University of Southern Queensland
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Evaluating the Differences and Accuracies Between GNSS Applications Using PPP.

A dissertation submitted by

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Abstract

Global Navigation Satellite Systems (GNSS) are satellite systems with global coverage. There are currently several GNSS systems in operation today including the United States NAVSTAR Global Positioning System, Russian GLONASS, Chinese Beidou and the European Union's Galileo system. The Galileo and Beidou systems are currently undergoing upgrading in order to achieve more sustainable and comprehensive worldwide exposure, ultimately providing users with a broader option of systems and wider more reliable coverage.

In recent years, in addition to the GPS constellation, the ability to utilise extra satellites made available through the GLONASS and Beidou systems has enhanced the capabilities and possible applications of the precise point positioning (PPP) method. Precise Point Positioning has been used for the last decade as a cost-effective alternative to conventional DGPS-Differential GPS with an estimated precision adequate for many applications. PPP requires handling different types of errors using proper models. PPP precision varies with the use of observations from different satellite systems (GPS, GLONASS and mixed GPS/GLONASS/Beidou) and the duration of observations. However, the fundamental differences between GPS, GLONASS, Beidou and Galileo and the lack of a fully tested global tracking network of multi-Global Navigation Satellite Systems necessitate the evaluation of their combined use. More studies are required in order to confirm the reliability and accuracy of the results obtained by the various methods of PPP. This is outside the scope of this paper.

This research paper will evaluate and analyse the accuracy and reliability between different GNSS systems using the Precise Point Positioning technique with emphasis on the function and performance of single systems compared with combined GNSS systems. A methodology was designed to ensure accurate and reliable results have been achieved. Solutions generated from identical data will be compared for bias, accuracy and reliability between single standalone GPS and combined GNSS systems. This study focused on the performance of these systems over a twenty four hour observation period, decimated into 1, 2, 6, 12 and 24 hours. The study found that the reliability and performance of GNSS systems over standalone GPS was insignificant over a twenty four hour period. In fact, where satellite availability and constellation are at a premium, standalone GPS systems can produce equivalent quality results compared with combined GNSS. Having said this, the combined GNSS systems achieved quicker convergence times than standalone systems.

With limited access and availability to resources, in particular GNSS receivers, the results can be seen as preliminary testing enhancing the knowledge of GNSS users. Nonetheless, this dissertation covers a wide range of topics and field testing providing relevant reliable data on the accuracy, precision and performance of both standalone and combined Global Navigation Satellite Systems.

LIMITATIONS OF USE

CANDIDATES CERTIFICATION

I certify that the ideas, designs and experimental work, results, analysis and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in other course or institution, except where specifically stated.

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NOMENCLATURE AND ACRONYMS

The following abbreviations have been used throughout the text and bibliography:-

AHD	Australian Height Datum
AHD71	Australian Height Datum 1971
APREF	Asia Pacific Reference Frame
CORS	Continually Operating Reference Station
FDMA	Frequency Division Multiple Access
GCC	Ground Control Centre
GCS	Galileo Control System
GDA94	Geocentric Datum of Australia 1994
GEO	Geostationary Earth Orbit
GRF	Galileo Reference System
GLONASS	Globalnaya navigatsionnaya sputnikovaya sistema (Global Navigation Satellite System)
GMS	Galileo Mission System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
ICSM	Intergovernmental Committee on Surveying and Mapping
IGS	International GNSS Service
IGS08	International GNSS Service 2008
ISS	International Space Station
ITRF	International Terrestrial Reference Frame
ITRF2008	International Reference Frame 2008
LPI	Land and Property Information
MCS	Master Control Station
MEO	Medium Earth Orbit
PPP	Precise Point Positioning
QZSS	Quasi Zenith Satellite System
RINEX	Receiver Independent Exchange Format
RNSS	Regional Navigation Satellite Systems
RTK	Real Time Kinematic Surveying
SBAS	Space Based Augmentation System
SCIMS	Survey Control Information Management System
SP	Standard Precision
SRNS	Satellite Radio Navigation System
SU	Survey Uncertainty
TBC	Trimble Business Centre

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Chapter 1 – Introduction

1.1 Project background

1.1.1 GNSS background information

Global Navigation Satellite Systems (GNSS) are satellite navigation systems with global coverage. There are several systems in operation today ranging from the United States NAVSTAR Global Positioning System (GPS) to Russian GLONASS system. These two systems are currently fully operational. Whereas the Chinese Beidou-2, European Union's Galileo and the Japanese Quasi-Zenith satellite positioning systems are currently in the expansion and development stage due to be optimally operational by the year 2020.

GNSS are used to pinpoint the geographic location of a user's receiver anywhere in the world (TechTarget, 2014). They use a system of triangulation to locate the user through calculations using a series of visible satellite. Each satellite transmits a coded signal at precise intervals.

The receiver converts signal information into position, velocity and time estimates (Trimble, 2014). Using the information transmitted, the receiver calculates the distances between it and the satellites which ultimately enable the receiver to determine its position.

Global Navigation Satellite Systems were initially created by the United States and Russian governments for military use. Since there initial inception however Global Navigation Satellite Systems have come a long way being used throughout various commercial, residential, construction, infrastructure as well as a host of other industries. Today the United States NAVSTAR system, better known as Global Positioning System or GPS is commonly used within the automobile industries for navigational purposes, fleet tracking, mining and recreational use such as fishing and hunting. More importantly perhaps is GNSS use throughout the mapping and surveying industries. The surveying and mapping industry has been revolutionised by the use of GNSS, involving satellites, ground reference station infrastructure and user equipment to determine positions around the world (Chris Rizos, 2005).

GNSS is revolutionizing and revitalizing the way nations operate in space, from guidance systems for the International Space Station's (ISS) return vehicle, to the management tracking and control of communication satellite constellations (Olla, 2015). The first global navigational satellite system in operation was the United States Global Positioning System (GPS). This system was originally developed for military purposes and is maintained and controlled by the United States Department of Defence. Prior to the development of the United States GPS system, the first satellite system was called Transit and was operational beginning in 1964. Transit had no timing devices aboard the satellites and the time it took a receiver to calculate its position was about 15 minutes (Reece, 2000). The current GPS is a vast improvement over the Transit system. The original use of GPS was as a military positioning, navigation, and weapons aiming system to replace not only Transit, but other navigation systems as well (Reece, 2000). It has higher accuracy and stable atomic clocks on board to achieve precise time transfer. The first GPS satellite was launched in 1978 and the first products for civilian consumers appeared in the mid 1980's (Reece, 2000). The GPS system was made available to the civil community in the year 1984 by than president Ronal Reagan. The system is consistently being improved and upgraded with new satellite replacing older outdated ones.

The Russian GLONASS system was also formed in 1982 by the country’s military defence force and is currently operated by the Russian government. The system provides an alternative to the Global Positioning System and is the second alternative navigational system in operation with global coverage and of comparable precision. Toward the end of the 1960s the military identified a need for Satellite Radio Navigation System (SRNS) for use in precision guidance of the new generation of ballistic missiles. The existing Tsiklon satellite system that was available at the time could not be used for this purpose due to the lack of satellite availability, accuracies and the fact that the system required several minutes of observation time by the receiving station to obtain a fix on a position. Hence the introduction of navigation satellites with autonomous orbit corrections known as the Globalnaya Navigatsionnay Sputnikovaya Sistema (GLONASS) system was created.

In the early nineties the European Union saw the need for Europe to have its own global satellite navigation system. The European Commission and European Space Agency joined forces to build Galileo, an independent European system under civilian control (Agency, 2014). Although the system is currently set to be fully operational by the year 2020, the system still provides a highly accurate global positioning service under civilian control. It is inter-operable with GPS and GLONASS. Galileo receivers compute their position in the Galileo Reference System using satellite technology and based on triangulation principles (Agency, 2014). As mentioned, the United States GPS, Russian GLONASS and Chinese Beidou systems, although available for civil service are all militarily controlled systems, which means these systems may be switched off or made less precise when desired, usually during times of conflict. With the world becoming ever more dependent on services provided by satellite navigation within our daily lives, having these systems reduced or switched off has the potential to severely disrupt everyday activities and businesses such as business, banking, transport, aviation, communication etc. This is where having a system within civilian control has its advantages (Agency, 2014).

The Chinese government decided to build their own global navigation system in 1980. It was initially developed as a regional system for the Chinese Government (Dawoud, 2012).

This system is known as the Chinese Beidou2 GNSS system, which is China's second generation satellite navigation system that will be capable of providing positioning, navigation, and timing services to users on a continuous worldwide basis (Agency, 2014). Although the plan in the year 1997 was to have the regional system evolve from a regional to global solution, the formal approval by the Government of the development and deployment of BDS System was done in 2006 and it is expected to provide global navigation services by 2020, similarly to that of GPS, GLONASS or Galileo systems (Agency, 2014). Further, in 2011 the Beidou system was announced to provide initial operational service providing initial passive positioning for the Asia-Pacific region having a constellation of ten satellites. The number of satellites were increased by a total of five additional satellites in 2012, where the number of satellites will continue to increase ultimately evolving towards global navigation capabilities by the year 2020 (Agency, 2014).

1.1.2 Performance analysis GNSS systems using PPP

Precise Point Positioning is a satellite based positioning technique aiming at high accuracies in close to real time. The technique is capable of producing these high accuracies of centimetre to sub centimetre positioning using a single GNSS receiver, eliminating the constraints of base of baseline length and simultaneous observations at both rover and reference stations (Katrin Huber, 2010). It is a combination of the original absolute positioning concept and differential positioning techniques. PPP was developed based only on GPS observations, the accuracy, availability and reliability of positioning is dependent on the number of visible satellites at any given time. One way of ensuring an increase in availability of satellites is to integrate GPS and GLONASS observations. Today such integrations in Precise Point Positioning are available and will be discussed later on. The PPP technique is essential in single receiver observations in order to correct for the various errors that are inherent in raw observation data. These errors are caused by such things as atmospheric composition, differences in satellite and receiver clock accuracies, differences in modelled and actual satellite position and orientation and geological effects.

One negative factor to PPP is the fact that current commercial software does not provide processing of measurements taken using PPP techniques. Processing is usually done using scientific software or one of several online PPP services (K. Dawidowicz, 2014). The main challenge of dual frequency precise point positioning is that it takes up to thirty minutes to obtain a centimetre level accuracy. As mentioned, PPP is one of two techniques used for high accuracy GNSS based positioning with the other being the network based Real Time Kinematic (RTK). PPP is a powerful and efficient technology used for civilian and scientific applications worldwide. Although PPP has advantages such as high computational efficiency, not requiring dedicated reference stations it requires a long convergence time to achieve a desired accuracy (Pan Li, 2014). The precise point positioning technique combines precise clocks and orbits calculated from a global network. Pseudorange multipath and pseudorange noise are the largest remaining unmanaged error sources in PPP. It is believed that reducing the effects of multipath and noise on the pseudorange observable, accurate estimates of carrier phase float ambiguities will be attained sooner, ultimately reducing the initial convergence period of PPP (Garrett Seepersad, 2014). With the use of modernized GPS, Beidou, Galileo and GLONASS there are several advantages to be gained such as the availability of more visible satellites, greater signal power levels and more potential observable combinations, which may result in improved positional accuracy, availability and reliability. Both the pseudorange multipath and noise represent the largest remaining unmanaged error source in PPP. The amplitude of the multipath-induced errors in carrier phase observations is limited to a quarter wavelength or about 5 cm, but is typically well below 2 cm. Pseudorange multipath can have a magnitude of up to 10–20 m as it depends directly on the distance to the reflector. Currently, Hatch filtering is being performed in the position domain of the PPP software to mitigate pseudorange multipath and noise with minimal improvements in the rate of convergence (Garrett Seepersad 2014). Pseudorange multipath and noise can be corrected using several different methods to ultimately reduce convergence times and increase accuracies.

1.1.3 Project Context

Documenting the effects and reliability as well as the differences and accuracies between the different GNSS systems using the Precise Point Positioning technique is of extreme importance particularly to the surveying industry. GNSS systems have come a long way since there initial inception in the mid to late 1900’s. These systems have revolutionized the surveying and construction industries in many ways allowing surveyors to obtain highly accurate positioning information for both as built and design information, as well as provide GPS based machine guidance systems which in turn provide accurate grading information to machine operators. This ultimately ensures tasks are completed much more efficiently and economically than conventional surveying methods using an EDM, while maintaining the high accuracies required by both the surveyor and the client.

With the growing influence of these systems within the construction, civil, infrastructure, mining and more importantly the surveying industries, the demand for quality, efficiency and economic viability has increased dramatically. The industry has become more dependent on these systems and therefore it is imperative that surveyors gain greater understanding and awareness of Global Navigation Satellite Systems, there functionality and accuracies.

This paper will analyse the benefits, accuracies and differences between the different GNSS systems through both single and combined systems using PPP technique.

The paper will further focus on different physical and application details and specifications to evaluate them in terms of practical relevance. It is imperative that surveyors and other industry professionals understand and gain confidence of the mechanics, accuracies and configurations of systems they will use throughout their careers.

1.2 Project Aims and Objectives

1.2.1 Project Aims

Although GNSS are currently in in use and heavily relied upon within the surveying industry particularly surveying within the construction, infrastructure and civil sectors, the technical aspects of these systems including their performances within robust and diverse terrain are usually misunderstood. Surveyors will at some stage throughout there working careers work with GNSS systems and it is imperative that these systems are understood.

On this, the aim of the project is to provide relevant technical information on the performance of GNSS systems and their accuracies, both through single GNSS system and a combination of systems to test whether these combinations achieve quicker convergence, accuracy and reliability compared with the use of only a single system.

1.2.2 Project Objectives

The objectives of the study are to:

1. Gain understanding of systems by performing a literature review
2. A Performance analysis of GNSS systems using Precise Point Positioning (PPP)
3. Accuracy of stand-alone verse combined Global Navigation Satellite Systems
4. Research technical specifications for differences in GNSS systems
5. Research geographical differences of GNSS systems
6. Process data and analyse results
7. Compare post-processed solutions to known coordinates to evaluate accuracy and precision of solutions for twenty four hour logging times
8. Conclusion

With the Beidou and Galileo systems currently in the upgrading stage before they are fully functional and universally accessible, the performance analysis using the Precise Point Positioning Technique as well as the testing of stand-alone verse combined GNSS systems will be completed with a focus on the United States NAVSTAR Global Positioning System (GPS) and the Russian GLONASS navigational systems.

1.3 Chapter Summary

This project seeks to, by means of research, find aspects of design, physical limitations or advantages that will provide a level of differentiation between current stand along Global Navigation Satellite Systems and combined GNSS. This chapter has provided an overview of the general characteristics of GNSS systems, as well as provide an insight into the performance analysis of GNSS systems using the Precise Point Positioning technique. It also further seeks to quantify the practical consequences of those potential differences in the context of Australian GNSS user. The following chapter will review the literature surrounding the physical, application and control perspectives, as well as the technology in order to provide a base knowledge from which to design and carry out the necessary experiments and interpret the findings.

Chapter 2 – Literature Review

2.1 Introduction

The United States government's policies has evolved over time as the industry has moved from the GPS system being the only system to a broader international framework. The development of other systems such as the GLONASS, Galileo and Beidou has changed the dynamic into a multinational and multi system context (Madry, 2015). With the realisation that high precision services provided by both the United States GPS and Russian GLONASS may not be reliable during times of conflict with the systems being controlled by the country's military services respectively, the need has arisen across much of the globe where a necessary alternative to these systems be created, hence the introduction of self-contained GNSS systems such as the European Union's Galileo and Chinese Beidou systems. This issue has been further addressed, by the implementation of additional resources to GPS and GLONASS base receivers to form Space Based Augmentation Systems (SBAS) or Regional Navigation Satellite Systems (RNSS).

To assess the differences, accuracies and advantages or limitations between stand alone and combined between any two or more Global Navigation Satellite Systems we need to gain an understanding of the development of each system.

2.2 Physical Application

Global Navigation Satellite Systems consist of three major components or segments. These segments are known as the space segment, control segment and user segment (Grush 2006). The space segment comprises the physical, orbiting components such as the satellites, space vehicles, constellations, clock signals structure radio etc.

The United States Global Positioning System was the first GNSS system and is currently fully functional. The system was initially launched in the late 1970's by the United States Department of Defence and currently provides global coverage using space segment satellite constellation of 24 satellites providing universal coverage. GPS satellite fly in medium earth orbit at an altitude of approximately 20,200km, with an orbital radius of approximately 26,600km, each satellite circling the earth twice a day. The satellites in the GPS constellation are arranged into six equally-spaced orbital planes surrounding the Earth. Each plane contains four "slots" occupied by baseline satellites. The orbital plane is inclined by 55 degrees with respect to the equator, which in turn are equally spaced 60° around the equator. This 24-slot arrangement ensures users can view at least four satellites from virtually any point on the planet (National Coordination Office for Space Based Positioning, 2015). The signals relayed from the satellite requires a direct line to the GPS receiver and cannot penetrate water, soil, walls, or other obstacles such as trees, buildings, and bridges.

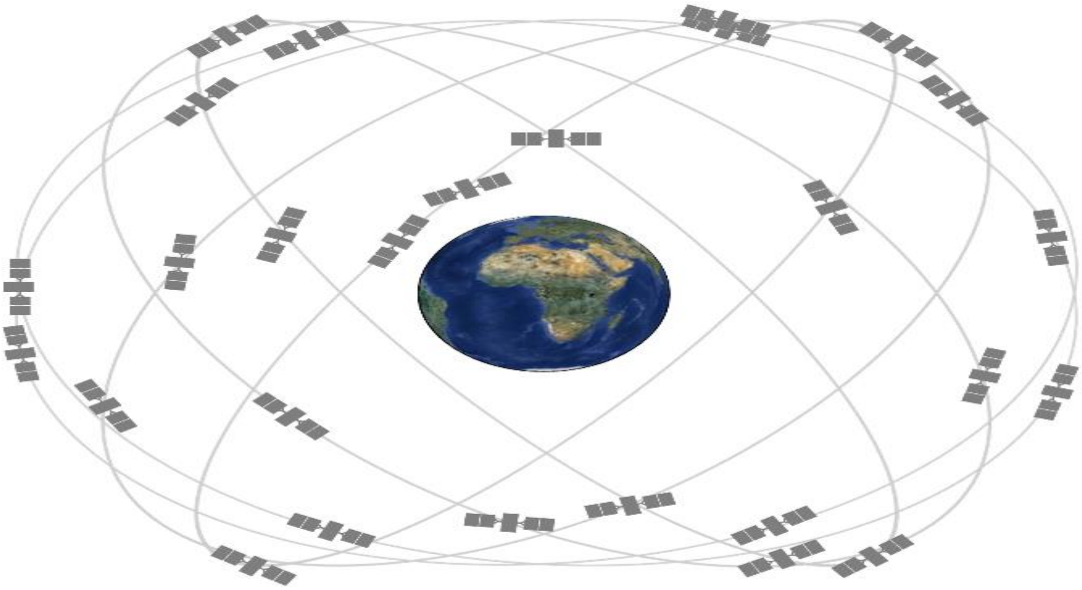


Figure 1.1 – Expandable 24-slot constellation, (National Coordination Office for Space Based Positioning, 2015)

All signals transmitted by the satellite are derived from the fundamental frequency (f0) of the satellite oscillator. The two carrier frequencies used are f1 and f2 with corresponding wavelengths of nineteen and twenty four centimetres respectively (Positrim, 2012). The satellites initially transmitted Coarse/Acquisition (C/A) code signals modulated on the L1 carrier only at (1575.42MHz) band and the P-code (Precise or Protected) code on both the L1 and the L2 (1227.60MHz) bands (National Coordination Office for Space Based Positioning, 2015). Clock accuracy is one of the most important factors in achieving positioning accuracy, In a study by (T K Yeh, 2007), a 1–2 cm positioning error was found due to improperly modelled receiver clock errors (T K Yeh, 2007). In GPS positioning, receiver clock errors are considered systematic errors that can be reduced by differencing the GPS code and phase observables (Ta-Kang Yeh, 2009).

The Russian GLONASS system as mentioned previously was formed by the country's military defence force and currently operated by the Russian government. This satellite system is currently fully operational consisting of twenty four operational satellites separated over three 120° orbital planes (Agency, 2014). Within each plane there are a total of eight satellites, separated by forty five degrees in argument of latitude. The difference in the argument of latitude of satellites in equivalent slots in two different orbital planes is 15 degrees. Each satellite is identified by its slot number, which defines the orbital plane and its location within the plane (Agency, 2014). The GLONASS system operates in circular orbits at an altitude of approximately nineteen kilometres. This arrangement ensures the visibility of a minimum of 5 satellites available from any position on the earth at any given time.

Figure 1.2 – GLONASS constellation (Agency, 2011c).

GLONASS system uses Frequency Division Multiple Access (FDMA) to transmit its ranging signals, in both the L1 and L2 bands. According to this scheme, each satellite transmits navigation signals on its own carrier frequency, so that two GLONASS satellites may transmit navigation signals on the same carrier frequency if they are located in antipodal slots of a single orbital plane (Rodríguez, 2011). Figure 2 below shows the satellites assigned to each of the GLONASS planes.

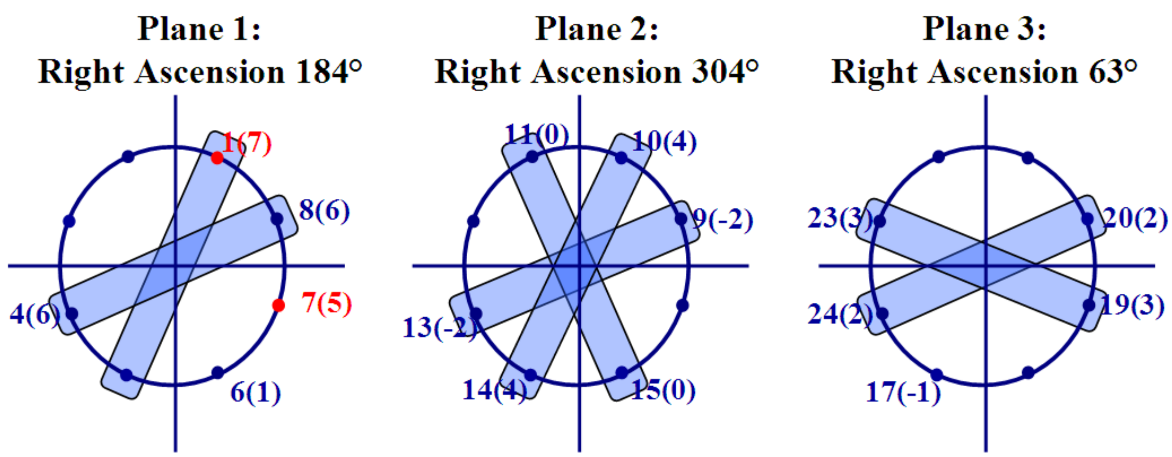


Figure 1.3 – Assignment of GLONASS satellites in each plane (Rodríguez, 2011).

Two different types of signals are transmitted by GLONASS satellites, Standard Precision (SP) and High Precision (HP) in both the L1 and L2 bands (Rodríguez, 2011). The modern GLONASS also transmits FDMA signals on the L3 band. The L1 band does not coincide with the GPS and

Galileo L1 bands. The L1 band ranges from 1602.5625 MHz to 1615.5MHz. The GLONASS satellites each transmit on slightly different L1 and L2 frequencies, with P- code on both L1 and L2, and with C/A code, at present, only on L1. GLONASS-M satellites reportedly transmit the C/A code on L2. The L2 frequencies run from 1240 MHz to 1260 MHz. Finally the L3 signal centres around the 1202.025 MHz. This L3 band was introduced to the GLONASS K-1 satellites in the year 2012.

The Galileo System is Europe's navigational satellite system which provides high accuracies for global positioning. The system is interoperable with both the GPS and GLONASS navigational systems. The system's receivers compute their positions in the Galileo Reference System (GRF) using satellite technology and based on the triangulation principles (Agency 2013). The main functions of the Galileo Space segment are to generate and transmit code and carrier phase signals and to store and retransmit the navigation message sent by the Control Segment. These transmissions are controlled by highly stable atomic clocks on board the satellites (Agency, 2014). The space segment when fully operational will consist of thirty satellites, 27 operational and 3 spares, in medium earth orbit at an altitude of approximately twenty three thousand kilometres across three orbital planes inclined at fifty six degrees to the equator, spread evenly around each plane taking approximately fourteen hours to orbit the earth (Agency, 2014). The combination of the orbital inclination and the flight altitude of the satellites will considerably increase the coverage of the Polar Regions (Cojocaru, 2009).

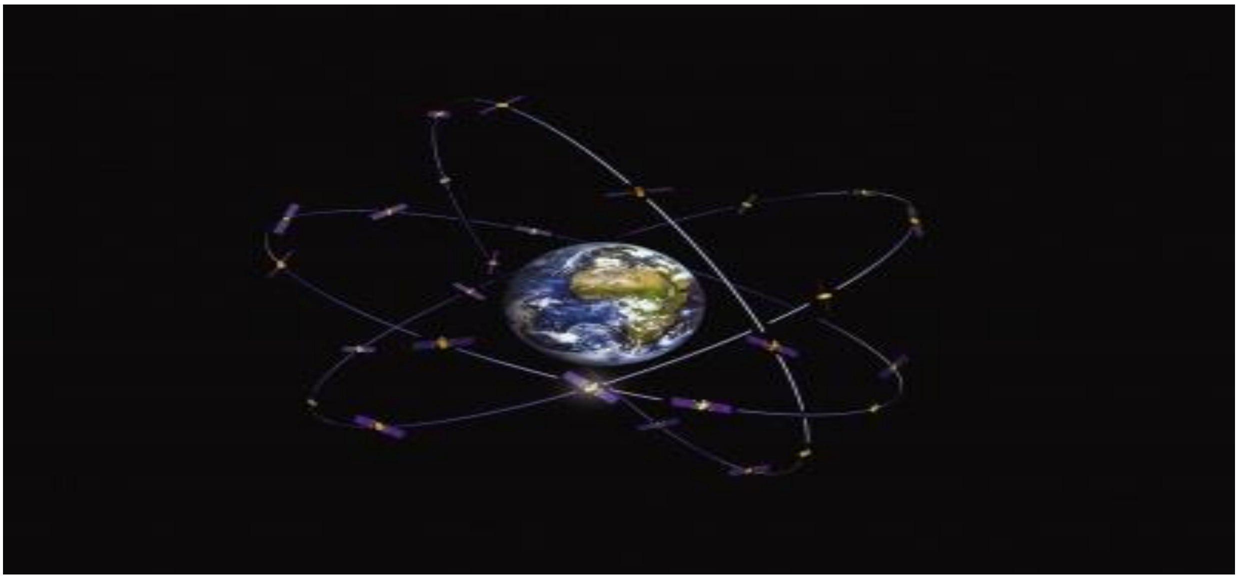


Figure 1.4 – Galileo Space Segment (Agency, 2014)

Each Galileo satellite will broadcast ten different navigation signals. The frequencies used by these satellites are between the range of 1.1 to 1.6 GHz band; a range of frequencies that are particularly well suited for mobile navigation and communication services (Agency, 2007). These signals make it possible for Galileo to offer services open services (OS), Safety of Life (SOL), commercial (CS) and public regulated services (PRS). The open services signal uses L1, E5A, and E5B as well as combinations such as using L1 and E5a for best ionospheric error cancellation. All satellites transmit signals at the same frequency, which are distinguished by receivers through the addition of a code to each signal. This code is different for each satellite and its design is one of many arts involved in making a good satellite navigation system (Agency, 2007).

