0.0087	0.0070	352.7	0.0094
CS73	S27°30'47.0741"	151°57' 29.2206"	616.653	0.0090	0.0075	352.8	0.0100
CS74	S27°30'41.1296"	151°57' 48.5454"	617.758	0.0089	0.0073	354.7	0.0112
CS76	S27°30'15.6269"	151°58' 17.0374"	520.127	0.0092	0.0071	353.9	0.0094
CS77	S27°30' 7.1644"	151°58' 28.3748"	443.718	0.0092	0.0071	355.9	0.0098
CS78	S27°29'58.0960"	151°58' 34.3487"	486.845	0.0089	0.0071	356.1	0.0112
CS86	S27°30'58.2684"	152° 0' 26.9202"	392.872	0.0101	0.0084	2.5	0.0147
CS67A	S27°31'19.1643"	151°56' 37.0276"	604.419	0.0091	0.0076	1.2	0.0142

GPS Baseline Observation Summary
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From	To	DX	DY	DZ	dLat	dLong	dHt	Stand	Length	PPM
PM40970	CS92	190.670	-398.512	-322.453	-0.001	0.004	0.005	0.90	546.940	11.02
CS79	CS75	944.611	897.234	-980.703	0.002	-0.008	0.007	1.33	1630.674	6.53
CS75	PM35751	395.373	1254.509	-64.264	-0.008	0.002	0.037	4.72	1316.906	29.03
CS79	10KBM	857.226	2947.708	589.262	0.003	-0.001	0.011	1.21	3125.868	3.50
10KBM	PM112793	-2243.487	-2125.904	2444.701	0.005	0.013	-0.021	2.48	3940.719	6.43
PM40970	PM66947	877.832	-2384.225	-3170.531	-0.006	0.005	-0.021	1.97	4062.928	5.42
PM112799	CS15	787.352	5125.176	3455.129	-0.006	0.000	-0.061	3.96	6230.992	9.80
PM40970	PM85731	-1455.844	-3277.278	67.927	0.003	-0.001	-0.020	1.67	3586.732	5.65
CS84	PM68101	532.034	-3149.964	-3591.865	0.003	-0.004	0.022	2.03	4806.957	4.63
PM35751	PM68101	-869.800	-7259.084	-4100.087	0.004	-0.012	-0.008	0.77	8382.217	1.81
PM85731	CS101	811.370	-824.547	-2124.781	-0.005	-0.001	-0.021	2.42	2419.276	9.02
PM85731	PM66947	2333.671	893.051	-3238.469	-0.002	0.001	-0.008	0.63	4090.384	2.04

PM66947	CS101	-1522.297	-1717.606	1113.687	0.000	-0.007	-0.006	0.96	2551.049	3.70
PM85731	CS107	455.484	-3165.141	-3576.452	0.002	0.001	-0.022	1.54	4797.561	4.52
PM51843	CS32	430.934	2593.121	1948.148	-0.003	0.002	-0.003	0.42	3271.889	1.26
CS79	PM35751	1339.978	2151.752	-1044.973	-0.005	-0.001	0.033	3.60	2741.814	12.22
**										
CS79	PM112793	-1386.254	821.778	3033.977	0.005	-0.008	0.012	1.20	3435.409	4.24
PM40970	PM68101	2557.959	-218.571	-4179.163	-0.003	-0.003	-0.008	0.62	4904.725	1.81
CS107	CS108	-176.073	-381.466	-35.114	-0.001	0.000	0.001	0.19	421.605	3.06
PM35751	CS70	560.193	-208.229	-965.725	-0.004	0.000	0.008	1.23	1135.694	8.24
CS92	CS101	-835.124	-3703.318	-1734.409	0.015	-0.000	-0.032	3.06	4173.747	8.34
PM51843	CS22	2179.178	3848.915	47.891	0.000	-0.000	-0.012	0.94	4423.264	2.62
CS84	PM112793	-1324.424	2779.148	4587.177	-0.008	-0.008	-0.010	1.06	5524.487	2.69
PM51843	PM112799	3619.055	567.007	-5366.166	0.004	0.006	-0.012	0.89	6497.291	2.14
PM51843	CS40	-2101.070	488.013	4272.056	-0.008	-0.001	0.002	0.64	4785.720	1.67
CS107	CS101	355.904	2340.583	1451.670	0.002	-0.002	0.018	2.51	2777.111	6.69
PM112799	PM51843	-3619.037	-567.013	5366.176	-0.005	-0.002	0.034	2.56	6497.290	5.23
CS107	PM66947	1878.186	4058.186	337.987	-0.006	-0.005	0.016	1.42	4484.494	4.03
PM51843	CS45	-2185.172	-2239.023	1732.451	0.006	-0.004	0.028	2.60	3576.253	7.97
CS56	PM35751	-1031.094	-4522.572	-2735.054	0.006	-0.015	-0.001	1.05	5384.917	2.99
PM35751	CS45	3513.472	3593.212	-2520.692	0.014	0.004	0.026	1.86	5622.236	5.33
PM112799	CS22	-1439.863	3281.901	5414.052	0.007	-0.007	0.012	0.94	6492.768	2.38
CS45	CS62	-2456.608	-2627.892	1939.529	-0.001	-0.007	0.030	2.62	4086.871	7.60
CS45	CS63	-1413.579	-3827.479	-970.587	0.005	-0.004	0.038	3.53	4194.024	9.29
**										
PM112799	CS04	3556.369	5813.283	-638.482	-0.002	-0.004	0.010	0.68	6844.682	1.58
PM35751	CS62	1056.823	965.333	-581.154	-0.014	-0.010	0.023	3.67	1544.825	18.47
**										
CS70	CS63	1539.628	-25.997	-2525.574	0.003	0.002	-0.027	3.74	2957.981	9.07
**										
PM35751	CS70	560.177	-208.220	-965.749	0.008	0.000	-0.018	2.64	1135.705	17.67
PM35751	10KBM	-482.741	795.949	1634.252	-0.000	-0.001	-0.003	0.47	1880.785	1.82
PM40970	CS79	2087.809	4888.733	965.911	0.004	-0.002	0.007	0.87	5402.929	1.59
PM85731	CS92	1646.532	2878.747	-390.372	0.000	-0.003	0.050	5.83	3339.258	15.08
**										
PM40970	CS84	2025.957	2931.369	-587.286	0.003	-0.006	0.011	1.14	3611.417	3.54
PM35751	CS84	-1401.803	-4109.124	-508.207	0.002	0.003	0.003	0.42	4371.295	1.15
CS84	CS79	61.859	1957.356	1553.204	-0.001	-0.000	0.008	1.14	2499.502	3.26
PM66947	PM68101	1680.115	2165.673	-1008.632	-0.005	0.003	-0.004	0.96	2920.662	2.57
10KBM	CS56	1513.838	3726.582	1100.807	0.000	-0.019	0.025	2.76	4170.239	7.53
PM85731	CS108	279.410	-3546.611	-3611.574	0.010	-0.004	-0.023	1.59	5069.516	4.96
CS70	PM57526	-1910.378	-4166.254	207.424	0.006	0.001	-0.007	1.03	4588.054	2.07
PM57526	PM68101	480.395	-2884.591	-3341.788	0.006	0.001	-0.007	1.01	4440.629	2.04
CS04	CS15	-2768.906	-688.175	4093.641	0.029	-0.003	0.059	4.84	4989.822	13.14
**										
CS15	CS22	-2227.262	-1843.240	1958.895	0.011	0.002	0.008	1.26	3492.206	4.00
CS40	CS52	-1509.773	-2354.158	409.717	0.003	0.006	-0.025	3.26	2826.543	9.26
CS52	CS62	-1031.012	-3000.683	-1009.819	-0.016	0.026	-0.026	3.19	3329.687	11.95
**										
CS52	CS56	-1056.723	556.492	2306.403	0.002	0.003	-0.000	0.37	2597.275	1.29
CS40	CS32	2532.006	2105.102	-2323.886	-0.012	-0.001	0.009	1.27	4030.255	3.86
CS32	CS22	1748.247	1255.795	-1900.243	-0.009	-0.001	-0.000	0.89	2871.291	2.99

CS52	CS45	1425.641	-372.853	-2949.326	-0.004	-0.001	0.016	1.97	3296.967	4.85
CS63	CS62	-1043.020	1199.585	2910.110	0.004	-0.000	-0.004	0.44	3315.967	1.54
PM112799	CS04	3556.367	5813.302	-638.499	0.009	0.012	-0.008	1.25	6844.699	2.44
CS04	CS05	-267.986	-414.810	76.126	-0.002	-0.001	-0.000	0.33	499.679	4.41
CS05	CS06	-80.194	512.509	592.958	-0.002	-0.001	-0.000	0.33	787.842	2.82
CS06	CS07	-196.307	-17.097	331.567	-0.002	-0.001	-0.000	0.30	385.701	5.08
CS07	CS08	-308.767	-157.881	392.926	-0.002	-0.001	-0.000	0.32	524.075	3.94
CS08	CS09	-231.568	-45.868	369.470	-0.002	-0.001	-0.000	0.31	438.447	4.73
CS09	CS10	-389.290	-311.073	370.861	-0.001	0.001	0.004	0.69	621.169	7.87
CS10	CS11	-221.458	-207.799	197.361	-0.001	0.001	0.004	0.61	362.182	11.18
CS11	CS12	-303.168	-94.009	449.576	-0.001	0.001	0.005	0.74	550.334	9.02
CS01	CS02	-322.607	-399.330	187.050	0.001	-0.002	-0.008	1.26	546.376	15.43
CS02	CS03	-294.995	-440.711	133.483	0.001	-0.001	-0.008	1.30	546.869	15.66
CS03	CS04	-257.103	-351.060	128.644	0.001	-0.002	-0.007	1.16	453.756	16.81
CS14	CS13	264.407	186.040	-308.242	0.001	-0.001	-0.004	0.69	446.693	10.33
CS13	CS12	257.387	-60.824	-480.401	0.001	-0.001	-0.005	0.76	548.391	9.25
CS15	CS16	-362.784	-217.949	449.900	-0.000	0.000	0.005	0.74	617.676	8.07
CS16	CS17	-285.019	-167.493	306.904	0.000	0.000	0.004	0.59	451.087	9.07
CS17	CS18	-280.630	-145.717	313.324	0.000	0.000	0.004	0.63	445.150	9.49
CS14	CS15	-248.417	173.099	524.179	-0.002	0.002	0.005	0.81	605.341	9.07
CS21	CS22	-353.068	-302.828	305.718	0.000	0.000	0.005	0.64	556.620	8.12
CS22	CS23	-209.972	-118.929	274.881	0.000	-0.001	0.004	0.70	365.776	12.32
CS21	CS20	337.457	264.890	-309.174	-0.000	-0.000	-0.005	0.67	528.803	8.66
CS23	CS24	-82.359	263.522	382.926	-0.000	-0.001	0.005	0.72	472.079	10.04
CS20	CS19	368.021	496.978	-109.174	0.000	0.000	-0.006	0.95	627.969	9.49
CS19	CS18	240.268	247.389	-164.721	0.000	-0.000	-0.004	0.67	382.182	11.14
CS32	CS33	-331.247	-335.386	258.834	-0.001	-0.000	0.005	0.83	537.776	10.26
CS31	CS30	199.055	-50.877	-409.785	0.001	0.001	-0.004	0.65	458.405	9.27
CS30	CS29	213.333	-34.908	-421.723	0.001	0.000	-0.004	0.63	473.899	8.77
CS29	CS28	59.299	312.715	210.709	0.001	0.000	-0.003	0.53	381.713	9.21
CS28	CS27	241.652	239.064	-204.840	0.001	0.001	-0.005	0.77	396.871	11.93
CS27	CS26	146.551	-227.424	-511.328	0.001	0.001	-0.005	0.79	578.493	8.75
CS26	CS25	189.504	382.532	66.908	0.001	0.000	-0.004	0.58	432.110	8.91
CS107	CS108	-176.073	-381.466	-35.114	-0.001	0.000	0.001	0.19	421.605	3.06
CS25	CS24	188.195	405.468	61.984	-0.000	0.001	-0.005	0.72	451.291	10.44
CS107	CS106	283.640	479.888	-86.872	-0.000	-0.001	-0.010	1.52	564.172	18.71
CS36	CS37	-300.871	-98.377	421.910	-0.000	-0.000	0.002	0.31	527.456	3.94
CS106	CS105	238.169	561.879	121.411	-0.000	-0.001	-0.012	1.67	622.233	18.57
CS36	CS35	416.306	229.026	-507.413	0.000	0.000	-0.002	0.34	695.148	3.48
CS105	CS104	92.162	488.256	248.443	-0.002	-0.000	0.003	0.52	555.528	6.42
CS35	CS34	304.680	27.086	-478.074	0.000	0.000	-0.002	0.29	567.555	3.62
CS104	CS103	-50.667	316.257	371.422	-0.002	-0.000	0.003	0.56	490.449	7.47
CS34	CS33	308.810	263.876	-252.705	0.000	0.000	-0.002	0.29	478.387	4.04
CS103	CS102	-128.663	250.218	448.409	-0.002	-0.000	0.003	0.60	529.371	7.35
CS53	CS54	-228.963	46.551	456.960	0.001	-0.000	-0.003	0.55	513.228	7.12
CS102	CS101	-78.763	244.099	348.852	-0.002	-0.000	0.003	0.52	432.996	7.89
CS53	CS71	201.011	-23.153	-402.312	-0.001	0.000	0.003	0.55	450.329	7.98
CS101	CS100	-47.562	419.853	399.769	0.002	-0.004	-0.008	1.42	581.681	15.93
CS71	CS52	109.276	-67.702	-234.844	-0.001	0.000	0.003	0.45	267.724	10.84
CS52	CS51	214.109	-132.915	-459.013	0.000	-0.002	-0.000	0.38	523.644	4.83
CS98	CS97	115.109	429.605	146.608	0.003	-0.006	-0.007	1.36	468.300	20.46

CS52	CS44	368.947	400.668	-213.774	-0.001	-0.002	-0.002	0.45	585.112	5.12
CS98	CS99	-74.090	-424.906	-246.342	-0.003	0.006	0.009	1.68	496.708	21.57
CS44	CS43	316.799	343.111	-261.809	-0.001	-0.001	-0.002	0.44	535.379	5.42
CS54	CS55	-261.998	315.069	734.067	0.002	0.000	-0.005	0.78	840.694	6.25
CS55	CS56	-255.488	104.019	478.208	0.001	-0.000	-0.004	0.57	552.066	6.97
CS43	CS42	371.402	570.399	-142.867	-0.001	-0.002	-0.003	0.49	695.490	4.81
CS42	CS41	281.584	628.789	151.315	-0.001	-0.002	-0.003	0.48	705.380	4.81
CS41	CS40	171.011	411.206	57.401	-0.001	-0.001	-0.002	0.43	449.032	5.85
CS40	CS39	229.400	496.559	84.316	0.000	0.000	-0.002	0.33	553.447	3.89
CS39	CS38	258.147	378.598	-82.526	0.000	0.000	-0.002	0.27	465.604	3.90
CS38	CS37	382.531	276.205	-406.768	0.000	0.000	-0.002	0.34	622.960	3.68
CS46	CS45	122.507	-88.059	-307.582	0.000	-0.002	-0.000	0.38	342.592	7.33
CS46	CS47	-262.739	20.193	559.371	-0.000	0.003	0.000	0.39	618.333	4.53
CS47	CS48	-166.250	18.267	337.985	-0.000	0.003	0.001	0.40	377.103	7.10
CS48	CS49	-208.279	34.610	403.551	-0.000	0.003	0.001	0.45	455.447	6.55
CS49	CS50	-227.873	28.486	422.960	-0.000	0.003	0.001	0.45	481.282	6.13
CS50	CS51	-223.866	50.337	458.878	-0.000	0.003	0.001	0.43	513.049	5.46
CS58	CS59	-177.482	-487.156	-150.936	0.005	-0.004	-0.010	1.83	540.002	22.39
CS59	CS60	-86.362	-210.804	-25.729	0.005	-0.004	-0.008	1.53	229.257	42.64
CS58	CS57	260.417	615.057	28.000	-0.006	0.004	0.013	2.23	668.503	21.67
CS60	CS61	-169.322	-509.069	-136.654	0.005	-0.003	-0.011	1.87	553.620	22.32
CS57	CS52	245.451	626.711	279.394	-0.007	0.007	0.013	2.36	728.748	22.42
CS61	CS62	-92.012	-551.921	-389.167	0.006	-0.004	-0.012	2.00	681.567	20.11
CS62	CS67	142.314	-333.718	-558.668	0.001	0.001	0.000	0.25	666.131	2.47
CS62	CS68	-99.862	-421.989	-235.832	-0.004	-0.001	0.001	0.75	493.623	9.67
CS67	CS66	279.036	-119.951	-599.443	0.002	0.001	0.000	0.28	671.998	2.83
CS66	CS65	253.461	-276.168	-701.405	-0.003	0.001	-0.001	0.46	795.286	3.97
CS65	CS64	265.781	-82.341	-510.409	-0.003	0.001	-0.000	0.43	581.324	4.97
CS64	CS63	102.429	-387.401	-540.180	-0.003	0.001	-0.000	0.43	672.582	4.34
CS70	CS69	334.709	438.391	-47.388	0.006	0.001	0.002	0.88	553.591	10.93
CS69	CS68	62.067	313.194	196.099	0.005	0.002	0.001	0.85	374.697	14.72
CS31	CS32	-218.303	-373.839	34.393	-0.001	-0.001	0.004	0.59	434.275	9.24
CS92	CS91	247.381	323.321	-98.892	0.000	-0.001	-0.010	1.40	418.943	23.29
CS92	CS93	-212.283	-173.247	82.566	-0.004	0.009	0.022	3.83	286.174	85.05

