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ACCURACY PERFORMANCE ASSESSMENT OF AUSPOS: A COMPRATIVE ANALYSIS WITH TBC AND GAMIT/GLOBK

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BSc Geomatics

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ACCURACY PERFORMANCE ASSESSMENT OF AUSPOS: A COMPARATIVE ANALYSIS WITH TBC AND GAMIT/GLOBK

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A Dissertation Submitted to the Department of Geospatial Sciences and Technology in Partially Fulfilment of the Requirements for the Award of Bachelor of Science in Geomatics (BSc. GM) of Ardhi University

CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the Ardhi University dissertation titled **"Accuracy Performance Assessment of AUSPOS: A Comparative Analysis with TBC and GAMIT/GLOBK"** in partial fulfillment of the requirements for the award of degree of Bachelor of Science in Geomatics at Ardhi University.

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(Main Supervisor) (Second Supervisor)

Date ………………………... Date …………………...

DECLARATION AND COPYRIGHT

I, NGIMBUDZI, BARAKA E hereby declare that, the contents of this dissertation are the results of my own findings through my study and investigation, and to the best of my knowledge they have not been presented anywhere else as a dissertation for diploma, degree or any similar academic award in any institution of higher learning.

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(Candidate)

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DEDICATION

I dedicate this dissertation to my parents, Ezekiel and Elda Ngimbudzi, whose unwavering support and belief in my abilities have been the driving force behind my academic journey. Your love, and encouragement, and sacrifices have given me the strength to overcome challenges and pursue my dreams. Thank you for always looking out for me and being there for me. I love you all.

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Finally, I dedicate this work to future researchers in the field. May it serve as a stepping stone for further exploration and contribute to the advancement of knowledge in this area. May your own dedication and perseverance be rewarded with meaningful discoveries and significant contributions to your respective disciplines.

ABSTRACT

This research presents a comparative analysis of the accuracy performance of AUSPOS, TBC, and GAMIT/GLOBK in surveying applications. The study assesses the positional accuracy by analyzing the difference between calculated positions and references coordinates. TBC (Trimble Business Center) was used in the research as a point of comparison with AUSPOS, so as to examine the performance of AUSPOS within one day observation period and analyzing the accuracy and consistency of positioning solutions at differently hourly intervals. ECEF coordinates obtained from the TBC and AUSPOS software' was used to assess the accuracy performance of software in comparison with the reference ECEF coordinates obtained from the GAMIT/GLOBK software. AUSPOS generally showing better performance, with RMSE values ranging from 0.016 to 0.021 meters and TBC with RMSE values ranging from 0.092 to 0.116 meters.

Both AUSPOS and GAMIT/GLOBK exhibit similar trends in RMSE values over time, with both showing a decreasing trend, indicating improved accuracy with longer observation periods. AUSPOS demonstrates overall stability and accuracy, with RMSE values ranging from 0.006 to 0.027 meters, but experiences occasional spikes. GAMIT/GLOBK shows initial stability (0.008 to 0.017 meters) but experiences spikes on specific days before stabilizing at lower levels. These findings suggest that while AUSPOS and GAMIT/GLOBK offer stable and accurate positioning solutions, GAMIT/GLOBK demonstrates more consistent performance.

Based on the findings, it is concluded that AUSPOS, an online GNSS processing service provided by Geoscience Australia, can be used as an alternative in geodetic surveying when high accuracy is not immediately required. It offers quick and reasonably accurate positioning solutions, making it suitable for preliminary surveys, rapid field checks, and for scenarios requiring immediate result, AUSPOS can be beneficial. While GAMIT/GLOBK outperform AUSPOS in terms of accuracy, AUSPOS remains a cost-effective and accessible option. It can serve as a valuable tool for independent validation of survey data, and establishment of control points. However, for critical projects demanding the highest precision, specialized software like GAMIT/GLOBK may still be preferable.

Keywords: AUSPOS, TBC, GAMIT/GLOBK, Root Mean Square Error (RMSE),

Positional Accuracy

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ACRONYMS AND ABBREVIATIONS

AUSPOS	Australian National GPS Positioning Operations
CORS	Continuously Operating Reference Stations
CRCSI	Cooperative Research Centre for Spatial Information
GAMIT	GPS Analysis at Massachusetts Institute of Technology
GLOBK	Global Kalman Filter
GLONASS	Russian Global Navigation Satellite System
GPS	Global Positioning System
NGCA	National GNSS Campaign Archive
PPP	Precise Point Positioning
RINEX	Receiver Independent Exchange Format
RMSE	Root Mean Square Error
RTK	Real Time Kinematics
SINEX	Solution Independent Exchange
SIO	Scripps Institution of Oceanography
TBC	Trimble Business Centre
TEQC	Translation, Editing and Quality Checking

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The level of accuracy achieved in Global Navigation Satellite System (GNSS) positioning depends on the method of measurements and techniques of processing field data (Rizos, 1999; Seeber, 2003). As such, new innovations in GNSS measurements and data processing methods continue to emerge. To obtain more accurate positioning, GPS observations should be collected in relative static surveying mode, and then computed with different post-processing scientific or commercial software (Ocalan, 2016). However, the usage of such software is also quite difficult because they generally require deep knowledge of the GNSS and experience in the processing. Furthermore, they mostly need a licensing fee. Regarding the improvements in information technology and GNSS data processing methodology, many new opportunities have been offered to the users. In this respect, several institutions, research centres or organizations have developed web-based online GNSS processing services and they have started to become a strong alternative to the conventional data processing method. The only requirement for using these services which are generally provided free of charge with limitless usage, is a computer having an Internet connection and web browser (Alkan *et al*., 2016).

These services are designed to be as simple as possible for the user and with minimal input. Users of such systems have to perform uploading/sending of their collected RINEX data by using the web site of these services, e-mail or ftp sites to the system and selecting a few options such as static/kinematic modes, datum, antenna etc. With these services, when the data is received to the service, processing starts and the results (together with the coordinates, process reports along with other necessary information for analyzing the results) are sent to the user in a short amount time. Figure 1.1 illustrates how these web-based online services work to provide their outputs to the users. Some of these services process not only the GPS but also the data of other systems, particularly those of GLONASS, and provide resilience and a higher accurate positioning service in certain cases to their users (Alkan *et al*., 2016).

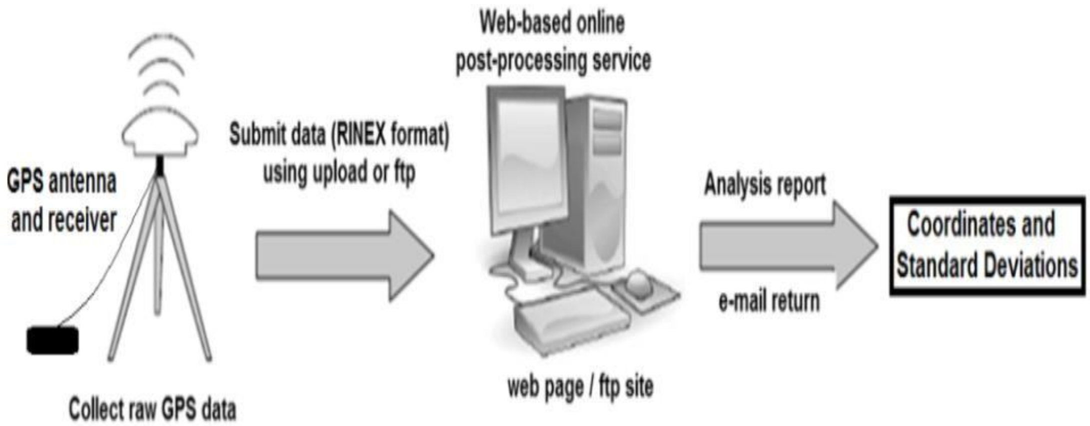


figure 1 1 The main working illustration of web-based online services (Ocalan, 2016)

As of today, there are several web-based online GNSS processing services, in which some of them calculate the coordinates with a relative solution approach (e.g., AUSPOS, Trimble RTX, OPUS,); or with the PPP technique (e.g., CSRS-PPP, magicGNSS, APPS). The services evaluated with the relative solution, use the fixed-point positions which relate to International GNSS Service (IGS) and/or CORS Networks as reference points and calculates the coordinates of the points with the relative method. The use of these systems saves time and labor by eliminating the need for a reference station and knowledge, training and usage of the GNSS processing software (Alkan *et al*., 2016).

AUSPOS (Australian National GPS Positioning Operations) is a free online GPS data processing service provided by Geoscience Australia. AUSPOS takes advantage of both the IGS Stations Network and the IGS product range, and works with data collected anywhere on earth; users submit their dual frequency geodetic quality GPS RINEX data observed in a static mode to your GPS data processing system. AUSPOS is commonly used for surveying, mapping, and navigation applications. It accepts only dual-frequency GPS data in static mode for more than 1-hour data span (preferably 2-hour). Data can be sent to the service through the web site or using ftp site. The service utilizes a relative method for positioning by establishing a network consisting of the nearest 15 IGS and/or CORS stations using the best available IGS products. The service aims to assist a variety of users from the private and public sector who require GDA94 and ITRF coordinates. AUSPOS uses the Bernese GNSS Software for processing baselines, IGS orbits and IGS network stations. Solutions are available for anywhere on the earth (Janssen V. & McElroy S., 2020).