By using many signals this allows the receiver to estimate the ionospheric delay errors. This error occurs when the signal is delayed when travelling through the ionosphere, which in turn makes the distance from the satellite to the user appear longer than it actually is which will lead to large positional errors if not corrected. Lower frequency signals experience longer delays than signals with higher frequencies. Therefore, by combining measurements to the same satellite at two different frequencies it is possible to produce another measurement where the ionospheric delay error has been cancelled out (Agency, 2007). The shape of the spectrum of the signal is due to the modulation adopted for Galileo. This modulation has been chosen to avoid interference with other satellite navigation systems such as the United States GPS system on the L1 band. The Modulation adopted is called BOC (1,1), which means Binary Offset Carrier of rate (1,1) (Agency, 2007). By adopting this modulation this ultimately allows both the GPS and Galileo systems to use the same frequency while avoiding mutual interference.

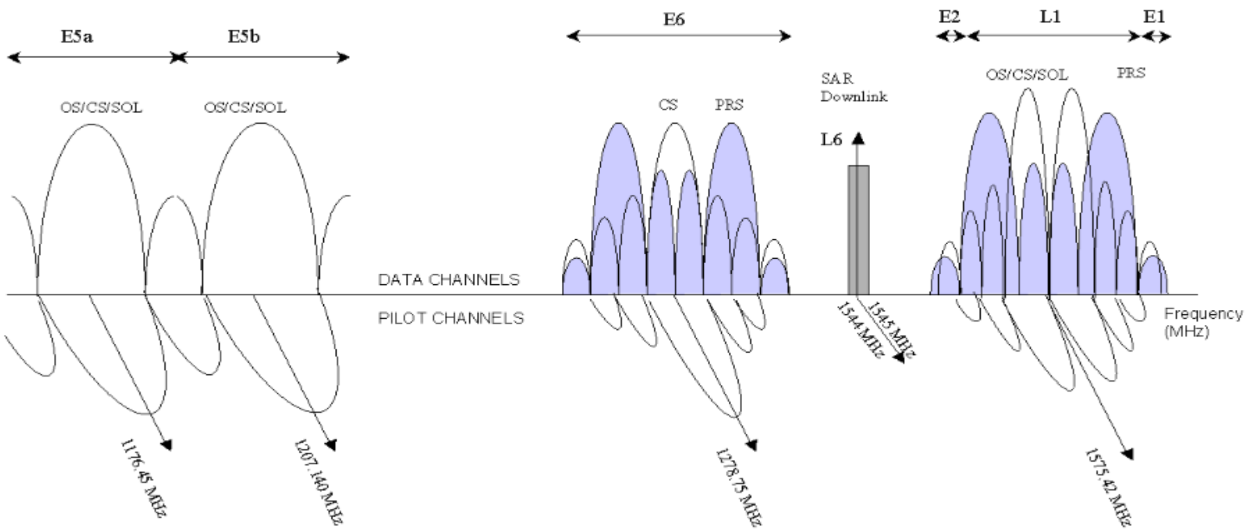


Figure 1.5 – Each Galileo Satellite will broadcast 10 different navigation signals (Agency, 2007).

Further to the above the Chinese Beidou-2 Navigation Satellite System consists of fourteen satellites providing service to most part of the Asia Pacific region since December 2012. This system is currently being upgraded and upon completion will consist of thirty five satellites providing open services to user's world-wide. This space segment consists of five Geostationary Earth Orbit satellites (GEO), five Inclined Geosynchronous Orbit (IGSO) and twenty four Medium

Earth Orbit (MEO) satellites (Office 2013). The GEO satellites operate in orbit at approximately thirty five kilometres and are positioned at 58.75°E, 80°E, 110.5°E, 140°E and 160°E respectively. The IGSO satellites operate with an orbital altitude of approximately thirty six kilometres and an inclination of fifty five degrees to the equatorial plane. Finally the Medium Earth Orbit satellites orbit at an altitude of twenty one kilometres and as with the IGSO satellites operate at fifty five degrees to the equatorial plane. The satellite recursion period is thirteen rotations within seven days (Office 2013). Beidou's current constellation of 5 geostationary, five inclined geosynchronous orbit and four middle earth orbiting spacecraft are transmitting open and authorised signals at B1 (1561.098 MHz) and B2 (1207.14 MHz) and an authorized service at B3 (1268.52 MHz) (Spirent, 2015). Figure 6 below shows Biedou-2 space augmentation.

Figure 1.6 – Chinese Beidou-2 Space Segment (Pace, 2010).

The Chinese Beidou system transmits signals in three different bands, these include the B1 (1561.098 MHz) and B2 (1207.14 MHz) and an authorized service at B3 (1268.52 MHz) (Pace, 2010). The B1, B2 and B3 signals are equivalent to the Galileo's E2, E5B and E6 signals respectively. The current (Phase II) B1 open service signal uses quadrature phase shift keying (QPSK) modulation with 4.092 megahertz bandwidth centred at 1561.098 MHz. The Beidou Phase III plan for the B1 civil signal calls for sifting to the L1 frequency centred at 1575.42 MHz and transmitting a multiplex binary offset carrier (MBOC 6,1,1/11) modulation similar to the modernized GPS civil signal (L1C) and the Galileo L1 Open Service signal (Spirent, 2015). The signals are based on the CDMA principle, the signals are highly complex like those of Galileo and the future GPS satellites. As mentioned previously the Chinese Beidou signals overlap with the Europeans Galileo GNSS system. This overlapping is convenient from a receiver's point of view, however it does raise the issue of inter-system interferences. The Chinese Beidou system is due to be fully operational with worldwide coverage by the year 2020.

2.3 Control Perspective

The GPS control segments consist of a global network of ground facilities that track the GPS satellites, monitor their transmissions, perform analyses, and send commands and data to the constellation. The current operational control segment includes a master control station, an alternate master control station, 12 command and control antennas, and 16 monitoring sites (Parkinson 2013).

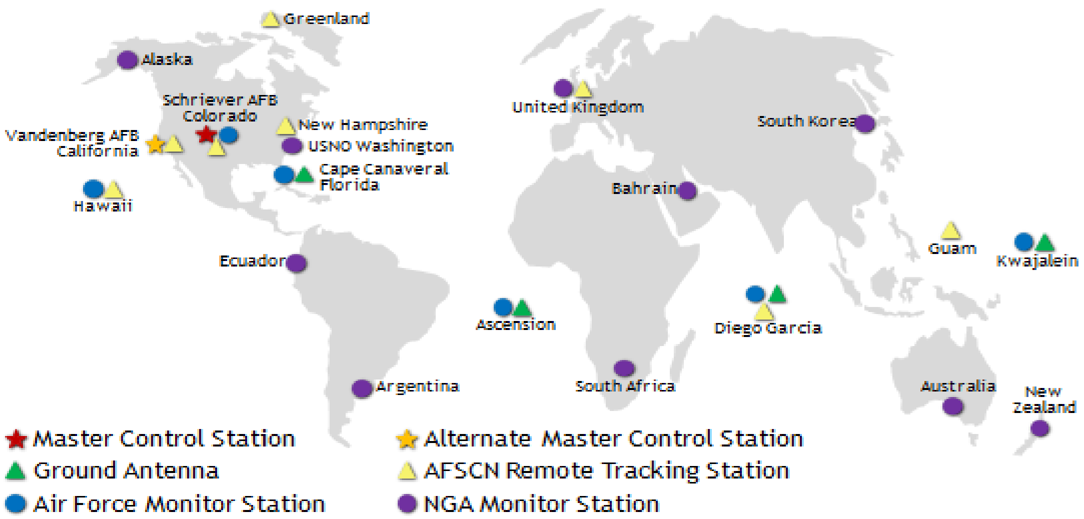


Figure 1.7 – United States GPS Control Segment (GPS.gov, 2015)

The master control station (MCS) located at the Schriever Air Force Base in Colorado is responsible for the overall management of the remote monitoring and transmission sites. It performs the primary control segment functions, providing command and control of the GPS constellation (GPS.gov, 2015). The MCS ensures the health and accuracy of the satellite constellation is maintained as well as generating and uploading navigation messages. It receives navigation information from the monitor stations, and utilizes this information to compute the precise locations of the GPS satellites in space, and then uploads this data to the satellites (GPS.gov, 2015).

Six monitor stations are located at Schriever Air Force Base in Colorado, Cape Canaveral, Florida, Hawaii, Ascension Island in the Atlantic Ocean, Diego Garcia Atoll in the Indian Ocean, and Kwajalein Island in the South Pacific Ocean. Six additional monitoring stations were added in 2005 in Argentina, Bahrain, United Kingdom, Ecuador, Washington DC, and Australia (Administration, 2014) this can be seen in figure 7 above. These monitoring stations are used to check the position, speed, altitude and the overall health of the orbiting satellites.

Furthermore, the control segment uses measurements collected by the monitor stations to predict the behaviour of each satellite's orbit and clock. The prediction data is up-linked, or transmitted, to the satellites for transmission back to the users (Administration, 2014). One monitoring station can track up to eleven satellites at any given time ensuring satellite orbits and clocks remain within acceptable limits. Each satellite is checked twice a day as they orbit around the earth by the monitoring stations and any variables caused by the gravity of the moon, sun and pressure of solar radiation are passed through to the MCS (Administration, 2014). There are four ground antennas located at Kwajalein Atoll, Ascension Island, Diego Garcia, and Cape Canaveral which are used to communicate with satellites for command and control purposes. These antennas also transmit correction information to individual satellites.

The Russian GLONASS ground control segment consists of a system control centre located in Krasnoznamensk, a network of five telemetry, tracking and command centres, the central clock located in Schelkovo near Moscow, two laser ranging stations as well as a network of four monitoring and measuring stations. The Figure 8 below shows the location of these control centres and stations (Agency, 2011b).

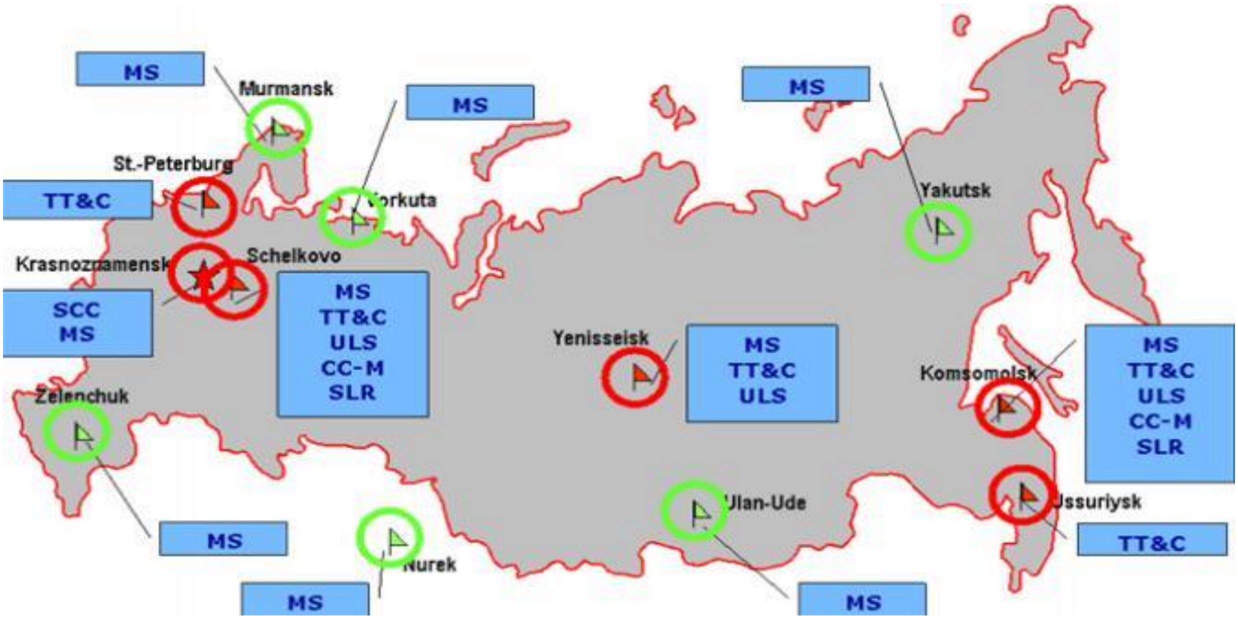


Figure 1.8 – Location of control and command centres and stations within Russia (Agency, 2011b).

This Ground control segment like the US GPS system is responsible for the proper operation of the GLONASS system, whereby it monitors the status of the satellites, determines the ephemerides and satellite clock offsets and uploads the navigation data to the satellites twice a day.

The ground control segment is responsible for Beidou satellite systems operation and control. Furthermore, it consists of the Master Control Station, Time Synchronization/Upload Stations (TS/US) and Monitor Stations (Office 2013). The main control station main tasks include collecting observation data from the TS/US and monitoring stations to process the data, perform mission planning and scheduling, observe and calculate satellite clock bias and finally to monitor the satellite payload and analyse anomalies (Office 2013). The TS/US is used to measure the satellite clock biases and upload satellite NAV messages. Furthermore, main tasks of monitor stations are to continuously observe satellite NAV signals, and to provide real-time data to the Master Control Stations (Office 2013).

The Beidou control segment is currently expanding as the Beidou-2 GNSS network evolves and is expected to be fully operational in the year 2020. Galileo will consist of two control centres and a global network of transmitting and receiving stations (Agency, 2011a). The two ground control centres (GCC) will manage control functions supported by a Galileo control system (GCS) and mission functions supported by a dedicated Galileo Mission System (GMS) (Agency, 2011a). The GMS will handle navigation system control while the GCS will handle spacecraft housekeeping and constellation maintenance (Agency, 2011a). As mentioned, and as with the other GNSS systems, the GCS is responsible for the management of satellites as well as constellation control. Its functional elements are deployed within the Galileo Control Centres (GCC) and the five globally distributed Telemetry Tracking and Control (TT&C) stations. To manage this, the GCS will use a global network of nominally five TTC stations to communicate with each satellite on a scheme combining regular, scheduled contacts, long-term test campaigns and contingency contacts (Agency, 2011a).

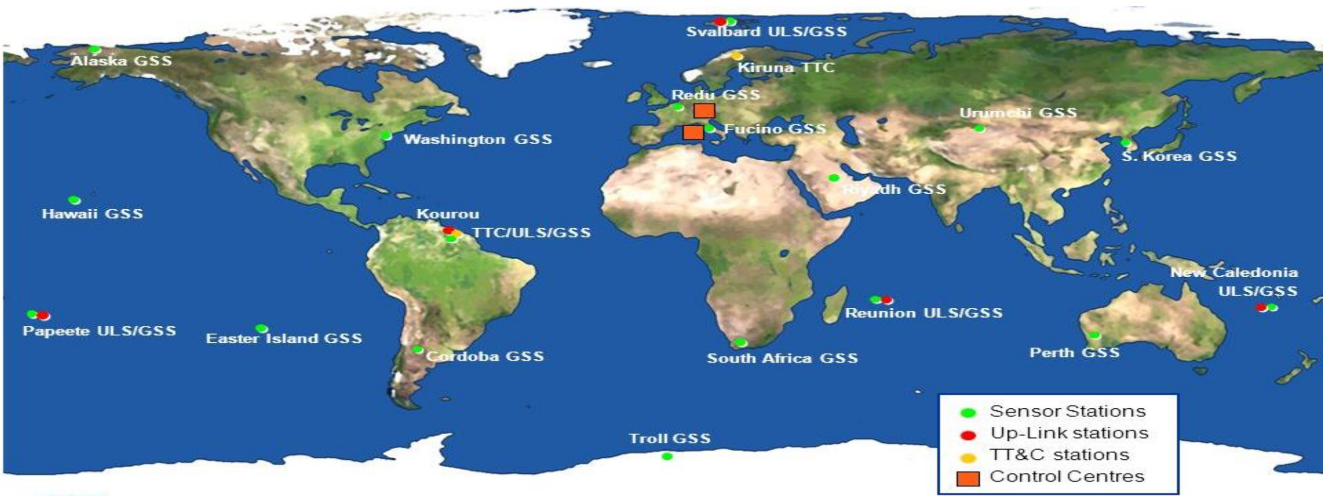


Figure 1.9 – Configuration of Galileo Ground Segment (Smet, 2009).

The Galileo GNSS system broadcasts a total a six signals supporting the public regulated services, commercial, open and safety of life services. Galileo runs a total of five different services which include:

- The Galileo Open Service (OS) data which is a free and open service with high accuracy, however the integrity or quality of information cannot be guaranteed. These are transmitted on the E5a, E5b and E2-L1-E1 carrier frequencies
- Commercial Service (CS) data which are transmitted on the E5b, E6 and E2-L1-E1 carriers. The signal supports precise local differential applications using the open signal overlaid with the signal on E6 as well as supporting the integration of the Galileo applications and wireless communication networks.
- Safety of Life Services (SoL) comprises signal reliability data at a universal level. This further includes integrity and Signal in Space Accuracy (SISA) data.
- Public Regulated Services (PRS) this service is intended for government, law enforcement, health services as well as a host of other industries, ultimately offering highly accurate and improved continuity of services. These signals are transmitted on the E6 and L1 carrier frequencies.

2.4 The User Segment

The User segment within the United States GPS Global Navigation Satellite System consists of the GPS receiver equipment, which receive signals from the satellites and uses the transmission to calculate the users three dimensional position and time on the earth's surface. This is very much similar with other currently available GNSS systems. Generally the user segment consists of hardware such as radio receivers, processors and antennas which are used to receive satellite signals and determine pseudoranges, and solve the navigation equations in order to obtain three dimensional coordinates and provide a very accurate time (GPS.gov, 2015).

2.5 Performance Analysis GNSS Systems Using PPP

Precise Point Positioning is a satellite based positioning technique aiming at high accuracies in close to real time. The technique is capable of producing these high accuracies of centimetre to sub centimetre positioning using a single GNSS receiver, eliminating the constraints of baseline length and simultaneous observations at both rover and reference stations (Katrin HUBER, 2010). It is a combination of the original absolute positioning concept and differential positioning techniques. PPP was developed based only on GPS observations, the accuracy, availability and reliability of positioning is dependent on the number of visible satellites at any given time. One way of ensuring an increase in availability of satellites is to integrate GPS and GLONASS observations. Today such integrations in Precise Point Positioning are available and will be discussed later on.

One negative factor to PPP is the fact that current commercial software does not provide processing of measurements taken using PPP techniques. Processing is usually done using scientific software or one of several online PPP services (K. Dawidowicz, 2014). The main challenge of dual frequency precise point positioning is that it takes up to thirty minutes to obtain a centimetre level accuracy. As mentioned, PPP is one of two techniques used for high accuracy GNSS based positioning with the other being the network based Real Time Kinematic (RTK). PPP is a powerful and efficient technology used for civilian and scientific applications worldwide. Although PPP has advantages such as high computational efficiency, not requiring dedicated reference stations it requires a long convergence time to achieve a desired accuracy (Pan Li 2014). The precise point positioning technique combines precise clocks and orbits calculated from a global network.

Pseudorange multipath and pseudorange noise are the largest remaining unmanaged error sources in PPP. It is believed that reducing the effects of multipath and noise on the pseudorange observable, accurate estimates of carrier phase float ambiguities will be attained sooner, ultimately reducing the initial convergence period of PPP (Garrett Seepersad, 2014). With the use of modernized GPS, Beidou, Galileo and GLONASS there are several advantages to be gained such as the availability of more visible satellites, greater signal power levels and more potential observable combinations, which may result in improved positional accuracy, availability and reliability. Both the pseudorange multipath and noise represent the largest remaining unmanaged error source in PPP. The amplitude of the multipath-induced errors in carrier phase observations is limited to a quarter wavelength or about 5 cm, but is typically well below 2 cm. Pseudorange multipath can have a magnitude of up to 10–20 m as it depends directly on the distance to the reflector. Currently, Hatch filtering is being performed in the position domain of the PPP software to mitigate pseudorange multipath and noise with minimal improvements in the rate of convergence (Garrett Seepersad, 2014). Pseudorange multipath and noise can be corrected using several different methods to ultimately reduce convergence times and increase accuracies.

The tables provided in Table 1 and Table 2 below are a summary of examined methods used to mitigate pseudorange multipath and noise by using both raw observable data and using the stochastically de-weighting observables respectively.

Table 2.1

Raw pseudorange correction	Same day	Running averaging
Multipath	Yes	Yes
Noise	Yes	Yes
Real time	No	Yes
Extra data required	Yes	No
Complexity	High	Medium
Limitations	Post-processing required	Filter has a convergence period
% datasets improved	57	48

Table showing Summary of examined methods to mitigate pseudorange multipath and noise by correcting the raw observables (Garrett Seepersad 2014).

Table 2.2

Stochastic de-weighting	Multipath weighting	Elevation weighting
Multipath	Yes	No
Noise	Yes	No
Real time	Yes	Yes
Extra data required	No	No
Complexity	Medium	Low
Limitations	Increased complexity	Too general
% datasets improved	34	–

Summary of examined methods to mitigate pseudorange multipath and noise by stochastically de-weighting observables (Garrett Seepersad 2014).

Multipath linear combination is used as shows in the tables above, through correcting the raw pseudorange observable through direct methodology, and the second being through stochastically de-weight pseudorange observables. Through both these methods it was found through testing from Garrett Seepersad and Sunil Bisnath throughout their paper 'Reduction of PPP convergence period through pseudorange multipath and noise mitigation' that minimal improvements were noted using the multipath observable from the previous day. Using multipath from the same day was possible in real time and post processing modes which had an improvement rate of convergence for forty eight and fifty seven percent respectively, with an improvement in rate of convergence for thirty four percent of data was observed when pseudorange measurements were stochastically de-weighted using the multipath observable (Garrett Seepersad, 2014). Datasets with no improvements from directly correcting the raw pseudorange observables (43%) or stochastically de-weighting the pseudorange observables (66%) presented similar quality of results as the conventional PPP solution (Garrett Seepersad, 2014).

PPP is a cost effective technique enabling static, sub-centimetre horizontal and few centimetre vertical positioning with a single GPS receiver, unlike other methods such as relative GPS, RTK and Network RTK which require multiple receivers. PPP is used for processing static and kinematic data, both in real-time and post-processing. The downside however is the fact that PPP requires a lengthy initialisation period for the carrier phase ambiguities to converge to stable values and for position solution to reach its optimal precision (Garrett Seepersad, 2014).

2.6 Quality of AUSPOS Online PPP Software Coordinates

It has been documented by Geoscience Australia (GA) that the quality of computed coordinates using online PPP software will be dependent on a number of factors, including the proximity of International GPS (IGPS) station, the quality of these IGPS orbit products and finally the quantity of data submitted. According to GA observing for a period of twenty four hours using a single receiver should provide the user with an accuracy of approximately 0.010m and 0.030m in both the horizontal and vertical positioning respectively. Further, an approximation has been made for observation logging times of less than twelve hours may produce accuracies in horizontal and vertical positioning of 0.020m and 0.050m respectively. These approximations will be tested for accuracy and analysed in later chapters.

Further, research into the quality of vertical data provided by online PPP with particular focus on the AUSPOS software found that the heights that are derived from AUSPOS will not be precisely matched to the Australian Height Datum (AHD) data provided by SCIMS. This is because AUSPOS computes the AHD value by subtracting the AUSGeoid98 site value from the processed ellipsoidal height. This will provide an approximation of AHD levels however unfortunately is not near to exact values. To increase this accuracy GA recommends that if the station is greater than one hundred kilometres from the nearest IGS station, a longer observation period will increase the accuracy of three dimensional coordinates.

2.7 Differential GNSS (DGNSS)

Four simultaneously measured pseudoranges are required to mitigate for the four unknowns at any given time, which are the three components of position as well as clock bias. Geometrically this is achieved by a sphere being tangent to the four spheres defined by the pseudoranges. The centre of the sphere resembles the unknown position with its radius representing the range correction caused by the receiver clock errors (Bernhard Hoffmann-Wellenhof, 2008). In two dimensional case only 3 satellites are required, as can be seen in figure 10 below.

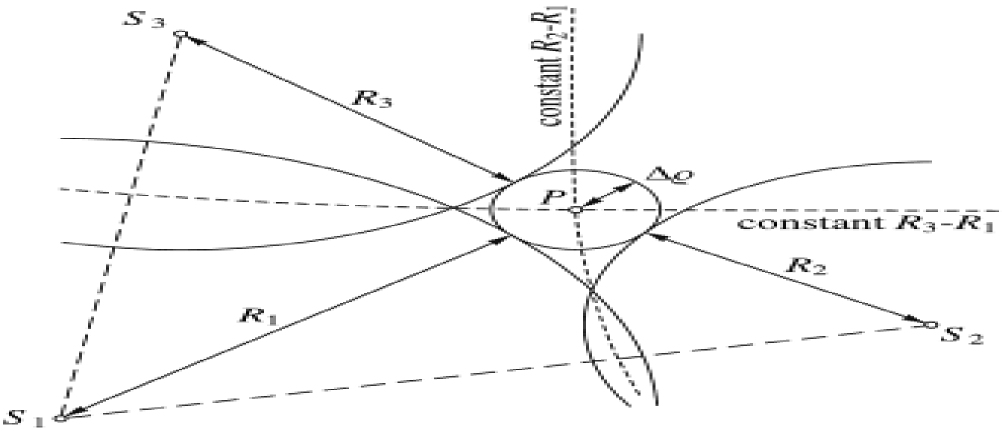


Figure 2.1 – Two dimensional pseudorange positioning. Centre of sphere is unknown position with radius representing range correction, calculated using three satellites (Bernhard Hoffmann-Wellenhof, 2008).