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CS93	CS94	-200.118	-459.456	36.715	-0.005	0.009	0.029	4.78	502.489	60.71

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CS95	CS96	-14.703	-334.294	-335.125	-0.003	0.005	0.026	4.14	473.580	57.01

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CS91	CS90	261.267	433.934	-43.055	0.000	-0.001	-0.011	1.53	508.343	21.34
CS90	CS89	248.692	393.780	-120.522	-0.001	-0.002	0.002	0.42	481.078	5.42
CS89	CS88	223.902	493.703	-46.732	-0.001	-0.002	0.002	0.44	544.112	5.06
CS84	CS83	142.909	599.109	66.508	0.001	-0.002	0.009	1.32	619.498	14.24
CS04	CS01	874.679	1191.103	-449.195	0.001	-0.006	-0.006	1.04	1544.528	5.28
CS83	CS82	33.498	300.654	262.859	0.002	-0.001	0.006	1.02	400.761	16.70
CS82	CS81	-250.741	152.006	467.394	0.001	-0.002	0.009	1.36	551.755	15.97
CS81	CS80	-15.900	365.985	417.262	0.002	-0.001	0.008	1.17	555.252	14.22
CS84	CS85	-332.146	-310.351	142.814	0.002	0.003	-0.009	1.60	476.482	20.86
CS87	CS88	-123.480	-460.500	-131.951	0.001	0.002	-0.007	1.14	494.690	15.51
CS70	CS72	-160.195	-99.889	264.524	-0.007	0.003	0.005	1.30	324.982	28.00
CS72	CS73	-279.753	-91.834	427.509	-0.007	0.002	0.010	1.83	519.095	22.94

CS73	CS74	-324.804	-427.965	161.802	-0.006	0.000	0.013	2.28	561.099	25.69
CS74	CS75	-190.760	-426.614	176.228	-0.006	-0.001	0.012	2.14	499.445	27.12
CS75	CS76	-420.412	-133.981	565.184	-0.001	-0.004	-0.009	1.32	717.029	13.29
CS76	CS77	-192.597	-250.028	266.352	-0.001	-0.003	0.003	0.67	412.978	10.56
CS77	CS78	-224.602	-66.221	227.700	-0.003	-0.005	0.005	1.18	326.617	22.14
CS78	CS79	-107.006	-447.029	-78.524	-0.003	-0.005	0.004	1.13	466.317	15.80
CS79	CS80	-152.116	-539.581	-339.189	-0.002	0.002	-0.009	1.32	655.237	13.89
CS100	CS99	50.458	388.599	254.032	0.003	-0.006	-0.008	1.64	466.999	22.40
CS94	CS95	-95.802	-615.188	-334.366	-0.005	0.003	0.037	6.18	706.707	53.53

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CS96	CS97	-119.954	-458.200	-137.314	-0.002	0.004	0.027	4.11	493.144	54.72

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CS86	CS85	121.077	454.102	110.580	-0.002	-0.003	0.009	1.47	482.800	19.67
CS86	CS87	-277.342	-460.182	55.334	0.002	0.003	-0.009	1.46	540.137	17.65
CS62	CS67A	149.395	-320.777	-562.996	-0.004	0.000	-0.001	0.58	664.967	5.65
CS67A	CS66	271.948	-132.889	-595.109	-0.004	0.000	-0.001	0.58	667.660	5.59

Station Observation Summary
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Stn	Horiz	Vert
PM40970	12	6
CS92	10	5
CS79	16	8
CS75	8	4
PM35751	22	11
10KBM	8	4
PM112793	6	3
PM66947	10	5
PM112799	12	6
CS15	10	5
PM85731	12	6
CS84	14	7
PM68101	10	5
CS101	14	7
CS107	14	7
PM51843	12	6
CS32	10	5
CS108	6	3
CS22	12	6
CS40	12	6
CS45	12	6
CS62	16	8
CS63	8	4
CS04	14	7
CS70	14	7
CS56	8	4
PM57526	4	2
CS52	18	9
CS05	4	2

CS06	4	2
CS07	4	2
CS08	4	2
CS09	6	3
CS10	4	2
CS11	4	2
CS12	4	2
CS01	6	3
CS02	4	2
CS03	4	2
CS14	4	2
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CS16	4	2
CS17	4	2
CS18	4	2
CS21	4	2
CS23	4	2
CS20	4	2
CS24	4	2
CS19	4	2
CS33	6	3
CS31	4	2
CS30	4	2
CS29	4	2
CS28	4	2
CS27	4	2
CS26	4	2
CS25	6	3
CS106	4	2
CS36	4	2
CS37	4	2
CS105	6	3
CS35	4	2
CS104	4	2
CS34	4	2
CS103	4	2
CS102	4	2
CS53	4	2
CS54	4	2
CS71	4	2
CS100	4	2
CS51	4	2
CS98	4	2
CS97	6	3
CS44	4	2
CS99	4	2
CS43	4	2
CS55	4	2
CS42	4	2
CS41	4	2
CS39	4	2

CS38	4	2
CS46	4	2
CS47	4	2
CS48	4	2
CS49	4	2
CS50	4	2
CS58	4	2
CS59	4	2
CS60	4	2
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CS61	4	2
CS67	4	2
CS68	6	3
CS66	6	3
CS65	4	2
CS64	4	2
CS69	4	2
CS91	4	2
CS93	4	2
CS94	4	2
CS95	4	2
CS96	4	2
CS90	6	3
CS89	4	2
CS88	6	3
CS83	4	2
CS82	4	2
CS81	4	2
CS80	4	2
CS85	4	2
CS87	4	2
CS72	6	3
CS73	6	3
CS74	4	2
CS76	6	3
CS77	6	3
CS78	4	2
CS86	4	2
CS67A	4	2

Summary of changes to stations
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Stn	Cons	dLat	dLong	dSpherHt
PM40970	N	0.471	1.087	-0.626
CS92	N	0.472	1.083	-0.631
CS79	N	0.480	1.084	-0.680
CS75	N	0.478	1.092	-0.687
PM35751	Y	0.003	0.004	0.042

10KBM	N	0.477	1.085	-0.691
PM112793	N	0.472	1.073	-0.670
PM66947	N	0.477	1.082	-0.606
PM112799	N	0.445	1.009	-0.625
CS15	N	0.452	1.009	-0.564
PM85731	N	0.468	1.087	-0.606
CS84	N	0.458	1.085	-0.628
PM68101	N	0.456	1.089	-0.650
CS101	Y	0.005	0.002	0.008
CS107	Y	0.006	0.027	0.010
PM51843	N	0.458	1.024	-0.628
CS32	N	0.461	1.023	-0.625
CS108	N	0.474	1.073	-0.605
CS22	N	0.458	1.024	-0.616
CS40	Y	0.005	-0.018	0.003
CS45	N	0.452	1.028	-0.655
CS62	N	0.443	1.039	-0.671
CS63	N	0.436	1.036	-0.679
CS04	Y	-0.020	0.004	-0.003
CS70	Y	-0.002	-0.018	-0.021
CS56	N	0.456	1.072	-0.706
PM57526	N	0.463	1.060	-0.678
CS52	Y	0.009	-0.011	0.036
CS05	N	0.441	0.992	-0.619
CS06	N	0.442	0.994	-0.619
CS07	N	0.444	0.995	-0.619
CS08	N	0.446	0.996	-0.619
CS09	Y	-0.004	-0.021	-0.002
CS10	N	0.449	0.995	-0.623
CS11	N	0.450	0.994	-0.627
CS12	N	0.452	0.993	-0.631
CS01	Y	-0.008	-0.037	0.023
CS02	N	0.432	0.995	-0.601
CS03	N	0.430	0.997	-0.592
CS14	N	0.447	0.996	-0.573
CS13	N	0.446	0.997	-0.569
CS16	N	0.452	1.008	-0.569
CS17	N	0.451	1.008	-0.573
CS18	N	0.451	1.008	-0.577
CS21	N	-6.888	3.493	-10.543
CS23	N	-6.888	3.494	-10.552
CS20	N	-6.888	3.493	-10.539
CS24	N	-6.888	3.495	-10.557
CS19	N	-6.888	3.492	-10.533
CS33	Y	-0.004	0.006	0.002
CS31	N	0.459	1.024	-0.601
CS30	N	0.458	1.023	-0.597
CS29	N	0.457	1.023	-0.593
CS28	N	0.456	1.022	-0.590
CS27	N	0.455	1.022	-0.585
CS26	N	0.454	1.021	-0.580

CS25	Y	0.013	-0.004	0.000
CS106	N	0.474	1.075	-0.594
CS36	N	1.717	-5.700	-0.951
CS37	N	1.717	-5.700	-0.953
CS105	Y	0.006	-0.015	-0.027
CS35	N	1.716	-5.700	-0.949
CS104	N	0.476	1.076	-0.586
CS34	N	1.716	-5.700	-0.947
CS103	N	0.478	1.076	-0.589
CS102	N	0.479	1.077	-0.592
CS53	N	0.471	1.052	-0.640
CS54	N	0.470	1.052	-0.637
CS71	N	0.473	1.051	-0.644
CS100	N	0.479	1.081	-0.587
CS51	N	0.474	1.053	-0.646
CS98	N	0.472	1.093	-0.567
CS97	Y	0.005	0.028	0.038
CS44	N	0.475	1.052	-0.644
CS99	N	0.475	1.088	-0.575
CS43	N	0.476	1.054	-0.641
CS55	N	0.469	1.052	-0.632
CS42	N	0.476	1.056	-0.639
CS41	N	0.477	1.058	-0.636
CS39	N	0.477	1.058	-0.631
CS38	N	0.477	1.058	-0.630
CS46	N	-9.051	-11.606	7.784
CS47	N	-9.050	-11.609	7.784
CS48	N	-9.050	-11.612	7.783
CS49	N	-9.050	-11.615	7.782
CS50	N	-9.050	-11.619	7.782
CS58	N	-8.336	-1.075	-7.093
CS59	N	-8.341	-1.071	-7.083
CS60	N	-8.345	-1.067	-7.075
CS57	N	-8.330	-1.079	-7.106
CS61	N	-8.351	-1.064	-7.065
CS67	N	-8.358	-1.061	-7.053
CS68	Y	0.030	0.005	0.019
CS66	N	-8.360	-1.062	-7.054
CS65	N	-8.357	-1.063	-7.053
CS64	N	-8.354	-1.064	-7.053
CS69	N	0.454	1.050	-0.695
CS91	N	0.475	1.080	-0.668
CS93	N	0.479	1.070	-0.700
CS94	N	0.484	1.060	-0.729
CS95	N	0.487	1.109	-0.583
CS96	N	0.490	1.104	-0.610
CS90	Y	0.017	-0.001	-0.044
CS89	N	0.475	1.083	-0.659
CS88	Y	0.003	0.002	-0.023
CS83	N	0.455	1.057	-0.675
CS82	N	0.454	1.058	-0.681

CS81	N	0.452	1.060	-0.689
CS80	N	0.451	1.061	-0.697
CS85	N	0.455	1.052	-0.657
CS87	N	0.466	1.065	-0.680
CS72	Y	-0.010	0.020	-0.004
CS73	Y	-0.010	0.020	-0.006
CS74	N	0.467	1.047	-0.694
CS76	Y	0.008	-0.025	-0.027
CS77	Y	0.035	0.020	-0.000
CS78	N	0.478	1.059	-0.705
CS86	N	0.466	1.066	-0.687
CS67A	N	0.492	1.004	-0.597

APPENDIX E

ESTIMATED ACCURACY OF THE ELLIPSOID, AHD DERIVED AND EMPIRICAL GEOID HEIGHTS AT THE 95% CONFIDENCE LEVEL

Title: Estimated Accuracy of the Ellipsoid (σ_h), AHD Derived (σ_H) and Empirical Geoid Heights (σ_N) at the 95% Confidence Level
Coordinate Source: Constrained Least-squares Adjustment of the Toowoomba Bypass Control Network: TB_Cntrl_Const_7.trc
Project Datum (ϕ,λ,h): GDA94 (GRS80 Ellipsoid)
Levelling Height Datum: AHD Derived
Units: h, H, N and σ in metres; σ^2 in metres squared