There have been many studies that compare the performance of AUSPOS with other online software. A notable study in GNSS post-processing was done by (Tariq *et al.*, 2017) to evaluate the accuracy of three online processing services (OPUS, AUSPOS, and CSRS-PPP) and one offline software (LGO v8.3). Two GNSS observation techniques (static and rapid-static) were used to obtain necessary data and the duration of observation for each point was divided into five periods (2hr, 4hr, 6hr, 8hr, and 10hr). The result obtained through the LGO software used in the Rapid Static (RS) technique shows a root mean square error (RMSE) of 0.011m which made it to be the closest software in terms of convergence with field measurements. AUSPOS gave better results among the online processing services with RMSE values of 0.041-0.018m, while OPUS results range between 0.043- 0.260m and CSRS-PPP results range between 0.046-0.250m respectively. It was concluded that there is no association between processing results at the same point for different free online processing services.

Previous study (Adam 2017) focused on the use of online and offline processing tools to improve the precision of a GPS passive station. In this study, GPS raw data of roughly 121hr was broken into 36 sub-files covering five days of observation, each containing a full of 24hr, 12hr, and 6hr of data at 1second epoch was collected and processing was done using CSRS-PPP, OPUS, AUSPOS along with offline-PPP software. The results revealed that the horizontal and vertical RMSE decreases with an increase of observation time. The RMSE for the horizontal and vertical components was found to be less than 6mm and 10mm respectively for all sessions and processing services. (El-Mowafy 2013) made a comparison between two of the online post-processing services (AUSPOS and CSRS-PPP) and used four datasets of 1hr, 1.5hr, 2hr, and 3hr of length in three different locations. It was concluded that AUSPOS has an accuracy of a few millimeters to a couple of centimeters in the static mode for the horizontal coordinates and centimeters in vertical while CSRS-PPP also gave the accuracy of few millimeters to centimeters for the planimetric positions, but the vertical error was up to a decimeter.

A study carried out by (Herbert *et al*., 2020) aimed on assessing the accuracy performance of two free online processing software AUSPOS and CSRS-PPP on short baselines. Between the two free online processing services tested over short baselines AUSPOS gives the better results than CSRS-PPP. Rizos, Johnston, and Han (2010) found that AUSPOS provided users with accurate positioning solutions. They evaluated AUSPOS user experiences by comparing its results with those of other GNSS processing software and found that AUSPOS outperformed other software in terms of accuracy.

Although this software option has been used for determining positions for some time and compared to other online services providing either relative solution or absolute solution, still, there is a lack of direct comparison of AUSPOS, the web-based online service performing relative solution, with the commercial and research software performing relative solution. While previous studies have compared AUSPOS to online PPP solutions services and offline software, there is a need to compare AUSPOS to TBC, a commercial software, and GAMIT/GLOBK, a scientific software to better understand its performance. This study fills this gap by providing an assessment of the accuracy of these software options.

1.2 Problem Statement of the Research

The level of accuracy achieved in Global Navigation Satellite System (GNSS) positioning depends on the method of measurements and techniques of processing field data. Conventional GNSS processing software such as commercial and scientific software have been used in data processing for many years. However, the usage of such software is also quite difficult because they generally require deep knowledge of the GNSS and experience in the processing. Furthermore, they mostly need a licensing fee posing some challenges to the user. Regarding the improvements in information technology and GNSS data processing methodology, many new opportunities have been offered to the users. In this respect, several institutions, research centres or organizations have developed web-based online GNSS processing services and they have started to become a strong alternative to the conventional data processing method. AUSPOS (Australian National GPS Positioning Service) is one such service, utilizing a relative solution approach for accurate positioning. Its accuracy and performance have been examined in comparison with other GNSS post-processing software options for several years. However, the comparison was primarily focused on comparing AUSPOS with online processing services and software options that use different processing strategies. Still, there is a lack of direct comparison between AUSPOS and the conventional GNSS processing software that employ the same processing strategies as AUSPOS. Therefore, this study aims to fill this gap by directly comparing accuracy performance of AUSPOS with TBC and GAMIT/GLOBK so as to evaluate suitability of AUSPOS for various surveying applications in comparison with TBC and GAMIT/GLOBK.

1.3 Research Objectives

1.3.1 Main Objective

The main objective of this study is to assess and compare the accuracy performance of AUSPOS, a web-based GNSS post-processing service, with RBC (Trimble Business Center) commercial software and GAMIT/GLOBK scientific software for various surveying applications, including control surveys, engineering surveys, and geodetic surveys. The study aims to assess the suitability of AUSPOS for these different surveying applications and provide valuable insights for surveying professionals and researchers in selecting the most appropriate software based on their specific needs.

1.3.2 Specific Objectives

The specific objectives of this research include:

i. Comparison of the accuracy of AUSPOS and TBC for one-day GPS observations that are splitted into different time intervals.
ii. Analysis of the performance of AUSPOS at different hourly intervals within the one-day observation period.
iii. Utilizing time series analysis techniques to evaluate the consistency and stability of positioning solutions provided by AUSPOS and GAMIT/GLOBK over the duration of the dataset.

1.4 Significance of the Research

This research holds significant importance for surveyors and the field of surveying as a whole. By comparing accuracy performance of AUSPOS, a freely accessible software, with commercial software like TBC, it provides valuable insights into its accuracy performance, accessibility, cost-effectiveness, and practical application in various surveying tasks, allowing surveyors and professionals to make informed decisions regarding their choice of software for accurate positioning. The research's findings contribute to improving surveying practices, expanding access to accurate positioning technology, and enhancing efficiency in surveying projects.

1.5 Beneficiaries of the Study

The potential beneficiaries of this research include:

i. Surveyors who use GNSS data for land surveying.
ii. Students and academics who study GNSS positioning techniques and need empirical data to evaluate different software options.

1.6 Scope and Limitations

The scope of this study encompasses a comparative analysis of the relative solution accuracy of AUSPOS, TBC, and GAMIT/GLOBK software. The comparison is conducted using data collected in 2020 from CORS (Continuously Operating Reference Station) stations located around the Ol Doinyo Lengai mountain. The dataset includes one-day GPS observations split into different hours for AUSPOS and TBC, as well as a six-months dataset for AUSPOS to evaluate its consistency and stability. Time series analysis techniques are utilized to evaluate the stability, consistency, and performance of AUSPOS and its counterparts over time. The study aims to assess the suitability of AUSPOS for various surveying applications, providing insights for potential users in these domains. However, this research has some limitations. Firstly, the comparison is based on a limited number of scenarios and datasets, which may not capture all possible surveying conditions. Secondly, the accuracy of the reference data and certain assumptions made during the data processing may influence the results. Finally, the study does not consider other GNSS post-processing software options beyond AUSPOS, TBC, and GAMIT/GLOBK.

1.7 Description of the Study Area

The study area for this research is centred around Ol Doinyo Lengai Mountain in Tanzania, where a number of Continuously Operating References Stations (CORS) have been placed. These CORS stations provide geodetic measurements, including data on crustal deformation and plate tectonic activity. In this research, the data collected from these CORS stations will be used to assess the accuracy performance of AUSPOS, a GNSS post-processing software in comparison with TBC. Figure 1.2 illustrates the location map of the GPS network used in the research.

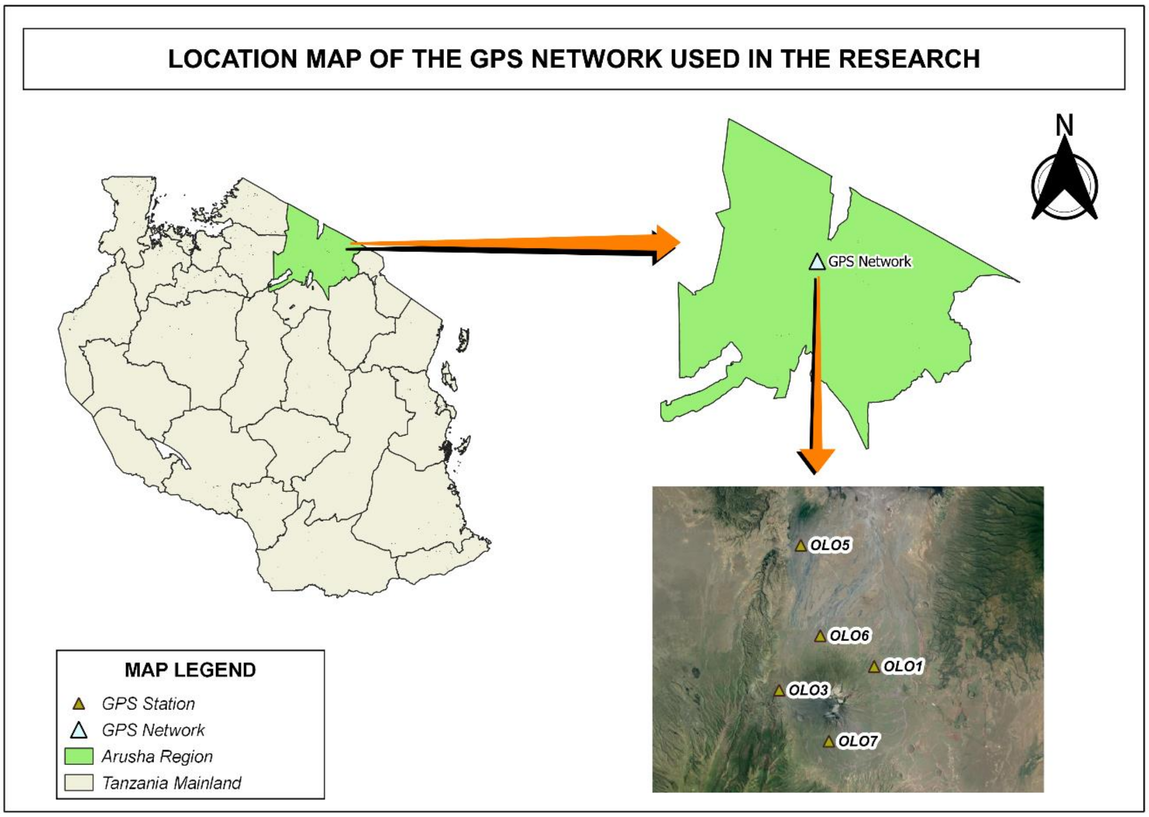


Figure 1 2 Location of the study area

1.8 Organization of the Research

This study contains the following chapters; Chapter one provides an introduction to the study, describing the background, research problem, objectives, significance, beneficiaries, scope, limitations. Chapter two presents a literature review covering GNSS positioning techniques, GNSS data processing software, previous studies on accuracy performance comparison, and gaps in existing literature. Chapter three details the methodology used for the study, including the data sources and acquisition, data format and quality check, and data processing strategies. Chapter four presents the results and analysis of the study, including a description of positional results and a comparative analysis of AUSPOS, GAMIT/GLOBK, and TBC accuracy performances. Chapter five concludes the study, summarizing the main findings, making recommendations for future research, and providing conclusions.