Differential GNSS requires one or more observations to base stations with known coordinates with the data than processed by differencing pseudo-range or carrier phase observations for all stations, which can be single, double or triple differencing.

Single differencing takes simultaneous measurements to one satellite from two different receivers reducing satellite clock and orbiting errors as well as reducing atmospheric errors in shorter baselines. Double differencing is where observations are taken to two different satellites by two receivers simultaneously. A single difference is undertaken for each satellite between the observed differences observed by receiver one compared with that observed by the second receiver. This process eliminates satellite and receiver clock errors as well as the reduction and in many cases elimination of orbital errors and atmospheric variables. Finally, triple differencing is performed by taking the difference between two double differences separated by a time interval, eliminating all clock bias errors and the integer ambiguity as well as atmospheric delay errors, reducing satellite ephemeris.

2.8 Chapter Summary

The use of GNSS is becoming more dependent upon throughout our daily lives. These systems are used for many different applications ranging from transport such as automobiles, aircraft, boats, ships, cyclists as well as a host of other applications, perhaps more importantly the surveying and mapping industries.

There are four main GNSS systems in operation today, however these are not the only systems online. Systems such as the Japanese Quasi Zenith Satellite System (QZSS) currently servicing the East Asia and Oceania region and undergoing an upgrade may very well become a major supplier of Global Navigation Satellites Systems universally available within the next few years. Global Navigation Satellite Systems consist of three major components or segments. These segments are known as the space segment, control segment and user segment. Each and every GNSS system must contain these components or segments to be able to function and missing any one of these segments will result in the total collapse and failure of the system. Each and every system orbits there satellites at different orbital planes spread at slightly different angles to one another.

Precise Point Positioning is a technique used to try and achieve high accuracies in close to real time. The technique has become quite popular as it is capable of producing these high accuracies of centimetre to sub centimetre positioning using a single GNSS receiver compared with differential positioning techniques. There are however negatives with this technique, the major issue being the length of time observations required to achieve centimetre level which at times may take in excess of thirty minutes. This unfortunately makes using the PPP technique unrealistic to use in real time, however where positioning may not be achieved due to lack of satellite visibility, and insufficient control quality within close proximity, this technique will provide the user with accurate reliable data where they may not have been in a position to do so using differential techniques. The combination of GNSS systems however hopes to overcome this issue and provide users with an alternative to differential positioning techniques as well as reduce time consumption and accuracy.

Chapter 3 – Methodology

3.1 Introduction

Although GNSS are currently in use and heavily relied upon within the surveying industry, particularly the construction, infrastructure and civil sectors, the technical aspects of these systems including their performances within robust and diverse terrain are usually misunderstood. Surveyors will at some stage throughout there working careers work with GNSS systems and it is imperative that these systems are understood.

On this, the aim of the project is to provide relevant technical information on the performance of GNSS systems and their accuracies, both through single GNSS system and a combination of systems to test whether these combinations achieve quicker convergence, accuracy and reliability compared with the use of only a single system.

The chapter further details the testing methods adopted, the equipment that will be utilised, site locations, and the processing service chosen to reduce the static observations. To achieve this testing, single GNSS receivers were used to record static satellite observation data over known geodetic quality coordinated points. The data is than submitted as a RINEX file to AUSPOS, a free processing service available to users online.

With the Beidou and Galileo systems currently in the upgrading stage before they are fully functional and universally accessible, the performance analysis using the Precise Point Positioning Technique as well as the testing of stand-alone verse combined GNSS systems will be completed with a focus on the United States NAVSTAR Global Positioning System (GPS) and the Russian GLONASS navigational systems.

This chapter will ultimately allow the viewer to understand how the project was developed and the testing procedures adopted. It will further provide the reader with an understanding of how the method will allow for the gathering of suitable and sufficient data in order to evaluate the performance of standalone verse combined GNSS systems.

3.2 Project Constraints

There are several factors that need to be taken into consideration for a suitable experimental design required for this study. These consideration governed the office and field equipment used as well as the survey marks selected for testing.

Survey marks with the highest possible positional quality have been chosen in order to obtain and compare the derived solution for accuracy. The survey marks chosen have a derived survey of Class A and above which according to the New South Wales Government Land & Property Information (LPI) are geodetic survey quality, which is ultimately the minimum standard acceptable when selecting suitable marks for testing.

To ensure multipath is eliminated from observations, the geodetic survey stations used require a clear, uninterrupted vision to the sky, be clear of obstruction and free from any potential causes of multipath. Further, as the stations will be occupied over prolonged periods of time it is necessary to ensure that the sites chosen are deemed safe for leaving survey equipment on site without the threat of interference or damage. Due to the fact a minimum of two receivers are required to collect data simultaneously it is imperative that the two geodetic stations chosen are within close proximity to one another to ensure travel time between sites is achieved in a reasonable time, as well as minimize the effect of any potential atmospheric discrepancies between the sites. This requirement as mentioned, is due to the desire to carry out concurrent measurements and ensure logistical challenges of operation between one site and the other are overcome. By adhering to the above constraints and solutions this will enable the best chance of obtaining reliable accurate data, ultimately leading to accurate and precise solutions.

The equipment used has been restricted to availability and access provided by Ultimate Positioning Group Pty Ltd. Only two trig stations will be used for survey and data collection due to the limited availability of receivers and geodetic quality control marks deemed suitable for use given the above constraints. The two trig stations chosen are 20km apart and travel between sites will take approximately half an hour satisfying the given constraints.

3.2.1 Equipment

Two Trimble R10 GNSS receivers utilising Trimble Access Version 2015 Firmware 3.0.2 have been made available by Ultimate Positioning Group Pty Ltd for use during the data collection process of the experiment. Further to the receivers, two tribrach's are required to mount the receivers onto the trig stations. The receivers will be placed at the two trig station locations chosen for observation and data collection. Trimble Business Centre (TBC) software will be used to convert the raw field data observed by the receivers into a Receiver Independent Exchange Format (RINEX) file, which is the format required for processing using the free online PPP software AUSPOS.

3.2.2 Field Method

According to the Intergovernmental Committee on Surveying and Mapping (ICSM), Guideline for Control Surveys by GNSS, Special Publications (SP1) the minimum required observation epoch to be no less than thirty seconds in order to achieve a nominal level of survey uncertainty (SU). This is SU<15mm for the horizontal position and SU<20mm for the vertical position better known as the ellipsoid height (Mapping, 2014). The length of time required for accurate horizontal positioning is between the range of six to twenty four hours, and a minimum of twenty four hours for height. Through testing, Ebner and Featherstone conclude that observations with a length of two days or more were required to achieve accurate and reliable results (Ebner, 2008).

Further, it was found through Martin et al (2011) that a, minimum of twelve hours was required for accurate horizontal positioning, and twenty four hours continuous measurements for accurate vertical positioning which reflects the recommendations set out by the ICSM. The two testing methods and results achieved by the two studies show conflicting recommendations, and this study will aim to resolve or at the very least confirm these recommendations. With a restriction on equipment availability and time constraints, the study will focus on the ICSM and Martin et al (2011) recommendations.

Each trig station for this study was occupied with a receiver for a twenty four hour period at an observation epoch of thirty seconds remaining consistent with recommendations done in previous studies, providing consistent comparable data. Occupations have be undertaken on two separate dates for each site to test repeatability. The observations at each site have been taken simultaneously ultimately ensuring the isolation of effects of error. Although the ideal scenario requires several receivers recording simultaneously through stand alone, followed by simultaneous occupations of combined GNSS, due to constraints around equipment availability and time frame, only two receivers may be used and hence, one receiver will be observing GPS only data while the other receiver will read a combination of GPS, GLONASS and Beidou satellites, eventually comparing the accuracy and precision of standalone vs combined GNSS.

As mentioned, due to constraints around the availability of GNSS receivers and time limitations, a third station was occupied by both GPS and GNSS receiver for a total of four 12 hour periods. Hence, standalone and GNSS observations were taken in two 12 hour blocks each, over two consecutive days.

3.2.3 Survey Trig Station Sites

The trig station sites were chosen with several elements in mind including accessibility, distance between each station to minimise travel time, positional location for best possible quality of signal, and the quality and accuracy of marks provided from LPI which meet the standard required for testing, in this case the stations have a Class A accuracy.

Cromer Heights Trig Station – TS10447 CROMER HEIGHTS [P]

GDA94 - CLASS A – ORDER 1 – High precision National Geodetic Survey

Published coordinates as at 26th August 2015

MGA56 Easting: 338387.374   Northing: 6266328.481

AHD71 - Class B – Accurate AHD

AHD71 RL 157.345

Figure 3.1 – Aerial Photo of Cromer Heights Trig Station set atop cliff face clear of obstruction.

Carrol Trig Station – TS1421 CARROL [P]

GDA94 - CLASS A – ORDER 1 – High precision National Geodetic Survey

Published coordinates as at 26th August 2015

MGA56 Easting: 332106.053   Northing: 6265786.668

AHD71 - Class B – Accurate AHD

AHD71 RL 165.773

Figure 3.2 – Aerial Photo of Carrol Trig Station set next to fire trail, showing light canopy cover.

Mccowen Trig Station – TS3018 MCCOWEN [P]

GDA94 - CLASS A – ORDER 1 – High precision National Geodetic Survey

Published coordinates as at 26th October 2015

MGA56 Easting: 339054.780   Northing: 6273146.719

AHD71 - Class B – Accurate AHD

AHD71 RL 183.550

Figure 3.3 – Aerial Photo of Mccowen Trig Station set atop of rock cliff clear of obstruction and potential object interference.

3.3 Data Processing

3.3.1 Raw Data

The Trimble R10 receivers were set up to record and log the raw data in Trimble T02. This extension is than converted from the T02 file into a RINEX .15o extension file to enable compatibility with AUSPOS. In order to achieve this, the T02 is reduced in Trimble Business Centre software, before being edited and converted into the appropriate extension for reduction in online processing software AUSPOS. Upon conversion to RINEX, a twenty four hour solution will be provided for each field data file which will be used to compare and analyse the results between each other and known SCIMS coordinates. These observations will be further decimated into 1, 2, 6, 12 and 24 hours to test for convergence times and consistency in results.

3.3.2 Processed Data

In order to fulfil the commitments of the project, taking into consideration time constraints, the data will be processed using one single online service provider AUSPOS. Although it would have been ideal to process the data through several different online providers, this single provider and results provided will suffice the objectives of this research, maintaining consistency and accuracy of results provided.

3.3.3 Online PPP Post Processing Services – AUSPOS

AUSPOS is a free online GNSS data processing service provided by Geoscience Australia. The software takes advantage of both the International GNSS Service (IGS) stations network, and the IGS product range and works with data collected anywhere on earth (Australia, 2015). The user submits their raw static data as a RINEX file, where the observations are reduced and results are sent back to the user via email. The service utilises Bernese GNSS software and processing GPS data only. All computations are completed using this software. The Bernese system is geodetic parameter determination software system with high precision orbit parameters, earth orientation parameters and coordinate solution IGS products are used. It uses the RINEX raw data provided by the user as well as the fifteen nearest IGS and Asia Pacific Reference Frame (APREF) stations for reference stations and employs the double differencing technique in order to determine a precise solution. Coordinates of the IGS stations are constrained with uncertainties of one millimetre in the horizontal and two millimetres for the vertical. The figures 11 and 12 below shos the world wide positioning of IGS reference stations and APREF network in Australia respectively.

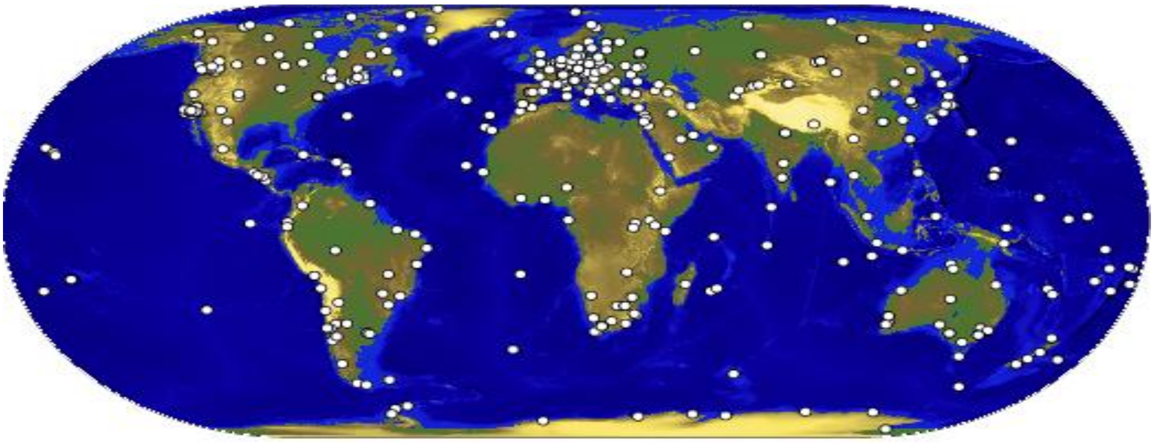


Figure 3.4 – IGS Tracking Network (Australia, 2015).

Figure 3.5 – APREF CORS Network in Australia – Pacific (Australia, 2015).

Observation error sources and there effects are taken into account either through modelling or estimation of related parameters. These error sources include such things as receiver clock errors, ionosphere and troposphere errors. All computation completed by AUSPOS are undertaken according to International Earth Rotation and Reference Systems Service (IERS) conventions. Further, all coordinates are computed in International Terrestrial Reference Frame 2008 (ITRF2008), with Australian users being provided with Geocentric Datum of Australia 1994 (GDA94) coordinates. These GDA94 coordinates are determined by an AUSPOS derived ITRF to GDA transformation model with the accuracy of this transformation being sub centimetre

(Australia, 2015).

3.3.4 Data Comparisons

Data analysis and comparisons of results were made in order to analyse and assess the performance of single and combined GNSS observations. These comparisons were made at the one, two, six, twelve and twenty four hour marks. The aim of this data analysis is to compare the performance of standalone verse combined static GNSS observations and results over periods of time, providing the user with greater knowledge and confidence.

Raw data observations were taken on two separate days over a combined forty eight hour period, in order to examine the extent satellite configuration, atmospheric and multipath affect the accuracy and precision of single and combined GNSS systems. The dissected observation files of both GPS and combined GNSS are processed and compared for precision and accuracy based on a twenty four hour observation period as mentioned previously.

3.4 Chapter Summary

This chapter has presented the reader with an outline on how the method for testing was established and how the resulting data will enable the comparison of accuracy, precision, convergence time and performance of standalone Global Navigation Satellite Systems verse combined GNSS. The following Chapter will exam the results of the experiment and provide the data necessary to evaluate performance and develop conclusions.

Chapter 4 – Results

4.1 Introduction

In this chapter, solutions obtained from the AUSPOS online post processing software will be compared in order to assess the various comparisons outlined in the aims and objectives earlier in the dissertation.

The result of these twenty four hour observations will be processed and presented as the best case solutions, ultimately creating a baseline of data where comparisons will be made between solution variations. Further, the results will be presented based on data types of GPS verse a combination of Global Navigation Satellite Systems. The results provided within this chapter will form the basis from which both comparisons and data analysis will be reviewed in chapter five.

At the conclusions of this chapter it is expected that the reader should have an understanding of solution bias, an overview of similarity in results obtained and the comparison between the SCIMS network and the solutions obtained.

4.2 Processed Solutions

AUSPOS provides solutions in both the GDA94 and MGA coordinate systems. The SCIMS coordinates provided are also in MGA format. Both the horizontal and vertical positioning provided by these two systems will be compared to one another. The vertical positioning will be in relation to the Australian Height Datum 1971 (AHD71). Further, the GPS only and combines GNSS observations will be compared to one another to analyse whether these systems provide similar or varying solutions.

4.3 Twenty Four Hour GNSS Observation Results (TS1421)

The following information presents the processed 24 hour observation files for the combined GNSS system. Solutions for the 24 hour observation files were obtained using the AUSPOS online processing software. The solutions have been compared with the known SCIMS coordinates provided from the LPI website, as well as a further comparison between the two reduced field files, testing convergence times, repeatability, accuracy and performance of combined systems.

4.3.1 Carrol Trig Station (TS 1421) 24 hour combined GNSS observation solutions.

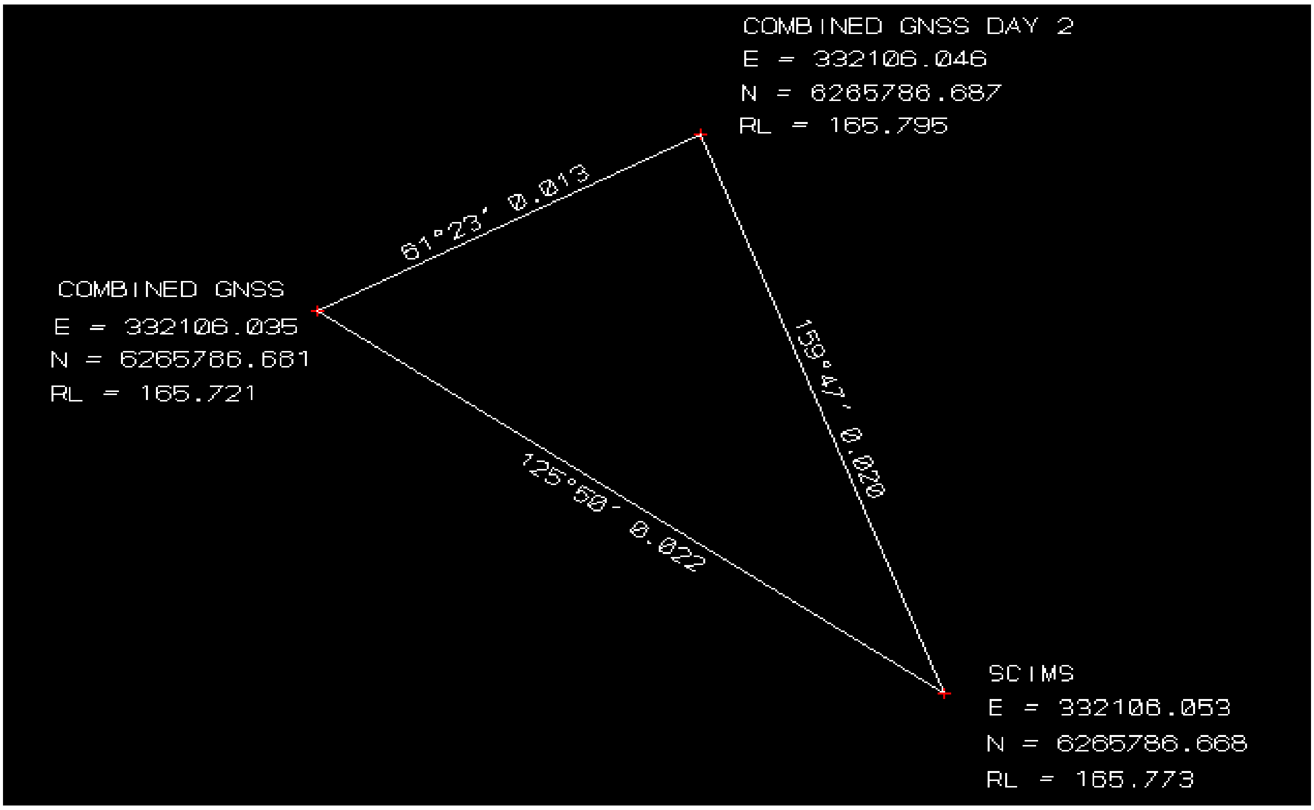


Figure 4.1 – Visual Comparison of TS 1421 SCIMS Coordinates and the combined GNSS solutions provided by AUSPOS for data observed on two separate dates at the Carrol Trig Station (TS 1421).

Figure 4.1 shows the separation between the SCIMS MGA coordinates, as well as the combined GNSS field observation coordinates provided by the online post processing software AUSPOS for both day one and day two observations taken within 3 weeks of one another. These solutions have been obtained and processed over a twenty four hour period. Tables 4.1 and 4.2 below show the comparisons between the twenty four hour observations decimated into the hourly time slots as mentioned above against the values of the known Carrol trig station coordinates. A further comparison was made between the two field data solutions obtained by AUSPOS to test for accuracy, precision and repeatability of data. This comparison can be seen in Table 4.3.

4.3.2 GNSS Vs TS1421

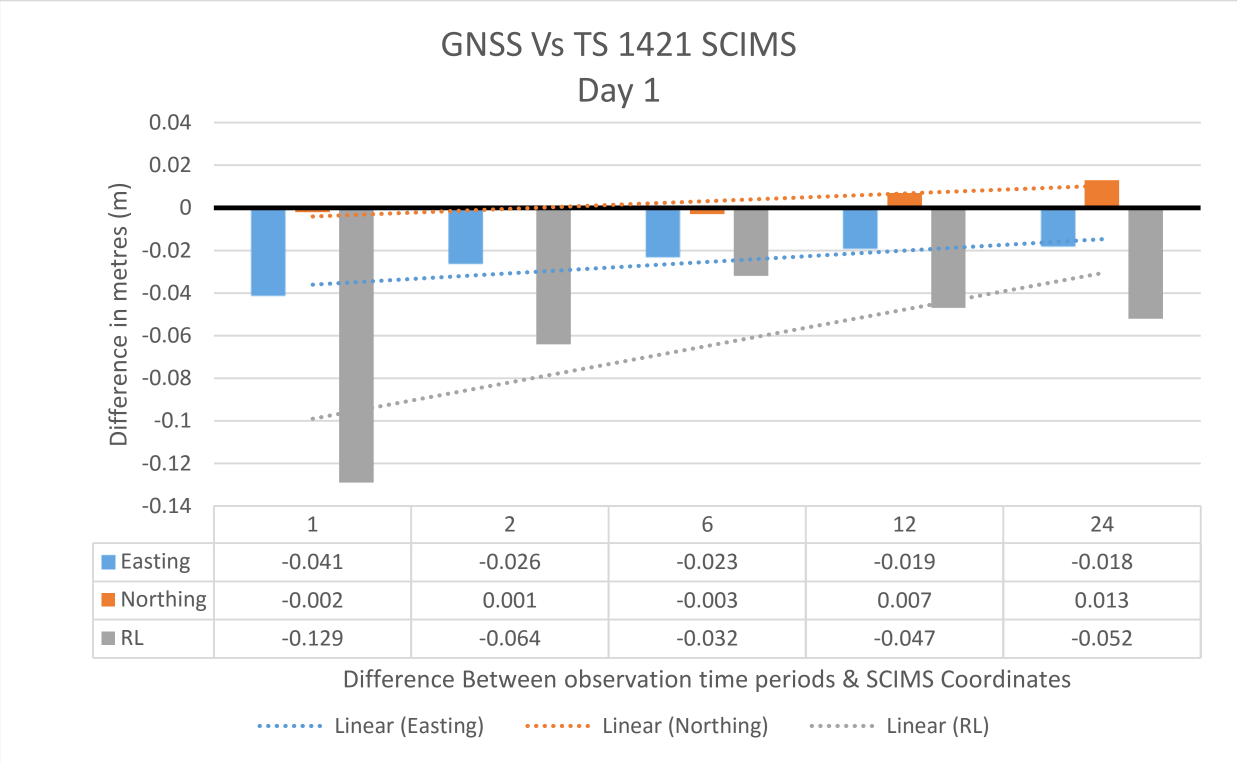
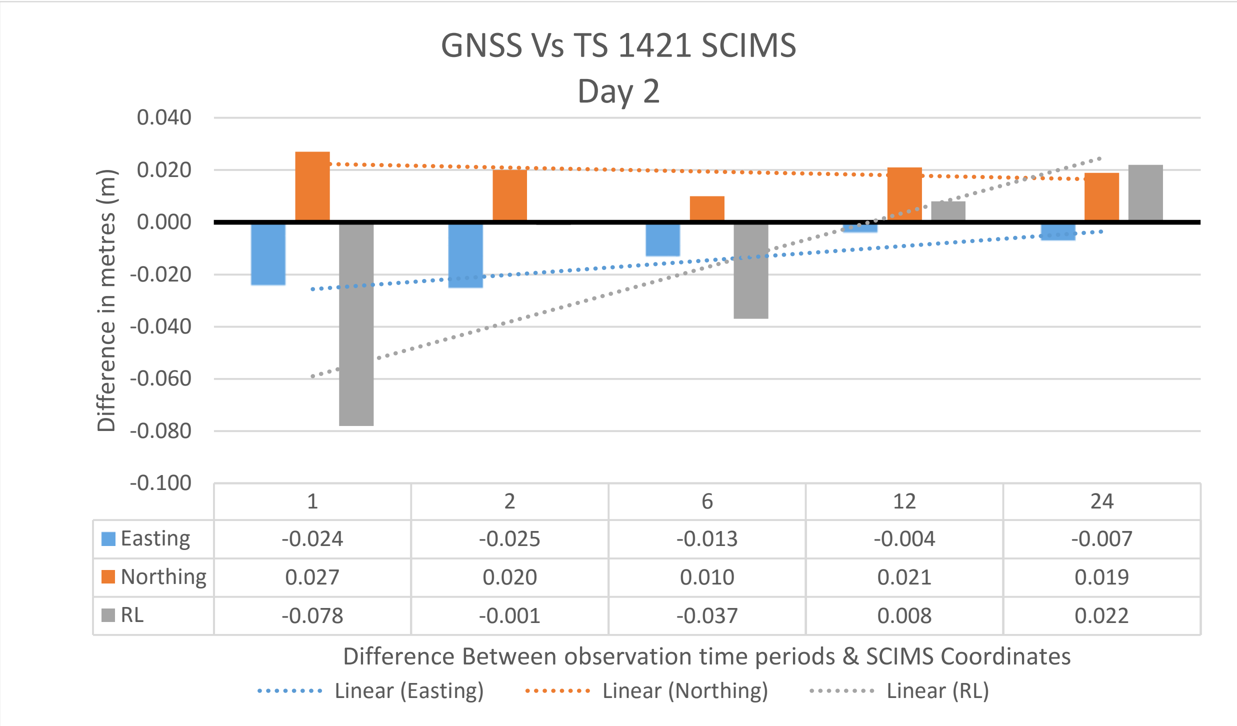


Table 4.1 – GNSS AUSPOS solutions Vs TS 1421 SCIMS coordinates.