	(GDA94)	(GDA94)	(GDA94)			95% C.I.	95% C.I.	(AHDD)			95% C.I.	95% C.I.
Stn	ϕ	λ	h	σ_h	σ_h^2	(σ_h x 1.96)	(σ_h^2 x 1.96)	H	σ_H	σ_H^2	(σ_H x 1.96)	(σ_H^2 x 1.96)
CS01	-27°37'10.3282"	151°46'11.2567"	561.530	0.0112	0.0001254	0.0219520	0.0002459	519.195	0.020	0.000400	0.039200	0.000784
CS02	-27°37'03.5082"	151°46'29.6524"	559.309	0.0119	0.0001416	0.0233240	0.0002776	516.939	0.020	0.000400	0.039200	0.000784
CS03	-27°36'58.8904"	151°46'48.9011"	543.069	0.0103	0.0001061	0.0201880	0.0002079	500.708	0.019	0.000361	0.037240	0.000708
CS04	-27°36'54.2756"	151°47'04.6151"	537.091	0.0056	0.0000314	0.0109760	0.0000615	494.745	0.019	0.000361	0.037240	0.000708
CS05	-27°36'51.4814"	151°47'22.5651"	537.290	0.0103	0.0001061	0.0201880	0.0002079	494.739	0.019	0.000361	0.037240	0.000708
CS06	-27°36'29.7017"	151°47'07.4785"	539.781	0.0123	0.0001513	0.0241080	0.0002965	497.419	0.019	0.000361	0.037240	0.000708
CS07	-27°36'17.6750"	151°47'11.4120"	532.261	0.0121	0.0001464	0.0237160	0.0002870	489.893	0.019	0.000361	0.037240	0.000708
CS08	-27°36'03.3919"	151°47'21.8075"	525.179	0.0101	0.0001020	0.0197960	0.0001999	482.796	0.019	0.000361	0.037240	0.000708
CS09	-27°35'50.0109"	151°47'27.2725"	515.638	0.0057	0.0000325	0.0111720	0.0000637	473.254	0.018	0.000324	0.035280	0.000635
CS10	-27°35'36.3844"	151°47'43.9767"	517.582	0.0111	0.0001232	0.0217560	0.0002415	475.179	0.018	0.000324	0.035280	0.000635
CS11	-27°35'29.2435"	151°47'54.4696"	512.105	0.0134	0.0001796	0.0262640	0.0003519	469.755	0.018	0.000324	0.035280	0.000635
CS12	-27°35'12.9486"	151°48'02.7136"	501.325	0.0151	0.0002280	0.0295960	0.0004469	458.898	0.018	0.000324	0.035280	0.000635
CS13	-27°34'55.2724"	151°48'05.1935"	505.405	0.0159	0.0002528	0.0311640	0.0004955	462.963	0.018	0.000324	0.035280	0.000635
CS14	-27°34'44.2145"	151°48'15.7257"	491.327	0.0159	0.0002528	0.0311640	0.0004955	448.875	0.017	0.000289	0.033320	0.000566
CS15	-27°34'24.5989"	151°48'14.4431"	515.237	0.0152	0.0002310	0.0297920	0.0004528	472.763	0.017	0.000289	0.033320	0.000566
CS16	-27°34'08.3845"	151°48'27.6936"	499.156	0.0170	0.0002890	0.0333200	0.0005664	456.674	0.017	0.000289	0.033320	0.000566
CS17	-27°33'56.9597"	151°48'37.9829"	509.674	0.0178	0.0003168	0.0348880	0.0006210	467.167	0.017	0.000289	0.033320	0.000566
CS18	-27°33'45.2533"	151°48'47.4965"	522.943	0.0181	0.0003276	0.0354760	0.0006421	480.413	0.017	0.000289	0.033320	0.000566
CS19	-27°33'39.0827"	151°48'59.5812"	530.887	0.0179	0.0003204	0.0350840	0.0006280	488.345	0.017	0.000289	0.033320	0.000566
CS20	-27°33'34.5905"	151°49'21.8834"	559.903	0.0168	0.0002822	0.0329280	0.0005532	517.355	0.016	0.000256	0.031360	0.000502
CS21	-27°33'23.0957"	151°49'36.2020"	569.708	0.0151	0.0002280	0.0295960	0.0004469	527.147	0.016	0.000256	0.031360	0.000502
CS22	-27°33'11.7623"	151°49'52.0072"	577.477	0.0124	0.0001538	0.0243040	0.0003014	534.891	0.016	0.000256	0.031360	0.000502
CS23	-27°33'01.9078"	151°49'59.4409"	564.673	0.0123	0.0001513	0.0241080	0.0002965	522.078	0.016	0.000256	0.031360	0.000502
CS24	-27°32'47.9193"	151°49'52.3910"	562.239	0.0109	0.0001188	0.0213640	0.0002329	519.632	0.016	0.000256	0.031360	0.000502
CS25	-27°32'50.0874"	151°50'08.6559"	568.313	0.0074	0.0000548	0.0145040	0.0001073	525.700	0.016	0.000256	0.031360	0.000502
CS26	-27°32'52.2169"	151°50'24.2065"	587.315	0.0112	0.0001254	0.0219520	0.0002459	544.695	0.016	0.000256	0.031360	0.000502
CS27	-27°32'33.9362"	151°50'19.4199"	560.579	0.0137	0.0001877	0.0268520	0.0003679	517.948	0.015	0.000225	0.029400	0.000441
CS28	-27°32'26.5307"	151°50'31.2571"	554.736	0.0147	0.0002161	0.0288120	0.0004235	512.094	0.015	0.000225	0.029400	0.000441
CS29	-27°32'34.0311"	151°50'42.3246"	567.686	0.0148	0.0002190	0.0290080	0.0004293	525.058	0.015	0.000225	0.029400	0.000441
CS30	-27°32'18.8114"	151°50'44.8713"	554.077	0.0142	0.0002016	0.0278320	0.0003952	511.415	0.015	0.000225	0.029400	0.000441

	(GDA94)	(GDA94)	(GDA94)			95% C.I.	95% C.I.	(AHDD)			95% C.I.	95% C.I.
Stn	ϕ	λ	h	σ_h	σ_h^2	(σ_h x 1.96)	(σ_h^2 x 1.96)	H	σ_H	σ_H^2	(σ_H x 1.96)	(σ_H^2 x 1.96)
CS31	-27°32'04.0115"	151°50'46.6593"	541.540	0.0127	0.0001613	0.0248920	0.0003161	498.879	0.015	0.000225	0.029400	0.000441
CS32	-27°32'02.7790"	151°51'02.4241"	539.921	0.0100	0.0001000	0.0196000	0.0001960	497.244	0.015	0.000225	0.029400	0.000441
CS33	-27°31'53.3131"	151°51'18.8946"	538.979	0.0072	0.0000518	0.0141120	0.0001016	496.288	0.015	0.000225	0.029400	0.000441
CS34	-27°31'43.8138"	151°51'32.6810"	553.275	0.0114	0.0001300	0.0223440	0.0002547	510.566	0.014	0.000196	0.027440	0.000384
CS35	-27°31'26.2001"	151°51'38.7873"	559.255	0.0137	0.0001877	0.0268520	0.0003679	516.525	0.014	0.000196	0.027440	0.000384
CS36	-27°31'07.6930"	151°51'53.2994"	554.574	0.0151	0.0002280	0.0295960	0.0004469	511.823	0.014	0.000196	0.027440	0.000384
CS37	-27°30'52.2520"	151°52'01.6294"	553.818	0.0153	0.0002341	0.0299880	0.0004588	511.059	0.014	0.000196	0.027440	0.000384
CS38	-27°30'37.4246"	151°52'17.0749"	549.612	0.0145	0.0002103	0.0284200	0.0004121	506.835	0.013	0.000169	0.025480	0.000331
CS39	-27°30'34.3088"	151°52'33.6732"	555.118	0.0131	0.0001716	0.0256760	0.0003364	512.325	0.013	0.000169	0.025480	0.000331
CS40	-27°30'37.2142"	151°52'53.5679"	565.926	0.0100	0.0001000	0.0196000	0.0001960	523.120	0.013	0.000169	0.025480	0.000331
CS41	-27°30'39.5126"	151°53'09.7177"	554.345	0.0131	0.0001716	0.0256760	0.0003364	511.529	0.013	0.000169	0.025480	0.000331
CS42	-27°30'44.5909"	151°53'34.7582"	581.761	0.0144	0.0002074	0.0282240	0.0004064	538.936	0.013	0.000169	0.025480	0.000331
CS43	-27°30'39.5906"	151°53'59.4638"	568.023	0.0144	0.0002074	0.0282240	0.0004064	525.181	0.012	0.000144	0.023520	0.000282
CS44	-27°30'30.2789"	151°54'15.9270"	551.634	0.0132	0.0001742	0.0258720	0.0003415	508.790	0.012	0.000144	0.023520	0.000282
CS45	-27°32'08.5462"	151°54'22.6587"	665.982	0.0145	0.0002103	0.0284200	0.0004121	623.169	0.012	0.000144	0.023520	0.000282
CS46	-27°31'57.4408"	151°54'21.9303"	656.397	0.0159	0.0002528	0.0311640	0.0004955	613.581	0.012	0.000144	0.023520	0.000282
CS47	-27°31'37.7046"	151°54'25.7897"	611.819	0.0169	0.0002856	0.0331240	0.0005598	569.004	0.012	0.000144	0.023520	0.000282
CS48	-27°31'25.6373"	151°54'28.0552"	593.313	0.0171	0.0002924	0.0335160	0.0005731	550.497	0.012	0.000144	0.023520	0.000282
CS49	-27°31'11.0089"	151°54'30.5164"	584.240	0.0168	0.0002822	0.0329280	0.0005532	541.416	0.012	0.000144	0.023520	0.000282
CS50	-27°30'55.6052"	151°54'33.5103"	579.006	0.0159	0.0002528	0.0311640	0.0004955	536.180	0.012	0.000144	0.023520	0.000282
CS51	-27°30'39.0652"	151°54'35.7330"	563.208	0.0139	0.0001932	0.0272440	0.0003787	520.369	0.012	0.000144	0.023520	0.000282
CS52	-27°30'22.0670"	151°54'35.1341"	574.242	0.0104	0.0001082	0.0203840	0.0002120	531.376	0.012	0.000144	0.023520	0.000282
CS53	-27°29'58.9601"	151°54'37.5365"	560.749	0.0153	0.0002341	0.0299880	0.0004588	517.876	0.012	0.000144	0.023520	0.000282
CS54	-27°29'42.4343"	151°54'39.9677"	548.381	0.0165	0.0002723	0.0323400	0.0005336	505.504	0.012	0.000144	0.023520	0.000282
CS55	-27°29'15.5903"	151°54'34.3363"	546.157	0.0168	0.0002822	0.0329280	0.0005532	503.260	0.012	0.000144	0.023520	0.000282
CS56	-27°28'57.6956"	151°54'35.3756"	568.855	0.0159	0.0002528	0.0311640	0.0004955	525.944	0.011	0.000121	0.021560	0.000237
CS57	-27°30'31.2947"	151°54'59.4873"	633.631	0.0137	0.0001877	0.0268520	0.0003679	590.766	0.011	0.000121	0.021560	0.000237
CS58	-27°30'32.9978"	151°55'23.7233"	593.558	0.0153	0.0002341	0.0299880	0.0004588	550.717	0.011	0.000121	0.021560	0.000237
CS59	-27°30'38.4366"	151°55'42.4263"	598.818	0.0156	0.0002434	0.0305760	0.0004770	555.967	0.011	0.000121	0.021560	0.000237
CS60	-27°30'39.5227"	151°55'50.6836"	590.303	0.0153	0.0002341	0.0299880	0.0004588	547.462	0.011	0.000121	0.021560	0.000237
CS61	-27°30'44.8118"	151°56'09.9519"	573.502	0.0139	0.0001932	0.0272440	0.0003787	530.680	0.011	0.000121	0.021560	0.000237
CS62	-27°30'58.7015"	151°56'29.2737"	595.020	0.0105	0.0001103	0.0205800	0.0002161	552.162	0.010	0.000100	0.019600	0.000196
CS63	-27°32'44.8222"	151°56'49.9736"	623.627	0.0154	0.0002372	0.0301840	0.0004648	580.859	0.010	0.000100	0.019600	0.000196
CS64	-27°32'25.1688"	151°56'39.2697"	615.536	0.0164	0.0002690	0.0321440	0.0005272	572.755	0.010	0.000100	0.019600	0.000196
CS65	-27°32'06.3627"	151°56'41.1770"	621.873	0.0162	0.0002624	0.0317520	0.0005144	579.070	0.010	0.000100	0.019600	0.000196
CS66	-27°31'40.8491"	151°56'36.6400"	611.186	0.0144	0.0002074	0.0282240	0.0004064	568.367	0.010	0.000100	0.019600	0.000196

	(GDA94)	(GDA94)	(GDA94)			95% C.I.	95% C.I.	(AHDD)			95% C.I.	95% C.I.
Stn	ϕ	λ	***h***	σ_h	σ_h^2	(σ_h x 1.96)	(σ_h^2 x 1.96)	**H**	σ_H	σ_H^2	(σ_H x 1.96)	(σ_H^2 x 1.96)
CS68	-27°31'07.1520"	151°56'44.5534"	606.112	0.0111	0.0001232	0.0217560	0.0002415	563.248	0.010	0.000100	0.019600	0.000196
CS69	-27°31'14.1902"	151°56'55.6876"	614.671	0.0109	0.0001188	0.0213640	0.0002329	571.819	0.010	0.000100	0.019600	0.000196
CS70	-27°31'11.4855"	151°57'15.5191"	671.932	0.0079	0.0000624	0.0154840	0.0001223	629.061	0.017	0.000289	0.033320	0.000566
CS71	-27°30'13.3759"	151°54'34.8327"	579.565	0.0132	0.0001742	0.0258720	0.0003415	536.698	0.017	0.000289	0.033320	0.000566
CS72	-27°31'02.4479"	151°57'21.4756"	633.456	0.0094	0.0000884	0.0184240	0.0001732	590.573	0.017	0.000289	0.033320	0.000566
CS73	-27°30'47.0741"	151°57'29.2206"	616.653	0.0100	0.0001000	0.0196000	0.0001960	573.786	0.016	0.000256	0.031360	0.000502
CS74	-27°30'41.1296"	151°57'48.5454"	617.758	0.0112	0.0001254	0.0219520	0.0002459	574.899	0.016	0.000256	0.031360	0.000502
CS75	-27°30'36.5345"	151°58'05.5310"	507.871	0.0094	0.0000884	0.0184240	0.0001732	465.025	0.016	0.000256	0.031360	0.000502
CS76	-27°30'15.6269"	151°58'17.0374"	520.127	0.0094	0.0000884	0.0184240	0.0001732	477.286	0.015	0.000225	0.029400	0.000441
CS77	-27°30'07.1644"	151°58'28.3748"	443.718	0.0098	0.0000960	0.0192080	0.0001882	400.885	0.015	0.000225	0.029400	0.000441
CS78	-27°29'58.0960"	151°58'34.3487"	486.845	0.0112	0.0001254	0.0219520	0.0002459	443.974	0.014	0.000196	0.027440	0.000384
CS79	-27°30'02.0921"	151°58'50.5561"	420.610	0.0103	0.0001061	0.0201880	0.0002079	377.768	0.014	0.000196	0.027440	0.000384
CS80	-27°30'13.6532"	151°59'10.5131"	471.535	0.0137	0.0001877	0.0268520	0.0003679	428.700	0.014	0.000196	0.027440	0.000384
CS81	-27°30'28.4653"	151°59'22.0126"	499.326	0.0151	0.0002280	0.0295960	0.0004469	456.505	0.014	0.000196	0.027440	0.000384
CS82	-27°30'46.3248"	151°59'22.6118"	455.558	0.0154	0.0002372	0.0301840	0.0004648	412.763	0.013	0.000169	0.025480	0.000331
CS83	-27°30'55.5731"	151°59'32.8562"	477.992	0.0147	0.0002161	0.0288120	0.0004235	435.232	0.013	0.000169	0.025480	0.000331
CS84	-27°30'59.8175"	151°59'54.5741"	371.128	0.0126	0.0001588	0.0246960	0.0003112	328.383	0.012	0.000144	0.023520	0.000282
CS85	-27°30'53.4880"	152°00'10.2399"	436.019	0.0143	0.0002045	0.0280280	0.0004008	393.234	0.012	0.000144	0.023520	0.000282
CS86	-27°30'58.2684"	152°00'26.9202"	392.872	0.0147	0.0002161	0.0288120	0.0004235	350.143	0.011	0.000121	0.021560	0.000237
CS87	-27°30'56.2399"	152°00'46.4687"	392.959	0.0140	0.0001960	0.0274400	0.0003842	350.244	0.011	0.000121	0.021560	0.000237
CS88	-27°31'01.6480"	152°01'03.3968"	358.981	0.0124	0.0001538	0.0243040	0.0003014	316.291	0.011	0.000121	0.021560	0.000237
CS89	-27°31'00.8103"	152°01'23.1105"	307.329	0.0130	0.0001690	0.0254800	0.0003312	264.660	0.010	0.000100	0.019600	0.000196
CS90	-27°30'56.8137"	152°01'40.0326"	282.615	0.0117	0.0001369	0.0229320	0.0002683	239.948	0.010	0.000100	0.019600	0.000196
CS91	-27°30'55.1646"	152°01'58.4615"	286.888	0.0123	0.0001513	0.0241080	0.0002965	244.212	0.010	0.000100	0.019600	0.000196
CS92	-27°30'51.3116"	152°02'13.0933"	300.526	0.0116	0.0001346	0.0227360	0.0002637	257.844	0.010	0.000100	0.019600	0.000196
CS93	-27°30'47.3381"	152°02'22.2957"	356.656	0.0134	0.0001796	0.0262640	0.0003519	313.957	0.010	0.000100	0.019600	0.000196
CS94	-27°30'46.8603"	152°02'40.5010"	305.454	0.0146	0.0002132	0.0286160	0.0004178	262.733	0.009	0.000081	0.017640	0.000159
CS95	-27°30'59.5517"	152°03'01.9373"	279.268	0.0147	0.0002161	0.0288120	0.0004235	236.748	0.009	0.000081	0.017640	0.000159
CS96	-27°31'11.3637"	152°03'12.9487"	306.704	0.0136	0.0001850	0.0266560	0.0003625	264.149	0.009	0.000081	0.017640	0.000159
CS97	-27°31'16.9521"	152°03'29.7463"	273.736	0.0110	0.0001210	0.0215600	0.0002372	231.189	0.008	0.000064	0.015680	0.000125
CS98	-27°31'22.6710"	152°03'45.5413"	253.166	0.0126	0.0001588	0.0246960	0.0003112	210.632	0.008	0.000064	0.015680	0.000125
CS99	-27°31'31.7738"	152°04'00.4854"	248.536	0.0132	0.0001742	0.0258720	0.0003415	206.006	0.007	0.000049	0.013720	0.000096
CS100	-27°31'41.1558"	152°04'13.8580"	244.063	0.0124	0.0001538	0.0243040	0.0003014	201.542	0.007	0.000049	0.013720	0.000096
CS101	-27°31'56.2560"	152°04'26.5645"	217.212	0.0094	0.0000884	0.0184240	0.0001732	174.708	0.007	0.000049	0.013720	0.000096
CS102	-27°32'09.0671"	152°04'33.0801"	215.398	0.0122	0.0001488	0.0239120	0.0002917	172.919	0.007	0.000049	0.013720	0.000096
CS103	-27°32'25.4512"	152°04'38.9416"	218.008	0.0133	0.0001769	0.0260680	0.0003467	175.525	0.006	0.000036	0.011760	0.000071