CHAPTER TWO

LITERATURE REVIEW

In this chapter, the literature review provides a comprehensive understanding of the GNSS positioning system, examines three specific data processing software tools (AUSPOS, GAMIT/GLOBK, and TBC), evaluates their features and limitations, reviews previous studies on accuracy performances, and identifies research gaps that the study aims to address.

2.1 Overview of GNSS Positioning System

Global Navigation Satellite System (GNSS) is a satellite-based positioning system that allows users to determine their precise location and time information anywhere on the Earth's surface. The system is comprised of a network of satellites in orbit around the Earth, ground control stations, and user receivers. The system works by transmitting signals from a network of satellites to a user's receivers, which uses these signals to calculate the user's position.

GNSS technology has become an essential tool in many applications, including navigation, surveying, mapping and geodesy. The Global Positioning System (GPS) is the most widely used GNSS system, with a global constellation of 31 satellites providing continuous coverage. Other GNSS systems include the Russian GLONASS, the European Galileo and the Chinese BeiDou. These systems use different satellites constellations and signal frequencies, but they all use similar GNSS positioning techniques to determine a user's location. GNSS technology has revolutionized many industries and applications, from agriculture to transportation to emergency response (Teunissen *et al*., 2017; Misra & Enge, 2011).

GNSS positioning techniques are used to determine a user's location with varying levels of accuracy and precision. Single-point positioning is the simplest technique and involves calculating a user's position using a signal from a single satellite. Differential positioning is a more accurate technique that involves comparing the signals from two or more receivers to calculate the user's position. RTK positioning is the real-time technique that use carrier phase measurements to achieve centimeter level accuracy. PPP is a post processing technique that achieve high accuracy by correcting for errors in the GNSS signals. Carrier phase positioning is a technique that uses the precise measurements of the phase of the carrier signals to achieve high accuracy (Teunissen *et al*., 2017).

2.2 GNSS Data Processing Software

GNSS data processing software is a set of computer programs used to process raw data collected by Global Navigation Satellite System (GNSS) receivers. These programs are designed to extract useful information from the raw data, such as the precise location and velocity of the receiver, as well as other parameters related to the state of atmosphere, Earth's gravity field, and other geophysical phenomena. GNSS data processing software is used to analyze data collected by GNSS receivers to determine the position, velocity, and timing information of a receiver's location (Xu *et al*., 2015)

The software typically includes a range of data processing algorithms and models, such as precise point positioning (PPP), differential positioning (DGPS), and kinematic positioning. These algorithms take into account a wide range of factors that can affect the accuracy and reliability of GNSS measurements, such as signal propagation delays, atmospheric refraction and multipath interference (El-Mowafy & El-Araby, 2014). There are various types of GNSS data processing software available, including online services, commercial software packages, and scientific software.

Online GNSS data processing services, such as OPUS (Online Positioning User Service), AUSPOS (Australian Online GPS Processing services), CSRS-PPP (Canadian Spatial Reference System Precise Point Positioning), and Trimble CenterPoint RTX, allow users to upload GNSS data and obtain high-precision positioning solutions online. These services are widely used by surveyors and geodetic professionals for rapid and accurate GNSS data processing.

Commercial GNSS data processing software packages, such as Bernese GNSS Software, Trimble Business Center (TBC) and Leica Geo Office, provide a comprehensive GNSS data processing capability, include precise point positioning, network solutions, and geodetic modeling. These software packages are widely used in industries such as surveying, construction, and transportation, where high precision GNSS data is required for various applications (Bernese GNSS Software, 2022; Trimble Inc, 2022; Leica Geosystems, 2022). For example, Trimble

Business Center provides a range of tools for processing GNSS data, including support for static and kinematic positioning, network adjustment, and data quality control (Trimble Inc, 2022).

Scientific GNSS data processing software, such as RTKLIB, GAMIT/GLOBK and JPL's Global Differential GPS System (GDGPS), are open-source software packages that are widely used in academic research and scientific applications. These software packages provide a high level of customization and flexibility for GNSS data processing, with a focus on advanced geodetic modeling and scientific applications. For example, RTKLIB is a popular open-source software package that supports real-time and post-processing GNSS data for a variety of 11 applications, including precision agriculture, surveying and autonomous vehicle navigation (Takasu & Yasuda, 2009).

2.2.1 AUSPOS: Background, Features and Functionalities

AUSPOS, or the Australian Positioning Service, is a GNSS (Global Navigation Satellite System) data processing service provided by Geoscience Australia, an Australian government agency responsible for geospatial information and research. AUSPOS was launched in 2000 and it processes data collected from GPS (Global Positioning System) and other GNSS satellites to provide accurate positioning information to the user all over the world (Geoscience Australia, 2021)

Australian Positioning Service was created as a collaborative effort between Geoscience Australia and the Cooperative Research Centre for Spatial Information (CRCSI). The goal of the project was to provide accurate GPS positioning information to users in Australia, while also supporting the development of precise positioning applications and improving the accuracy of geospatial data across the country. Over 10 years from 2011 to 2020, AUSPOS successfully processed more than 1 million jobs worldwide. After AUSPOS was launched in the cloud, more than 200,000 jobs were processed in 15 months, including about 100,000 submissions for the National GNSS Campaign Archive (NGCA) (Geoscience Australia, 2021).

AUSPOS takes advantage of the International GNSS Service (IGS) core network station data and products (e.g., final, rapid and ultra-rapid orbits depending on availability) together with CORS in and around Australia to compute precise coordinates, using static dual frequency

GPS carrier phase and code data of at least 1 hour duration (recommended minimum of 2 hours, maximum of 7 consecutive days). When submitting 30-second Receiver Independent Exchange (RINEX) data (version 2 and 3 are both accepted), users are required to specify the antenna type (using the IGS naming convention) and the verticality measured antenna height from the ground mark to the antenna Reference Point (ARP). Following processing, an AUSPOS report (pdf) is emailed to the user (generally within a few minutes), which includes the computed coordinates and their uncertainties, ambiguities resolution statistics, and an overview of the GPS processing strategy applied. For advanced users, Solution Independent Exchange (SINEX) files containing more detailed information are also available for download (Janssen & McElroy, 2022).

It accepts dual-frequency, geodetic-quality GNSS data in RINEX format that was observed in static mode. While the submitted RINEX file may contain data from multiple GNSS constellations (e.g., GPS, GLONASS, BeiDou and Galileo), only GPS data is used for processing. Similarly, submitted data is resampled (thinned) to a 30-second epoch interval regardless of the initial sampling rate. The AUSPOS website contains background information, a submission checklist, a step-by-step submission guide and frequently asked questions to help users submit data, understand the results and aid trouble shooting. It should be noted that datasets submitted to AUSPOS are neither retained by Geoscience Australia nor passed on to any third party (Janssen & McElroy, 2022).

Some the key features and functionalities of AUSPOS include:

i. Free to use: AUSPOS is available to all users free of charge.
ii. Accessible online: Users can access AUSPOS through a web-based interface, which makes it easy to use and accessible from anywhere with an internet connection.
iii. Real-time and post-processed data: AUSPOS provides both real-time and post processed GPS positioning data, depending on the user's need.
iv. Multiple coordinate systems: AUSPOS supports a range of different coordinate systems, including the Geocentric Datum of Australia (GDA94) and International Terrestrial Reference Frame (ITRF14).

v. User-friendly interface: AUSPOS features a simple and intuitive web-based interface that makes it easy for users to obtain the positioning information they need.

vi. Fast processing times: AUSPOS is designed to provide fast and efficient processing of GPS data, with processing times typically ranging from few minutes to a few hours.

vii. Accessible data archive: AUSPOS maintains an archive of all processed data, which is available for download by users who require access to historical positioning information.

2.2.2 GAMIT/GLOBK: Background, Features and Functionalities

GAMIT/GLOBK is a comprehensive GPS analysis package developed at MIT, the Harvard-Smithsonian Center for Astrophysics (CfA), and the Scripps Institution of Oceanography (SIO) for estimating station coordinates and velocities, stochastic or functional representations of post-seismic deformation, atmospheric delays, satellite orbits, and Earth orientation parameters (Herring *et al*., 2008).

In current practice, the GAMIT solution is not usually used directly to obtain the final estimates of station positions from a survey. Rather, GAMIT is used to produce estimates and an associated covariance matrix ("quasi-observations") of station positions and (optionally) orbital and Earth-rotation parameters which are then input to GLOBK or other similar programs to combine the data with those from other networks and times to estimate positions and velocities. GLOBK uses a Kalman filter (equivalent to sequential least squares if there are no stochastic parameters in the solution) which operates on covariance matrices rather than normal equations and hence requires a non-infinite a priori constraint to be specified for each parameter estimated. In order not to bias the combination, GAMIT generates the solution used by GLOBK with loose constraints on the parameters. Since phase ambiguities must be resolved (if possible) in the phase processing, however, GAMIT also generates several intermediate solutions with user-defined constraints before loosening the constraints for its final solution (Herring *et al*., 2008).