The results above show a comparison between the known TS 1421 trig station and solutions provided by AUSPOS. As we can see the solution at the twenty four hour mark are -0.018m and 0.013m in Easting and Northing respectively. We can see from the linear trend lines depicted above, that these lines are converging toward the zero line as observation time increases, indicating an increase in accuracy and reliability with prolonged observations. This is consistent with previous tests and studies completed.

4.3.3 GNSS Day 2 Vs TS1421

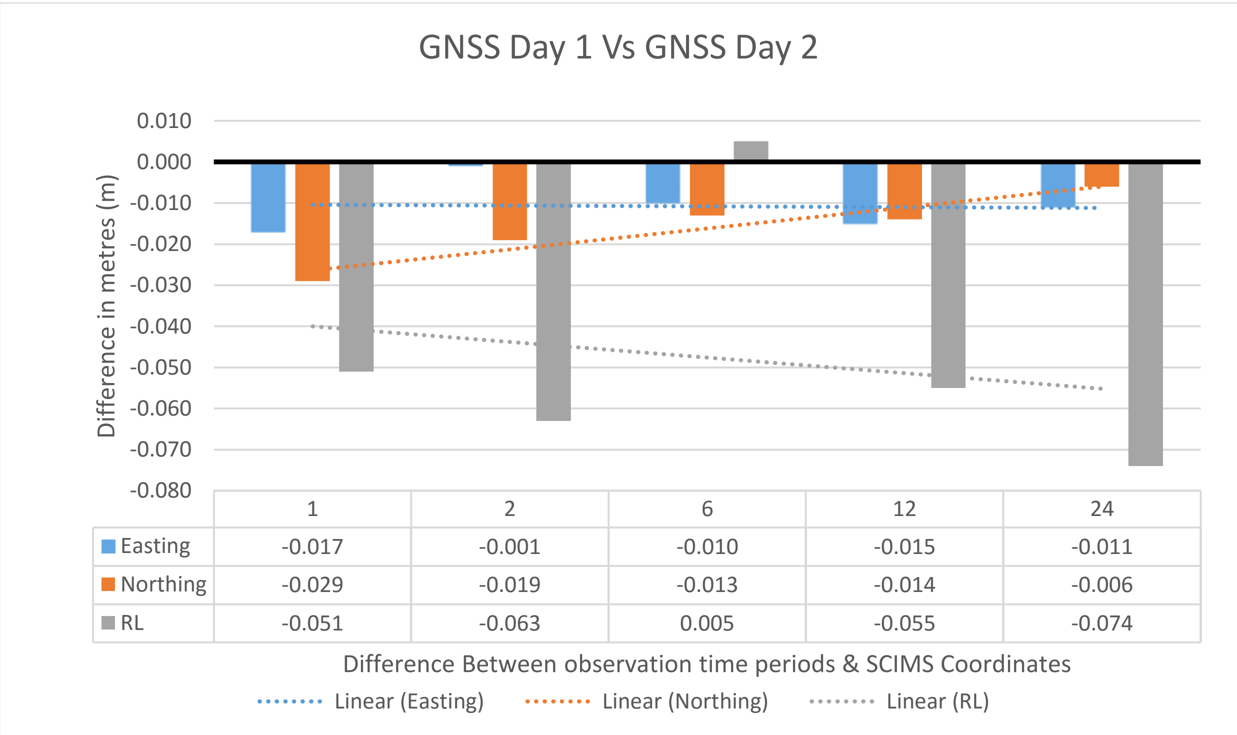


	1	2	6	12	24
Easting	-0.024	-0.025	-0.013	-0.004	-0.007
Northing	0.027	0.020	0.010	0.021	0.019
RL	-0.078	-0.001	-0.037	0.008	0.022

Table 4.2 – GNSS AUSPOS solutions Day 2 Vs TS 1421 SCIMS coordinates.

The results above show similar results to field tests completed in day one. Results appear to increase in accuracy with longer observation times in particular with the solutions obtained for AHD heights.

4.3.4 GNSS Day 1 Vs GNSS Day 2 Solutions



	1	2	6	12	24
Easting	-0.017	-0.001	-0.010	-0.015	-0.011
Northing	-0.029	-0.019	-0.013	-0.014	-0.006
RL	-0.051	-0.063	0.005	-0.055	-0.074

Table 4.3 – GNSS Day 1 Vs GNSS Day 2.

Table 4.3 provides a comparison between the two independent field observations completed over the Carrol trig station. As expected we can see that the largest residuals occur within the one hour observation time and gradually reduce as observation time's increase. There is a spike in the AHD RL row at the six hour observation time we see that this is not consistent with the vertical results at the other hour intervals. Data was processed for a second time to ensure no entry or user error was made, and the same results were achieved.

It is therefore possible that this outlier was a result of multipath error, due to the light overhead canopy over base station, or interference by a foreign object such as a bird or other object of some sort interfering with the receiver signal. Further, the outlier may have been the result of solar activity, and as both the standalone and combined sessions were conducted concurrently this result will be compared with that of the standalone at the six hour mark to find out whether or not solar activity may have indeed played a role or interfered with the result.

What has been made clear from the results provided above is the fact that the horizontal accuracy and precision improved with longer observation times, which is consistent with previous studies and assumptions made prior to undertaking these tests. The difference in horizontal positioning between the two field data files after twenty four hours of observation were -0.011m and -0.006m in Easting and Northing respectively, remaining consistent with recommendations and assumptions made by the ICSM. Having said this, it is quite surprising considering my initial expectation prior to undertaking field observations was that the solutions derived between the 24hour solutions would be quite similar, <10mm in horizontal positioning to the SCIMS coordinates provided for TS 1421. This will be further assessed with the GPS only solutions.

Through analysing the results above there appears to be a bias toward the North and South using AUSPOS. This cannot be certain at this point, and further comparisons will be made with additional field tests to see whether or not a consistent pattern arises with the results indicating a bias in solution.

A comparison will be made between the above GNSS solutions and the GPS solutions provided below to test whether these systems provide higher accuracies and precisions to the standalone system.

4.4 Twenty Four Hour GPS Observation Results (TS 10447)

The following information presents the processed 24 hour observation files for the standalone GPS system. Solutions for the 24 hour observation files were obtained using the AUSPOS online processing software. The solutions have been compared with the known SCIMS coordinates provided from the LPI website, as well as a further comparison between the two reduced field files, testing convergence times, repeatability, accuracy and performance of single systems.

4.4.1 Cromer Heights Trig Station (TS 10447) 24 hour GPS observation solutions.

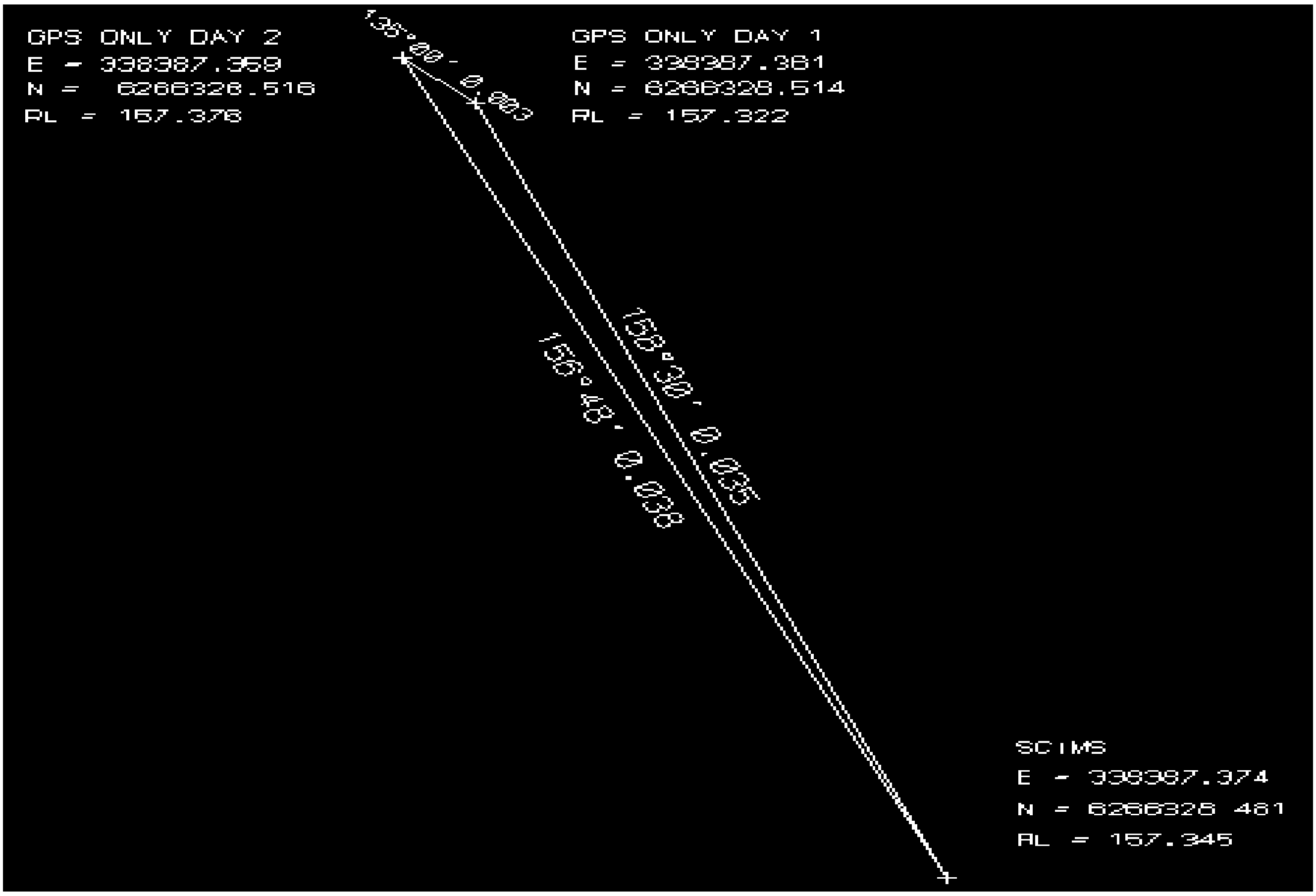
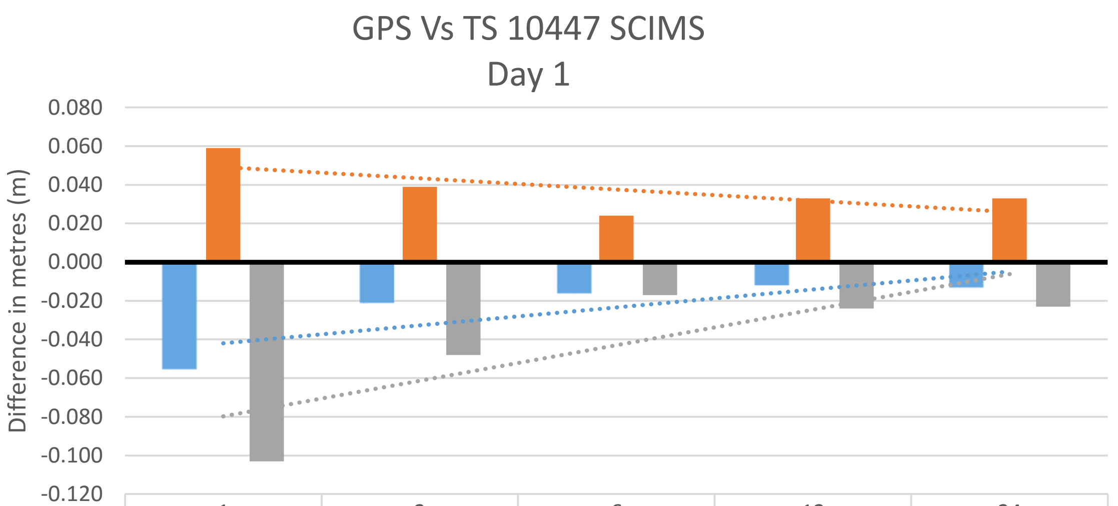


Figure 4.2 – Visual comparison TS 10447 SCIMS Coordinates and the GPS only solutions obtained by AUSPOS for data observed on two separate dates at the Cromer Heights Trig Station.

Figure 4.2 shows the separation between the TS 10447 SCIMS MGA coordinates, as well as the GPS only field observation coordinates provided by the online post processing software AUSPOS for both day one and day two observations taken within 3 weeks of one another. These solutions have been obtained and processed over a twenty four hour period.

Tables 4.4 and 4.5 below show the comparisons between the twenty four hour observations decimated into 1, 2, 6, 12 and 24 hour time slots, against the values of the known Carrol trig station coordinates (TS 10447). A further comparison was made between the two field data solutions obtained by AUSPOS to test for accuracy, precision and repeatability of data. This comparison can be seen in Table 4.6.

4.4.2 GPS Day 1 Vs TS10447



	1	2	6	12	24
Easting	-0.055	-0.021	-0.016	-0.012	-0.013
Northing	0.059	0.039	0.024	0.033	0.033
RL	-0.103	-0.048	-0.017	-0.024	-0.023

Table 4.4 – GPS AUSPOS solutions Vs TS 10447 SCIMS coordinates.

The above results are consistent, to within <10mm of the results achieved when comparing between the GNSS solutions and its respective receiver. These observations were observed concurrently with the above GPS only field observations, ensuring any atmospheric conditions which may impact on results obsolete, providing a solid base on which results may be accurately and reliable compared. The results thus far provide an interesting insight into the reliability and perhaps accuracy of the known coordinates provided by SCIMS. This may however, be coincidence and will be revisited once further results have been reduced and analysed.

Further to this, we can see through analysis of results above that they remain consistent with the combined GNSS systems, in the fact that positional accuracy and residuals decrease with increased observation times. It also shows residuals to be larger than the combined GNSS results in the first hour of observations which is most probably due to slower convergence time compared to combined systems.

4.4.3 GPS Day 2 Vs TS10447

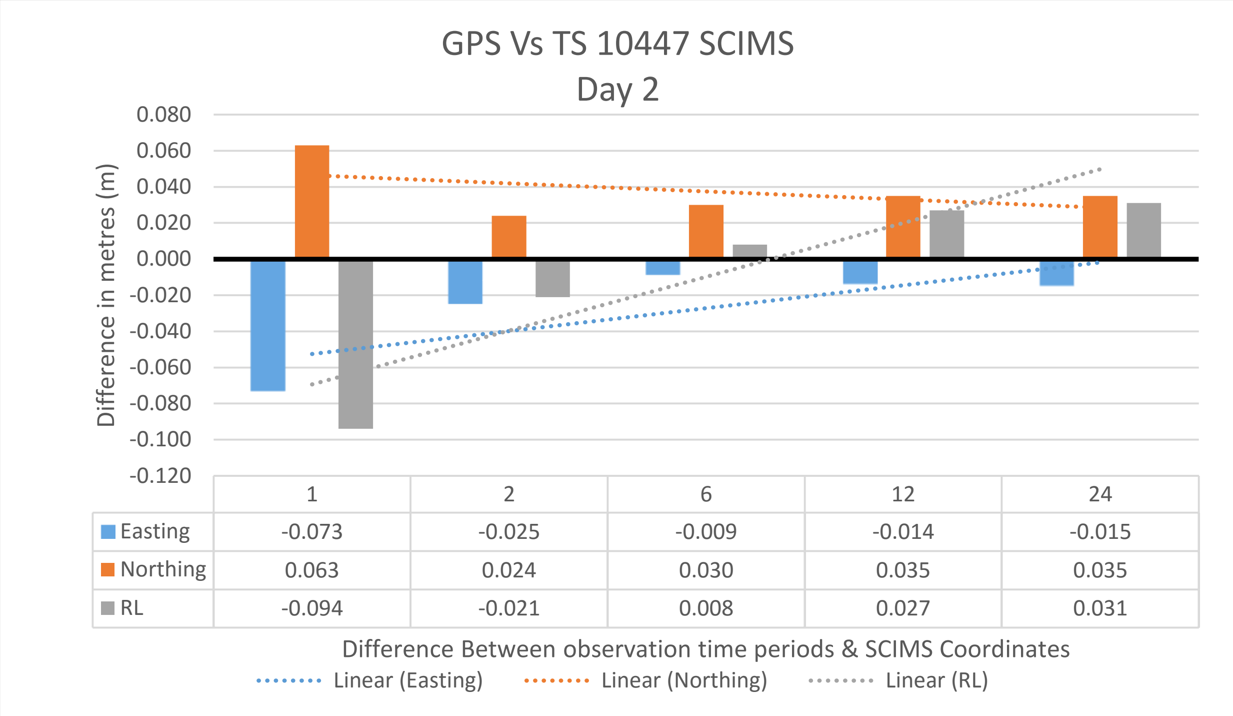


Table 4.5 – GPS AUSPOS solutions Day 2 Vs TS 10447 SCIMS coordinates.

The above results are quite similar to the results achieved on day 1 of field observations. Convergence time appears to take longer and impacts on the accuracy and reliability of results at the hour mark, with results evening out and residuals typically reducing as observation times are extended.

4.4.4 GPS Day 1 Vs GPS Day 2 Solutions

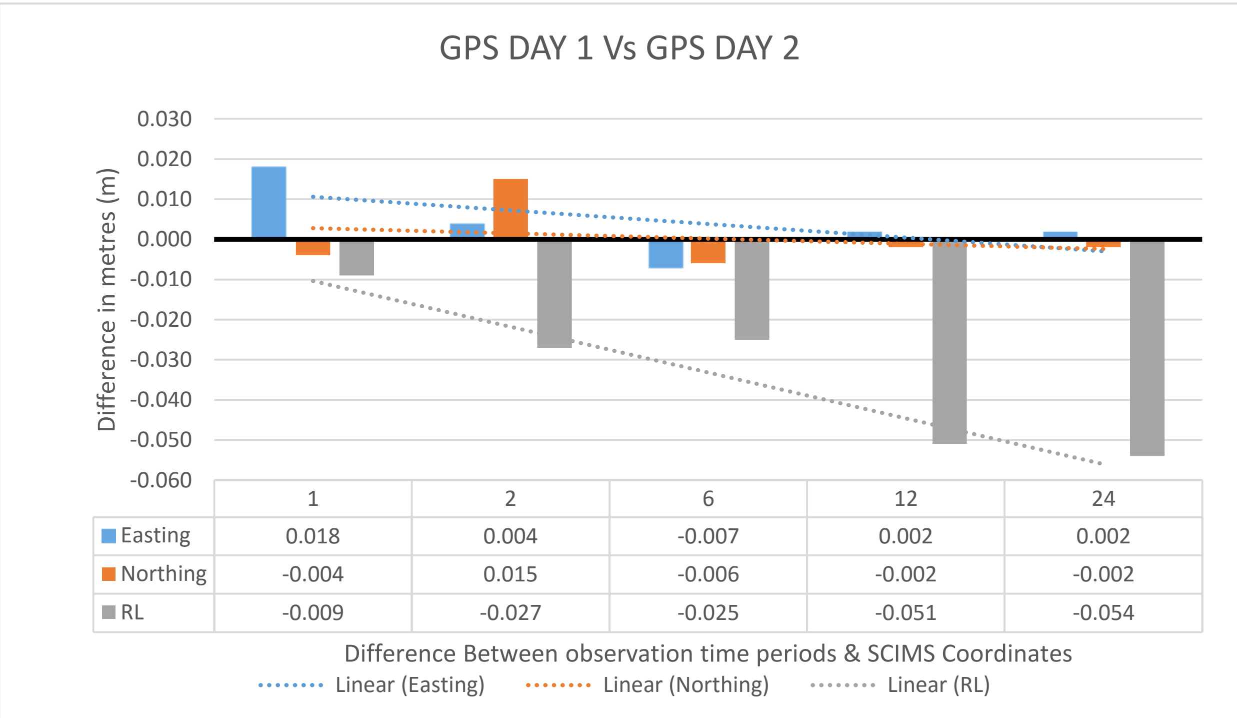


Table 4.6 – Day 1 GPS Vs Day 2 GPS

The results displayed in Table 4.6 are a comparison between the two GPS field observations taken over a 24 hour period. From the results above we can see that the final results are well within tolerance for the horizontal positioning. The results agree with each other to within 0.002m of each other in both Easting and Northing. We can see from the results that once again we have the largest residual on the one hour mark which is most likely due to convergence time, however this residual is smaller in comparison to the residuals obtained on the hour mark for the combined GNSS system solutions. As with combined GNSS and the results obtained on day one, the residual comparisons to the SCIMS marks remain consistent throughout the field tests thus far.

4.5 Twelve Hour GNSS Observation Results (TS 3018)

4.5.1 GNSS Day 1 Vs TS3018 (12 Hour)

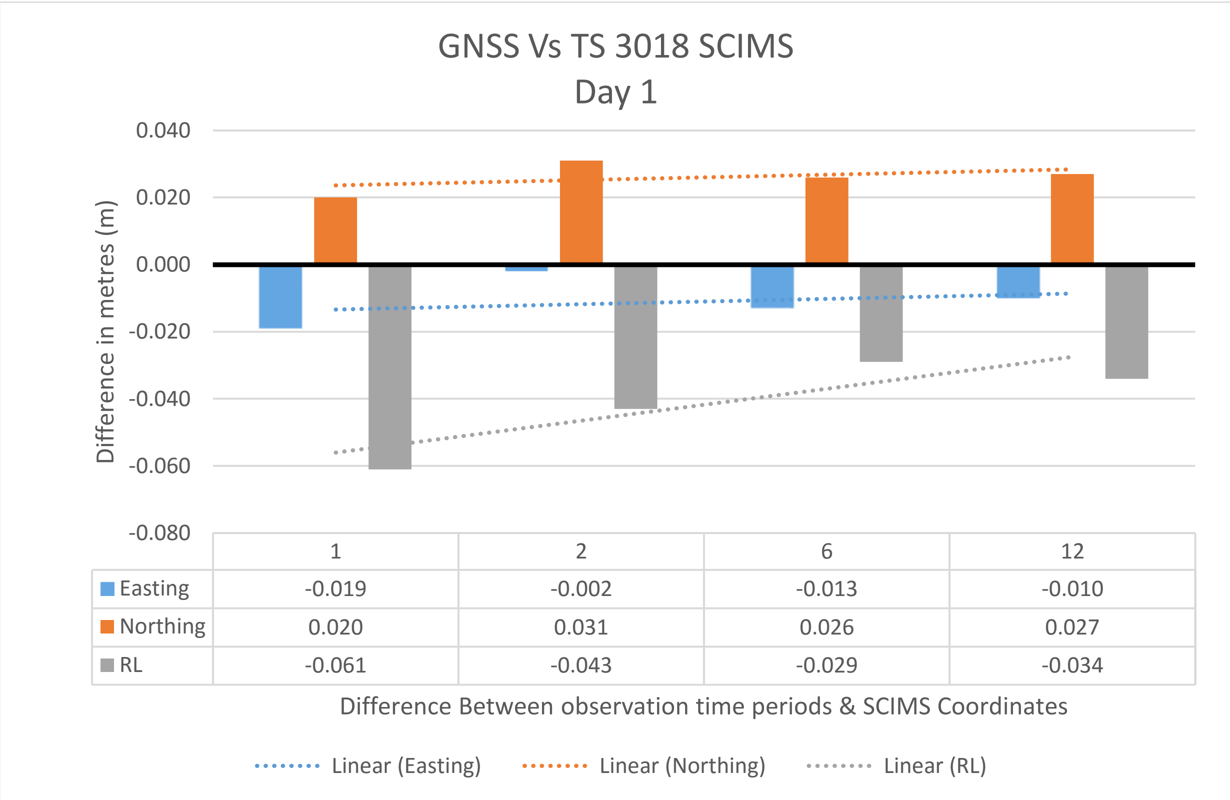


Table 4.7 – GNSS AUSPOS Solutions Vs TS 3018 SCIMS

The observation to trig station TS3018 was taken over a twelve hour duration on day one due to time constraint and access to Trimble R10 receiver. The results show a more consistent solution than the previous GNSS observations taken over trig station TS 1421. The 12 hour observation time frame is sufficient in particular for the horizontal positioning as per the recommendations made by the ICSM discussed in Chapter 3. Hence, the above results may be compared to the twenty four hour observations with particular emphasis as mentioned on the horizontal positioning solutions.