	(GDA94)	(GDA94)	(GDA94)			95% C.I.	95% C.I.	(AHDD)			95% C.I.	95% C.I.
Stn	ϕ	λ	***h***	σ_h	σ_h^2	**(σ_h x 1.96)**	**(σ_h^2 x 1.96)**	**H**	σ_H	σ_H^2	**(σ_H x 1.96)**	**(σ_H^2 x 1.96)**
CS104	-27°32'39.0469"	152°04'48.2614"	218.750	0.0128	0.0001638	0.0250880	0.0003211	176.291	0.006	0.000036	0.011760	0.000071
CS105	-27°32'48.4139"	152°05'05.5583"	203.158	0.0107	0.0001145	0.0209720	0.0002244	160.728	0.004	0.000016	0.007840	0.000031
CS106	-27°32'52.7006"	152°05'27.7184"	212.717	0.0124	0.0001538	0.0243040	0.0003014	170.307	0.001	0.000001	0.001960	0.000002
CS107	-27°32'49.8069"	152°05'48.0136"	195.653	0.0123	0.0001513	0.0241080	0.0002965	153.273	-0.002	0.000004	-0.003920	0.000008
CS108	-27°32'51.1624"	152°06'03.3038"	191.590	0.0137	0.0001877	0.0268520	0.0003679	149.204	0.000	0.000000	0.000000	0.000000
PM35751	-27°30'34.7743"	151°57'18.4195"	751.101	0.0076	0.0000578	0.0148960	0.0001132	708.203	0.014	0.000182	0.026460	0.000357
PM40970	-27°30'36.6897"	152°02'03.5264"	466.669	0.0125	0.0001563	0.0245000	0.0003063	423.956	0.010	0.000100	0.019600	0.000196
PM66947	-27°32'36.4499"	152°03'05.2715"	253.129	0.0147	0.0002161	0.0288120	0.0004235	210.615	0.010	0.000100	0.019600	0.000196
PM85731	-27°30'38.4820"	152°04'13.8654"	213.646	0.0140	0.0001960	0.0274400	0.0003842	170.998	0.010	0.000100	0.019600	0.000196
PM68101	-27°33'12.5407"	152°01'26.8412"	304.223	0.0186	0.0003460	0.0364560	0.0006781	261.665	0.010	0.000100	0.019600	0.000196
PM51843	-27°33'11.5512"	151°52'33.1649"	693.476	0.0155	0.0002403	0.0303800	0.0004709	650.640	0.010	0.000100	0.019600	0.000196
PM57526	-27°31'09.5767"	152°00'02.2281"	335.771	0.0282	0.0007952	0.0552720	0.0015587	293.062	0.012	0.000144	0.023520	0.000282
PM112793	-27°28'10.5208"	151°58'47.8521"	448.507	0.0192	0.0003686	0.0376320	0.0007225	405.571	0.010	0.000100	0.019600	0.000196
PM112799	-27°36'30.0339"	151°51'12.7222"	586.242	0.0204	0.0004162	0.0399840	0.0008157	543.758	0.010	0.000100	0.019600	0.000196

Mean σ_h	Mean σ_h^2	Mean σ_h x 1.96	Mean σ_h^2 x 1.96
0.0134	0.0001888	0.0262	0.0003701

Mean σ_H	Mean σ_H^2	Mean σ_H x 1.96	Mean σ_H^2 x 1.96
0.0127	0.0001781	0.0249	0.0003491

	(h - H)			95% C.I.	95% C.I.
Stn	**N_{CTRL}**	**σ_N**	**σ_N^2**	**(σ_N x 1.96)**	**(σ_N^2 x 1.96)**
CS01	42.335	0.0229	0.0005254	0.044928	0.0010299
CS02	42.370	0.0233	0.0005416	0.045614	0.0010616
CS03	42.361	0.0216	0.0004671	0.042360	0.0009155
CS04	42.346	0.0198	0.0003924	0.038824	0.0007690
CS05	42.551	0.0216	0.0004671	0.042360	0.0009155
CS06	42.362	0.0226	0.0005123	0.044362	0.0010041
CS07	42.368	0.0225	0.0005074	0.044150	0.0009945
CS08	42.383	0.0215	0.0004630	0.042175	0.0009075
CS09	42.384	0.0189	0.0003565	0.037007	0.0006987
CS10	42.403	0.0211	0.0004472	0.041449	0.0008765
CS11	42.350	0.0224	0.0005036	0.043983	0.0009870
CS12	42.427	0.0235	0.0005520	0.046050	0.0010819
CS13	42.442	0.0240	0.0005768	0.047073	0.0011305
CS14	42.452	0.0233	0.0005418	0.045623	0.0010619
CS15	42.474	0.0228	0.0005200	0.044697	0.0010193
CS16	42.482	0.0240	0.0005780	0.047122	0.0011329
CS17	42.507	0.0246	0.0006058	0.048243	0.0011874
CS18	42.530	0.0248	0.0006166	0.048670	0.0012086
CS19	42.542	0.0247	0.0006094	0.048385	0.0011944
CS20	42.548	0.0232	0.0005382	0.045472	0.0010550
CS21	42.561	0.0220	0.0004840	0.043120	0.0009487
CS22	42.586	0.0202	0.0004098	0.039675	0.0008031
CS23	42.595	0.0202	0.0004073	0.039556	0.0007983
CS24	42.607	0.0194	0.0003748	0.037946	0.0007346
CS25	42.613	0.0176	0.0003108	0.034552	0.0006091
CS26	42.620	0.0195	0.0003814	0.038280	0.0007476
CS27	42.631	0.0203	0.0004127	0.039817	0.0008089
CS28	42.642	0.0210	0.0004411	0.041164	0.0008645
CS29	42.628	0.0211	0.0004440	0.041302	0.0008703
CS30	42.662	0.0207	0.0004266	0.040484	0.0008362

	(h - H)			95% C.I.	95% C.I.
Stn	**N_{CTRL}**	**σ_N**	**σ_N^2**	**(σ_N x 1.96)**	**(σ_N^2 x 1.96)**
CS31	42.661	0.0197	0.0003863	0.038522	0.0007571
CS32	42.677	0.0180	0.0003250	0.035334	0.0006370
CS33	42.691	0.0166	0.0002768	0.032611	0.0005426
CS34	42.709	0.0181	0.0003260	0.035387	0.0006389
CS35	42.730	0.0196	0.0003837	0.038392	0.0007520
CS36	42.751	0.0206	0.0004240	0.040359	0.0008311
CS37	42.759	0.0207	0.0004301	0.040648	0.0008430
CS38	42.777	0.0195	0.0003793	0.038170	0.0007433
CS39	42.793	0.0185	0.0003406	0.036173	0.0006676
CS40	42.806	0.0164	0.0002690	0.032146	0.0005272
CS41	42.816	0.0185	0.0003406	0.036173	0.0006676
CS42	42.825	0.0194	0.0003764	0.038024	0.0007377
CS43	42.842	0.0187	0.0003514	0.036739	0.0006887
CS44	42.844	0.0178	0.0003182	0.034965	0.0006238
CS45	42.813	0.0188	0.0003543	0.036890	0.0006943
CS46	42.816	0.0199	0.0003968	0.039043	0.0007777
CS47	42.815	0.0207	0.0004296	0.040625	0.0008420
CS48	42.816	0.0209	0.0004364	0.040945	0.0008554
CS49	42.824	0.0206	0.0004262	0.040465	0.0008354
CS50	42.826	0.0199	0.0003968	0.039043	0.0007777
CS51	42.839	0.0184	0.0003372	0.035992	0.0006609
CS52	42.866	0.0159	0.0002522	0.031124	0.0004942
CS53	42.873	0.0194	0.0003781	0.038111	0.0007411
CS54	42.877	0.0204	0.0004163	0.039988	0.0008159
CS55	42.897	0.0206	0.0004262	0.040465	0.0008354
CS56	42.911	0.0193	0.0003738	0.037895	0.0007327
CS57	42.865	0.0176	0.0003087	0.034436	0.0006050
CS58	42.841	0.0188	0.0003551	0.036934	0.0006960
CS59	42.851	0.0191	0.0003644	0.037413	0.0007141
CS60	42.841	0.0188	0.0003551	0.036934	0.0006960
CS61	42.822	0.0177	0.0003142	0.034743	0.0006159
CS62	42.858	0.0145	0.0002103	0.028420	0.0004121
CS63	42.768	0.0184	0.0003372	0.035989	0.0006608
CS64	42.781	0.0192	0.0003690	0.037648	0.0007232
CS65	42.803	0.0190	0.0003624	0.037314	0.0007104
CS66	42.819	0.0175	0.0003074	0.034362	0.0006024

Stn	(h - H) N_{CTRL}	σ_N	σ_N^2	95% C.I. (σ_N x 1.96)	95% C.I. (σ_N^2 x 1.96)
CS68	42.864	0.0149	0.0002232	0.029283	0.0004375
CS69	42.852	0.0148	0.0002188	0.028993	0.0004289
CS70	42.871	0.0187	0.0003514	0.036742	0.0006888
CS71	42.867	0.0215	0.0004632	0.042185	0.0009080
CS72	42.883	0.0194	0.0003774	0.038074	0.0007396
CS73	42.867	0.0189	0.0003560	0.036981	0.0006978
CS74	42.859	0.0195	0.0003814	0.038280	0.0007476
CS75	42.846	0.0186	0.0003444	0.036372	0.0006749
CS76	42.841	0.0177	0.0003134	0.034696	0.0006142
CS77	42.833	0.0179	0.0003210	0.035118	0.0006292
CS78	42.871	0.0179	0.0003214	0.035140	0.0006300
CS79	42.842	0.0174	0.0003021	0.034066	0.0005921
CS80	42.835	0.0196	0.0003837	0.038392	0.0007520
CS81	42.821	0.0206	0.0004240	0.040359	0.0008311
CS82	42.795	0.0202	0.0004062	0.039501	0.0007961
CS83	42.760	0.0196	0.0003851	0.038462	0.0007548
CS84	42.745	0.0174	0.0003028	0.034104	0.0005934
CS85	42.785	0.0187	0.0003485	0.036589	0.0006830
CS86	42.729	0.0184	0.0003371	0.035986	0.0006607
CS87	42.715	0.0178	0.0003170	0.034897	0.0006213
CS88	42.690	0.0166	0.0002748	0.032489	0.0005385
CS89	42.669	0.0164	0.0002690	0.032146	0.0005272
CS90	42.667	0.0154	0.0002369	0.030167	0.0004643
CS91	42.676	0.0159	0.0002513	0.031070	0.0004925
CS92	42.682	0.0153	0.0002346	0.030018	0.0004597
CS93	42.699	0.0167	0.0002796	0.032771	0.0005479
CS94	42.721	0.0172	0.0002942	0.033616	0.0005766
CS95	42.520	0.0172	0.0002971	0.033783	0.0005823
CS96	42.555	0.0163	0.0002660	0.031964	0.0005213
CS97	42.547	0.0136	0.0001850	0.026659	0.0003626
CS98	42.534	0.0149	0.0002228	0.029253	0.0004366
CS99	42.530	0.0149	0.0002232	0.029285	0.0004376
CS100	42.521	0.0142	0.0002028	0.027909	0.0003974
CS101	42.504	0.0117	0.0001374	0.022971	0.0002692
CS102	42.479	0.0141	0.0001978	0.027568	0.0003878
CS103	42.483	0.0146	0.0002129	0.028598	0.0004173

	(h - H)			95% C.I.	95% C.I.
Stn	**N_{CTRL}**	**σ_N**	**σ_N^2**	**(σ_N x 1.96)**	**(σ_N^2 x 1.96)**
CS104	42.459	0.0141	0.0001998	0.027707	0.0003917
CS105	42.430	0.0114	0.0001305	0.022390	0.0002558
CS106	42.410	0.0124	0.0001548	0.024383	0.0003033
CS107	42.380	0.0125	0.0001553	0.024425	0.0003044
CS108	42.386	0.0137	0.0001877	0.026852	0.0003679
PM35751	42.898	0.0155	0.0002400	0.030365	0.0004704
PM40970	42.713	0.0160	0.0002563	0.031375	0.0005023
PM66947	42.514	0.0178	0.0003161	0.034847	0.0006195
PM85731	42.648	0.0172	0.0002960	0.033721	0.0005802
PM68101	42.558	0.0211	0.0004460	0.041391	0.0008741
PM51843	42.836	0.0184	0.0003403	0.036154	0.0006669
PM57526	42.709	0.0306	0.0009392	0.060068	0.0018409
PM112793	42.936	0.0216	0.0004686	0.042430	0.0009185
PM112799	42.484	0.0227	0.0005162	0.044530	0.0010117

Mean σ_N	Mean σ_N^2	Mean σ_N x 1.96	Mean σ_N^2 x 1.96
0.0189	0.0003669	0.0371	0.0007191

APPENDIX F

TOOWOOMBA BYPASS APPENDED LEVEL TRAVERSE AND CORRELATION ADJUSTMENT

MARKS	Run 1 Obs Height	Run 2 Obs Height	Calc Chain	Run 1 Calc Height	Run 2 Calc Height	Mean Calc Height	Diff	Correl. AHD	Corrn.	AHD	Remarks	Comments
PSM 66951	149.204	149.204	0	1000.000	1000.000	1000.000	-850.796	149.204	0.000	149.204	AHD 3rd Order NLN92	CS108 = 21K BM
PSM 27388	149.519	148.518	55	1000.315	1000.315	1000.315		149.519	-0.004	149.515	AHD 3rd Order NLN92	Brass Plug on Culvert
TBM 1	152.553	152.553	361	1003.349	1003.349	1003.349		152.553	-0.002	152.551		4_TBM 1 Bolt on Street Light
CS 107	153.275	153.275	446	1004.070	1004.072	1004.071		153.275	-0.002	153.273		5_Control Station 107
CS 105	160.720	160.722	1665	1011.520	1011.520	1011.520		160.724	0.004	160.728		5_Control Station 105
PSM 61102	170.764	170.763	1945	1021.563	1021.560	1021.562		170.766	0.006	170.771	AHD 3rd Order NLN92	4_PSM 61102 - Deep Driven Rod
CS 104	176.283	176.283	2198	1027.082	1027.080	1027.081		176.285	0.006	176.291		1_Control Station 104
CS 103	175.517	175.517	2873	1026.315	1026.315	1026.315		175.519	0.006	175.525		1_Control Station 103
PSM 78327	168.462	168.474	3988	1019.259	1019.271	1019.265		168.469	0.006	168.475		Brass Plug on Culvert
PSM 91199	171.929	171.941	4456	1022.726	1022.737	1022.732		171.936	0.007	171.942		Brass Plug on Culvert
PCM 7329		172.965	4523		1025.590	1025.585		174.789	0.007	174.796		1_PhotoControlMark 7329
CS 101	174.708	174.708	4831	1025.492	1025.503	1025.498		174.702	0.007	174.708		1_Control Station 101
PCM 7328A	176.916		5147	1029.468		1029.474		178.678	0.007	178.685		1_PhotoControlMark 7328A
CS 100		201.539	5423		1052.337	1052.331		201.535	0.007	201.542		1_Control Station 100
PSM 68695	180.435		5668	1031.218		1031.225		180.429	0.007	180.436		9_PSM 68695
CS 99		205.995	5919		1056.802	1056.795		205.999	0.007	206.006		1_Control Station 99
PSM 88832	185.487		6364	1036.272		1036.279		185.483	0.008	185.491	= 185.502 AHDD No Order SCDB	= 3K BM
PCM 7324	195.538		6584	1049.268		1049.276		198.480	0.008	198.488		2_PhotoControlMark 7324
CS 98	210.626	210.619	7282	1061.412	1061.428	1061.420		210.624	0.008	210.632		35_Control Station 98
CS 97	231.176	231.183	7769	1081.968	1081.986	1081.977		231.181	0.008	231.189		1_Control Station 97
CS 96	264.136	264.144	8312	1114.930	1114.943	1114.937		264.141	0.009	264.149		1_Control Station 96
TBM 2	264.369	264.376	8807	1115.161	1115.175	1115.168		264.372	0.009	264.381		9_TBM Nail in Stump 2
TBM 3	273.676	273.684	9160	1124.470	1124.482	1124.476		273.680	0.009	273.689		17_TBM Nail in Stump3
TBM 4	265.804	265.810	9505	1116.599	1116.607	1116.603		265.807	0.009	265.816		24_TBM Nail in Stump4
TBM 6	294.780		9827	1145.575		1145.580		294.784	0.009	294.793		35_TBM Nail in Stump6
TBM 7	316.064		10216	1166.861		1166.868		316.072	0.009	316.081		48_TBM Bolt in Tower7
TBM 5		260.864	10331		1111.660	1111.651		260.855	0.010	260.865		
CS 92	257.822		10585	1108.619		1108.630		257.834	0.010	257.844		19_Bench Mark 92
CS 91	244.189	244.216	11012	1094.986	1095.010	1094.998		244.202	0.010	244.212		25_Bench Mark 91