GAMIT is composed of distinct programs which perform the functions of preparing the data for processing (makexp and makex), generating reference orbits for the satellites (arc), computing residual observations (O-C's) and partial derivatives from a geometrical model

(model), detecting outliers or breaks in the data (autcln), and performing a least squares analysis (solve). Although the modules can be run individually, they are tied together through the data flow, particularly file-naming conventions, in such a way that most processing is best done with shell scripts and a sequence of batch files set up a driver module (fixdrv) for modeling, editing, and estimation. Though the data editing is almost always performed automatically, the solution 11 residuals can be displayed or plotted so that problematic data can be identified (cview) (Herring *et al*., 2008).

Likewise, GLOBK operates through distinct programs, which can be invoked with a single command or run separately. The primary functions are to combine quasi-observations either GAMIT/GLOBK "h-files" or the internationally accepted SINEX format from multiple networks and/or epochs (glred or globk), and to impose on this solution a reference frame appropriate to the scientific objective (glorg). Note that globk and glred are the same program, just called in different modes: glred to read data from one day at a time for generating time series, globk for stacking multiple epochs to obtain a mean position and/or velocity (Herring *et al*., 2008).

The full sequence of steps to take you from phase data to time series is accomplished with two shell scripts: sh_gamit looks for raw or RINEX data over a range of days and invokes the GAMIT programs to produce constrained and loose estimates of coordinates together with sky plots of phase data as a record of the processing; sh_glred uses the GAMIT results to produce time series of day-to-day repeatability or a combined h-file that may be further combined with those from other epochs to estimate station velocities. The only preparation required is assembling the meta-data from station logs; setting up the control files, most of which are common to all analyses of a particular era; and assembling the non-IGS phase data in one or more directories on your system (Herring *et al*., 2008).

2.2.3 TBC: Background, features and functionalities

Trimble Business Center (TBC) is a software package developed by Trimble for processing survey data, including GNSS (Global Navigation Satellite System), total station, and UAV (Unmanned Aerial Vehicle) data. The software was first released in 2012 and has been continuously updated since then (Trimble Inc, 2022).

TBC (Trimble Business Centre) was developed by Trimble for processing, managing, and analysing GNSS data collected from various sources, including surveying equipment and other data collection devices. TBC is designed to offer a comprehensive solution for geospatial data processing, including surveying, mapping, and construction applications. The software provides a wide range of features, including data management, quality control, and advanced processing algorithms for high accuracy results.

The processing strategy for TBC involves several steps, including

i. Project setting: Before data processing or importing the data, the project setting must start first. In TBC software the project settings involve general information (project name, user information), coordinate system (datum transformation, geoidal model, projection), units and baseline processing settings.

ii. Data Import: The second step in the TBC processing workflow involves importing the raw GNSS data into the software. The data can be sourced from various devices used for surveying and data collection. TBC supports multiple data formats, including RINEX (Receiver Independent Exchange) format, Trimble DAT, and other proprietary formats.

iii. Processing GPS baselines: TBC utilizes the imported GPS data to compute the relative positions between the base and rover stations. This computation involves precise algorithms and models to determine the baseline vector, which represents the spatial separation between the two stations.

iv. Network Adjustment: After the baseline processing, the positioning solution in TBC undergoes a network adjustment to further enhance the accuracy of the final result. TBC employs a relative positioning technique to determine the position. In this process, the network is adjusted by selecting one point as the control point. The adjustment involves refining the positions of all other points in the network relative to the control point, thereby improving the overall accuracy of the positioning solution.

2.2.4 Limitations and Sources of Errors

AUSPOS, GAMIT/GLOBK and TBC are all software packages commonly used in Geodesy and surveying. Each of these software packages has its own limitations and sources of errors.

For AUSPOS, it only processes GPS data and does not support other satellite-based positioning such as GLONASS, Galileo, or BeiDou. Also, it can't process the GPS data that is observed for more than 24 hrs. Additionally, AUSPOS may have errors due to the factors such as the quality and quantity of the data collected, the distance from the base station, and accuracy of the coordinates of the base station (Geoscience Australia, 2021). Errors may also arise due to the limitations of the models and algorithms used in the software, which may not account for all sources of errors, such as multipath, atmospheric delays, or satellite ephemeris errors (Rizos *et al*., 2013).

Regarding GAMIT/GLOBK, one limitation is that it requires a significant amount of computational power and expertise to use effectively. The software can also be sensitive to the quality of the input data and the choice of parameters used in the processing. Errors may arise due to the modeling assumptions used in the software, such as the assumption of a spheroidal Earth model, which may not accurately represent the shape of the Earth in certain regions (King *et al*., 2018). Errors may also arise due to the limited availability and quality of the reference frames used in the software (Block *et al*., 2004)

For TBC, limitations include the software's reliance on proprietary data formats and its limited ability to process data from non-Leica instruments. Errors can occur due to factors such as the quality of the input data, the choice of processing settings, and the accuracy of the instrument calibration. Additionally, TBC may have limited accuracy in areas with challenging terrain or environments, such as heavily forested regions or urban canyons (Leica Geosystems, 2022).

2.3 Previous Studies on Accuracy Performance Assessment of AUSPOS

There have been many studies that compare the performance of AUSPOS with other online software. A notable study in GNSS post-processing was done by Tariq *et al*., (2017) to evaluate the accuracy of three online processing services (OPUS, AUSPOS, and CSRS-PPP) and one offline software (LGO v8.3). Two GNSS observation techniques (static and rapid-static) were used to obtain necessary data and the duration of observation for each point was divided into five periods (2hr, 4hr, 6hr, 8hr, and 10hr). The result obtained through the LGO software used in the Rapid Static (RS) technique shows a root mean square error (RMSE) of 0.011m 11 which made it to be the closest software in terms of convergence with field measurements. AUSPOS gave better results among the online processing services with RMSE values of 0.0410.018m, while OPUS results range between 0.043- 0.260m and CSRS-PPP results range between 0.046-0.250m respectively. It was concluded that there is no association between processing results at the same point for different free online processing services.

A study carried out by Adam (2017) focused on the use of online and offline processing tools to improve the precision of a GPS passive station. In this study, GPS raw data of roughly 121hr was broken into 36 sub-files covering five days of observation, each containing a full of 24hr, 12hr, and 6hr of data at 1 second epoch was collected and processing was done using CSRS-PPP, OPUS, AUSPOS along with offline-PPP software. The results revealed that the horizontal and vertical RMSE decreases with an increase of observation time. The RMSE for the horizontal and vertical components was found to be less than 6mm and 10mm respectively for all sessions and processing services.

El-Mowafy (2013) made a comparison between two of the online post-processing services (AUSPOS and CSRS-PPP) and used four datasets of 1hr, 1.5hr, 2hr, and 3hr of length in three different locations. It was concluded that AUSPOS has an accuracy of a few millimeters to a couple of centimeters in the static mode for the horizontal coordinates and centimeters in vertical while CSRS-PPP also gave the accuracy of few millimeters to centimeters for the planimetric positions, but the vertical error was up to a decimeter. A study carried out by Herbert *et al*., (2020) aimed on assessing the accuracy performance of two free online processing software AUSPOS and CSRS-PPP on short baselines. Between the two free online processing services tested over short baselines AUSPOS gives the better results than CSRS-PPP.

Rizos, Johnston, and Han (2010) found that AUSPOS provided users with accurate positioning solutions. They evaluated AUSPOS user experiences by comparing its results with those of other GNSS processing software and found that AUSPOS outperformed other software in terms of accuracy. Similarly, Saracoglu and Dogan (2016) assessed the accuracy and reliability of AUSPOS online GNSS processing service and found that it provided users with accurate positioning solutions. They tested AUSPOS on static GNSS data sets collected in Turkey and compared its results with those of other software packages, including Bernese and

GAMIT/GLOBK. Their findings showed that AUSPOS achieved similar accuracy to Bernese and GAMIT/GLOBK, indicating its reliability as a source of high-accuracy positioning solution.

2.4 Gaps in Existing Literature

Previous studies have examined the accuracy and performance of AUSPOS in comparison with other online and offline GNSS post-processing software options such as OPUS, CSRS-PPP, and LGO. These studies have evaluated the software options in various scenarios, including different observation techniques, durations, and locations. They have generally concluded that AUSPOS provides accurate positioning solutions and outperforms other online processing services in some cases. However, there is still a lack of direct comparison between AUSPOS and commercial/research software that employ the same processing strategies as AUSPOS. TBC and GAMIT/GLOBK are examples of such software that share similar processing strategies with AUSPOS. Therefore, the study aims to address this gap by directly comparing the relative solution accuracy of AUSPOS with TBC and GAMIT/GLOBK.

CHAPTER THREE

METHODOLOGY

The methodology chapter provides a detailed description of the data sources, and acquisition methods. It also explains the data format and quality check procedures, as well as the data processing strategies used for each GNSS post-processing software option (AUSPOS, GAMIT/GLOBK, and TBC). Additionally, the chapter outlines the performance metrics used to evaluate the accuracy and performance of each software option. Overall, the methodology chapter serves as a guide for the reader to understand the methods used to collect and analyze the data, and to assess the validity and reliability of the study results.

3.1 Data Sources and Acquisition

The raw GNSS data used in this study was obtained from the UNAVCO website(www.unavco.org), which provides open access to a variety of geodetic data products, including GPS/GNSS data from CORS located all around the world. The data was downloaded for a one-year period, from January, 2020, to December, 2020. The sample of downloaded data was shown in the figure 3.1. The data (observation files) was available in RINEX format, which is a standard format for GNSS data that can be used by different software packages. Navigation files data were downloaded from GAMIT software.