4.5.2 GNSS Day 2 Vs TS3018 (12 Hour)

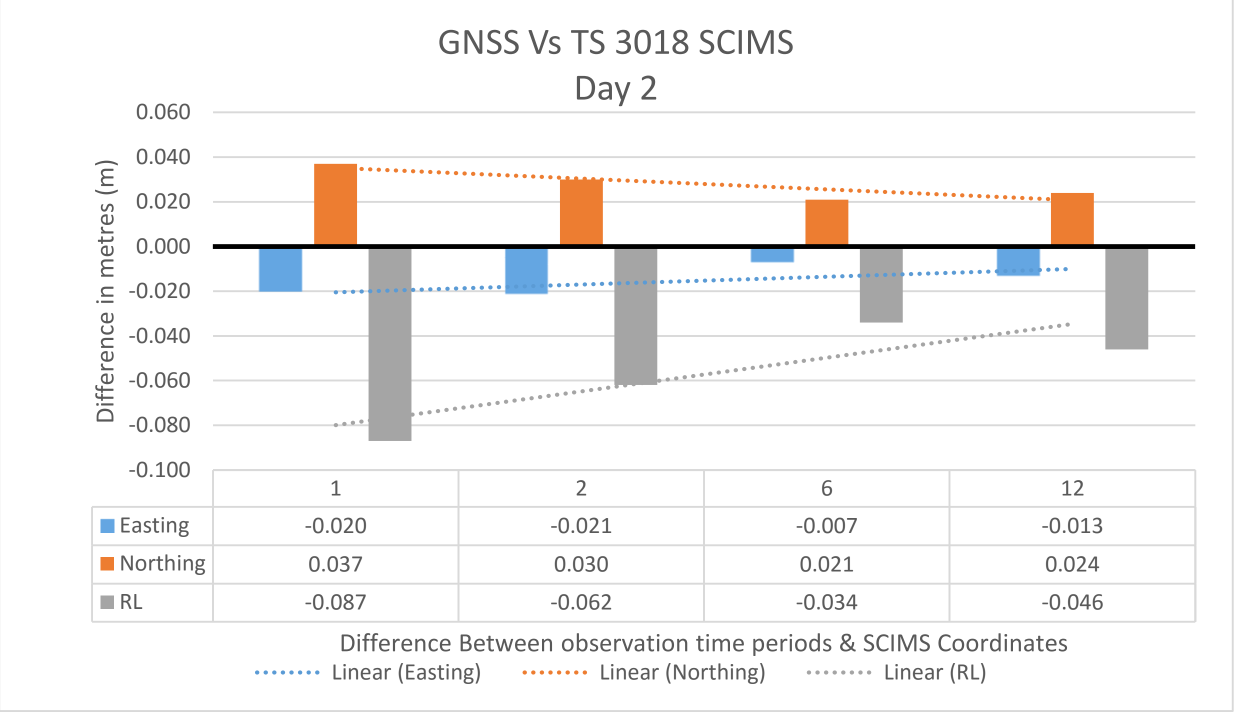
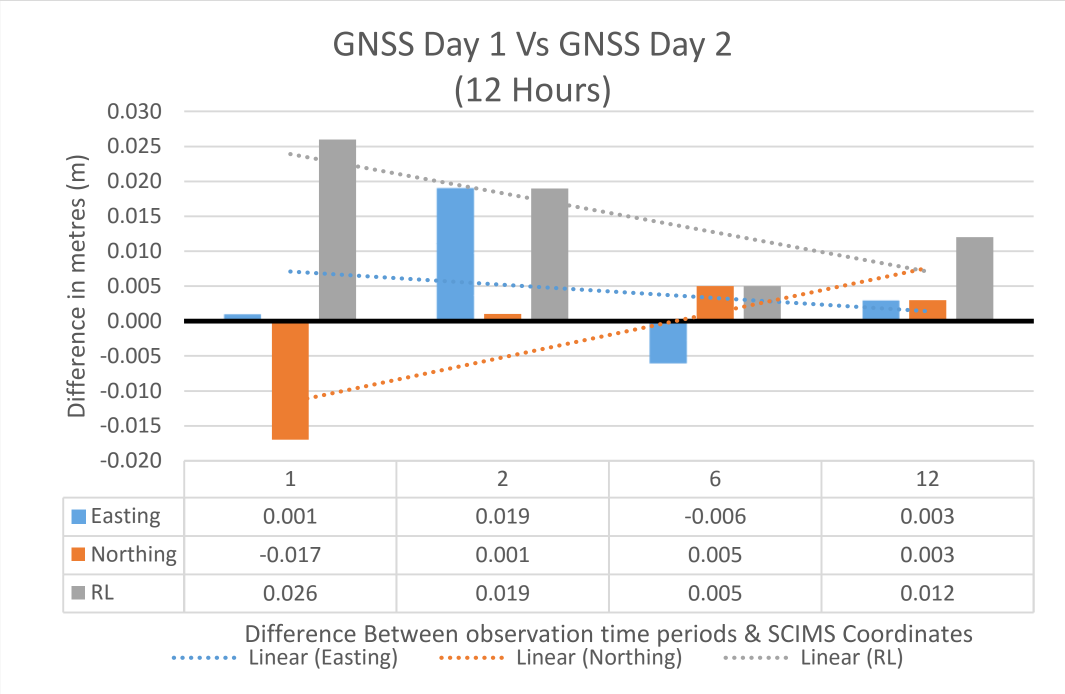


Table 4.8 – GNSS AUSPOS (12 Hour) Solutions Day 2 Vs TS 3018 SCIMS

Table 4.8 reveals a similar pattern and result to the day 1 twelve hour solutions displayed in Table 4.7. As we can see from the results the residuals in positioning from the one hour observation times to the twelve hour solutions are approximately 0.010m in two dimensional positioning, indicating an acceptable convergence rate, with positional accuracy and precision increasing with duration as with previous field studies completed thus far.

4.5.3 GNSS Day 1 Vs GNSS Day 2 (12 Hour)

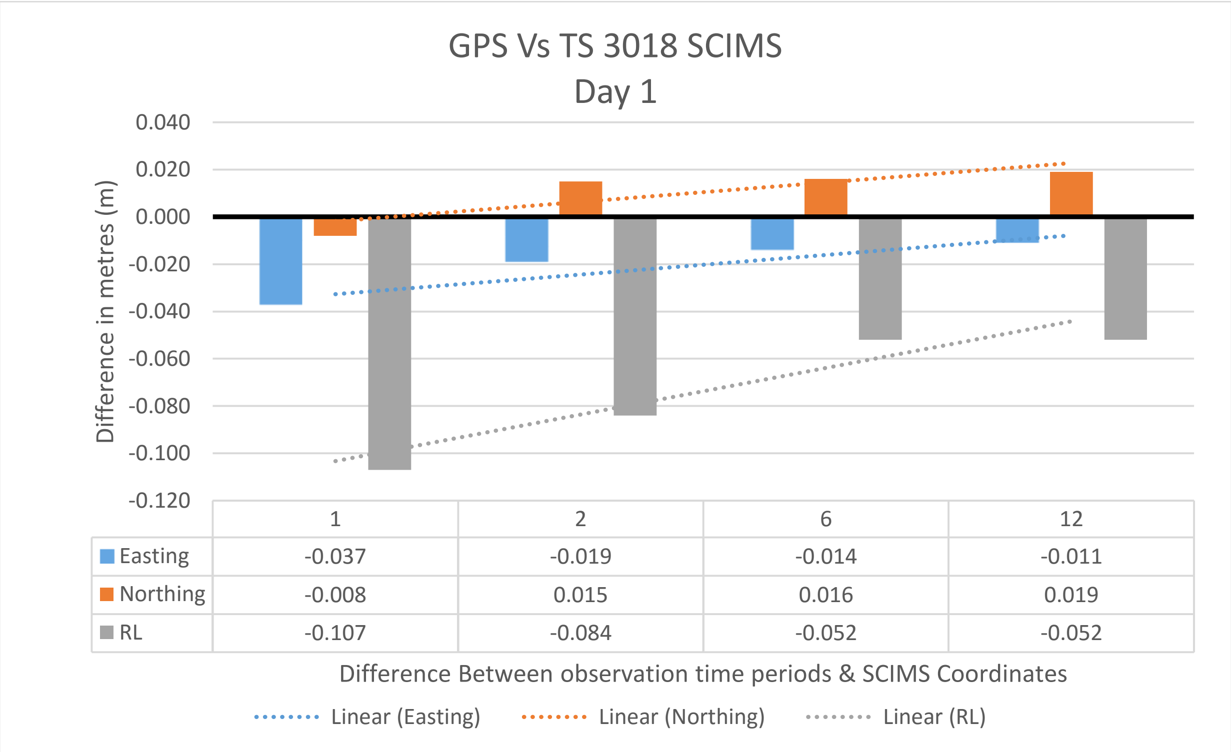


	1	2	6	12
Easting	0.001	0.019	-0.006	0.003
Northing	-0.017	0.001	0.005	0.003
RL	0.026	0.019	0.005	0.012

Table 4.9 – GNSS AUSPOS (12 Hour) Day 1 Vs Day 2 Solution Comparison

4.6 Twelve Hour GPS Observation Results (TS 3018)

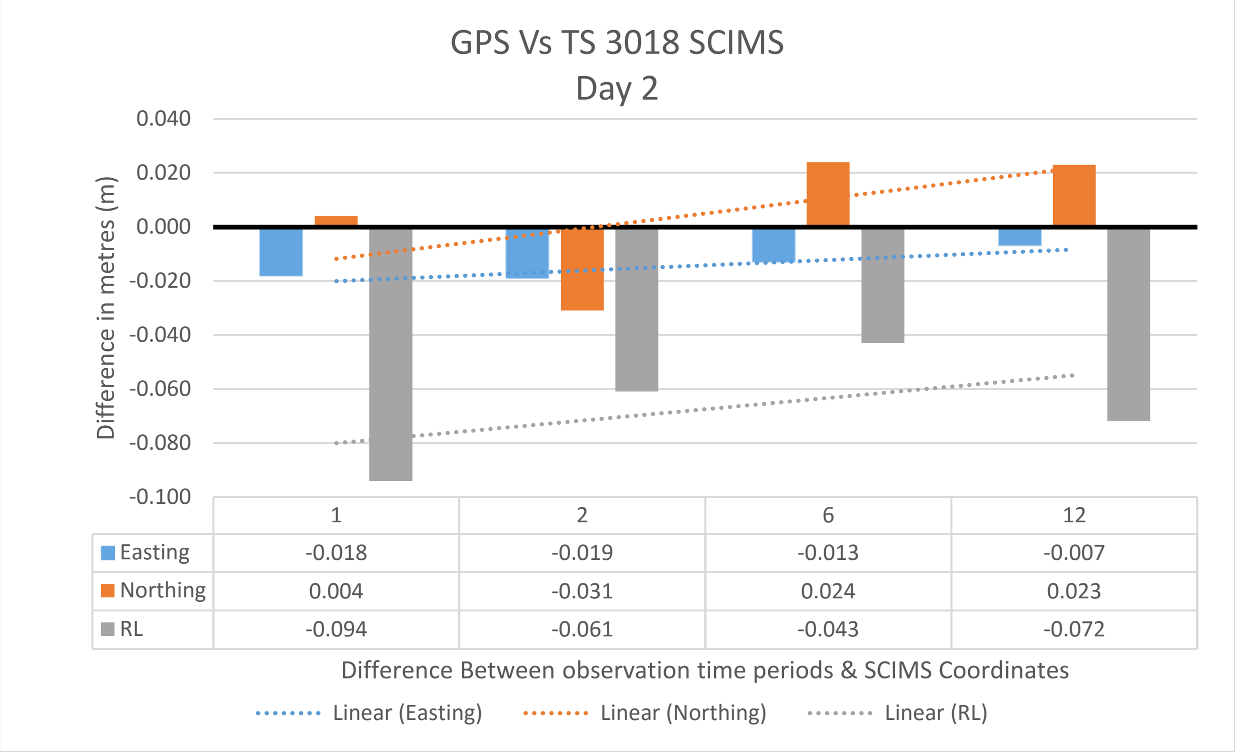
4.6.1 GPS Day 1 Vs TS3018 (12 Hour)



	1	2	6	12
Easting	-0.037	-0.019	-0.014	-0.011
Northing	-0.008	0.015	0.016	0.019
RL	-0.107	-0.084	-0.052	-0.052

Table 4.10 – GPS AUSPOS (12 Hour) solutions Vs TS3018 SCIMS coordinates.

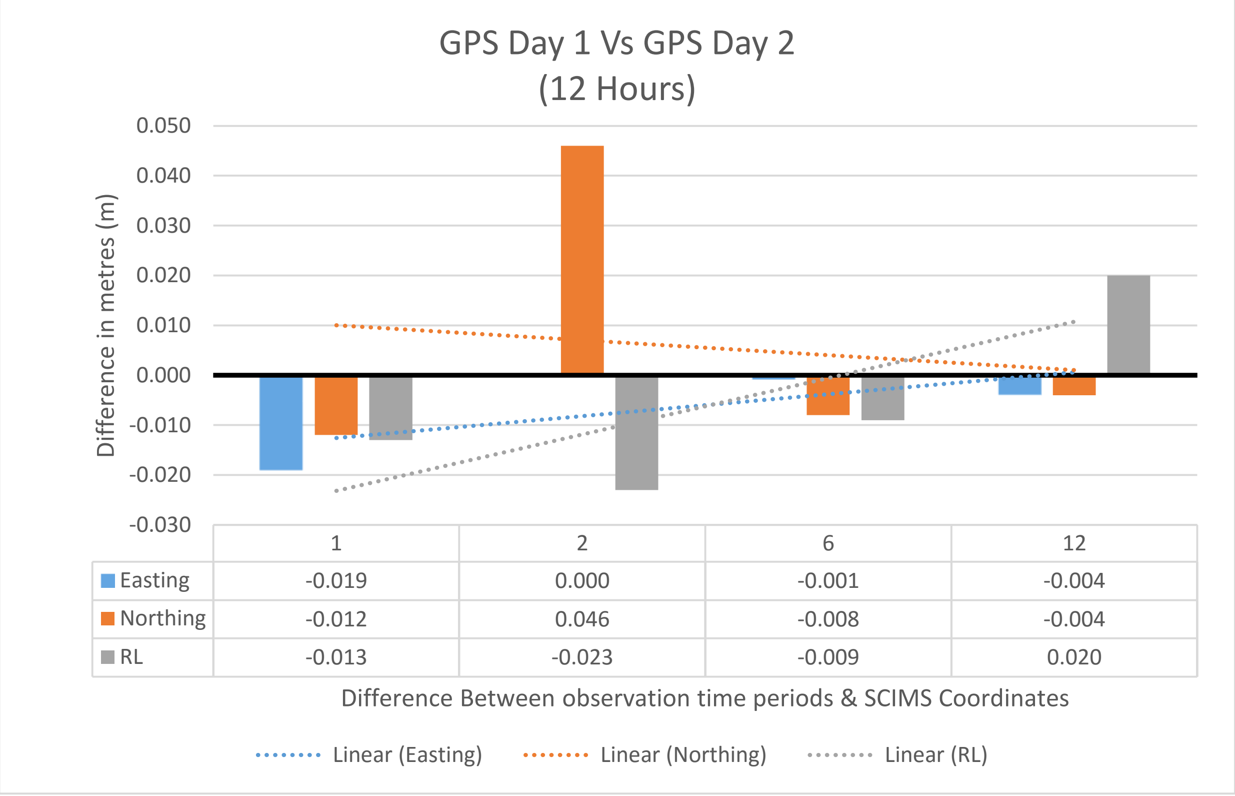
4.6.2 GPS Day 2 Vs TS3018 (12 Hour)



	1	2	6	12
Easting	-0.018	-0.019	-0.013	-0.007
Northing	0.004	-0.031	0.024	0.023
RL	-0.094	-0.061	-0.043	-0.072

Table 4.11 – GPS AUSPOS (12 Hour) solutions Day 2 Vs TS3018 SCIMS coordinates.

4.6.3 GPS Day 1 Vs Day 2 (12 Hour)



	1	2	6	12
Easting	-0.019	0.000	-0.001	-0.004
Northing	-0.012	0.046	-0.008	-0.004
RL	-0.013	-0.023	-0.009	0.020

Table 4.12 – GPS AUSPOS (12 Hour) Day 1 Vs Day 2 Solution Comparison

The table above provides a comparison between the two GPS observations taken over two twelve hour periods. The results fair reasonably well and compared with the twenty four hour observations taken on the previous trig stations. The heights remain consistent with previous solutions, coming in at approximately 0.050m when compared to the known SCIMS coordinates at the twelve hour mark. There is a spike at the two hour mark in the Northing direction. This is not consistent with solutions provided at the one, six or 12 hour mark. Although their appears to be a consistent pattern of bias toward the North when comparing with the SCIMS coordinates the bias tends to hover at approximately ten to twenty millimetres. The higher spikes tend to occur at the hour mark, which is most probably due to poor convergence. As this has occurred at the two hour mark, it may be assumed this result has been affected by multipath or atmospheric factors, or may be associated with an error in the processing phase. For this reason, it is fair to omit this reading from the results above.

4.7 Chapter Summary

Chapter 4 has provided an illustration of the solutions from GPS only and combined GNSS field observations and drawn a comparison of these results against both field observations obtained, and processed using the online post processing software AUSPOS and coordinates provided by SCIMS. It is clear that the GPS only solutions when compared remain consistent in accuracy and precision, although as expected have a slightly lower convergence rate to the combined GNSS systems, hence the larger residuals at the one hour mark. The GNSS solutions provided also provided consistent results with one another, including similar residuals the GPS only system obtained when with the known SCIMS coordinates. This, along with further results and analysis will be looked at in the following chapter.

Chapter 5 – Data Analysis

5.1 Introduction

The aim of this chapter will be to give meaning to the data captured and results presented above. Upon the conclusion of this chapter the reader should have gained a greater understanding of the performance of standalone and combined GNSS systems and how these systems compare to one another, including the effects of multipath and signal interference on GNSS signals. The reader should also gain a greater understanding and reasoning behind the compared SCIMS and Global Navigation Satellite System field observations obtained once processed through the AUSPOS online software. This chapter will also draw comparison with previous studies and contribute to the weight of those findings.

In order for this to be achieved, solutions of the field observations were obtained using the free online post processing software AUSPOS which have been presented in Chapter 4, and a comparison made between the two data files, observed on separate dates approximately three weeks apart initially, and a further 4 weeks for the third set of twelve hour observations. Specifically as stated, this will include the examination of solutions obtained using GPS only, a combination of GNSS systems and the comparison of these results to the SCIMS coordinates provided to test for repeatability and accuracy of results.

In addition, a comparison between the results of this study and those of previous ones will be made in order to reaffirm conclusions drawn upon, and address any conflicting findings.

5.2 Combined GNSS Solutions Analysis

The solutions provided by AUSPOS at the Carrol trig station (TS1421) provide a standard deviation residual of -0.011m and -0.006m in Easting and Northing respectively at the twenty four hour mark. Further to this, a difference of 0.003m in both the Easting and Northing direction was observed at the Mccowen trig station. This remains consistent with previous studies by Cai and Gao where an expected residual of <5mm can be expected when comparing solutions over a period of twelve hours or greater. The solution obtained at the Carrol trig station have a slightly higher residual. As the trig station is surrounded by light canopy, multipath appears to have affected the results slightly.

Further, an analysis of the results shown in the tables above indicate that the performance of GNSS systems improves with the length of observation times, in turn providing more accurate and precise results compared to shorter observation lengths. The reason being, PPP can take a user in excess of half an hour on occasions to for the user to obtain the accuracy they are after.

The trend lines provide an indication of the accuracy and precision of solutions by clearly showing the lines coming closer together with increased observation times, compared to the large separation of these lines around the one and two hour observation times in particular. The results tend to be almost identical in the horizontal positioning from the twelve hour mark through to the twenty four hour mark, supporting the theory that twelve hour observation are sufficient for accurate and reliable data.

5.3 GPS Only Solutions Analysis

The GPS only solutions provided by AUSPOS for both the Cromer Heights and Mccowen trig stations show the two field observations to be very similar when compared with one another. The residuals between both 24 hour field observations were 0.002m in both the Easting and Northing directions respectively. With the Mccowen results showing a residual of -0.004m in Easting and Northing respectively. This result, as with the results achieved by the GNSS system remains consistent with the research by Cai (Changsheng Cai, 2013), stating the expected accuracy to fall in the region of <5mm accuracy. The trig station was located in an area clear of any obstruction such as buildings and tree canopy, which ensured no multipath error or propagation were encountered. The results show a slower convergence rate is expected when using standalone systems against combined GNSS systems, as the larger residuals around at the one hour mark are generally higher than those encountered using the a combination of systems. This is particularly true, when comparing the height values between the two systems. The height accuracy and comparison will be visited later on in this chapter.

By comparing the results of both single systems and combined system GNSS over three locations and ensuring data was logged concurrently at both locations under the same environmental conditions provide a suitable comparison ensuring repeatability and environmental effects were cancelled out.

5.4 Combined GNSS Vs Standalone GPS

A previous study by (Changsheng Cai, 2013) found that although a combination of the GPS and GLONASS Global Navigation Satellite systems may have a significantly quicker convergence time compared with standalone systems, the combination of systems was found to produce minimal, if any positional accuracy where a number of GPS satellites were available with good geometry. The positional accuracy however, will be improved with shorter observation times due to the significant convergence rate speed compared with GPS only observation. The results achieved support this argument by Cai. The graphs show a higher residual around the one and two hour marks when using single systems compared to the combined GNSS where the residuals tended to be less significant. Hence, the extended observation times in the order of 12 hours or greater was shown to have no significant improvement in the precision or accuracy of results if sufficient GPS satellites with good geometry were available. With the addition of GPS satellites it is unlikely that combining these two systems for static positioning will achieve more accurate or precise results when observations times exceed the twelve hour mark.

5.5 Combined GNSS & GPS Vs SCIMS

The results were compared against SCIMS marks provided by the LPI. These SCIMS marks have been assigned class A for horizontal MGA positioning and Class B for vertical AHD positioning. According to the LPI these classes are of accurate first order positioning. After comparison with both the GPS only and combined GNSS the average residual between these two systems was found to be -0.012m in Easting and 0.024m in Northing when compared to the known SCIMS marks provided for the above mentioned trig stations. This was quite surprising considering the SCIMS coordinates were of a high class, these comparisons were expected to be within <10mm for horizontal positioning. As mentioned previously there is an average bias between the standalone GPS and combined GNSS systems when compared to SCIMS of approximately -0.012m to the East and 0.024m toward the North. This result appears consistent with previous studies where (O'Sullivan, 2014) found that the AUSPOS processing software had a bias to the North and West. Further studies by (Cleaver, 2013) compared different online post processing software solutions by comparing them to known survey control coordinates.

Cleaver found that the differences between average residuals obtained from each service provider after processing identical data was in the order of 0.020m for Easting, 0.010m Northing and 0.020m four height. This observed data was recorded over a twenty four hour period. He found that the processed coordinates indicated that baseline services were slightly more accurate than PPP services.

It was also found that a difference of between 0.020m and 0.030m in horizontal, and 0.100m to 0.150m in vertical were obtained when compared to a known point. The results obtained between the two field day observations appear to support this argument, with a slightly more accurate or reduced error in the vertical component.

5.5.1 SCIMS Vs Solutions Error.

An investigation was carried out to find out how the SCIMS coordinates were achieved by the LPI as the difference in horizontal and vertical residuals appeared to be slightly excessive even though the residuals obtained correspond to the testing and results obtained by Cleaver. It was found that the separation in coordinates and solutions is due to the fact that the AUSPOS online post processing software provide a solution based on the ITRF2008, independent of local control networks. The SCIMS marks on the other hand have been stretched and distorted to fit with existing control marks using least square adjustments. A study by (Baxter, 2014) found that the differences in coordinates between solutions derived from AUSPOS and other online post processing software and SCIMS can typically be in excess of 0.040m.

This is due to the original GDA94 adjustment and subsequent adjustments when coordinating survey marks throughout the state. Baxter suggests that these errors have been spread throughout the network and are more likely to be larger in areas with greater distances between control marks such as the rural areas of New South Wales. The results obtained throughout this study tend to support Baxter's claim and indicate that the northern suburbs of Sydney where these two trig stations were observed have a substantial difference in the order of approximately 15mm and 25mm in Easting and Northing respectively. Although the distances between these two trig stations and other trig stations for that matter are not long in length compared with urban areas, the steep and bushy terrain has the same effect on results as longer distances have been proven to have, when adjusting marks using least square adjustment packages.

Therefore, any solutions derived from AUSPOS or any other online PPP service provider for that matter would require the user to ensure a connection be made to the existing network, if network relevance was a requirement of a particular survey.

5.6 Solution Bias

As shown and mentioned earlier in this chapter, a bias was observed in the solutions. This bias comes about due to fact that to produce a solution, AUSPOS utilises the International GPS Service (IGS08) reference frame and the Asia Pacific Reference Frame (APREF). A total of fifteen IGS08 and APREF stations are used, with seven IGS08 core sites used along with eight non IGS08 core sites that are within close proximity to the surveyed station. That data is retrieved from Geoscience Australia's GNSS Data Archive. A precise solution using a 'double difference' technique is then computed using these stations.

The coordinates of the IGS stations are constrained with uncertainties of 1mm for horizontal and 2mm for the vertical. This than enables the formation of a denser reference network, which in turn enables the generation of a reliable regional ionospheric delay model and tropospheric corrections to support and improve ambiguity resolution (Dawson et al, 2014). AUSPOS utilises reference stations in various locations surrounding the survey station, including reference stations within 100km and in excess of two thousand kilometres. The geometry of the baselines could be a significant contributor to the observed bias.

5.7 Chapter Summary

The analysis of results has demonstrated that the solutions provided by AUSPOS for both GPS and combined GNSS systems are consistent with previous studies. The twenty four hour observations provide the most accurate results compared with shorter observation times. This is particularly true when looking to obtain more accurate consistent height data. The study has proven that shorter observation times may mean the user will not achieve the accuracy that he or she intends, and a minimum observation time of twelve and twenty four hours is required for accurate solutions in both horizontal and vertical positioning respectively. Further, it is quite clear that a combination of GNSS systems compared with standalone GPS does not necessarily lead to more accurate results. In fact the performance of standalone GPS over a 24 hour static observation period provide similar accuracy and precision to combined systems. However, it has been proven that a combination of systems achieves much quicker convergence time compared with standalone systems, which is an advantage where shorter observation times are required, or lengthy periods of observations are not possible. Finally, users should be aware that GNSS solutions will not fit with coordinates provided by SCIMS, due to the fact these survey marks have been distorted to fit with existing control networks. The user will need to ensure connections be made to the existing network.

Chapter 6 – Conclusion

6.1 Introduction

The aim of this study has been to evaluate the performance and accuracies of combined GNSS systems against standalone GPS using the online AUSPOS post processing software to reduce field observations and obtain solutions. To this end the paper has highlighted the fact that these systems whether combined or standalone produce accurate reliable results, with combined systems achieving quicker convergence rates in shorter periods of time compared with standalone, however this becomes less effective when observing static observations over prolonged periods of time, twelve hours for horizontal, and twenty four hours for vertical positioning.

6.2 Recommendations

This study has proven that single static receivers are capable of producing high quality precision, accuracy and reliability. The session logging time when in static mode should be in equal to, or in excess of twelve hours for accurate horizontal positioning and a minimum of twenty four hours for reliable vertical solutions. Where accurate results are required in relation to an existing network, it is recommended the user tie into several control network stations and reduce the results using least squares to ensure compatibility with the required existing network. This study analysed the results obtained by standalone GPS and combined GNSS systems over a twenty four hour period. Although the observations were tracked at the same date and time with one another, the limitation with time and in particular access to receiver equipment restricted these observations to one set of system per station, where the Carrol trig station was only observed through combined GNSS, and Cromer heights trig station GPS only. GPS and GNSS receiver's further logged data over Mccowen trig station, over two twelve hour periods for both standalone and combined GNSS systems. This was done due to the lack of receiver availability and more importantly the timing of availability meant logging over twenty four hour periods was not possible due to a lack of time constraint.

Further, constraint around the availability and access to receivers limited the field testing to three stations. A possible way for future studies to avoid this would be to ensure access and availability of more GNSS receivers, logging data to more stations. In addition, each trig station should be observed by both GPS and GNSS systems, completely eliminating any repeatability or bias which may creep into results.

Finally, the inclusion of other PPP service providers to process the solutions would be beneficial in testing the findings of this study. These providers should include MAGIC, OPUS and the new Trimble RTX PPP service. This RTX system has been designed specifically for the Australian user, providing the user with broader processing options and reliable comparable results.