MARKS	Run 1 Obs Height	Run 2 Obs Height	Calc Chain	Run 1 Calc Height	Run 2 Calc Height	Mean Calc Height	Diff	Correl. AHD	Corrn.	AHD	Remarks	Comments
CS 90	239.953	239.931	11604	1090.723	1090.745	1090.734		239.938	0.010	239.948		3_Control Station 90
CS 89	264.667	264.639	12235	1115.436	1115.454	1115.445		264.649	0.010	264.660		12_Control Station 89
CS 88	316.300	316.267	13081	1167.069	1167.084	1167.077		316.281	0.011	316.291		19_Control Station 88
CS 87	350.252	350.216	13668	1201.021	1201.037	1201.029		350.233	0.011	350.244		13_Control Station 87
CS 86	350.149	350.113	14334	1200.918	1200.937	1200.928		350.132	0.011	350.143		12_Control Station 86
CS 84	328.358	328.386	15820	1179.159	1179.175	1179.167		328.371	0.012	328.383		1_Control Station 84
PCM 7304	299.860		16073	1152.665		1152.674		301.878	0.012	301.890		1_PhotoControlMark 7304
PSM 57526	293.074	293.071	16231	1143.874	1143.894	1143.884		293.088	0.012	293.100	= 293.062 AHDD No Order SCDB	Brass Plug
TBM 8		369.648	16743		1220.472	1220.460		369.664	0.013	369.677		
TBM 9	436.744	437.712	17079	1287.513	1287.538	1287.525		436.729	0.013	436.742		21_TBM Nail in Tree 9
PCM 7303	450.235	450.207	17241	1301.003	1301.027	1301.015		450.219	0.013	450.232		7_PhotoControlMark 7303
CS 83	435.234	435.207	17396	1286.003	1286.027	1286.015		435.219	0.013	435.232		12_Control Station 83
CS 82	412.766	412.738	17851	1263.534	1263.558	1263.546		412.750	0.013	412.763		10_Control Station 82
PCM 7301	471.543	471.516	18637	1322.312	1322.339	1322.326		471.530	0.013	471.543		27_PhotoControlMark 7301
CS 81	456.506	456.478	18807	1307.275	1307.301	1307.288		456.492	0.014	456.505		32_Control Station 81
CS 80	428.700	428.675	19417	1279.469	1279.496	1279.482		428.686	0.014	428.700		33_Control Station 80
CS 78	443.949	443.970	20644	1294.740	1294.771	1294.756		443.960	0.014	443.974		1_Control Station 78
PCM 7282	390.287	390.296	21107	1241.072	1241.096	1241.084		390.288	0.015	390.303		28_PhotoControlMark 7282
CS 76	477.262		21743	1328.048		1328.067		477.271	0.015	477.286		1_Control Station 76
PCM 7278	464.459	464.472	22277	1315.806	1315.858	1315.832		465.036	0.015	465.051		1_PhotoControlMark 7278
TBM 10	523.495	523.508	22754	1374.284	1374.308	1374.296		523.500	0.015	523.515		1_TBM Nail in Tree 10
PCM 7261	570.130	570.149	22875	1422.033	1422.090	1422.061		571.265	0.016	571.281		1_PhotoControlMark 7261
TBM 11	575.811	575.820	22985	1426.590	1426.621	1426.605		575.809	0.016	575.825		12_TBM Nail in Tree 11
CS 74	574.884	574.894	23644	1425.663	1425.695	1425.679		574.883	0.016	574.899		1_Control Station 74
CS 73	573.762	573.782	24443	1424.549	1424.583	1424.566		573.770	0.016	573.786		1_Control Station 73
CS 611	576.066	576.087	24557	1426.855	1426.888	1426.872		576.076	0.016	576.092		12_Control Station 611
CS 72	590.546	590.568	25172	1441.335	1441.369	1441.352		590.556	0.017	590.573		1_Control Station 72
CS 70	629.057	529.051	26081	1479.824	1479.855	1479.840		629.044	0.017	629.061		1_Control Station 70
PSM 1206	627.149	627.149	26989	1477.901	1477.932	1477.917		627.121	0.017	627.138	AHD 3rd Order NLN92	1_PSM 1206

MARKS	Run 1 Obs Height	Run 2 Obs Height	Calc Chain	Run 1 Calc Height	Run 2 Calc Height	Mean Calc Height	Diff	Correl. AHD	Corrn.	AHD	Remarks	Comments
PSM 14578	624.939	624.939	27125	1475.691	1475.721	1475.706		624.910	-0.004	624.906	AHD 3rd Order NLN92	3_PSM 14578
PSM 91267	618.173	618.173	27401	1468.926	1468.956	1468.941		618.145	-0.006	618.139		6_PSM 91267
PSM 11260	618.836	618.836	27509	1469.588	1469.619	1469.604		618.808	-0.007	618.801	AHD 3rd Order NLN92	7_PSM 11260
PSM 706	621.341	621.341	27670	1472.093	1472.124	1472.109		621.313	0.002	621.315	AHD 3rd Order NLN92	9_PSM 706
PSM 1218	622.083	622.083	27782	1472.835	1472.866	1472.851		622.055	-0.006	622.049	AHD 3rd Order NLN92	10_PSM 1218
PSM 14654	626.484	626.484	27929	1477.237	1477.267	1477.252		626.456	-0.002	626.454	AHD 3rd Order NLN92	12_PSM 14654
PSM 1218	622.077	622.077	28086	1472.836	1472.867	1472.852		622.056	-0.007	622.049	AHD 3rd Order NLN92	8_PSM 1218
PSM 706	621.336	621.336	28168	1472.095	1472.126	1472.111		621.315	0.000	621.315	AHD 3rd Order NLN92	7_PSM 706
PSM 605	618.833	618.833	28354	1469.592	1469.623	1469.608		618.812	-0.003	618.809		5_PSM 605
PSM 91267	618.169	618.169	28457	1468.928	1468.959	1468.944		618.148	-0.004	618.143		4_PSM 91267
PSM 14578	624.937	624.937	28772	1475.696	1475.727	1475.712		624.916	-0.010	624.906	AHD 3rd Order NLN92	1_PSM 14578
PSM 1206	627.150	627.150	28887	1477.909	1477.940	1477.925		627.129	0.009	627.138	AHD 3rd Order NLN92	_PSM 1206
CP	631.078	631.078	29700	1481.837	1481.868	1481.853		631.057	0.010	631.066		10_Change Point 7272A
BM 70-2	629.072		29803	1479.831	1479.862	1479.847		629.051	0.010	629.060		11_Bench Mark 70-2
CS 69	571.817	571.808	30757	1422.592	1422.617	1422.605		571.809	0.010	571.819		1_Control Station 69
CS 68	563.244	563.236	31147	1414.022	1414.046	1414.034		563.238	0.010	563.248		PSM 107019
PCM		559.371	31300		1411.899	1411.887		561.091	0.010	561.101		Photo Control Mark 5251
CS 62	552.157	552.157	31686	1402.934	1402.960	1402.947		552.151	0.010	552.162		18_Control Station 62
PCM 7247	545.083	545.078	32264	1395.860	1395.891	1395.876		545.080	0.011	545.090		12_PhotoControlMark 7247
CS 61	530.673	530.670	32490	1381.448	1381.482	1381.465		530.669	0.011	530.680		8_Control Station 61
Station Railway	539.720	539.718	33001	1390.495	1390.531	1390.513		539.717	0.011	539.728		18_Station Railw
CS 60	547.452	547.454	33167	1398.226	1398.268	1398.247		547.451	0.011	547.462		14_Control Station 60
CS 59	555.956	555.960	33421	1406.729	1406.774	1406.752		555.956	0.011	555.967		9_Control Station 59
CS 58	550.705	550.711	34013	1401.478	1401.525	1401.502		550.706	0.011	550.717		3_Control Station 58
CS 57	590.756	590.763	34850	1441.527	1441.574	1441.551		590.755	0.011	590.766		PSM 92640 Brass Plug
CS 52	531.368	531.371	35726	1382.139	1382.182	1382.161		531.365	0.012	531.376		6_Control Station 52
CS 51	520.360	520.362	36205	1371.132	1371.173	1371.153		520.357	0.012	520.369		26_Control Station 51
CS 43	525.172	525.173	37631	1375.946	1375.983	1375.965		525.169	0.012	525.181		12_Control Station 43
CS 42	538.933	538.927	38414	1389.700	1389.739	1389.720		538.924	0.013	538.936		1_Control Station 42

MARKS	Run 1 Obs Height	Run 2 Obs Height	Calc Chain	Run 1 Calc Height	Run 2 Calc Height	Mean Calc Height	Diff	Correl. AHD	Corrn.	AHD	Remarks	Comments
CS 41	511.523	511.517	39201	1362.293	1362.331	1362.312		511.516	0.013	511.529		17_Control Station 41
CS 40	523.113	523.107	39604	1373.883	1373.922	1373.903		523.107	0.013	523.120	= 523.095 AHDD 4th Order SCDB	PSM 112810
CS 39	512.318	512.314	40155	1363.088	1363.128	1363.108		512.312	0.013	512.325		7_Control Station 39
CS 38	506.826	506.823	40644	1357.596	1357.638	1357.617		506.821	0.013	506.835		8_Control Station 38
CS 37	511.052	511.050	41293	1361.822	1361.860	1361.841		511.045	0.014	511.059		10_Control Station 37
CS 36	511.816	511.812	41964	1362.586	1362.624	1362.605		511.809	0.014	511.823		1_Control Station 36
CS 35	516.516	516.515	42646	1367.287	1367.326	1367.307		516.511	0.014	516.525		17_Control Station 35
CS 33	496.281	496.277	43962	1347.050	1347.089	1347.070		496.274	0.015	496.288		6_Control Station 33
CS 32	497.237	497.234	44561	1348.006	1348.044	1348.025		497.229	0.015	497.244		8_Control Station 32
PCM	503.347		45049	1354.117		1354.137		503.341	0.015	503.356		4_PhotoControlMark
PCM 128	504.449		45119	1357.296		1357.317		506.521	0.015	506.536		1_PhotoControlMark 128, Int c, 7135
CS 30	511.405	511.407	45343	1362.174	1362.218	1362.196		511.400	0.015	511.415		9_Control Station 30
CS 28	512.088	512.084	45740	1362.855	1362.894	1362.875		512.079	0.015	512.094		5_Control Station 28
CS 27	517.940	517.937	46167	1368.709	1368.748	1368.729		517.933	0.015	517.948		10_Control Station 27
CS 25	525.694	525.689	46771	1376.463	1376.498	1376.481		525.685	0.016	525.700		5_Control Station 25
CS 23	522.070	522.067	47212	1372.839	1372.877	1372.858		522.062	0.016	522.078		52_Control Station 23
CS 22	534.884	534.878	47632	1385.653	1385.689	1385.671		534.875	0.016	534.891		47_Control Station 22
CS 21	527.141	527.154	48164	1377.911	1377.942	1377.927		527.131	0.016	527.147		42_Control Station 21
PCM	514.396		48644	1367.710		1367.727		516.931	0.016	516.947		1_PhotoControlMark Int c, 1010
CS 20	517.345	517.344	48753	1368.117	1368.153	1368.135		517.339	0.016	517.355		34_Control Station 20
CS 19	488.333	488.335	49412	1339.106	1339.143	1339.125		488.329	0.017	488.345		24_Control Station 19
CS 18	480.400	480.404	49800	1331.173	1331.212	1331.193		480.397	0.017	480.413		20_Control Station 18
CS 17	467.152	467.158	50280	1317.925	1317.967	1317.946		467.150	0.017	467.167		15_Control Station 17
CS 16	456.659	456.665	50826	1307.431	1307.475	1307.453		456.657	0.017	456.674		10_Control Station 16
CS 15	472.750	472.755	51477	1323.521	1323.563	1323.542		472.746	0.017	472.763		1_Control Station 15, 15
CS 14	448.859	448.865	52114	1299.633	1299.674	1299.654		448.858	0.017	448.875		22_Control Station 14
CS 13	462.948	462.953	52551	1313.722	1313.761	1313.742		462.946	0.018	462.963		17_Control Station 13
CS 12	458.883	458.887	53229	1309.657	1309.695	1309.676		458.880	0.018	458.898		11_Control Station 12
CS 11	469.739	469.744	53968	1320.513	1320.553	1320.533		469.737	0.018	469.755		5_Control Station 11

MARKS	Run 1 Obs Height	Run 2 Obs Height	Calc Chain	Run 1 Calc Height	Run 2 Calc Height	Mean Calc Height	Diff	Correl. AHD	Corrn.	AHD	Remarks	Comments
CS 10	475.165	475.167	54356	1325.938	1325.976	1325.957		475.161	0.018	475.179		1_Control Station 10, 10
CS 9	473.240	473.241	55086	1324.014	1324.049	1324.032		473.236	0.018	473.254		5_Control Station 9
CS 8	482.784	482.784	55563	1333.556	1333.591	1333.574		482.778	0.019	482.796		10_Control Station 8
CS 7	489.883	489.880	56101	1340.654	1340.686	1340.670		489.874	0.019	489.893		5_Control Station 7
CS 6	497.408	497.406	56474	1348.180	1348.211	1348.196		497.400	0.019	497.419		10_Control Station 6
CS 3	500.695	500.692	57579	1351.469	1351.499	1351.484		500.688	0.019	500.708		5_Control Station 3
CS 2	516.930	516.921	58144	1367.702	1367.729	1367.716		516.920	0.020	516.939		10_Control Station 2
CS 1	519.185	519.179	58702	1369.958	1369.985	1369.972		519.176	0.020	519.195		14_Control Station 1
BM 19K		18.357	59205		1386.138	1386.124		535.328	0.020	535.348		_Bench Mark 19K
PSM 71151	28.061	28.058	59948	1395.809	1395.839	1395.824		545.028	0.020	545.048	AHD 3rd Order NLN92	34_PSM 71151 Class C
BM20K		24.955	60178		1392.737	1391.723		540.927	0.020	540.947		_Bench Mark 20K
BM 21K	9.518	9.510	61199	1377.266	1377.291	1377.279		526.483	0.018	526.501		49_Bench Mark 21K
BM 22K	10.872	10.866	62199	1378.620	1378.647	1378.633		527.837	0.017	527.854		61_Bench Mark 22K
PSM 68804	13.952	13.945	63008	1381.700	1381.726	1381.713		530.917	0.015	530.932	= 530.907 AHDD No Order SCDB	70_PSM 68804
PSM 62571	1.676	1.665	65034	1369.424	1369.446	1369.435		518.639	0.012	518.651	AHD 3rd Order NLN92	90_PSM 62571
PSM 62171	9.821	9.808	66147	1377.569	1377.589	1377.579		526.783	0.006	526.789		101_PSM 62171
PSM 62569	36.156	36.144	66953	1403.904	1403.925	1403.915		553.119	0.001	553.120	AHD 3rd Order NLN92	111_PSM 62569
PSM		34.003	66995		1401.782	1401.772		550.976	0.000	550.976		PSM not identified
PSM 62573	44.384	44.367	67393	1412.132	1412.149	1412.140		561.344	-0.008	561.336	AHD 3rd Order NLN92	117_PSM 62573
PSM 53835	28.862	28.841	68188	1396.610	1396.622	1396.616		545.820	-0.014	545.806	AHD 3rd Order NLN92	125_PSM 53835