The data acquisition process typically involved downloading the raw GNSS data in RINEX format from the UNAVCO website. RINEX files contain the measurements and observations recorded by GNSS receivers. These files are the primary input for GNSS data processing software. Once the RINEX files are downloaded, they need to be imported or loaded into the software options used for analysis. This import step allows the software to access and process the raw GNSS data. Raw GNSS data and the associated observation files were uploaded into each software option. For AUSPOS, the data were uploaded to the Geoscience Australia online portal. For GAMIT/GLOBK and TBC, the data were uploaded to the respective software platforms installed on a computer.

3.2 Data Format & Quality Check

Data format and quality check are essential components of any GNSS data processing. The raw GNSS data collected from the CORS network around Ol Doinyo Lengai volcano were downloaded from UNAVCO website (www.unavco.org) for the year 2020. The data were the Receiver Independent Exchange (RINEX) format as shown in the figure 3.1. RINEX format is a widely accepted standard for GNSS data.

```
olo10010 - Notepad
File  Edit  Format  View  Help
     2.11           OBSERVATION DATA    M (MIXED)           RINEX VERSION / TYPE
teqc  2019Feb25                         20230502 16:18:03UTCPGM / RUN BY / DATE
Linux2.6.32-573.12.1.el6.x86_64|x86_64|gcc|Win64-MinGW64|=+ COMMENT
teqc  2019Feb25     UNAVCO Archive Ops  20200102 00:56:09UTCCOMMENT
Solaris x86 5.10|AMD64|cc SC5.8 -xarch=amd64|=+|=+          COMMENT
BIT 2 OF LLI FLAGS DATA COLLECTED UNDER A/S CONDITION       COMMENT
OLO1                                                        MARKER NAME
                                                            MARKER NUMBER
D. Sarah Stamps     Virginia Tech                           OBSERVER / AGENCY
5702R51151          TRIMBLE NETR9       5.22                REC # / TYPE / VERS
5000117576          TRM57971.00     NONE                    ANT # / TYPE
  5158237.0196  3740835.1872  -302267.4432                  APPROX POSITION XYZ
        0.0000        0.0000        0.0000                  ANTENNA: DELTA H/E/N
     1     1                                                WAVELENGTH FACT L1/2
    20    L1    L2    C1    P2    P1    S1    S2    C2    L5# / TYPES OF OBSERV
          C5    S5    L6    C6    S6    L7    C7    S7    L8# / TYPES OF OBSERV
          C8    S8                                          # / TYPES OF OBSERV
    15.0000                                                 INTERVAL
    18                                                      LEAP SECONDS
input file: olo1202001010000a.tgd                           COMMENT
RINEX file created by UNAVCO GPS Archive.                   COMMENT
For more information contact archive-gps@unavco.org         COMMENT
Monument ID: 25134                                          COMMENT
UNAVCO 4-char name:   OLO1                                  COMMENT
4-char name from Log or data file: OLO1                     COMMENT
Monument location: -2.734205 35.950217 988.2                COMMENT
Visit ID: 119596                                            COMMENT
                                                            COMMENT
OLO1_Ol_Doinyo_Lengai_TZA2016                               COMMENT
                                                            COMMENT
doi:10.7283/T5TB15P4                                        COMMENT
End of DB comments                                          COMMENT
 SNR is mapped to RINEX snr flag value [0-9]                COMMENT
  L1 & L2: min(max(int(snr_dBHz/6), 0), 9)                  COMMENT
teqc windowed:  end  @ 2020 Jan  1 01:00:00.000             COMMENT
  2020     1     1     0     0    0.0000000     GPS         TIME OF FIRST OBS
                                                            END OF HEADER
 20  1  1  0  0  0.0000000  0 18R16G31R03G14R18G16R14R17G10G32G21G26
                                R02G25R15G29G20G15
 125665297.735 5  97739688.380 5  23524816.617    23524815.293    23524813.910
        35.100          33.700    23524814.313
```

figure 3 1 RINEX file created by UNAVCO GPS Archive

The RINEX data format was then checked for quality using the TEQC (Translation, Editing, and Quality Checking) software as shown in the figure 3.2, and the result was displayed in the table 3.1. The quality check process included removing any satellite data with missing or incomplete information, removing any outliers and errors in the data, and checking for any cycle slips or hardware malfunctions. The TEQC software also generated quality check reports for each data file. These reports provided information on the percentage of valid data, the number of cycle slips, the signal-to-noise ratio, and other quality indicators. Any data file with quality check issues was reprocessed or removed from the study.

After the quality check process, one day data file was splitted into 2-hour, 4-hour, 6-hour, 8-hour, 10 hour and 12-hour intervals using the TEQC software so as to examine the accuracy and performance of AUSPOS in comparison with TBC within one day observation and analysing the accuracy and consistency of positioning solutions at different hourly intervals. The resulting data files were then used for further processing using AUSPOS and TBC software packages.

Table 3 1 Data Quality Check for 2020 Jan 1 observations

FILE NAME	TIME		OBSERVATION		PERCENTAGE	REMARK
	FIRST EPOCH	LAST EPOCH	POSSIBLE OBSERVATION	COMPLETE OBSERVATION		
OLO 1	00:00	23:59	56777	55158	97	GOOD
OLO 3	00:00	23:59	56809	48552	85	GOOD
OLO 5	00:00	23:59	56804	56697	100	GOOD
OLO 6	00:00	23:59	56797	56768	100	GOOD
OLO 7	00:00	23:59	28397	27200	96	GOOD

```
olo1B0010 - Notepad
File  Edit  Format  View  Help
version: teqc  2019Feb25

 SV+-----------------|-----------------|-----------------|-----------------|+ SV
 15|LL                                                                      | 15
 25|sssssssssssssssssssssssssssssssssssssssssssLsLLssssssLLL                | 25
 16|oooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo| 16
 31|eeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeee| 31
 10|ssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssss| 10
 32|ssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssss| 32
 21|oooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo| 21
 26|ssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssssss| 26
 14|oooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo| 14
 29|eeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeeee| 29
 20|oooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo| 20
 27|                  LsssLLLssssssLLssLssssssssssssssssssssssssssssssssssss| 27
  8|                                                                  LIssss|  8
R 2|NNNNNNNNNNNNNNNNNNNNNNNNNLLNLLLL                                        |R 2
R14|NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNLL                  |R14
R16|NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNL           |R16
R17|NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN|R17
R 3|NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN|R 3
R15|NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN|R15
R18|NNNNNLNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN|R18
R 5|                     LNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN|R 5
Obs|iihhhhhhhhhhhhhhhhiiijjjjjjjjjjjiiiiiiiiiiiiiiiiiiiiiihhgggggfffffgggggg|Obs
Clk|                                                                        |Clk
   +-----------------|-----------------|-----------------|-----------------|+
00:00                                                                      02:00
2020 Jan  1                                                          2020 Jan  1

*********************
QC of RINEX  file(s) : olo1B0010.20o
*********************

4-character ID          : OLO1
Receiver type           : TRIMBLE NETR9 (# = 5702R51151) (fw = 5.22)
Antenna type            : TRM57971.00     NONE (# = 5000117576)

Time of start of window : 2020 Jan  1  00:00:00.000
Time of   end  of window : 2020 Jan  1  02:00:00.000
Time line window length : 120.00 minute(s), ticked every 30.0 minute(s)
Observation interval    : 15.0000 seconds
Total satellites w/ obs : 21
```

figure 3 2 Quality check of RINEX file

3.3 Data Processing Strategies

The data processing strategy section of the methodology chapter provides a detailed explanation of the step-by-step procedures for processing the raw GNSS data using the AUSPOS, TBC and GAMIT/GLOBK.

3.3.1 AUSPOS Processing Strategy

The processing strategy of AUSPOS (Australian Online GPS processing Service) follows several steps as shown in the Figure 3.3.