6.3 Conclusion

The project aimed to achieve a greater understanding of the accuracies and reliability of standalone systems verse combined GNSS. It was found that over an observation period of twenty four hours, there was minimal impact on the accuracy or reliability of results using either combined or standalone systems. However, through decimating the observation field files into one, two, three, twelve and twenty four hour blocks, as well as through literature review and previous studies it has been recognised and proven through testing that when observing over shorter periods of time combined systems achieved a quicker convergence rate than using a single system such as GPS. Cia and Gao found that GPS solutions were more accurate than GLONASS solutions when tested against one another as independent systems.

This study proved that over a twenty four hour period solution accuracy is not detrimentally affected nor does it appear to provide any improvement in accuracy. In fact with good satellite constellation and availability it is possible to achieve a slightly more accurate result using single standalone GPS over combined systems. Unfortunately due to constraints covered earlier including access and availability to GNSS receivers, travel time between the two stations, and security this limited the amount of suitable trig stations available. It would have been ideal to observe another round of observations, with combined and standalone stations swapped to ensure repeatability and eliminate any bias or multipath which may have impact the results. Regrettably, due to the limited access and availability of receivers this was not possible, and testing was limited to three stations.

Further, it was discovered when looking to compare the online solutions to the state survey coordinates provided by SCIMS, that these coordinates are not necessarily an accurate representation of true position today and therefore deemed unsuitable for assessing the accuracy of the results. In the case where solutions are required to fit within an existing network such as the SCIMS network, the user will be required to observe and connect to several known marks within that particular network, with a least square adjustment completed ensuring solutions are compatible with network.

The solutions obtained by the online PPP processing software AUSPOS were consistent with previous studies, as explained and elaborated on in previous chapters. It would have been more appropriate to test the field data using a variety of software such as MAGIC, OPUS and the Trimble RTX post processing software. The results may than be compared to one another to test for any bias which may occur and ensure repeatability. Unfortunately due to time constraints this was not able to be achieved, and may be tested in future studies.

Chapter 7 – References

ADMINISTRATION, F. A. 2014. *Satellite Navigation - GPS - Control Segment* [Online]. United States: United States Department of Transport. Available: http://www.faa.gov/ [Accessed 24th May 2015].

AGENCY, E. S. 2007. *Galileo Navigation Signals and Frequencies* [Online]. Europe: European Space Agency.Available:http://www.esa.int/Our_Activities/Navigation/The_future__Galileo/Galileo_navigation_signals_and_frequencies [Accessed 17 May 2015].

AGENCY, E. S. 2011a. *Galileo Ground Segment* [Online]. Europe: European Space Agency. Available: http://www.navipedia.net/index.php/Galileo_Ground_Segment [Accessed 25th May 2015].

AGENCY, E. S. 2011b. *GLONASS Ground Segment* [Online]. navipedia. Available: http://www.navipedia.net/index.php/GLONASS_Ground_Segment [Accessed 25th May 2015].

AGENCY, E. S. 2011c. *Glonass Space Segment* [Online]. European Space Agency. Available: http://www.navipedia.net/index.php/GLONASS_Space_Segment [Accessed 16 May 2015].

AGENCY, ES 2013, 'Galileo General Introduction', p. 5, viewed 17 May 2015.

AGENCY, E. S. 2014. *Galileo General Introduction* [Online]. Available: http://www.navipedia.net/index.php/Main_Page [Accessed 16th April 2015].

AGENCY, ES 2014, 'GLONASS General Introduction', p. 1, viewed 24 October 2014.

AUSTRALIA, G. 2015. AUSPOS - Introduction [Online]. Canberra Australian Government -Geoscience Australia. Available: http://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/auspos/faq1 [Accessed 23rd June 2015].

BERNHARD HOFFMANN-WELLENHOF, H. L., ELMAR WASLE 2008. GNSS-Global Navigation Satellite Systems: GPS, GLONASS, Galileo, and more. *GPS, GLONASS, Galileo & more.* Austria: Springer Science & Business Media, 2007.

BRUNEL UNIVERSITY, UK. Available: http://encyclopedia.jrank.org/articles/pages/6617/Global-Navigation-Satellite-Systems.html [Accessed 13th April 2015].

CHANGSHENG CAI, Y. G. 2013. Modeling and assessment of combined GPS/GLONASS precise point positioning. 17. Available: http://link.springer.com/article/10.1007/s10291-012-0273-9 [Accessed 19th October 2015].

CHRIS RIZOS, M. B. H., AND S. HEWITSON 2005. New Global Navigation Satellite System Developments and Their Impact on Survey Service Providers and Surveyors.

Cleaver, B 2013, Evaluation of the performance of web-based GNSS post processing systems, University of Southern Queensland, Toowoomba, viewed September 2015, http://eprints.usq.edu.au/id/eprint/24710

COJOCARU, S 2009, 'GPS-GLONASS-GALILEO: A Dynamical Comparison', The Journal of Navigation, vol. 62, pp. 135–150, The Royal Institute of Navigation.

DAWOUD, S. 2012. GNSS principles and comparison. Germany: Potsdam University.

Dawson, J Jia, M Moore, M 2014, AUSPOS: Geoscience Australia's on-line GPS positioning service, Geoscience Australia, Canberra Australia [Accessed 24th May 2015].

GARRETT SEEPERSAD, S. B. 2014. Reduction of PPP convergence period through pseudorange multipath and noise mitigation. *GPS Solutions*, 3.

GPS.GOV. 2015. *GPS.gov Control Segment* [Online]. United States: National Coordination Office for Space-Based Positioning, Navigation and Timing. Available: http://www.gps.gov/systems/gps/control/ [Accessed 24th May 2015].

GRUSH, B 2006, 'Is Galileo Enough?', p. 2, viewed 25/10/2014.

K. DAWIDOWICZ, G. K. 2014. Coordinate estimation accuracy of static precise point positioning using on-line PPP service, a case study. 49**,** 55.

KATRIN HUBER, F. H., CHRISTOPH ABART, ANA KARABATIC, ROBERT WEBER, PHILIPP BERGLEZ 2010.

MADRY, S. 2015. Global Navigation Satellite Systems and Their Applications New York: Springer - Verlag New York.

MAPPING, I. C. O. S. A. 2014. Guideline for Control Surveys by GNSS. *Special Publication 1.* Australia.

Martín, A Anquela, A Capilla, R & Berné, J 2011, PPP technique analysis based on time convergence, repeatability, IGS products, different software processing, and GPS+GLONASS constellation, Journal of Surveying Engineering American Society of Civil Engineers, August 2011, Reston, Virginia, pp 99-108, viewed June 2016, http://web.b.ebscohost.com.ezproxy.usq.edu.au/ehost/pdfviewer/pdfviewer?vid=3&sid=6552eb0f-2d39-40be-8158-02fec4bbc534%40sessionmgr198&hid=123

NATALIA GRALA, M. B. 2009. ANALYSIS OF GNSS RECEIVER ACCURACY IN THE FOREST ENVIRONMENT. VII. Available: http://ptip.org.pl/download/files/RG2009z2-GralaBrach.pdf [Accessed 18th October 2015].

NATIONAL COORDINATION OFFICE FOR SPACE BASED POSITIONING, N. A. T. 2015. *GPS.gov - Space Segment* [Online]. United States: United States Government. Available: http://www.gps.gov/systems/gps/space/ [Accessed 9 May 2015].

OLLA, P. 2015. *Global Navigation Satellite Systems - INTRODUCTION, BACKGROUND: WHAT IS GNSS?, CURRENT TRENDS: NAVSTAR GLOBAL POSITIONING SYSTEM, GLONASS* [Online].

O'SULLIVAN, D. 2014. Evaluation of Precise Point Positioning Services. Bachelor of Spatial Science, University of Southern Queensland.

PACE, S. 2010. Expert Advice - The Strategic Significance of Compass. Available: http://gpsworld.com/gnss-systemcompassexpert-advice-the-strategic-significance-compass-10826/ [Accessed 24th May 2015].

PAN LI, X. Z. 2014. Modelling and Performance Analysis of GPS/GLONASS/BDS Precise Point Positioning. *China Satellite Navigation Conference 2014 Proceedings: Volume 3.* Springer Berlin Heidelberg.

POSITRIM. 2012. *High Accuracy GNSS Solutions and Services* [Online]. Germany. Available: http://www.positim.com/index_gnss.html [Accessed 12 May 2015].

PPP: Precise Point Positioning - Constraints and Opportunities. 17.

REECE, M. E. 2000. Global Positioning System. *In:* CLARK, P. L. J. (ed.). New Mexico Institute of Mining and Technology: New Mexico Institute of Mining and Technology.

RODRÍGUEZ, J. A. Á. 2011. *GLONASS Signal Plan* [Online]. Germany: University FAF Munich. Available: http://www.navipedia.net/index.php/GLONASS_Signal_Plan [Accessed 16 May 2015].

SMET, P. D. 2009. The European GNSS Programme EGNOS and Galileo. 30.

SPIRENT. 2015. *Inside GNSSengineering Solutions from the Global Navigation Satellite System Community* [Online]. United States: Gibbins Media & Research Available: http://www.insidegnss.com/aboutcompass [Accessed 24th May 2015].

TA-KANG YEH, C. H., GUOCHANG XU, CHUAN-SHENG WANG, CHIEN-CHIH LEE 2009. Determination of global positioning system (GPS) receiver clock errors: impact on positioning accuracy. 7.

TECHTARGET. 2014. *GNSS (GLOBAL NAVIGATION SATELLITE SYSTEM)* [Online]. Available:http://searchnetworking.techtarget.com/definition/GNSS.

T K YEH, C. S. W., B F CHAO, C S CHEN, C W LEE 2007. Automatic data-quality monitoring for continuous GPS tracking stations in Taiwan. 10.

TRIMBLE. 2014. *Trimble GPS Triangulation* [Online]. Available:http://www.trimble.com/gps_tutorial/howgps-triangulating.aspx 2014].

Appendices

Appendix A – Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/ENG4222 RESEARCH PROJECT

PROJECT SPECIFICATION

STUDENT: **WAFEEK ISMAIL**

TOPIC: Evaluating the differences and accuracies between GNSS applications using PPP.

SUPERVISOR: Dr Zhenyu Zhang

ENROLMENT: ENG4111 – S1, 2015
ENG4112 – S2, 2015

PROJECT AIM: The project seeks to provide relevant technical information on the performance of GNSS systems and their accuracies, both through single GNSS system and a combination of systems to test whether these combinations achieve quicker convergence, accuracy and reliability compared with the use of only a single system. The project will further analyse the general characteristics of Global Navigation Satellite Systems.

PROGRAMME: **Issue 1, 17th March 2015**

1. Provide information and research on the project background, including GNSS background information, project aims and objectives, scope of project.
2. Literature Review on the physical and application perspective of GNSS systems. Possible literature review on accuracies of the different satellite systems.
3. Conduct experimentation methodology. Four part stage.

A) Obtain information regarding trig stations, receiver and equipment information and practical training in the handling of equipment.

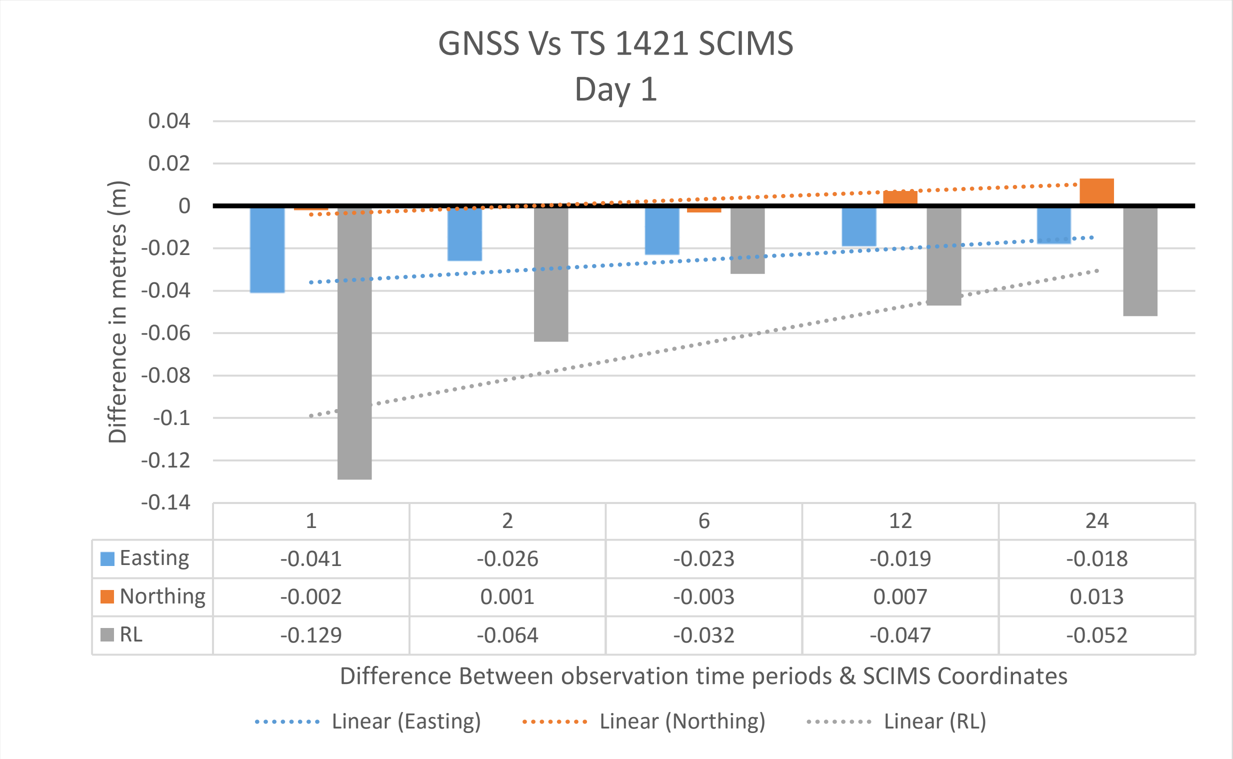
B) Design field procedure to obtain raw field data results. Methodology most likely to include field survey over 24 hour period. This may be extended to two 24 hour periods, time permitting.

C) Raw data will be reduced using one of several PPP software available online.

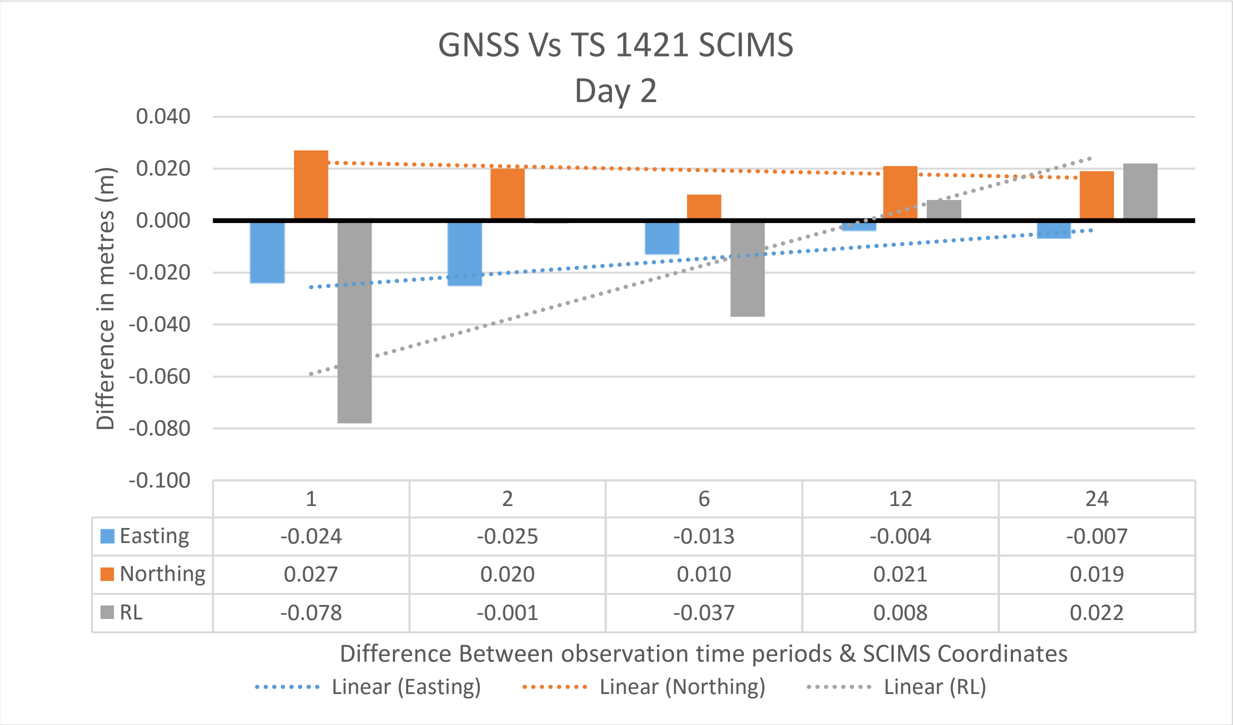
D) Analysis/evaluation of results.

4. Evaluation of physical aspects of GNSS systems, including signal structures, frequency bands, signal strengths, availability and a host of other physical configurations.
5. Discussion and conclusion.

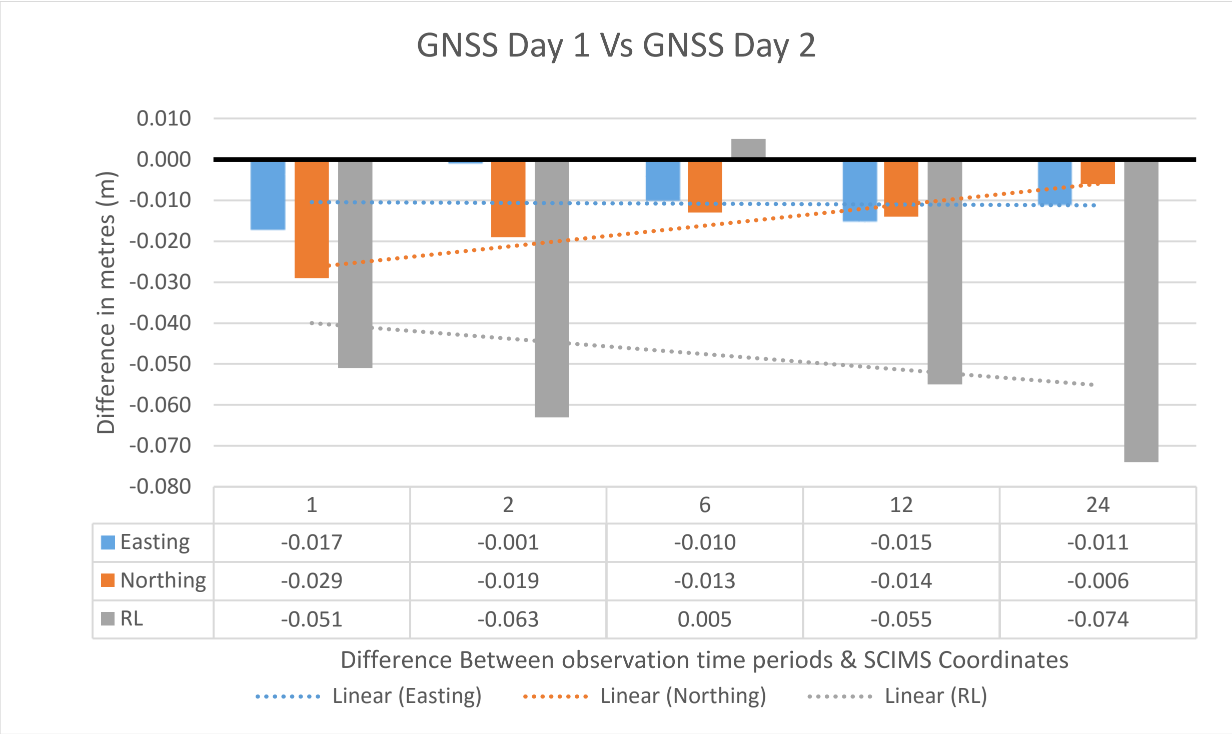
Appendix B – 24 Hour Solutions Combined GNSS (TS1421)



	1	2	6	12	24
Easting	-0.041	-0.026	-0.023	-0.019	-0.018
Northing	-0.002	0.001	-0.003	0.007	0.013
RL	-0.129	-0.064	-0.032	-0.047	-0.052

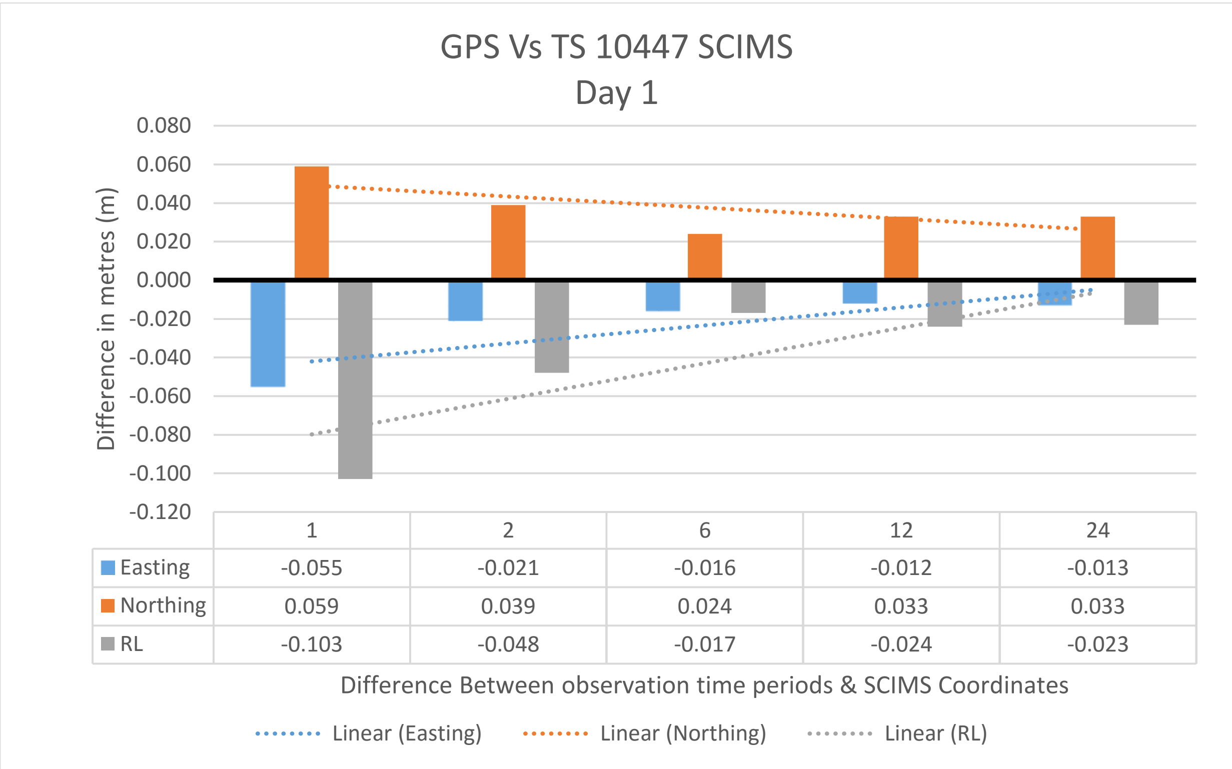


	1	2	6	12	24
Easting	-0.024	-0.025	-0.013	-0.004	-0.007
Northing	0.027	0.020	0.010	0.021	0.019
RL	-0.078	-0.001	-0.037	0.008	0.022

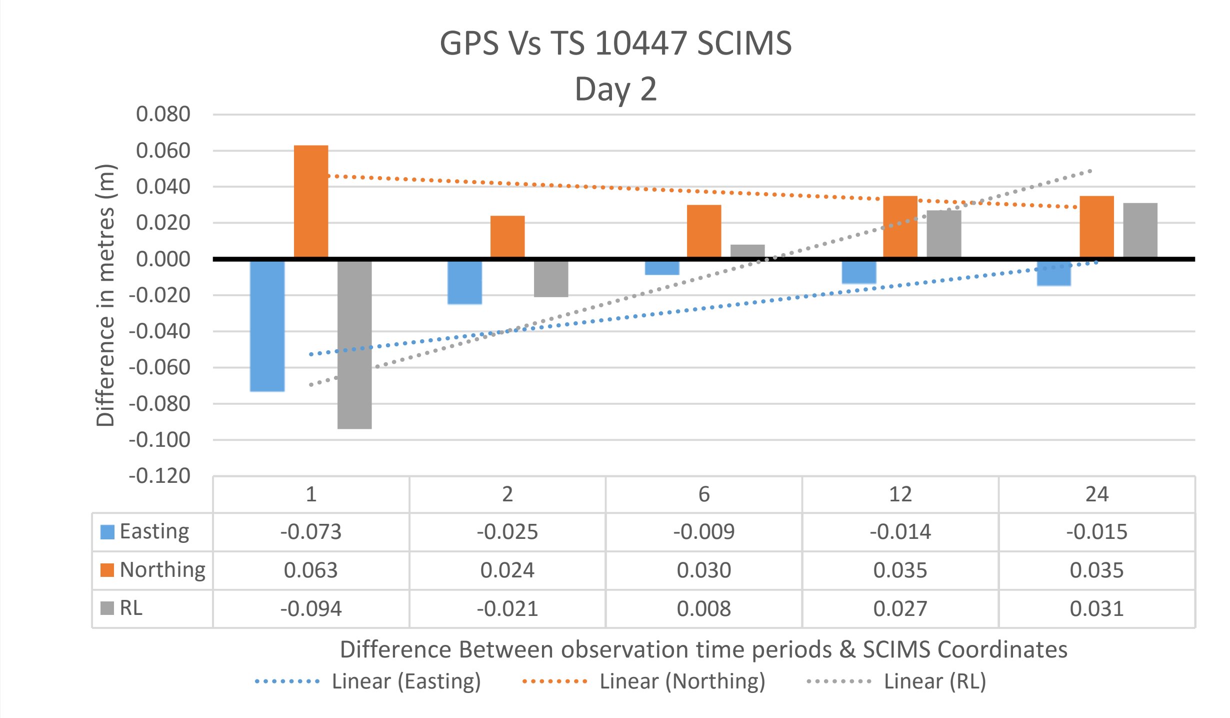


	1	2	6	12	24
Easting	-0.017	-0.001	-0.010	-0.015	-0.011
Northing	-0.029	-0.019	-0.013	-0.014	-0.006
RL	-0.051	-0.063	0.005	-0.055	-0.074