APPENDIX G

NUMERICAL RESULTS OF THE *ABSOLUTE* COMPARISONS OVER INCREASING AHD HEIGHT

LIST OF TABLES

Table G.1
Descriptive Statistics of the *Absolute* Differences between the GPS-AHDD Control Data and EGM96 over Increasing AHD Height

AHD Height [m]	*No. of points*	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*Outliers*
> 200	*107*	-0.808	-1.377	-1.138	0.109	1.143	1 (0.93%)
> 300	*93*	-0.981	-1.377	-1.172	0.062	1.173	3 (3.23%)
> 400	*86*	-0.988	-1.377	-1.183	0.049	1.184	3 (3.49%)
> 500	*57*	-1.159	-1.361	-1.200	0.030	1.200	1 (1.75%)
> 600	*5*	-1.218	-1.361	-1.260	0.059	1.261	0

Table G.2
Descriptive Statistics of the *Absolute* Differences between the GPS-AHDD Control Data and EIGEN2/EGM96 over Increasing AHD Height

AHD Height [m]	*No. of points*	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*Outliers*
> 200	*107*	-0.188	-0.753	-0.513	0.107	0.524	1 (0.93%)
> 300	*93*	-0.360	-0.753	-0.547	0.061	0.550	3 (3.23%)
> 400	*86*	-0.367	-0.753	-0.557	0.048	0.559	3 (3.49%)
> 500	*57*	-0.533	-0.736	-0.574	0.031	0.575	1 (1.75%)
> 600	*5*	-0.593	-0.736	-0.635	0.058	0.637	0

Table G.3
Descriptive Statistics of the *Absolute* Differences between the GPS-AHDD Control Data and UCPH2/EGM96 over Increasing AHD Height

AHD Height [m]	*No. of points*	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*Outliers*
> 200	*107*	-0.173	-0.736	-0.499	0.107	0.511	1 (0.93%)
> 300	*93*	-0.345	-0.736	-0.533	0.061	0.536	3 (3.23%)
> 400	*86*	-0.353	-0.736	-0.544	0.048	0.546	3 (3.49%)
> 500	*57*	-0.519	-0.722	-0.561	0.030	0.562	1 (1.75%)
> 600	*5*	-0.580	-0.722	-0.621	0.058	0.624	0

Table G.4
Descriptive Statistics of the *Absolute* Differences between the GPS-AHDD Control Data and PGM2000A over Increasing AHD Height

AHD Height [m]	*No. of points*	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*Outliers*
> 200	*107*	-0.138	-0.702	-0.464	0.107	0.476	1 (0.93%)
> 300	*93*	-0.310	-0.702	-0.498	0.061	0.502	3 (3.23%)
> 400	*86*	-0.317	-0.702	-0.509	0.048	0.511	3 (3.49%)
> 500	*57*	-0.484	-0.687	-0.526	0.030	0.527	1 (1.75%)
> 600	*5*	-0.545	-0.687	-0.586	0.058	0.589	0

Table G.5
Descriptive Statistics of the *Absolute* Differences between the GPS-AHDD Control Data and the SBA Technique (Bi-cubic Interpolation) over Increasing AHD Height

AHD Height [m]	*No. of points*	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*Outliers*
> 200	*107*	-2.038	-2.379	-2.176	0.038	2.176	3 (2.80%)
> 300	*93*	-2.114	-2.379	-2.183	0.032	2.184	2 (2.15%)
> 400	*86*	-2.114	-2.379	-2.185	0.033	2.185	2 (2.33%)
> 500	*57*	-2.145	-2.342	-2.187	0.028	2.187	1 (1.75%)
> 600	*5*	-2.216	-2.342	-2.245	0.055	2.245	0

Table G.6
Descriptive Statistics of the *Absolute* Differences between the GPS-AHDD Control Data and the RBA Technique (Bi-cubic Interpolation) over Increasing AHD Height

AHD Height [m]	*No. of points*	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*Outliers*
> 200	*107*	-2.103	-2.444	-2.240	0.038	2.240	3 (2.80%)
> 300	*93*	-2.178	-2.444	-2.247	0.032	2.247	2 (2.15%)
> 400	*86*	-2.178	-2.444	-2.249	0.033	2.249	2 (2.33%)
> 500	*57*	-2.208	-2.406	-2.251	0.028	2.251	1 (1.75%)
> 600	*5*	-2.280	-2.406	-2.308	0.055	2.309	0

Table G.7
Descriptive Statistics of the *Absolute* Differences between the GPS-AHDD Control Data and AUSGeoid93 (Bi-cubic Interpolation) over Increasing AHD Height

AHD Height [m]	*No. of points*	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*Outliers*
> 200	*107*	-0.336	-0.655	-0.479	0.059	0.482	0
> 300	*93*	-0.336	-0.655	-0.485	0.059	0.489	0
> 400	*86*	-0.336	-0.655	-0.485	0.061	0.489	0
> 500	*57*	-0.420	-0.655	-0.504	0.053	0.506	0
> 600	*5*	-0.561	-0.655	-0.588	0.038	0.589	0

Table G.8
Descriptive Statistics of the *Absolute* Differences between the GPS-AHDD Control Data and AUSGeoid98 (Bi-cubic Interpolation) over Increasing AHD Height

AHD Height [m]	*No. of points*	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*Outliers*
> 200	*107*	-0.491	-0.802	-0.623	0.039	0.625	3 (2.80%)
> 300	*93*	-0.536	-0.802	-0.630	0.034	0.631	2 (2.15%)
> 400	*86*	-0.536	-0.802	-0.631	0.035	0.632	2 (2.33%)
> 500	*57*	-0.602	-0.786	-0.637	0.030	0.638	1 (1.75%)
> 600	*5*	-0.671	-0.786	-0.701	0.048	0.702	0

Table G.9
Descriptive Statistics of the *Absolute* Differences between the GPS-AHDD Control Data and the SBA Technique (Bi-linear Interpolation) over Increasing AHD Height

AHD Height [m]	*No. of points*	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*Outliers*
> 200	*107*	-2.032	-2.378	-2.176	0.039	2.176	3 (2.80%)
> 300	*93*	-2.113	-2.378	-2.184	0.033	2.184	2 (2.15%)
> 400	*86*	-2.113	-2.378	-2.186	0.033	2.186	2 (2.33%)
> 500	*57*	-2.146	-2.344	-2.189	0.028	2.189	1 (1.75%)
> 600	*5*	-2.218	-2.344	-2.247	0.054	2.248	1 (20.0%)

Table G.10
Descriptive Statistics of the *Absolute* Differences between the GPS-AHDD Control Data and the RBA Technique (Bi-linear Interpolation) over Increasing AHD Height

AHD Height [m]	*No. of points*	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*Outliers*
> 200	*107*	-2.098	-2.443	-2.240	0.039	2.241	3 (2.80%)
> 300	*93*	-2.177	-2.443	-2.248	0.033	2.248	2 (2.15%)
> 400	*86*	-2.177	-2.443	-2.250	0.033	2.250	2 (2.33%)
> 500	*57*	-2.209	-2.408	-2.252	0.028	2.252	1 (1.75%)
> 600	*5*	-2.282	-2.408	-2.311	0.054	2.312	0

Table G.11
Descriptive Statistics of the *Absolute* Differences between the GPS-AHDD Control Data and AUSGeoid93 (Bi-linear Interpolation) over Increasing AHD Height

AHD Height [m]	*No. of points*	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*Outliers*
> 200	*107*	-0.355	-0.678	-0.499	0.067	0.503	0
> 300	*93*	-0.355	-0.678	-0.507	0.067	0.511	0
> 400	*86*	-0.355	-0.678	-0.508	0.069	0.513	0
> 500	*57*	-0.421	-0.678	-0.530	0.063	0.534	0
> 600	*5*	-0.596	-0.678	-0.620	0.033	0.620	0

Table G.12
Descriptive Statistics of the *Absolute* Differences between the GPS-AHDD Control Data and AUSGeoid98 (Bi-linear Interpolation) over Increasing AHD Height

AHD Height [m]	*No. of points*	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*Outliers*
> 200	*107*	-0.487	-0.802	-0.624	0.040	0.625	3 (2.80%)
> 300	*93*	-0.535	-0.802	-0.631	0.035	0.632	2 (2.15%)
> 400	*86*	-0.535	-0.802	-0.632	0.036	0.633	2 (2.33%)
> 500	*57*	-0.603	-0.788	-0.638	0.031	0.639	1 (1.75%)
> 600	*5*	-0.673	-0.788	-0.703	0.048	0.705	0

APPENDIX H

SCATTER PLOTS OF THE *RELATIVE* COMPARISONS OVER ALL 6,670 POSSIBLE BASELINES

LIST OF FIGURES

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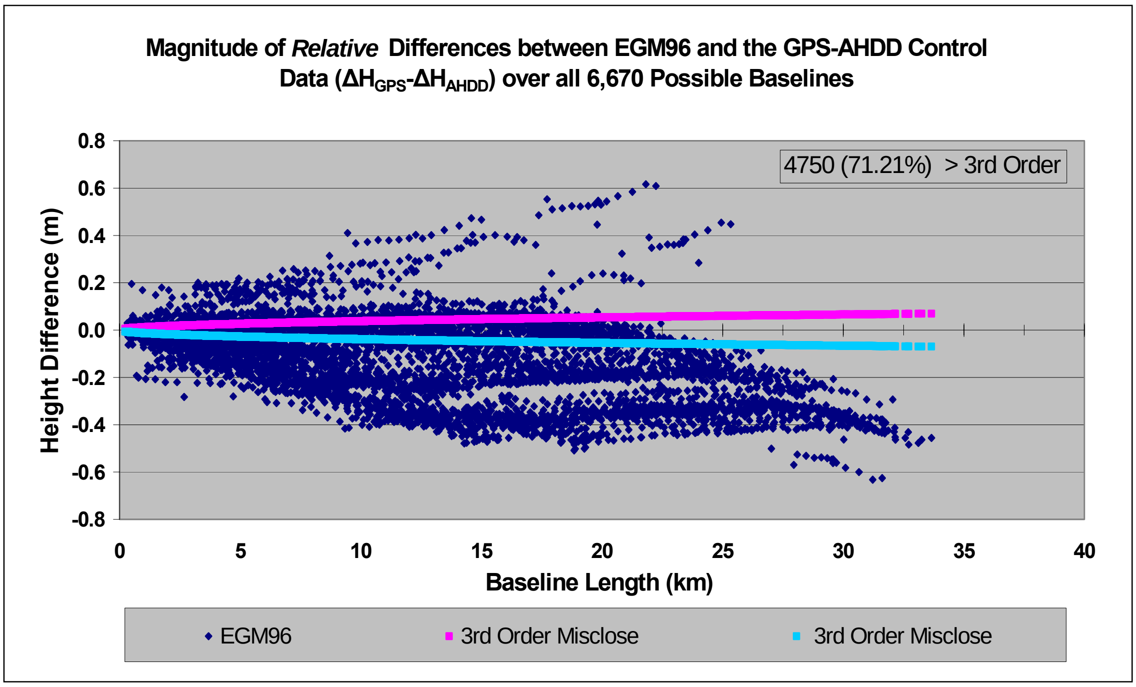

Figure H.1 Magnitude of *Relative* Differences between EGM96 and the GPS-AHDD Control Data (ΔH_{GPS}-ΔH_{AHDD}) over all 6,670 Possible Baselines [Maximum allowable misclose under Australian 3rd Order levelling specifications also shown]

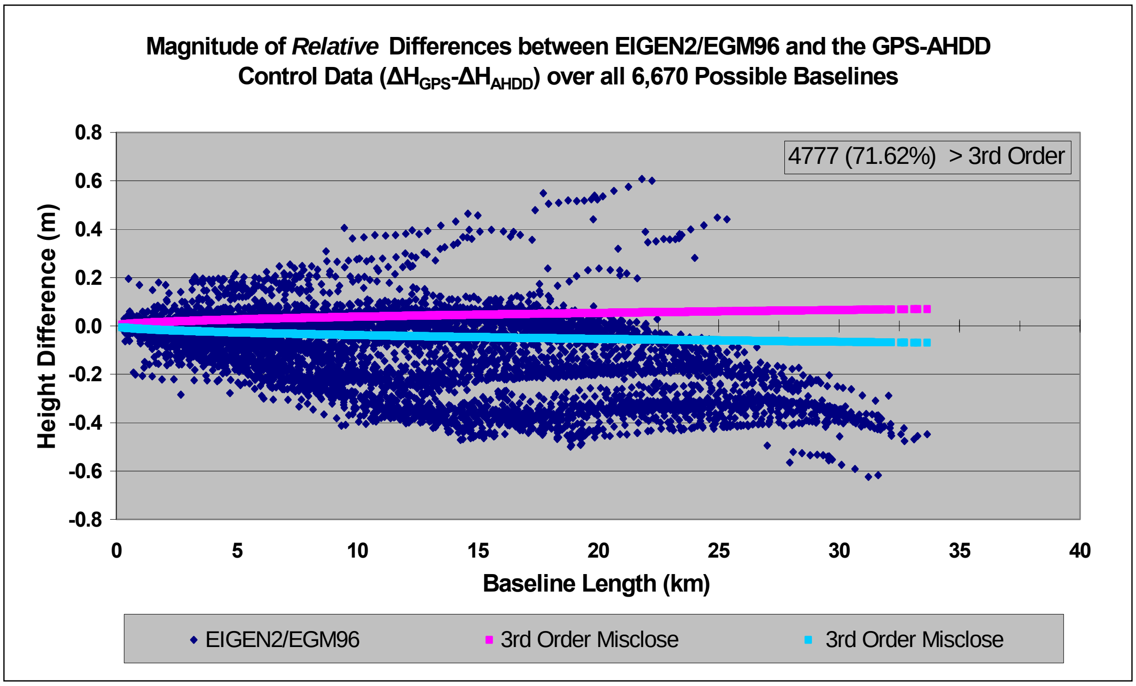

Figure H.2 Magnitude of *Relative* Differences between EIGEN2/EGM96 and the GPS-AHDD Control Data (ΔH_{GPS}-ΔH_{AHDD}) over all 6,670 Possible Baselines [Maximum allowable misclose under Australian 3rd Order levelling specifications also shown]

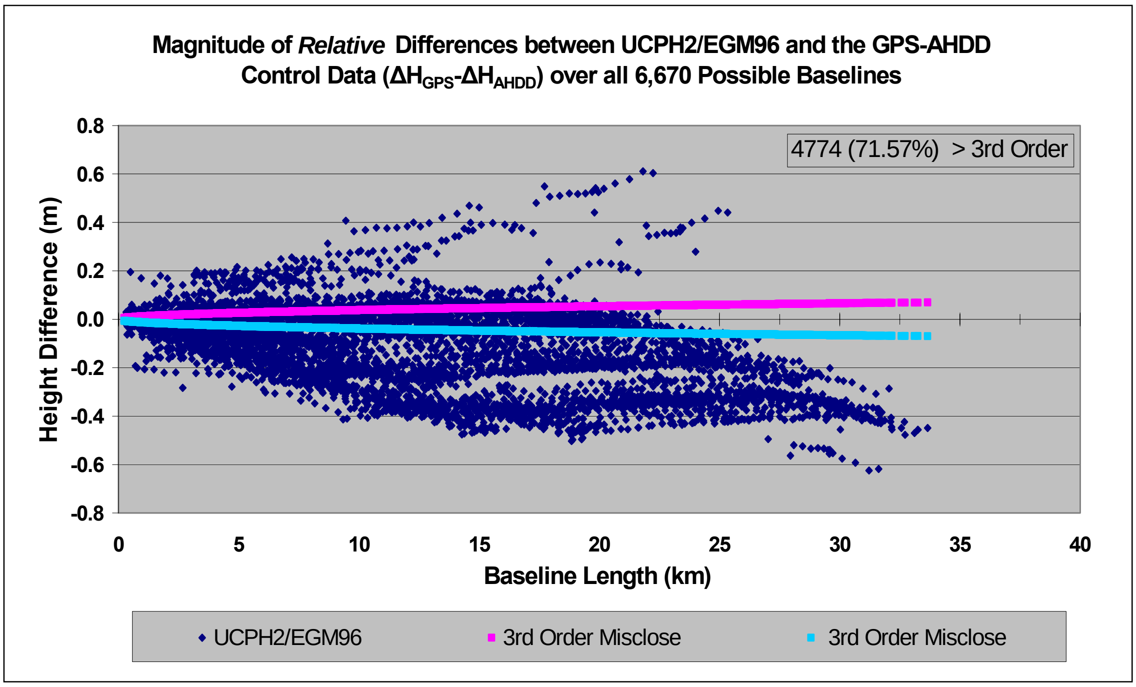

Figure H.3 Magnitude of *Relative* Differences between UCPH2/EGM96 and the GPS-AHDD Control Data (ΔH_{GPS}-ΔH_{AHDD}) over all 6,670 Possible Baselines [Maximum allowable misclose under Australian 3rd Order levelling specifications also shown]