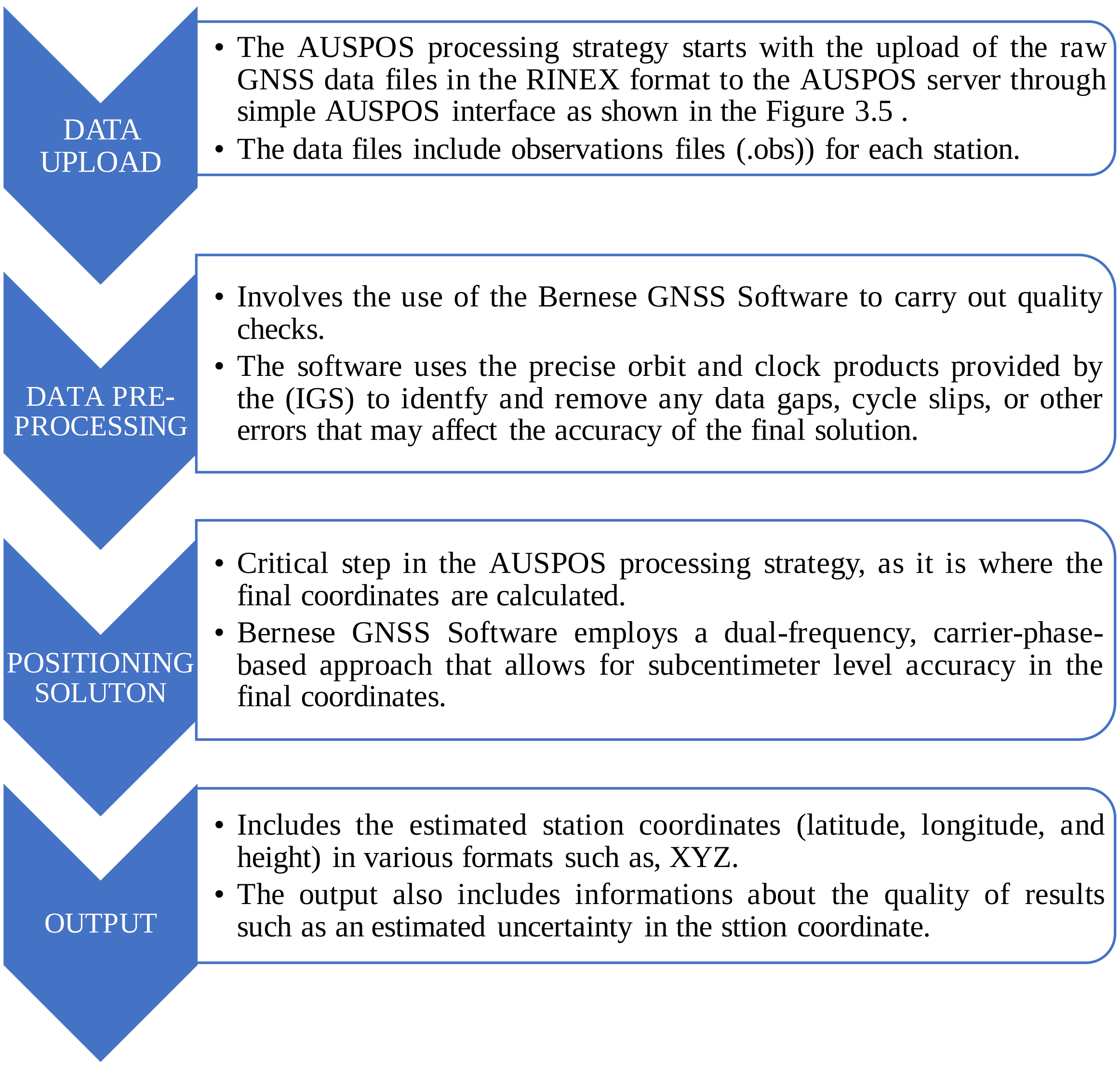


Figure 3 3 AUSPOS processing strategy workflow

Figure 3.4 and 3.5 below illustrate the sample of output of AUSPOS report, in ITRF14 using GRS80 ellipsoid sent to the users via email and Interface of AUSPOS respectively.

3 Computed Coordinates, ITRF2014

All coordinates are based on the IGS realisation of the ITRF2014 reference frame. All the given ITRF2014 coordinates refer to a mean epoch of the site observation data. All coordinates refer to the Ground Mark.

3.1 Cartesian, ITRF2014

Station	X (m)	Y (m)	Z (m)	ITRF2014 @
OL01	5158236.923	3740835.135	-302267.448	01/01/2020
OL03	5163694.097	3733963.693	-304475.985	01/01/2020
OL05	5162364.357	3735464.452	-291147.343	01/01/2020
OL06	5161197.875	3736841.295	-299447.244	01/01/2020
OL07	5160792.461	3737529.456	-309142.625	01/01/2020
ABPO	4097216.541	4429119.203	-2065771.182	01/01/2020
ADIS	4913652.568	3945922.837	995383.517	01/01/2020
DJIG	4583085.943	4250982.661	1266243.202	01/01/2020
HARB	5084657.606	2670325.401	-2768480.899	01/01/2020
HRAO	5085352.439	2668396.128	-2768731.291	01/01/2020
MAL2	4865385.437	4110717.484	-331137.379	01/01/2020
MAYG	4379104.227	4418744.612	-1401897.796	01/01/2020
MBAR	5482951.121	3260442.866	-66519.612	01/01/2020
NKLG	6287385.696	1071574.857	39133.196	01/01/2020
SEYG	3597835.884	5240884.102	-516780.953	01/01/2020
ULDI	4796680.890	2930311.696	-3005435.624	01/01/2020
VACS	3215946.907	5047449.762	-2198718.156	01/01/2020
ZAMB	5415352.959	2917210.200	-1685888.606	01/01/2020

Figure 3 4 AUSPOS output

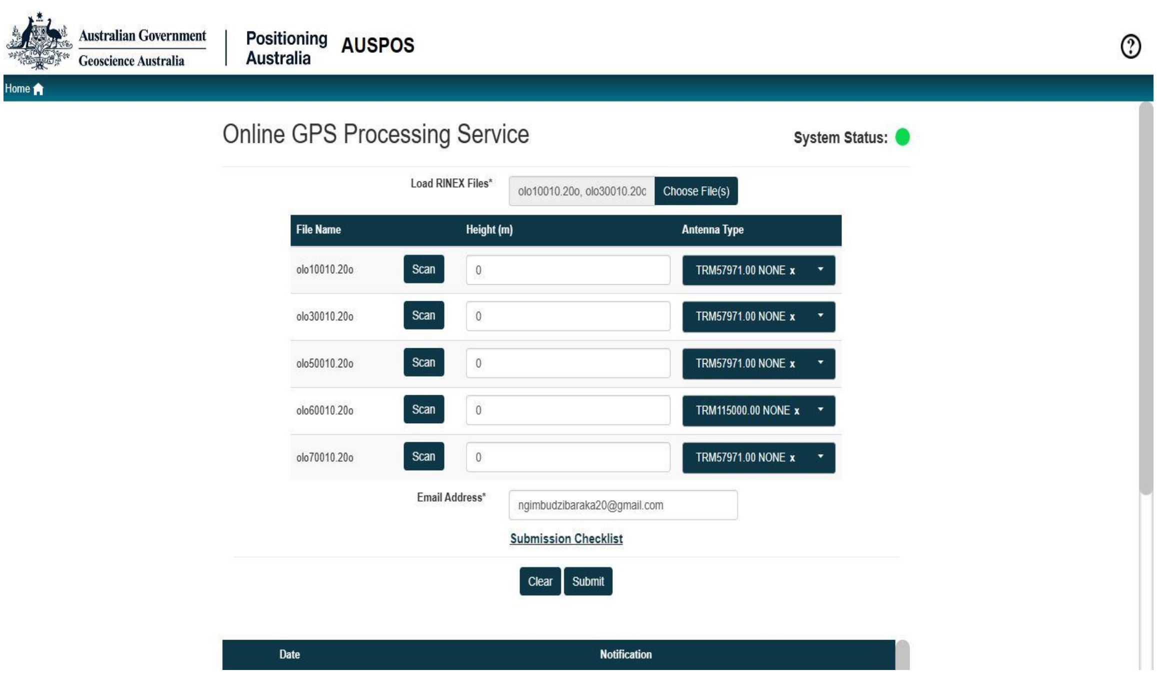


Figure 3 5 AUSPOS Interface

3.3.2 GAMIT/GLOBK Processing Strategy

GAMIT/GLOBK use relative positioning technique on determination of position. It bases on two stages, firstly is to process the data by the GAMIT where by the primary output is loosely constrained solution (H-) file of parameter estimate and covariance. Before processing by GAMIT, Station.info were prepared and verified. Station.info is a file which containing the information of stations used during processing such as antenna type. The sh_gamit shell script was used to process data for GAMIT, since it's a master for running GAMIT. This script, sh_gamit looks for raw or RINEX data over a range of days and invokes the GAMIT programs to produce constrained and loose estimates of coordinates together with sky plots of phase data as a record of the processing.

Secondly stage, is to process data by GLOBK. The loosely estimate coordinates and covariance obtained from GAMIT was then run by GLOBK for combination of data to estimate station position, generating velocity field estimates and time series in a well-defined and often different reference frame. globk used to stack multiple epochs to obtain a mean position and/or velocity. Likewise, GLOBK operates through distinct programs, which can be invoked with a single command or run separately. The primary functions are to combine quasi-observations either GAMIT/GLOBK "h-files" or the internationally accepted SINEX format from multiple networks and/or epochs (glred or globk), and to impose on this solution a reference frame appropriate to the scientific objective (glorg). Note that globk and glred are the same program, just called in different modes: glred to read data from one day at a time for generating time series, globk for stacking multiple epochs to obtain a mean position and/or velocity.

3.3.3 TBC Processing Strategy

The processing strategy for TBC (Trimble Business Centre) involves several steps, as shown in the figure 3.6 below