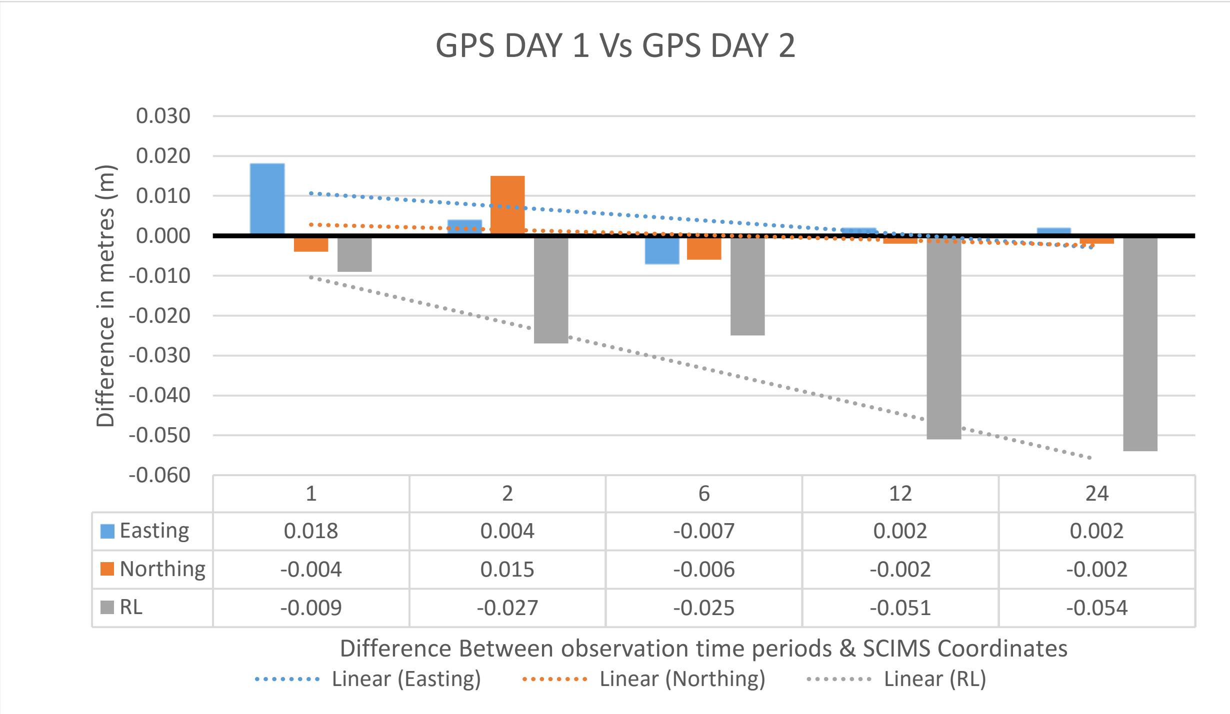
Appendix C – 24 Hour Solutions Standalone GPS (TS10447)



	1	2	6	12	24
Easting	-0.055	-0.021	-0.016	-0.012	-0.013
Northing	0.059	0.039	0.024	0.033	0.033
RL	-0.103	-0.048	-0.017	-0.024	-0.023

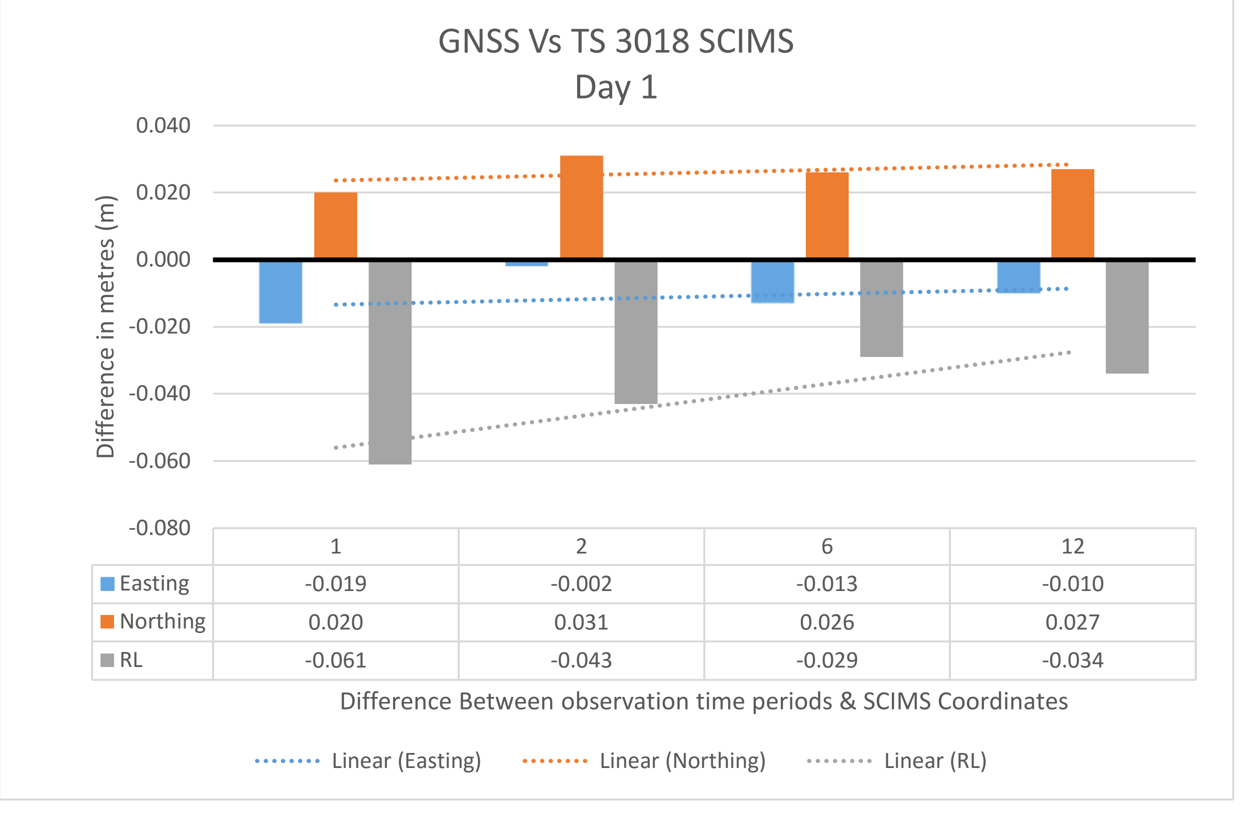


	1	2	6	12	24
Easting	-0.073	-0.025	-0.009	-0.014	-0.015
Northing	0.063	0.024	0.030	0.035	0.035
RL	-0.094	-0.021	0.008	0.027	0.031

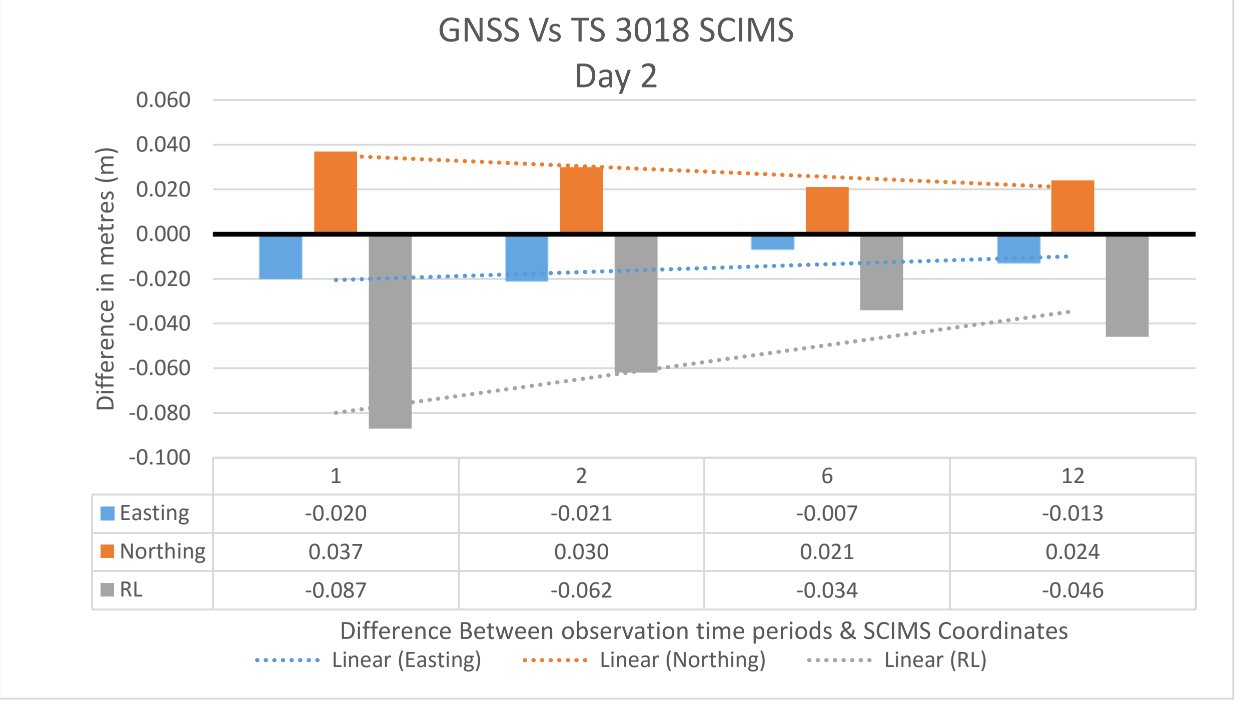


	1	2	6	12	24
Easting	0.018	0.004	-0.007	0.002	0.002
Northing	-0.004	0.015	-0.006	-0.002	-0.002
RL	-0.009	-0.027	-0.025	-0.051	-0.054

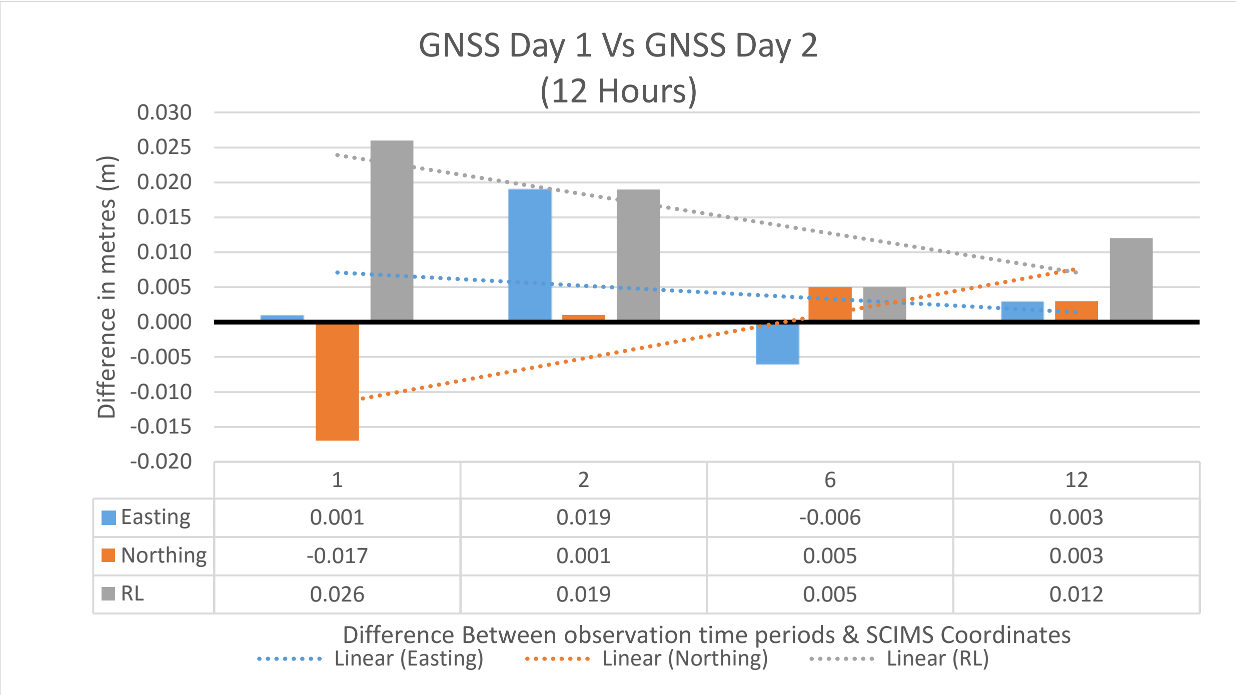
Appendix D – 12 Hour Solutions GNSS (TS3018)



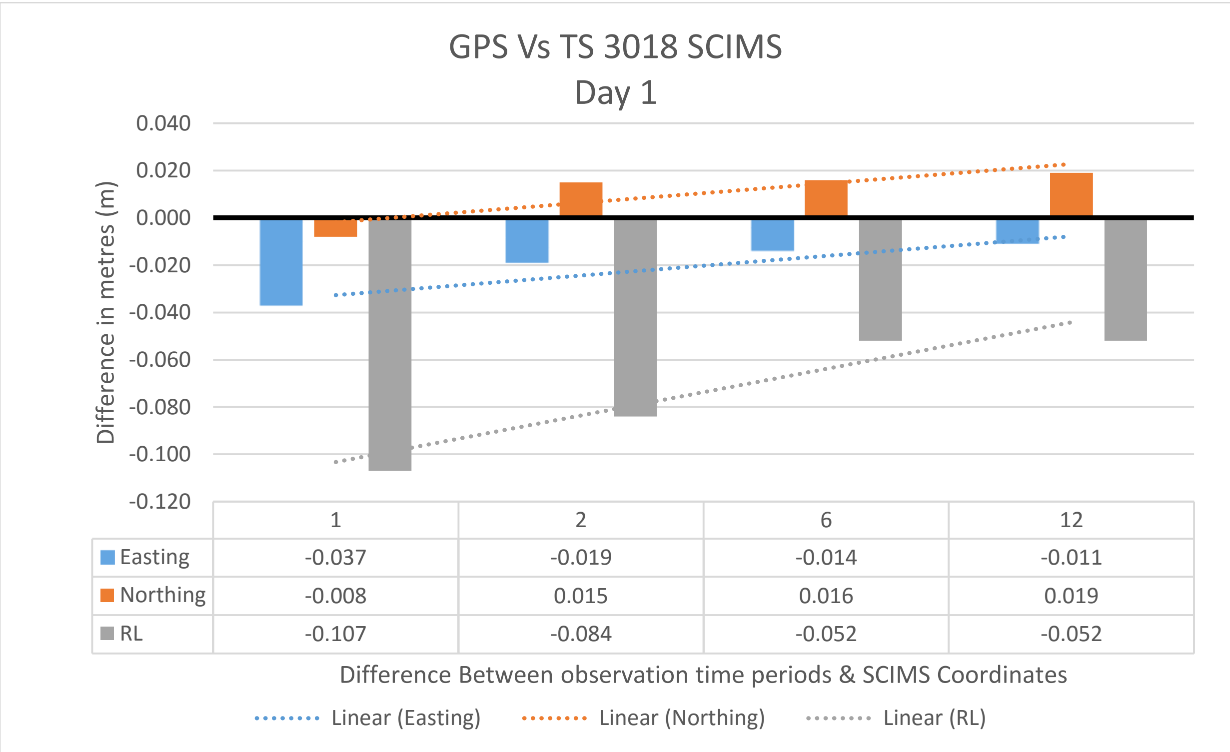
	1	2	6	12
Easting	-0.019	-0.002	-0.013	-0.010
Northing	0.020	0.031	0.026	0.027
RL	-0.061	-0.043	-0.029	-0.034

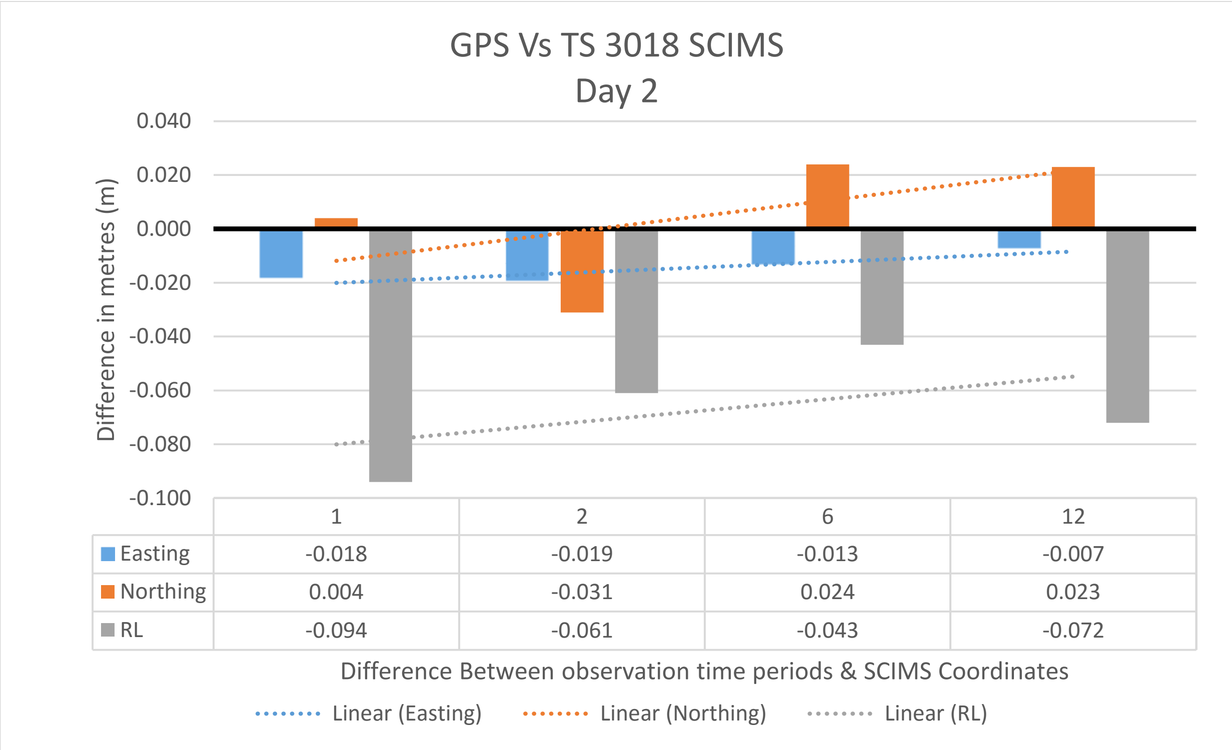


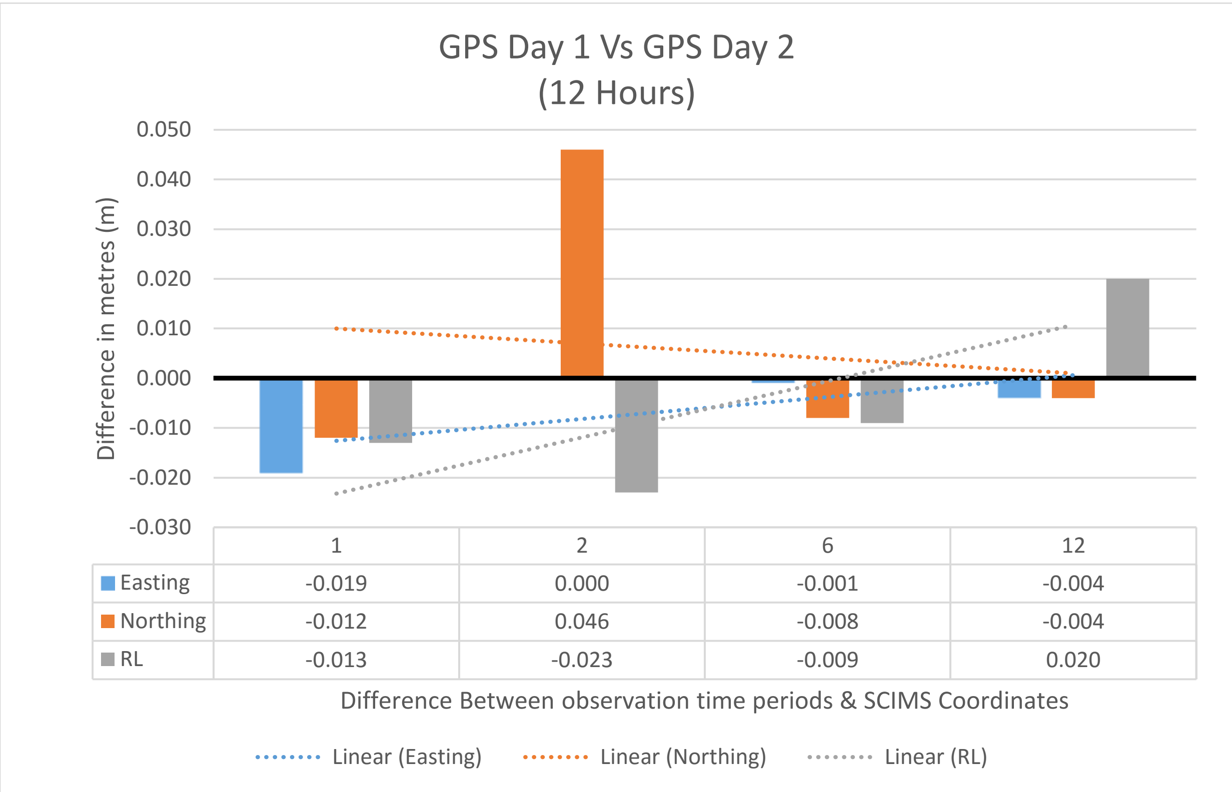
	1	2	6	12
Easting	-0.020	-0.021	-0.007	-0.013
Northing	0.037	0.030	0.021	0.024
RL	-0.087	-0.062	-0.034	-0.046



Appendix E – 12 Hour Solutions GPS (TS3018)




GPS Vs TS 3018 SCIMS
Day 2
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
Difference in metres (m)
1
2
6
12
Easting -0.018 -0.019 -0.013 -0.007
Northing 0.004 -0.031 0.024 0.023
RL -0.094 -0.061 -0.043 -0.072
Difference Between observation time periods & SCIMS Coordinates
Linear (Easting)
Linear (Northing)
Linear (RL)


GPS Day 1 Vs GPS Day 2
(12 Hours)
0.050
0.040
0.030
0.020
0.010
0.000
-0.010
-0.020
-0.030
Difference in metres (m)
1
2
6
12
Easting -0.019 0.000 -0.001 -0.004
Northing -0.012 0.046 -0.008 -0.004
RL -0.013 -0.023 -0.009 0.020
Difference Between observation time periods & SCIMS Coordinates
Linear (Easting)
Linear (Northing)
Linear (RL)

Appendix F – SCIMS Survey Mark Reports Example

SCIMS SURVEY MARK REPORT AS AT: 26-OCT-2015

Your Reference: null Search Number: 298840

MARK NAME STATUS	COORDINATES AND HEIGHTS				CLASS	ORDER	PU	SOURCE	CSF CONVERGENCE AUSGEOID09
TS 1421	MGA	332106.053	6265786.668	56	A	1	n/a	235356	0.999918
CARROL [P]	GDA94	-33° 44' 04.84620"	151° 11' 15.61830"						-1° 00' 24.15"
	AHD71	165.773			B	2	n/a	235356	23.218
TS 10447	MGA	338387.374	6266328.481	56	A	1	n/a	235356	0.999893
CROMER HEIGHTS [P]	GDA94	-33° 43' 50.77713"	151° 15' 19.96640"						-0° 58' 08.00"
	AHD71	157.345			B	2	n/a	235356	23.227

Map Legend

SCIMS Mark Types (Colour codes refer to the assigned accuracy "Class")

SS	PM	TS	CR	MM	CP	GB	
							Established GDA & Accurate AHD
							Established GDA Only
							Accurate AHD Only
							Unknown of Less Accurate GDA & AHD

Established GDA coordinates are assigned accuracy class 2A, A, B or C
Accurate AHD heights are assigned accuracy class L2A, LA, LB, LC, LD, 2A, A or B

Mark Status *

F Found Intact
N Not Found
D Destroyed
S Subsidence Area
U Uncertain
R Restricted Access

* Where available, the Mark Status is appended to the Mark Number in the map

Disclaimer: This report has been generated by various sources and is provided for information purposes only. Land and Property Information (LPI), a division of the Department of Finance and Services does not warrant or represent that the information is free from errors or omission, or that it is exhaustive. LPI gives no warranty in relation to the information, especially material supplied by third parties.LPI accepts no liability for loss, damage, or costs that you may incur relating to any use or reliance upon the information in this report.

SURVEY MARK

Mark	Name	Alias
TS 1421	CARROL [P]	n/a

Status	Date	Comments
	n/a	n/a

Location	Monument	Date Placed	Placed By
GROUND LEVEL	CONC PILLAR	1-JAN-1973	DEPARTMENT OF LANDS

GDA94

Easting	Northing	Zone	Latitude	Longitude
332106.053	6265786.668	56	-33° 44' 04.84620"	151° 11' 15.61830"

Class	Order	Positional Uncertainty	Local Uncertainty	GDA Updated
A	1	n/a	n/a	18-FEB-2014

Source	Type	Method	Date issued	Issued By
235356	ADJUSTMENT	GEOLAB	28-JUN-2013	MICHAEL LONDON

Previous Reference	Location	File Number
n/a	n/a	n/a

Comments
GREATER SYDNEY SUBSPINE TRANSACTION #100093

MGA Combined Scale Factor	MGA Convergence
0.999918	-1° 00' 24.15"

AusGeoid09
23.218

AHD71

Height
165.773

Class	Order	Positional Uncertainty	Local Uncertainty	AHD Updated
B	2	n/a	n/a	18-FEB-2014

Source	Type	Method	Date issued	Issued By
235356	ADJUSTMENT	GEOLAB	28-JUN-2013	MICHAEL LONDON

Previous Reference	Location	File Number
n/a	n/a	n/a

Comments
GREATER SYDNEY SUBSPINE TRANSACTION #100093

TRIG STATION

Trig Type	55/11	Station Originally Established By
PILLAR	n/a	DEPARTMENT OF LANDS

GNB Approved	Reference	Reserve No.	Reserve Name
3-SEP-1976	11414	n/a	n/a

BEACON

Description	Date Placed	Placed By
MAST AND VANES	1-JAN-1973	DEPARTMENT OF LANDS

Vane Top Height	Vane Diameter
1.92	0.59

VISITATION LOG

Date	Organisation	Comments
10-JUL-1973	n/a	ORIGINAL TRIG PLUG FOUND. CONCRETE PILLAR PLACED VERTICALLY OVER OLD G. M.
1-JAN-1972	n/a	PLUG FOUND, REMAINS OF CAIRN.
1-JAN-1960	n/a	PLUG FOUND.