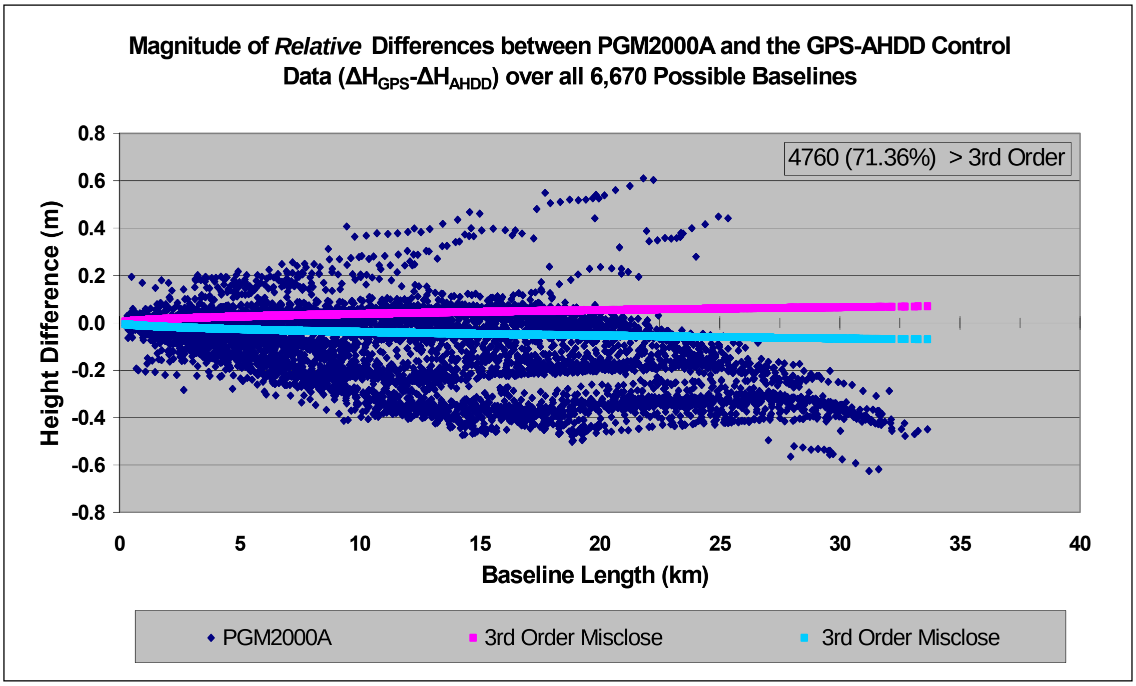

Figure H.4 Magnitude of *Relative* Differences between PGM2000A and the GPS-AHDD Control Data (ΔH_{GPS}-ΔH_{AHDD}) over all 6,670 Possible Baselines [Maximum allowable misclose under Australian 3rd Order levelling specifications also shown]

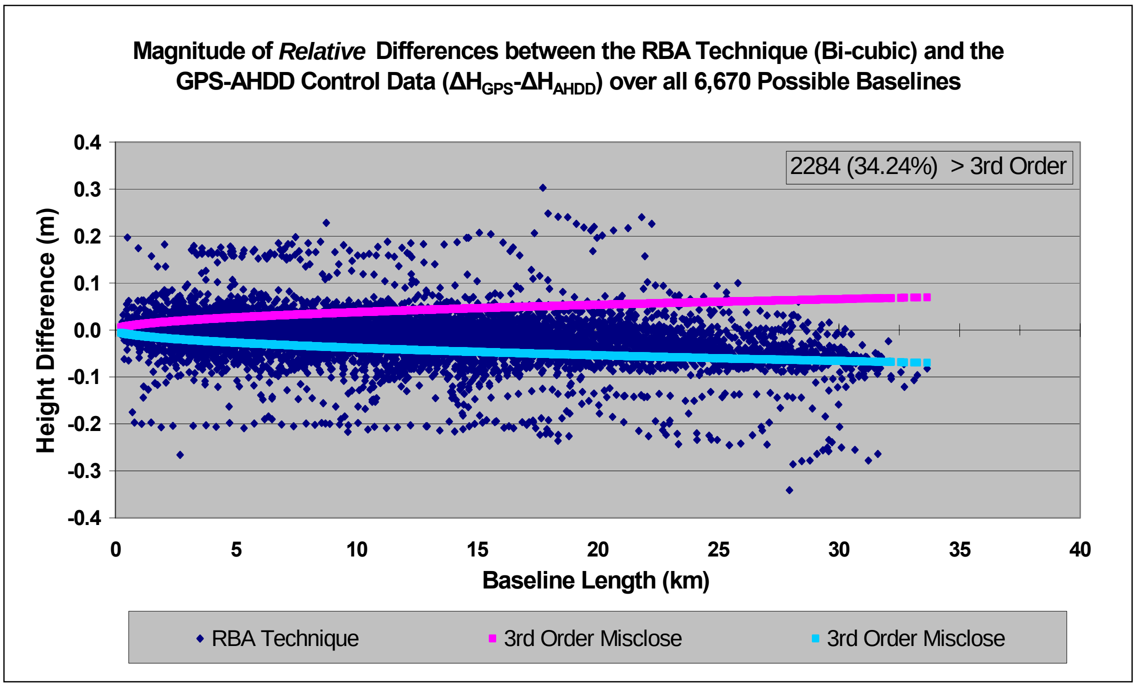

Figure H.5 Magnitude of *Relative* Differences between the RBA Technique (Bi-cubic) and the GPS-AHDD Control Data (ΔH_{GPS}-ΔH_{AHDD}) over all 6,670 Possible Baselines [Maximum allowable misclose under Australian 3rd Order levelling specifications also shown]

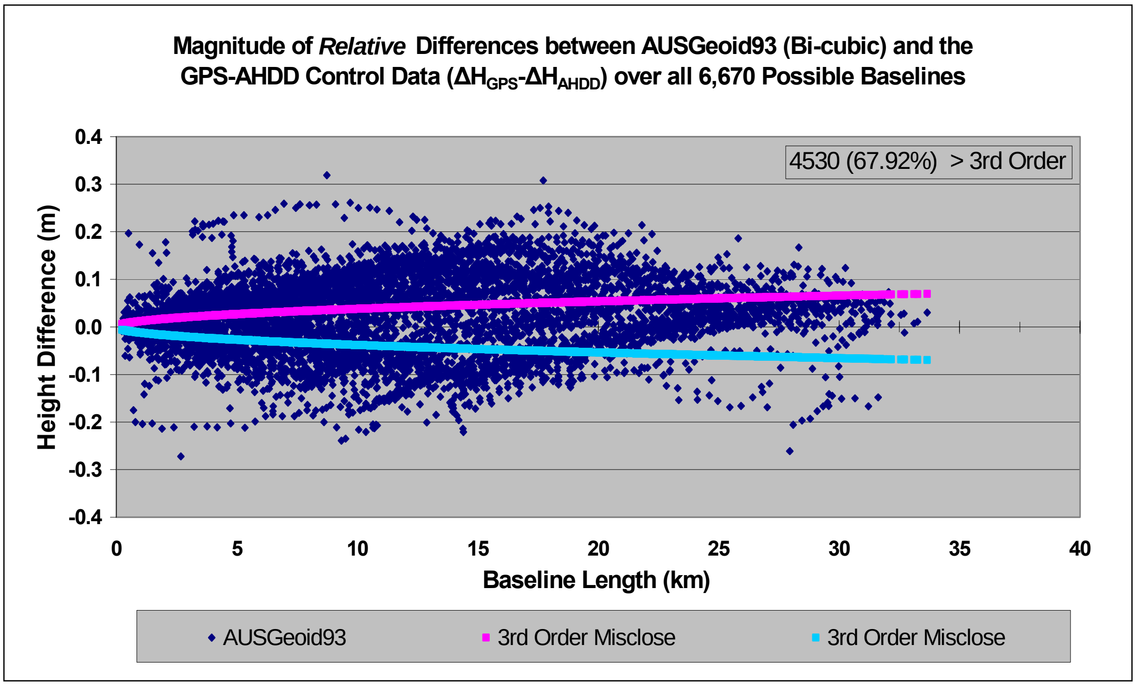

Figure H.6 Magnitude of *Relative* Differences between AUSGeoid93 (Bi-cubic) and the GPS-AHDD Control Data (ΔH_{GPS}-ΔH_{AHDD}) over all 6,670 Possible Baselines [Maximum allowable misclose under Australian 3rd Order levelling specifications also shown]

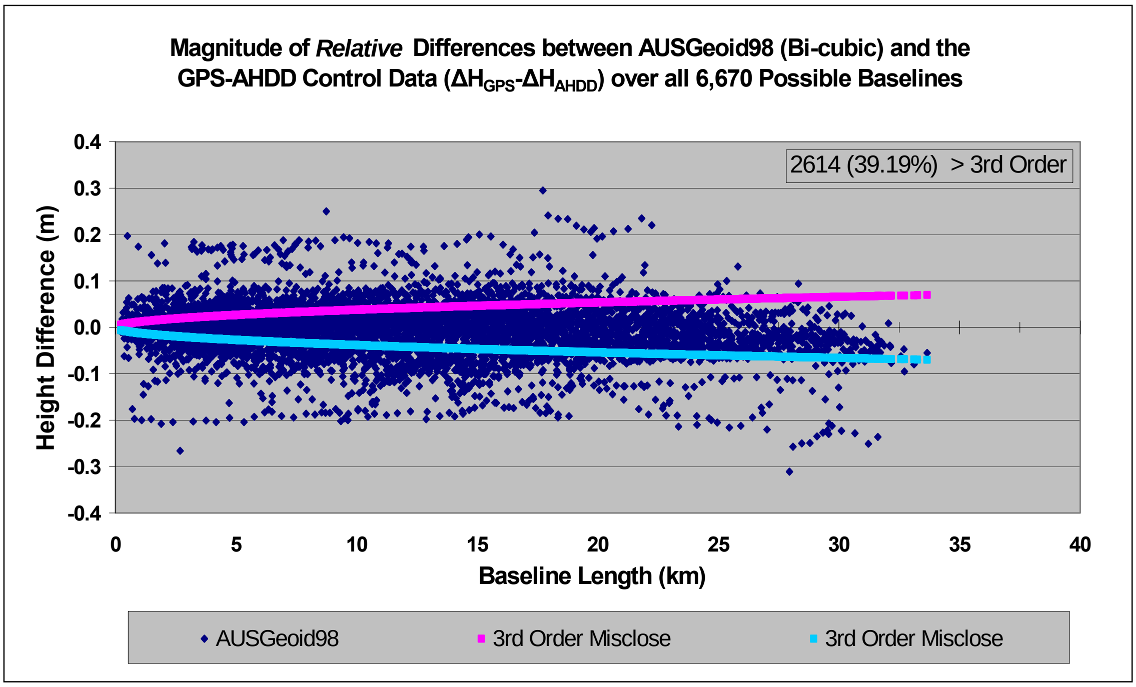

Figure H.7 Magnitude of *Relative* Differences between AUSGeoid98 (Bi-cubic) and the GPS-AHDD Control Data (ΔH_{GPS}-ΔH_{AHDD}) over all 6,670 Possible Baselines [Maximum allowable misclose under Australian 3rd Order levelling specifications also shown]

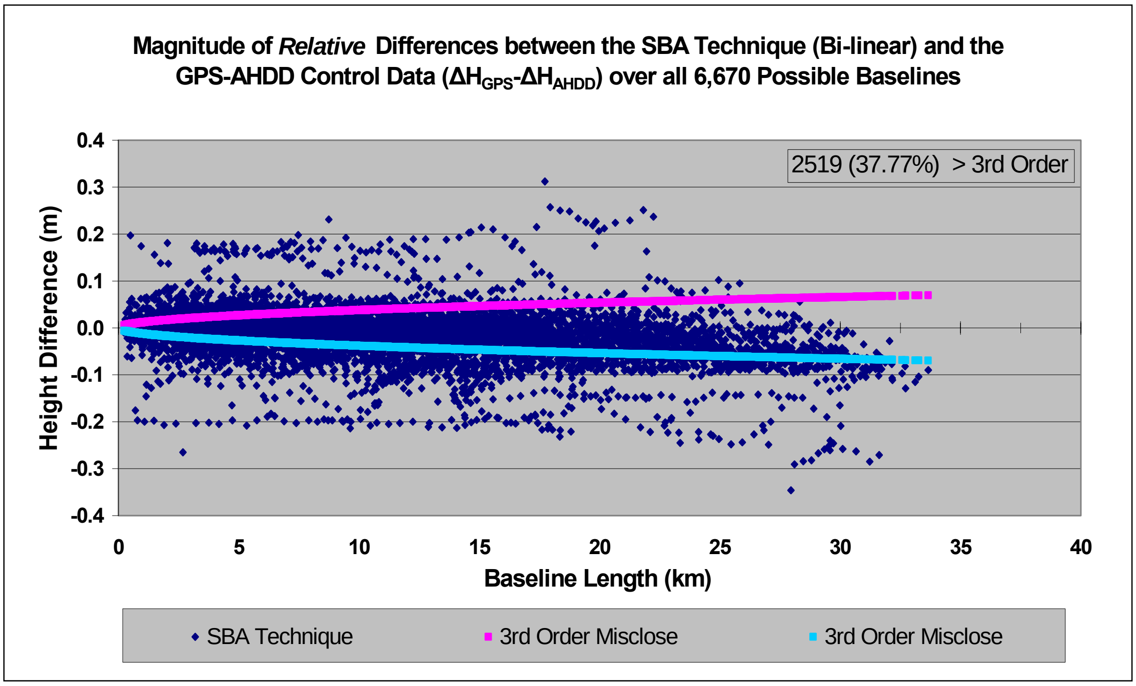

Figure H.8 Magnitude of *Relative* Differences between the SBA Technique (Bi-linear) and the GPS-AHDD Control Data (ΔH_{GPS}-ΔH_{AHDD}) over all 6,670 Possible Baselines [Maximum allowable misclose under Australian 3rd Order levelling specifications also shown]

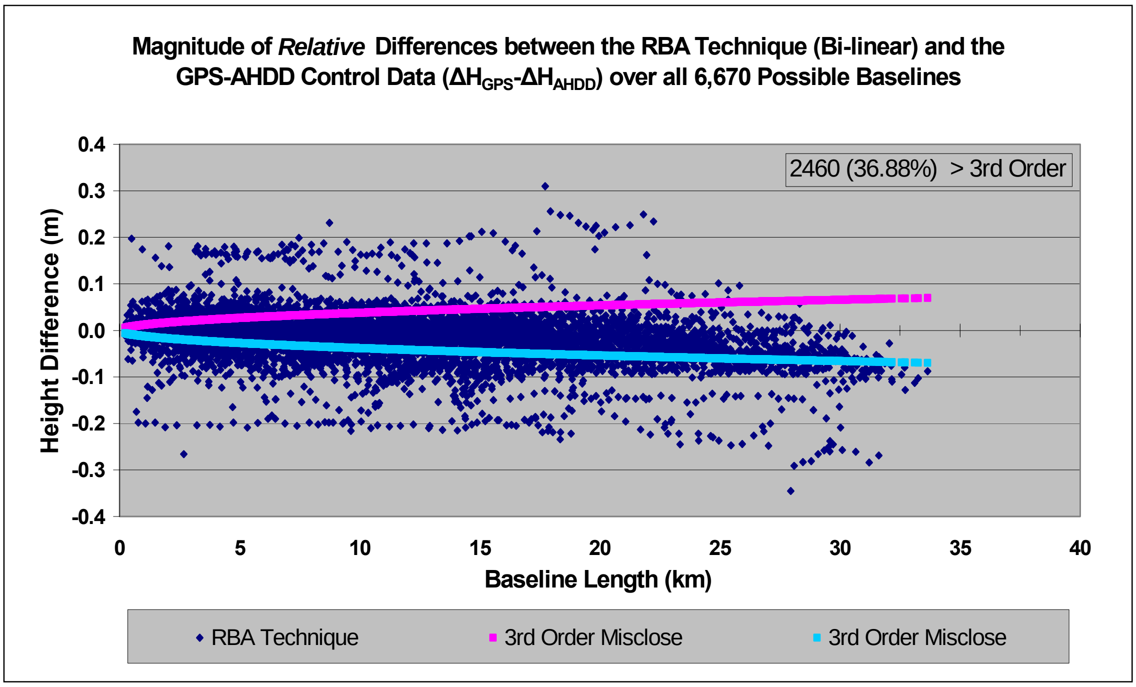

Figure H.9 Magnitude of *Relative* Differences between the RBA Technique (Bi-linear) and the GPS-AHDD Control Data (ΔH_{GPS}-ΔH_{AHDD}) over all 6,670 Possible Baselines [Maximum allowable misclose under Australian 3rd Order levelling specifications also shown]