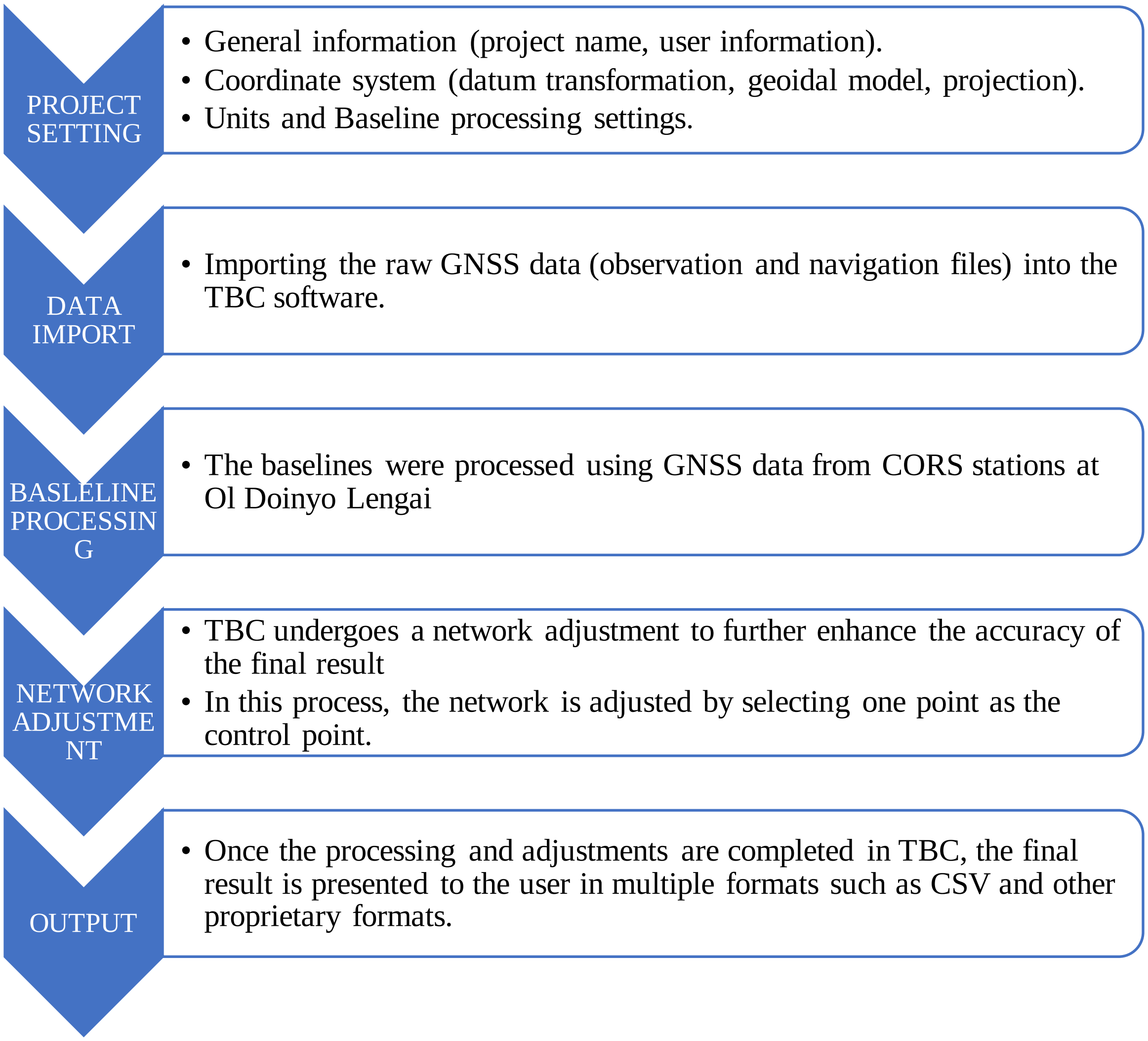


Figure 3 6 TBC processing strategy workflow

i. Project setting

Before data processing or importing the data, the project setting must start first. In TBC software the project settings involve general information (project name, user information), coordinate system (datum transformation, geoidal model, projection), units and baseline processing settings

ii. Data import

The second step in the TBC processing workflow involves importing the raw GNSS data into the software. TBC supports RINEX (Receiver Independent Exchange) format. The data files include observation files (.obs) and navigation files (.nav) for each station were imported to the software. Stations included in the data import were OLO 1, OLO 3, OLO 5, OLO 6, and OLO 7, in the RINEX format.

iii. Processing GNSS baselines

The baselines were processed using GNSS data from CORS stations at Ol Doinyo Lengai in 2020, specifically from OLO 1, OLO 3, OLO 5, OLO 6, and OLO 7. The baseline report was checked to see the number of baselines that pass or fail. This process formed the basis for the final positioning solution.

iv. Network Adjustment

After the baseline processing, the positioning solution in TBC undergoes a network adjustment, as shown in the figure 3.7 to further enhance the accuracy of the final result. In this process, the network is adjusted by selecting one point as the control point.

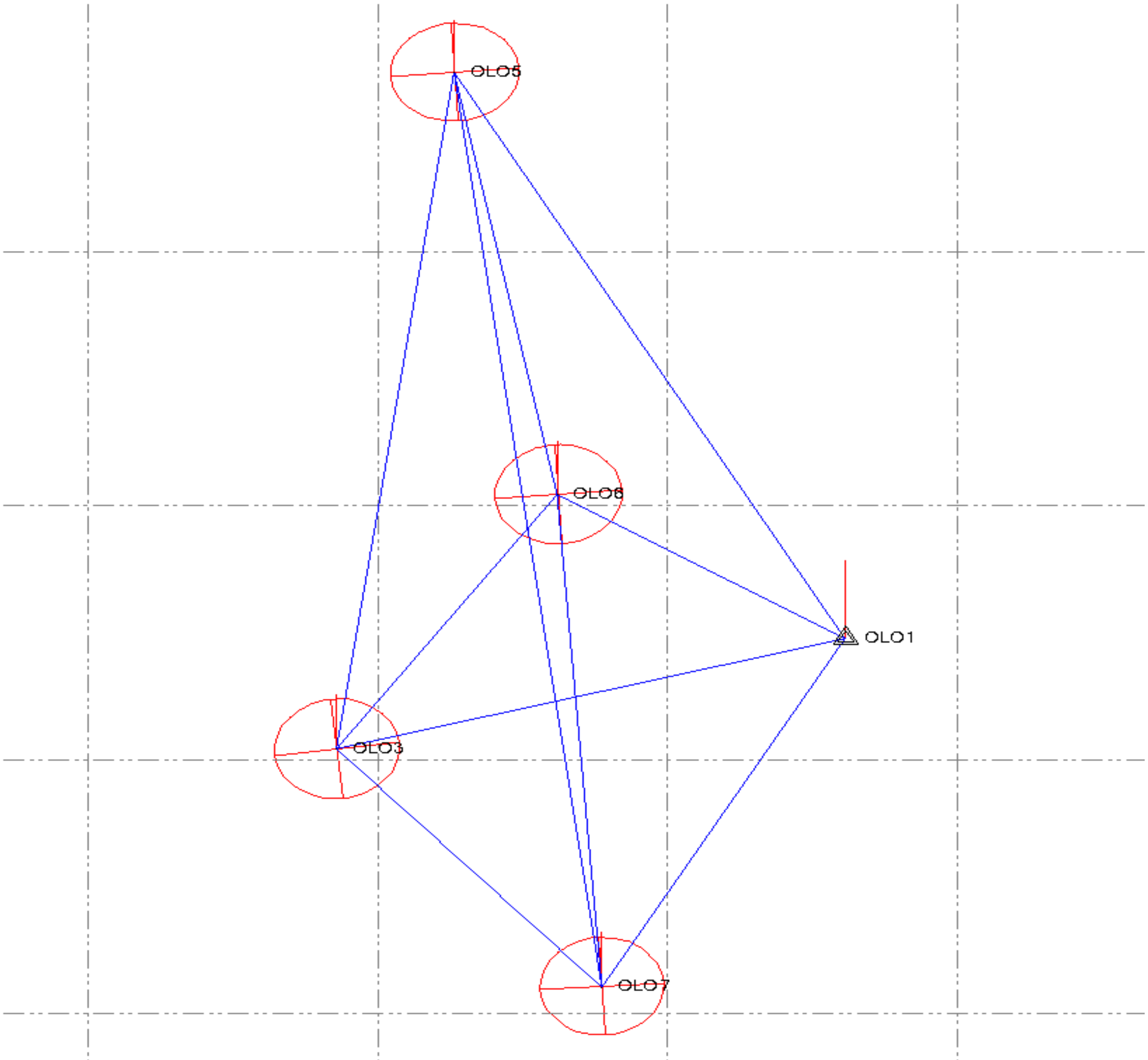


Figure 3 7 Network Adjustment

(see Appendix B for a detailed Network Adjustment Report)

v. Output

Once the processing and adjustments was completed in TBC, the final result was presented in multiple formats such as, CSV, and other proprietary formats. The output includes essential information such as station coordinates, accuracy estimates, and additional relevant details.

3.4 Performance Metrics

Performance metrics served as standardized measures to evaluate the accuracy, precision, convergence time, computational efficiency, and user-friendliness of the software tools. Each metric offered specific insights into different aspects of the software's performance and helped determine its suitability for specific applications. The selected performance metrics for this research included:

a. Positional Discrepancy

Positional discrepancy measured the variations between the computed positions and the reference data, providing an indication of the agreement or disagreement between the software-derived positions and the known ground truth or established control points. It assessed the positional accuracy of the software tools by quantifying the level of deviation from the reference data.

b. Root Mean Square Error (RMSE)

RMSE was a commonly used metric to assess the overall accuracy of the software tools' positioning solutions. It calculated the average positional deviation between the computed positions and the reference data, considering both the horizontal and vertical components. In this study, the aim was to evaluate the performance of AUSPOS and TBC software tools as the time of observation increases, using RMSE as a measure of accuracy.

c. Time Series Analysis

Time series analysis evaluated the stability and consistency of the software tools' positioning solutions over a specified time period. It allowed for the detection of any trends, patterns, or systematic errors in the computed positions over time. In this study, time series analysis was performed using both AUSPOS and GAMIT/GLOBK to assess their performance over six months.

CHAPTER FOUR

RESULT AND ANALYSIS

This chapter presents the findings of the analysis of AUSPOS in comparison with TBC and GAMIT/GLOBK for various surveying applications. The analysis includes one day of GPS observation data for the AUSPOS vs. TBC comparison and six months of GPS observation data for the AUSPOS vs. GAMIT/GLOBK comparison.

4.1 Results

Performance metrics such as Root Mean Square Error (RMSE), and positional discrepancies were calculated to evaluate the agreement and variability between the software outputs. Time series analysis was conducted to evaluate the consistency and reliability of AUSPOS and GAMIT/GLOBK over an extended period.

4.1.1 Results obtained from AUSPOS and TBC software

In this section, the results of the positional accuracy and impacts of increasing time assessment of AUSPOS and TBC software were presented. The assessment was conducted by comparing the UTM coordinates obtained from these software's with the reference coordinates obtained from GAMIT/GLOBK in the International Terrestrial Reference Frame 2014 (ITRF 2014). The differences between the coordinates obtained from the software and the reference coordinates were calculated to determine the positional discrepancy and Root Mean Square Error at each survey station.