VISITATION LOG

Date	Organisation	Comments
1-JAN-1883	DEPARTMENT OF LANDS	ORIGINAL STATION ESTABLISHED.

SURVEY MARK

Mark	Name	Alias
TS 10447	CROMER HEIGHTS [P]	n/a

Status	Date	Comments
	n/a	n/a

Location	Monument	Date Placed	Placed By
GROUND LEVEL	STEEL PILLAR	23-NOV-1979	INTEGRATION SURVEY DIVISION

GDA94

Easting	Northing	Zone	Latitude	Longitude
338387.374	6266328.481	56	-33° 43' 50.77713"	151° 15' 19.96640"

Class	Order	Positional Uncertainty	Local Uncertainty	GDA Updated
A	1	n/a	n/a	18-FEB-2014

Source	Type	Method	Date issued	Issued By
235356	ADJUSTMENT	GEOLAB	28-JUN-2013	MICHAEL LONDON

Previous Reference	Location	File Number
n/a	n/a	n/a

Comments
GREATER SYDNEY SUBSPINE TRANSACTION #100093

MGA Combined Scale Factor	MGA Convergence
0.999893	-0° 58' 08.00"

AusGeoid09
23.227

AHD71

Height
157.345

Class	Order	Positional Uncertainty	Local Uncertainty	AHD Updated
B	2	n/a	n/a	18-FEB-2014

Source	Type	Method	Date issued	Issued By
235356	ADJUSTMENT	GEOLAB	28-JUN-2013	MICHAEL LONDON

Previous Reference	Location	File Number
n/a	n/a	n/a

Comments
GREATER SYDNEY SUBSPINE TRANSACTION #100093

TRIG STATION

Trig Type	55/11	Station Originally Established By
PILLAR	n/a	INTEGRATION SURVEY DIVISION

GNB Approved	Reference	Reserve No.	Reserve Name
28-MAR-1980	14989	n/a	n/a

BEACON

Description	Date Placed	Placed By
MAST AND VANES	23-NOV-1979	INTEGRATION SURVEY DIVISION

Vane Top Height	Vane Diameter
1.47	0.6

Appendix G – RINEX File Example

Appendix H – Trimble R10 GNSS Receiver Specifications

DATASHEET

Trimble R10 GNSS System

PERFORMANCE SPECIFICATIONS

Measurements

- Measuring points sooner and faster with Trimble HD-GNSS technology
- Increased measurement productivity and traceability with Trimble SurePoint electronic tilt compensation
- Worldwide centimeter level positioning using Trimble CenterPoint RTX satellite delivered corrections
- Reduced downtime due to loss of radio signal with Trimble xFill technology
- Advanced Trimble Maxwell 6 Custom Survey GNSS chips with 440 channels
- Future-proof your investment with Trimble 360 GNSS tracking
- Satellite signals tracked simultaneously:
  - GPS: L1C/A, L1C, L2C, L2E, L5
  - GLONASS: L1C/A, L1P, L2C/A, L2P, L3
  - SBAS: L1C/A, L5 (For SBAS satellites that support L5)
  - Galileo: E1, E5a, E5B
  - BeiDou (COMPASS): B1, B2
- CenterPoint RTX, OmniSTAR HP, XP, G2, VBS positioning
- QZSS, WAAS, EGNOS, GAGAN
- Positioning Rates: 1 Hz, 2 Hz, 5 Hz, 10 Hz, and 20 Hz

POSITIONING PERFORMANCE[1]

Code differential GNSS positioning

Horizontal .... 0.25 m + 1 ppm RMS
Vertical .... 0.50 m + 1 ppm RMS
SBAS differential positioning accuracy[2] .... typically <5 m 3DRMS

Static GNSS surveying

High-Precision Static
  Horizontal .... 3 mm + 0.1 ppm RMS
  Vertical .... 3.5 mm + 0.4 ppm RMS
Static and Fast Static
  Horizontal .... 3 mm + 0.5 ppm RMS
  Vertical .... 5 mm + 0.5 ppm RMS

Real Time Kinematic surveying

Single Baseline <30 km
  Horizontal .... 8 mm + 1 ppm RMS
  Vertical .... 15 mm + 1 ppm RMS
Network RTK[3]
  Horizontal .... 8 mm + 0.5 ppm RMS
  Vertical .... 15 mm + 0.5 ppm RMS
RTK start-up time for specified precisions[4] .... 2 to 8 seconds
Trimble CenterPoint RTX
  Horizontal .... 4 cm
  Vertical .... 9 cm
  RTX convergence time for specified precisions[12] .... 30 minutes or less
  RTX QuickStart convergence time for specified precisions[12] .... 5 minutes or less
Trimble xFill[5]
  Horizontal .... RTK[6] + 10 mm/minute RMS
  Vertical .... RTK[6] + 20 mm/minute RMS

HARDWARE

Physical

Dimensions (W×H) .... 11.9 cm x 13.6 cm (4.6 in x 5.4 in)
  Weight .... 1.12 kg (2.49 lb) with internal battery, internal radio with UHF antenna, 3.57 kg (7.86 lb) items above plus range pole, controller & bracket
Temperature[7]
  Operating .... –40° C to +65° C (–40° F to +149° F)
  Storage .... –40° C to +75° C (–40° F to +167° F)
Humidity .... 100%, condensing
Ingress Protection .... IP67 dustproof, protected from temporary immersion to depth of 1 m (3.28 ft)
Shock and vibration .... Tested and meets the following environmental standards:
  Shock .... Non-operating: Designed to survive a 2 m (6.6 ft) pole drop onto concrete. Operating: to 40 G, 10 msec, sawtooth
  Vibration MIL-STD-810F, FIG.514.5C-1

Electrical

- Power 11 to 24 V DC external power input with over-voltage protection on Port 1 and Port 2 (7-pin Lemo)
- Rechargeable, removable 7.4 V, 3.7 Ah Lithium-ion smart battery with LED status indicators
- Power consumption is 5.1 W in RTK rover mode with internal radio[8]
- Operating times on internal battery[8]:
  - 450 MHz and 900 MHz receive only option .... 5.5 hours
  - 450 MHz and 900 MHz receive/transmit option (0.5 W) .... 4.5 hours
  - 450 MHz receive/transmit option (2.0 W) .... 3.7 hours
  - Cellular receive option .... 5.0 hours

COMMUNICATIONS AND DATA STORAGE

- Serial: 3-wire serial (7-pin Lemo)
- USB v2.0: supports data download and high speed communications
- Radio Modem: fully integrated, sealed 450 MHz wide band receiver/transmitter with frequency range of 403 MHz to 473 MHz, support of Trimble, Pacific Crest, and SATEL radio protocols:
  - Transmit power: 2 W
  - Range: 3–5 km typical / 10 km optimal[10]
- Cellular: integrated, 3.5 G modem, HSDPA 7.2 Mbps (download), GPRS multi-slot class 12, EDGE multi-slot class 12, UMTS/HSDPA (WCDMA/FDD) 850/1900/2100MHz, Quad-band EGSM 850/900/1800/1900 MHz, GSM CSD, 3GPP LTE
- Bluetooth: fully integrated, fully sealed 2.4 GHz communications port (Bluetooth®)[11]
- WiFi: 802.11 b,g, access point and client mode, WPA/WPA2/WEP64/WEP128 encryption
- External communication devices for corrections supported on – Serial, USB, Ethernet, and Bluetooth ports
- Data storage: 4 GB internal memory; over three years of raw observables (approx. 1.4 MB /day), based on recording every 15 seconds from an average of 14 satellites
- CMR+, CMRx, RTCM 2.1, RTCM 2.3, RTCM 3.0, RTCM 3.1 input and output
- 24 NMEA outputs, GSOF, RT17 and RT27 outputs

WebUI

- Offers simple configuration, operation, status, and data transfer
- Accessible via WIFI, Serial, USB, and Bluetooth

Supported Trimble Controllers

- Trimble TSC3, Trimble Slate, Trimble CU, Trimble Tablet Rugged PC

CERTIFICATIONS

FCC Part 15 (Class B device), 22, 24; R&TTE CE Mark; C-Tick, A-Tick; PTCRB; WFA

1 Precision and reliability may be subject to anomalies due to multipath, obstructions, satellite geometry, and atmospheric conditions. The specifications stated recommend the use of stable mounts in an open sky view, EMI and multipath clean environment, optimal GNSS constellation configurations, along with the use of survey practices that are generally

Appendix I – Online AUSPOS PPP Solutions Example

Australian Government
Geoscience Australia

AUSPOS GPS Processing Report

September 15, 2015

This document is a report of the GPS data processing undertaken by the AUSPOS Online GPS Processing Service (version: AUSPOS 2.2) . The AUSPOS Online GPS Processing Service uses International GNSS Service (IGS) products (final, rapid, ultra-rapid depending on availability) to compute precise coordinates in ITRF anywhere on Earth and GDA94 within Australia. The Service is designed to process only dual frequency GPS phase data.

An overview of the GPS processing strategy is included in this report.

Please direct any correspondence to geodesy@ga.gov.au

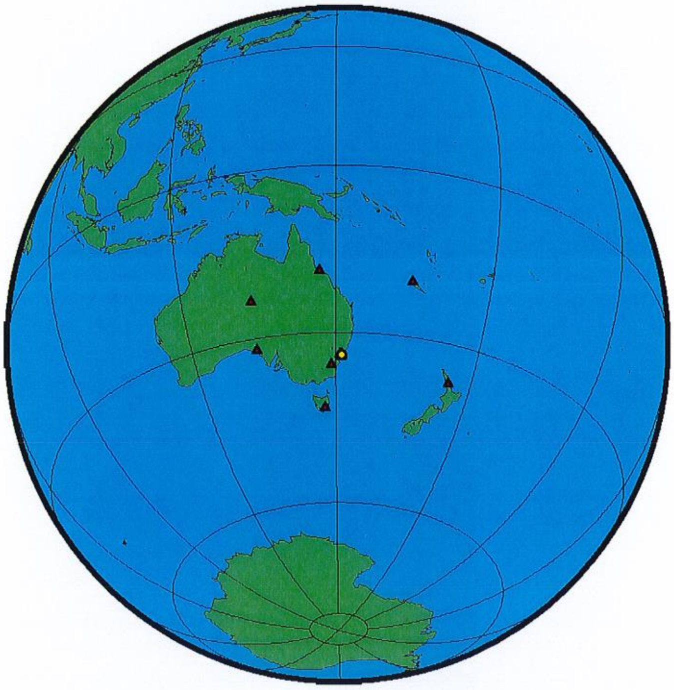
Geodesy
Geoscience Australia
Cnr Jerrabomberra and Hindmarsh Drive
GPO Box 378, Canberra, ACT 2601, Australia
Freecall (Within Australia): 1800 800 173
Tel: +61 2 6249 9111. Fax +61 2 6249 9929
Geoscience Australia
Home Page: http://www.ga.gov.au

1 User Data

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

Station (s)	Submitted File	Antenna Type	Antenna Height (m)	Start Time	End Time
GPS0	GPS02480.150	TRMR10 NONE	0.130	2015/09/05 01:38:30	2015/09/06 05:44:00

2 Processing Summary



Date	User Stations	Reference Stations	Orbit Type
2015/09/05 01:38:30	GPS0	ALIC AUCK CEDU CWN2 FTDN HOB2 KOUC MGRV PBOT SYDN TID1 TOW2 UNSW VLWD WFAL	IGS rapid

Remark: An IGS Rapid Orbit product has been used in this computation, IGS Rapid orbits are usually of very high quality. However, to ensure you achieve the highest quality coordinates please resubmit approximately 2 weeks after the observation session end to ensure the use of the IGS Final Orbit product.

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 Geoscience Australia (GA) derived coordinate transformation process. GA recommends that users within Australia use GDA94 coordinates. For general and technical information on GDA94 see http://www.ga.gov.au/earth-monitoring/geodesy/geodetic-datums/GDA.html and http://www.icsm.gov.au/icsm/gda/gdatm/

3.1 Cartesian, GDA94

Station	X (m)	Y (m)	Z (m)
GPS0	-4655709.553	2553623.455	-3521750.250
ALIC	-4052051.770	4212836.195	-2545106.023
CEDU	-3753472.147	3912741.041	-3347961.040
CWN2	-4659371.293	2564524.197	-3509116.900
FTDN	-4647526.042	2552333.024	-3533122.843
HOB2	-3950071.265	2522415.203	-4311638.515
MGRV	-4642160.052	2591122.094	-3512053.102
PBOT	-4640490.144	2549860.066	-3544077.598
SYDN	-4648240.003	2560636.548	-3526319.019
TID1	-4460996.051	2682557.126	-3674443.854
TOW2	-5054582.666	3275504.562	-2091539.887
UNSW	-4644468.639	2549957.957	-3538921.082
VLWD	-4635059.588	2571670.941	-3535486.687
WFAL	-4622251.221	2562686.311	-3558920.577

3.2 Geodetic, GRS80 Ellipsoid, GDA94

AHD is computed from an Australia wide gravimetric geoid model that has been aposteriori fitted to AHD. The derived AHD is only provided for sites within the extents of the AUSGEOID09 (Version 1.01) product, see http://www.ga.gov.au/earth-monitoring/geodesy/geodetic-datums/geoid.html.

Station	Latitude (DMS)	Longitude (DMS)	Ellipsoidal Height(m)	Derived AHD (m)
GPS0	-33 43 50.77607	151 15 19.96591	180.549	157.322
ALIC	-23 40 12.44598	133 53 07.84815	603.3451	587.495
CEDU	-31 52 00.01661	133 48 35.37582	144.8201	153.614
CWN2	-33 35 37.33400	151 10 17.59702	218.0597	194.344
FTDN	-33 51 18.23320	151 13 30.88393	27.9147	5.145
HOB2	-42 48 16.98549	147 26 19.43581	41.1171	44.735
MGRV	-33 37 35.49110	150 49 51.54253	45.2249	21.328
PBOT	-33 58 26.51856	151 12 43.38725	34.5283	12.237
SYDN	-33 46 51.18428	151 09 01.35705	85.6753	62.635
TID1	-35 23 57.15620	148 58 47.98451	665.4074	646.336
TOW2	-19 16 09.42811	147 03 20.46546	88.2189	29.465
UNSW	-33 55 03.63452	151 13 54.63307	86.9685	64.450
VLWD	-33 52 50.30956	150 58 37.79243	42.6632	19.930
WFAL	-34 08 03.18114	150 59 41.88772	251.6409	229.784

3.3 MGA Grid, GRS80 Ellipsoid, GDA94

Station	East (m)	North (m)	Zone	Ellipsoidal Height (m)	Derived AHD (m)
GPS0	338387.361	6266328.514	56	180.549	157.322
ALIC	386352.407	7381850.770	53	603.345	587.495
CEDU	387415.779	6473725.241	53	144.820	153.614
CWN2	330336.133	6281393.648	56	218.060	194.344
FTDN	335817.405	6252497.110	56	27.915	5.146
HOB2	535873.403	5260777.217	55	41.117	44.734
MGRV	298805.002	6277143.361	56	45.225	21.328
PBOT	334826.507	6239282.748	56	34.528	12.237
SYDN	328742.556	6260601.375	56	85.675	62.635
TID1	679807.860	6080884.471	55	665.407	646.335
TOW2	505851.333	7869375.319	55	88.219	29.465
UNSW	336547.272	6245564.258	56	86.969	64.451
VLWD	312919.835	6249236.667	56	42.663	19.930
WFAL	315117.353	6221146.477	56	251.641	229.784

3.4 Positional Uncertainty (95% C.L.) - Geodetic, GDA94

Station	Longitude(East) (m)	Latitude(North) (m)	Ellipsoidal Height(Up) (m)
GPS0	0.008	0.008	0.016
ALIC	0.008	0.008	0.016
AUCK	0.008	0.008	0.016
CEDU	0.008	0.008	0.016
CWN2	0.008	0.008	0.016
FTDN	0.008	0.008	0.016
HOB2	0.007	0.008	0.016
KOUC	0.008	0.008	0.016
MGRV	0.008	0.008	0.016
PBOT	0.008	0.008	0.016
SYDN	0.008	0.008	0.016
TID1	0.008	0.008	0.016
TOW2	0.008	0.008	0.016
UNSW	0.008	0.008	0.016
VLWD	0.008	0.008	0.016
WFAL	0.008	0.008	0.016

3.5 ITRF to GDA94 Transformation Parameters

Transformation parameters between ITRF 2008 and GDA 94 are calculated on a solution by solution basis via a Helmert Transformation using the parameters and approach detailed in ITRF to GDA94 Coordinate Transformations, J.Dawson and A.Woods, Journal of Applied Geodesy, 4(2010), no.4, pp. 189-199.

$$\begin{pmatrix} X_{GDA94} \\ Y_{GDA94} \\ Z_{GDA94} \end{pmatrix} = \begin{pmatrix} T_x \\ T_y \\ T_z \end{pmatrix} + (1+S_c) \begin{pmatrix} 1 & R_z & -R_y \\ -R_z & 1 & R_x \\ R_y & -R_x & 1 \end{pmatrix} \begin{pmatrix} X_{ITRF} \\ Y_{ITRF} \\ Z_{ITRF} \end{pmatrix}$$

where

$$\begin{aligned} T_x &= -0.05389(m) \\ T_y &= 0.00963(m) \\ T_z &= 0.05152(m) \\ S_c &= 1.2073e-08 \\ R_x &= 1.60447e-07(radians) \\ R_y &= 1.35185e-07(radians) \\ R_z &= 1.33055e-07(radians) \end{aligned}$$

The above transformation parameters are only valid for the epoch 05/09/2015.

4 Computed Coordinates, ITRF2008

All computed coordinates are based on the IGS realisation of the ITRF2008 reference frame. All the given ITRF2008 coordinates refer to a mean epoch of the site observation data. All coordinates refer to the Ground Mark.

4.1 Cartesian, ITRF2008

Station	X (m)	Y (m)	Z (m)	ITRF2008 @
GPS0	-4655710.259	2553623.360	-3521749.220	05/09/2015
ALIC	-4052052.572	4212836.004	-2545104.820	05/09/2015
AUCK	-5105681.423	461564.011	-3782181.141	05/09/2015
CEDU	-3753473.021	3912741.022	-3347959.916	05/09/2015
CWN2	-4659371.999	2564524.100	-3509115.868	05/09/2015
FTDN	-4647526.749	2552332.932	-3533121.814	05/09/2015
HOB2	-3950072.081	2522415.329	-4311637.575	05/09/2015
KOUC	-5751223.025	1617967.312	-2225743.376	05/09/2015
MGRV	-4642160.762	2591121.999	-3512052.068	05/09/2015
PBOT	-4640490.852	2549859.977	-3544076.570	05/09/2015
SYDN	-4648240.711	2560636.455	-3526317.989	05/09/2015
TID1	-4460996.797	2682557.079	-3674442.827	05/09/2015
TOW2	-5054583.269	3275504.176	-2091538.704	05/09/2015
UNSW	-4644469.346	2549957.867	-3538920.054	05/09/2015
VLWD	-4635060.298	2571670.851	-3535485.656	05/09/2015
WFAL	-4622251.933	2562686.226	-3558919.549	05/09/2015

4.2 Geodetic, GRS80 Ellipsoid, ITRF2008

Geoid-ellipsoidal separations, in this section, are computed using a spherical harmonic synthesis of the global EGM2008 geoid. More information on the EGM2008 geoid can be found at http://earth-info.nga.mil/GandG/wgs84/gravitymod/egm2008/

Station	Latitude (DMS)	Longitude (DMS)	Ellipsoidal Height(m)	Derived Above Geoid Height(m)
GPSO	-33 43 50.73794	151 15 19.98232	180.454	157.608
ALIC	-23 40 12.40472	133 53 07.87322	603.245	588.101
AUCK	-36 36 10.22002	174 50 03.79037	132.678	97.745
CEDU	-31 51 59.97549	133 48 35.40032	144.729	153.772
CWN2	-33 35 37.29584	151 10 17.61353	217.964	194.638
FTDN	-33 51 18.19506	151 13 30.90031	27.820	5.427
HOB2	-42 48 16.94651	147 26 19.45048	41.034	44.747
KOUC	-20 33 31.27906	164 17 14.41887	84.120	23.673
MGRV	-33 37 35.45285	150 49 51.55917	45.130	21.530
PBOT	-33 58 26.48042	151 12 43.40358	34.433	12.497
SYDN	-33 46 51.14611	151 09 01.37349	85.580	62.888
TID1	-35 23 57.11749	148 58 48.00130	665.315	646.468
TOW2	-19 16 09.38862	147 03 20.48780	88.109	30.174
UNSW	-33 55 03.59639	151 13 54.64942	86.873	64.725
VLWD	-33 52 50.27135	150 58 37.80891	42.568	20.139
WFAL	-34 08 03.14294	150 59 41.90408	251.546	229.993

4.3 Positional Uncertainty (95% C.L.) - Geodetic, ITRF2008

Station	Longitude(East) (m)	Latitude(North) (m)	Ellipsoidal Height(Up) (m)
GPSO	0.004	0.003	0.008
ALIC	0.004	0.003	0.008
AUCK	0.006	0.003	0.009
CEDU	0.004	0.003	0.007
CWN2	0.004	0.003	0.008
FTDN	0.004	0.003	0.007
HOB2	0.003	0.003	0.007
KOUC	0.005	0.003	0.008
MGRV	0.004	0.003	0.007
PBOT	0.004	0.003	0.007
SYDN	0.004	0.003	0.008
TID1	0.004	0.003	0.007
TOW2	0.004	0.003	0.007
UNSW	0.004	0.003	0.007
VLWD	0.004	0.003	0.008
WFAL	0.004	0.003	0.008

5 Ambiguity Resolution - Per Baseline

Baseline	Ambiguities Resolved	Baseline Length (km)
FTDN - MGRV	85.2 %	44.467
CEDU - FTDN	91.5 %	1638.392
PBOT - UNSW	98.1 %	6.514
AUCK - KOUC	83.3 %	2043.647
PBOT - WFAL	79.0 %	26.786
FTDN - SYDN	96.1 %	10.759
FTDN - HOB2	78.0 %	1045.670
MGRV - TOW2	91.4 %	1629.825
FTDN - PBOT	93.8 %	13.252
FTDN - TID1	89.6 %	267.812
KOUC - TOW2	88.3 %	1802.983
FTDN - VLWD	83.8 %	23.129
ALIC - CEDU	90.0 %	907.625
FTDN - GPSO	97.8 %	14.070
CWN2 - MGRV	85.7 %	31.817
AVERAGE	88.8%	633.783

Please note for a regional solution, such as used by AUSPOS, an average ambiguity resolution of 50% or better for the network indicates a reliable solution.

6 Computation Standards

6.1 Computation System

Software	Bernese GNSS Software Version 5.2.
GNSS system(s)	GPS only.

6.2 Data Preprocessing and Measurement Modelling

Data preprocessing	Phase preprocessing is undertaken in a baseline by baseline mode using triple-differences. In most cases, cycle slips are fixed by the simultaneous analysis of different linear combinations of L1 and L2. If a cycle slip cannot be fixed reliably, bad data points are removed or new ambiguities are set up A data screening step on the basis of weighted postfit residuals is also performed, and outliers are removed.
Basic observable	Carrier phase with an elevation angle cutoff of 7° and a sampling rate of 3 minutes. However, data cleaning is performed a sampling rate of 30 seconds. Elevation dependent weighting is applied according to $1/\sin(e)^2$ where e is the satellite elevation.
Modelled observable	Double differences of the ionosphere-free linear combination.
Ground antenna phase centre calibrations	IGS08 absolute phase-centre variation model is applied.
Tropospheric Model	A priori model is the GMF mapped with the DRY-GMF.
Tropospheric Estimation	Zenith delay corrections are estimated relying on the WET-GMF mapping function in intervals of 2 hour. N-S and E-W horizontal delay parameters are solved for every 24 hours.
Tropospheric Mapping Function	GMF
Ionosphere	First-order effect eliminated by forming the ionosphere-free linear combination of L1 and L2. Second and third effect applied.
Tidal displacements	Solid earth tidal displacements are derived from the complete model from the IERS Conventions 2010, but ocean tide loading is not applied.
Atmospheric loading	Applied
Satellite centre of mass correction	IGS08 phase-centre variation model applied
Satellite phase centre calibration	IGS08 phase-centre variation model applied
Satellite trajectories	Best available IGS products.
Earth Orientation	Best available IGS products.

6.3 Estimation Process

Adjustment	Weighted least-squares algorithm.
Station coordinates	Coordinate constraints are applied at the Reference sites with standard deviation of 1mm and 2mm for horizontal and vertical components respectively.
Troposphere	Zenith delay parameters and pairs of horizontal delay gradient parameters are estimated for each station in intervals of 2 hours and 24 hours.
Ionospheric correction	An ionospheric map derived from the contributing reference stations is used to aid ambiguity resolution.
Ambiguity	Ambiguities are resolved in a baseline-by-baseline mode using the Code-Based strategy for 180-6000km baselines, the Phase-Based L5/L3 strategy for 18-200km baselines, the Quasi-Ionosphere-Free (QIF) strategy for 18-2000km baselines and the Direct L1/L2 strategy for 0-20km baselines.

6.4 Reference Frame and Coordinate Uncertainty

Terrestrial reference frame	IGS08 station coordinates and velocities mapped to the mean epoch of observation.
Australian datum	GDA94 coordinates determined via Helmert transformation from ITRF using the Dawson and Woods (2010) parameters.
Derived AHD	For stations within Australia, AUSGeoid09 is used to compute AHD. AUSGeoid09 is the Australia-wide gravimetric quasigeoid model that has been a posteriori fitted to the Australian Height Datum.
Above-geoid heights	Earth Gravitational Model EGM2008 released by the National Geospatial-Intelligence Agency (NGA) EGM Development Team is used to compute above-geoid heights. This gravitational model is complete to spherical harmonic degree and order 2159, and contains additional coefficients extending to degree 2190 and order 2159.
Coordinate uncertainty	Coordinate uncertainty is expressed in terms of the 95% confidence level for both GDA94 and ITRF2008. Uncertainties are scaled using an empirically derived model which is a function of data span, quality and geographical location.