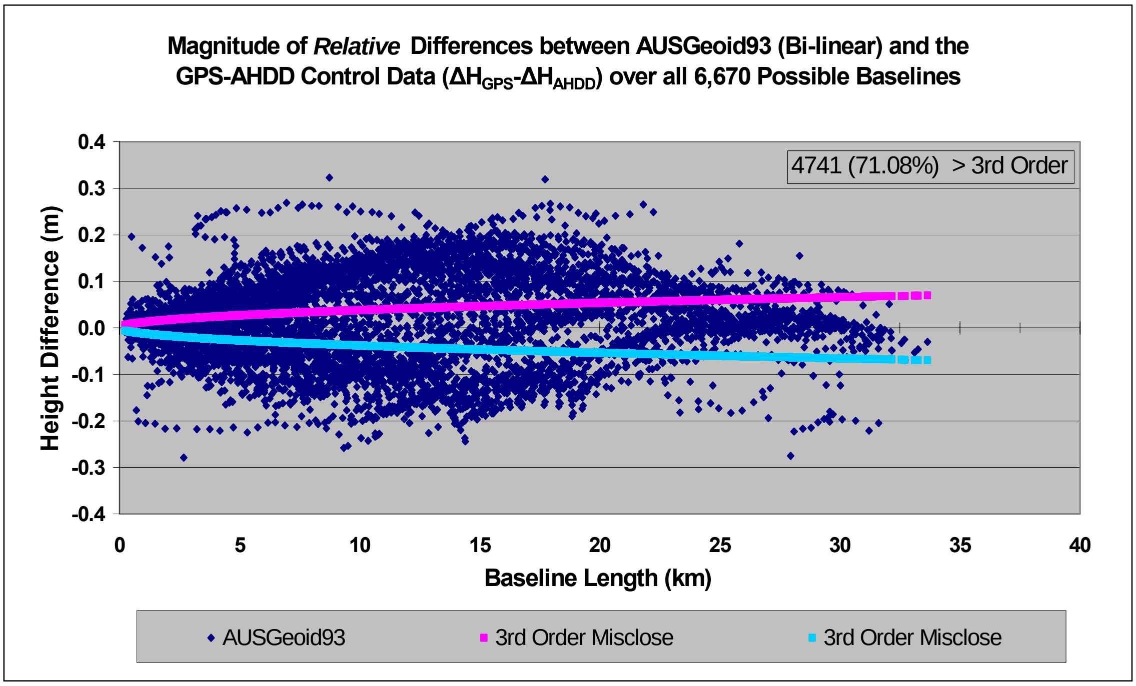

Figure H.10 Magnitude of *Relative* Differences between AUSGeoid93 (Bi-linear) and the GPS-AHDD Control Data (ΔH_{GPS}-ΔH_{AHDD}) over all 6,670 Possible Baselines [Maximum allowable misclose under Australian 3rd Order levelling specifications also shown]

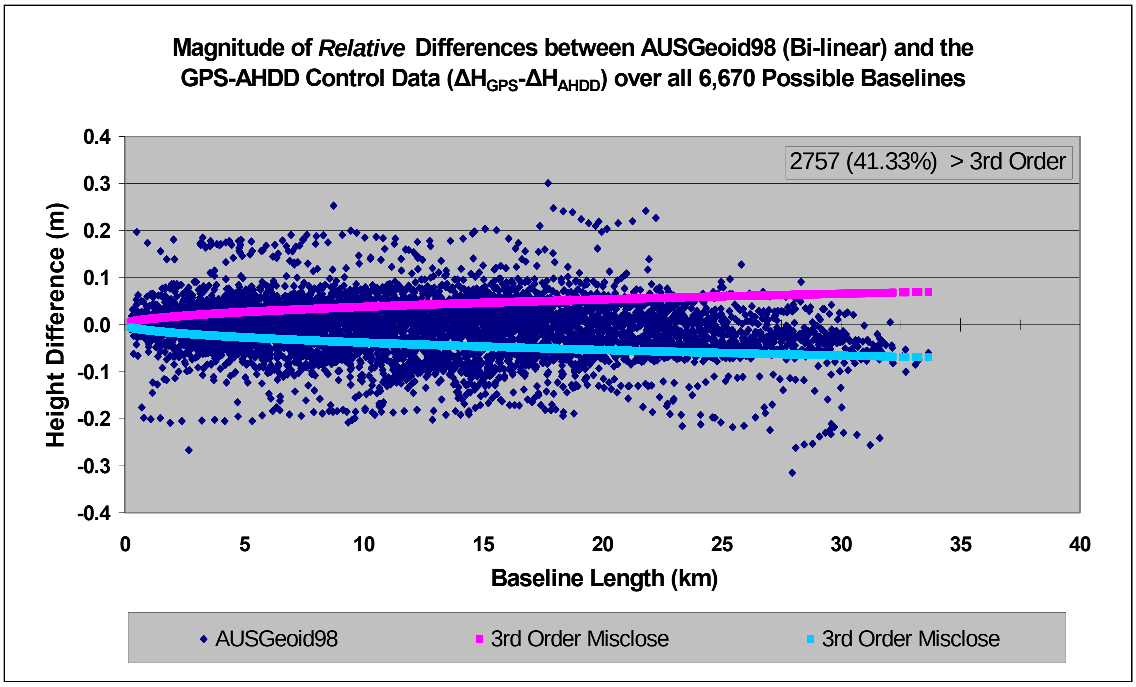

Figure H.11 Magnitude of *Relative* Differences between AUSGeoid98 (Bi-linear) and the GPS-AHDD Control Data (ΔH_{GPS}-ΔH_{AHDD}) over all 6,670 Possible Baselines [Maximum allowable misclose under Australian 3rd Order levelling specifications also shown]

APPENDIX I

NUMERICAL RESULTS OF THE *RELATIVE* COMPARISONS OVER INCREASING AHD HEIGHT

LIST OF TABLES

Table I.1
Descriptive Statistics of the *Relative* Differences between the GPS-AHDD Control Data and EGM96 over Increasing AHD Height

AHD Height [m]	*No. of baselines*	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*Outliers*	*Mean ppm*
> 200	*5,671*	0.569	-0.553	0.070	0.137	0.154	36 (0.63%)	6.49
> 300	*4,278*	0.396	-0.380	0.021	0.084	0.087	25 (0.58%)	2.20
> 400	*3,655*	0.389	-0.373	0.003	0.069	0.069	76 (2.08%)	0.38
> 500	*1,596*	0.162	-0.202	-0.015	0.040	0.043	52 (3.26%)	-2.16
> 600	*10*	0.035	-0.143	-0.037	0.078	0.083	0	-7.84

Table I.2
Descriptive Statistics of the *Relative* Differences between the GPS-AHDD Control Data and EIGEN2/EGM96 over Increasing AHD Height

AHD Height [m]	*No. of baselines*	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*Outliers*	*Mean ppm*
> 200	*5,671*	0.565	-0.548	0.068	0.135	0.151	36 (0.63%)	6.32
> 300	*4,278*	0.393	-0.376	0.020	0.084	0.086	25 (0.58%)	2.10
> 400	*3,655*	0.386	-0.369	0.003	0.068	0.069	77 (2.11%)	0.32
> 500	*1,596*	0.160	-0.204	-0.015	0.041	0.043	51 (3.20%)	-2.27
> 600	*10*	0.035	-0.143	-0.037	0.078	0.083	0	-7.86

Table I.3
Descriptive Statistics of the *Relative* Differences between the GPS-AHDD Control Data and UCPH2/EGM96 over Increasing AHD Height

AHD Height [m]	*No. of baselines*	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*Outliers*	*Mean ppm*
> 200	*5,671*	0.563	-0.549	0.068	0.136	0.152	36 (0.63%)	6.32
> 300	*4,278*	0.391	-0.377	0.020	0.084	0.086	25 (0.58%)	2.05
> 400	*3,655*	0.383	-0.369	0.002	0.068	0.068	75 (2.05%)	0.24
> 500	*1,596*	0.163	-0.203	-0.015	0.040	0.043	51 (3.20%)	-2.28
> 600	*10*	0.034	-0.142	-0.037	0.077	0.082	0	-7.83

Table I.4
Descriptive Statistics of the *Relative* Differences between the GPS-AHDD Control Data and PGM2000A over Increasing AHD Height

AHD Height [m]	*No. of baselines*	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*Outliers*	*Mean ppm*
> 200	*5,671*	0.564	-0.549	0.069	0.136	0.152	36 (0.63%)	6.34
> 300	*4,278*	0.392	-0.377	0.020	0.084	0.086	25 (0.58%)	2.08
> 400	*3,655*	0.385	-0.370	0.003	0.068	0.069	74 (2.02%)	0.28
> 500	*1,596*	0.162	-0.203	-0.015	0.040	0.043	51 (3.20%)	-2.26
> 600	*10*	0.034	-0.142	-0.037	0.077	0.082	0	-7.84

Table I.5
Descriptive Statistics of the *Relative* Differences between the GPS-AHDD Control Data and the SBA Technique (Bi-cubic Interpolation) over Increasing AHD Height

AHD Height [m]	*No. of baselines*	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*Outliers*	*Mean ppm*
> 200	*5,671*	0.341	-0.304	0.012	0.053	0.054	197 (3.47%)	1.11
> 300	*4,278*	0.265	-0.228	0.001	0.046	0.046	175 (4.09%)	0.14
> 400	*3,655*	0.265	-0.228	-0.001	0.046	0.046	158 (4.32%)	-0.06
> 500	*1,596*	0.147	-0.197	-0.009	0.038	0.039	51 (3.20%)	-1.35
> 600	*10*	0.005	-0.126	-0.049	0.062	0.077	0	-10.36

Table I.6
Descriptive Statistics of the *Relative* Differences between the GPS-AHDD Control Data and the RBA Technique (Bi-cubic Interpolation) over Increasing AHD Height

AHD Height [m]	*No. of baselines*	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*Outliers*	*Mean ppm*
> 200	*5,671*	0.341	-0.303	0.012	0.053	0.054	197 (3.47%)	1.06
> 300	*4,278*	0.266	-0.228	0.001	0.046	0.046	174 (4.07%)	0.12
> 400	*3,655*	0.266	-0.228	0.000	0.047	0.047	158 (4.32%)	-0.05
> 500	*1,596*	0.146	-0.198	-0.009	0.039	0.040	51 (3.20%)	-1.35
> 600	*10*	0.005	-0.126	-0.049	0.063	0.077	0	-10.31

Table I.7
Descriptive Statistics of the *Relative* Differences between the GPS-AHDD Control Data and AUSGeoid93 (Bi-cubic Interpolation) over Increasing AHD Height

AHD Height [m]	*No. of baselines*	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*Outliers*	*Mean ppm*
> 200	*5,671*	0.272	-0.319	-0.026	0.079	0.083	17 (0.30%)	-2.40
> 300	*4,278*	0.272	-0.319	-0.046	0.069	0.083	33 (0.77%)	-4.79
> 400	*3,655*	0.272	-0.319	-0.053	0.068	0.086	36 (0.98%)	-5.87
> 500	*1,596*	0.177	-0.235	-0.052	0.053	0.074	13 (0.81%)	-7.70
> 600	*10*	0.007	-0.094	-0.038	0.040	0.054	0	-7.92

Table I.8
Descriptive Statistics of the *Relative* Differences between the GPS-AHDD Control Data and AUSGeoid98 (Bi-cubic Interpolation) over Increasing AHD Height

AHD Height [m]	*No. of baselines*	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*Outliers*	*Mean ppm*
> 200	*5,671*	0.311	-0.295	0.000	0.055	0.055	149 (2.63%)	0.02
> 300	*4,278*	0.266	-0.250	-0.013	0.047	0.048	149 (3.48%)	-1.32
> 400	*3,655*	0.266	-0.250	-0.016	0.047	0.050	131 (3.58%)	-1.73
> 500	*1,596*	0.161	-0.184	-0.021	0.037	0.043	45 (2.82%)	-3.05
> 600	*10*	0.005	-0.115	-0.047	0.052	0.068	0	-9.81

Table I.9
Descriptive Statistics of the *Relative* Differences between the GPS-AHDD Control Data and the SBA Technique (Bi-linear Interpolation) over Increasing AHD Height

AHD Height [m]	*No. of baselines*	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*Outliers*	*Mean ppm*
> 200	*5,671*	0.346	-0.312	0.012	0.054	0.056	192 (3.39%)	1.15
> 300	*4,278*	0.265	-0.231	0.001	0.046	0.046	174 (4.07%)	0.07
> 400	*3,655*	0.265	-0.231	-0.002	0.047	0.047	158 (4.32%)	-0.20
> 500	*1,596*	0.149	-0.198	-0.011	0.038	0.040	51 (3.20%)	-1.56
> 600	*10*	0.006	-0.126	-0.049	0.062	0.077	0	-10.31

Table I.10
Descriptive Statistics of the *Relative* Differences between the GPS-AHDD Control Data and the RBA Technique (Bi-linear Interpolation) over Increasing AHD Height

AHD Height [m]	*No. of baselines*	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*Outliers*	*Mean ppm*
> 200	*5,671*	0.345	-0.310	0.012	0.054	0.055	193 (3.40%)	1.10
> 300	*4,278*	0.266	-0.231	0.000	0.046	0.046	174 (4.07%)	0.05
> 400	*3,655*	0.266	-0.231	-0.002	0.047	0.047	158 (4.32%)	-0.21
> 500	*1,596*	0.148	-0.199	-0.011	0.039	0.040	50 (3.13%)	-1.57
> 600	*10*	0.006	-0.126	-0.049	0.062	0.077	0	-10.31

Table I.11
Descriptive Statistics of the *Relative* Differences between the GPS-AHDD Control Data and AUSGeoid93 (Bi-linear Interpolation) over Increasing AHD Height

AHD Height [m]	*No. of baselines*	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*Outliers*	*Mean ppm*
> 200	*5,671*	0.279	-0.323	-0.024	0.092	0.095	6 (0.11%)	-2.26
> 300	*4,278*	0.279	-0.323	-0.048	0.082	0.095	22 (0.51%)	-5.02
> 400	*3,655*	0.279	-0.323	-0.058	0.079	0.098	27 (0.74%)	-6.42
> 500	*1,596*	0.187	-0.257	-0.062	0.064	0.089	2 (0.13%)	-9.20
> 600	*10*	0.007	-0.082	-0.032	0.036	0.047	0	-6.79

Table I.12
Descriptive Statistics of the *Relative* Differences between the GPS-AHDD Control Data and AUSGeoid98 (Bi-linear Interpolation) over Increasing AHD Height

AHD Height [m]	*No. of baselines*	*Max.* [m]	*Min.* [m]	*Mean* [m]	*STD* [m]	*RMS* [m]	*Outliers*	*Mean ppm*
> 200	*5,671*	0.315	-0.301	0.001	0.057	0.057	140 (2.47%)	0.07
> 300	*4,278*	0.267	-0.253	-0.013	0.048	0.049	148 (3.46%)	-1.37
> 400	*3,655*	0.267	-0.253	-0.017	0.048	0.051	130 (3.56%)	-1.83
> 500	*1,596*	0.162	-0.185	-0.022	0.038	0.043	42 (2.63%)	-3.20
> 600	*10*	0.005	-0.115	-0.047	0.052	0.068	0	-9.81