4.1.2 Positional Accuracy Assessment of AUSPOS and TBC software

Table 4.2 presents the ECEF coordinates obtained from AUSPOS and TBC software, along with the reference ECEF coordinates from GAMIT/GLOBK shown in the table 4.1. The X, Y and Z coordinates are provided for each station. To assess the positional accuracy, the differences between the coordinates obtained from the software and the reference coordinates were calculated. The differences in X, Y and Z coordinates were computed by subtracting the coordinates obtained from the software to those from the reference coordinates for each station. These differences represent the positional discrepancy between the software and the known reference points. The mathematical calculations are shown below:

ΔX = X_reference - X_software

ΔY = Y_reference - Y_software

ΔZ = Z_reference - Z_software

Table 4 1 Reference ECEF coordinates in ITRF 2014, GRS80 ellipsoid obtained from GAMIT/GLOBK

Station	X (m)	Y (m)	Z (m)
OLO 1	5158236.913	3740835.142	-302267.438
OLO 3	5163694.095	3733963.708	-304475.976
OLO 5	5162364.356	3735464.468	-291147.335
OLO 6	5161197.864	3736841.306	-299447.236
OLO 7	5160792.460	3737529.475	-309142.616

Table 4 2 ECEF coordinates in ITRF 2014, GRS80 ellipsoid obtained from AUSPOS and TBC for one day observations

	AUSPOS			TBC		
Station	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)
OLOI	5158236.923	3740835.135	-302267.448	5158237.005	3740835.210	-302267.444
OL03	5163694.097	3733963.693	-304475.985	5163694.180	3733963.769	-304475.980
OL05	5162364.357	3735464.452	-291147.343	5162364.436	3735464.529	-291147.339
OL06	5161197.875	3736841.295	-299447.244	5161197.959	3736841.373	-299447.238
OL07	5160792.461	3737529.456	-309142.625	5160792.545	3737529.537	-309142.622

Using these calculations, the positional discrepancies were obtained for each station. For instance, at OLOI station, the positional discrepancy was calculated as follows:

Difference: GAMIT/GLOBK (reference) - AUSPOS

ΔX = 5158236.913 - 5158236.923= -0.010

ΔY = 3740835.142 - 3740835.135= -0.007

ΔZ = -302267.448 – (-302267.438) = -0.010

Positional Discrepancy:

Discrepancy = sqrt ($\Delta X^2 + \Delta N^2 + \Delta Y^2$)

Discrepancy = sqrt ($(-0.010)^2 + (-0.007)^2 + (-0.010)^2$)

Discrepancy = 0.016

The same calculations were performed for all other stations, and the positional discrepancies were obtained accordingly as shown in the table 4.3. These discrepancies provide insights into the accuracy of the software at each survey station.

Table 4 3 Positional Discrepancies between AUSPOS, TBC and Reference Coordinates

Stations	AUSPOS							
	ΔX (m)	ΔY (m)	ΔZ (m)	Positional discrepancy (m)	Δx (m)	ΔY (m)	ΔZ (m)	Positional discrepancy (m)
OLO1	-0.010	0.007	0.010	0.016	-0.092	-0.068	0.006	0.092
OLO3	-0.002	0.015	0.009	0.018	-0.085	-0.061	0.004	0.105
OLO5	-0.001	0.016	0.008	0.018	-0.08	-0.061	0.004	0.101
OLO6	-0.011	0.011	0.008	0.017	-0.095	-0.067	0.002	0.116
OLO7	-0.001	0.019	0.009	0.021	-0.085	-0.062	0.006	0.105

To visualize the variations in overall positional accuracy across different stations, a graph of positional discrepancy against station was plotted as shown in the figure 4.1. This graph allows us to compare the magnitude of discrepancies and identify any patterns. The y-axis represents the positional discrepancy in meters, and the x-axis represents the station names.

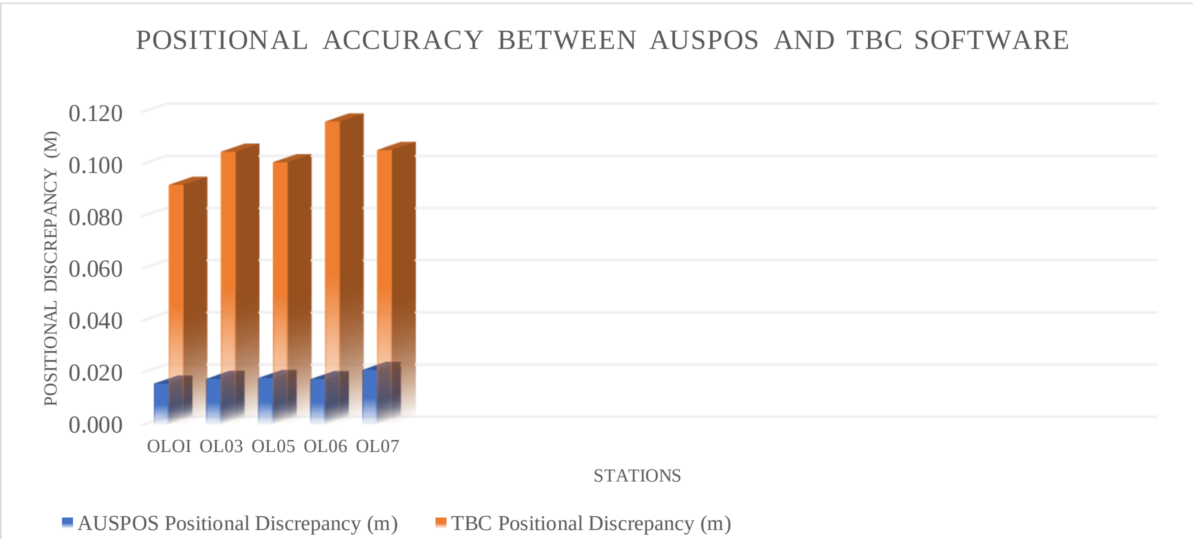


Figure 4 1 Positional Accuracy between AUSPOS and TBC

4.1.3 Analysis of Results of AUSPOS vs. TBC: Positional Accuracy

The analysis of the positional discrepancies between AUSPOS, TBC, and the reference coordinates obtained from GAMIT/GLOBK in surveying application provides insights into the accuracy and performance of these software in the specific surveying context. Here are the key observations and discussions:

- AUSPOS Positional Discrepancy

The positional discrepancy values for AUSPOS (ranging from 0.016 to 0.021 meters) represent the overall magnitude of the differences in both x, y and z coordinates between AUSPOS and the reference coordinates from GAMIT/GLOBK.

- TBC Positional Discrepancy:

The positional discrepancy values for TBC (ranging from 0.092 to 0.116 meters) represent the overall magnitude of the differences in both x, y and z coordinates between TBC and the reference coordinates from GAMIT/GLOBK.

Based on the results obtained from the comparison between AUSPOS and TBC in normal surveys, the following conclusions can be made:

- Positional Accuracy: AUSPOS exhibits relatively small positional discrepancies compared to the TBC software.
- Consistency: AUSPOS and TBC demonstrate consistency in their positioning results, with similar patterns of discrepancies observed across the surveyed stations. This suggests that both software solutions are reliable and provide consistent outcomes.

4.1.4 AUSPOS vs. TBC software Accuracy Performance: Impact of Increasing Time

In this section, the comparative performance of AUSPOS and TBC software in GPS processing with respect to increasing time intervals was analyzed. Root Mean Square Error (RMSE) values were examined to assess the accuracy and reliability of the two software packages. Table 4.4 presents the UTM coordinates of OLO 3 obtained from AUSPOS and TBC software at different time intervals, allowing for a comparison of their performance. The table serves as a basis for evaluating the accuracy and reliability of the two software packages in GPS processing.

Table 4 4 ECEF Coordinates of OLO 3, in ITRF14 and GRS80 ellipsoid obtained from AUSPOS and TBC software

Hours	AUSPOS			TBC		
	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)
2 Hrs.	5163694.088	3733963.688	-304475.983	5163694.189	3733963.765	-304475.983
4 Hrs.	5163694.093	3733963.693	-304475.982	5163694.183	3733963.767	-304475.982
6 Hrs.	5163694.100	3733963.697	-304475.983	5163694.184	3733963.769	-304475.983
8 Hrs.	5163694.100	3733963.696	-304475.983	5163694.187	3733963.768	-304475.983
10 Hrs.	5163694.103	3733963.696	-304475.984	5163694.184	3733963.767	-304475.984
12Hrs.	5163694.099	3733963.692	-304475.982	5163694.183	3733963.768	-304475.982
24 Hrs.	5163694.097	3733963.693	-304475.985	5163694.180	3733963.769	-304475.985

To calculate the Root Mean Square Error (RMSE) for AUSPOS and TBC using the reference points OLO 3 (5163694.095, 3733963.708, -304475.976), the differences between the reference points and the coordinates obtained from each software were compared.

For AUSPOS:

$\Delta X\_AUSPOS = X_{GAMIT} - X_{AUSPOS}$

$\Delta Y\_AUSPOS = Y_{GAMIT} - Y_{AUSPOS}$

$\Delta Z\_AUSPOS = Z_{GAMIT} - Z_{AUSPOS}$

For TBC:

$\Delta X\_TBC = X_{GAMIT} - X_{TBC}$

$\Delta Y\_TBC = Y_{GAMIT} - Y_{TBC}$

$\Delta Z\_TBC = Z_{GAMIT} - Z_{TBC}$

Calculate the RMSE using the formula:

RMSE = sqrt $((\Delta X)^{\wedge 2} + (\Delta Y)^{\wedge 2} + (\Delta Z)^{\wedge 2}) / n)$

Where n is the number of data points (in this case n = 1)

$\Delta X\_AUSPOS = 5163694.095 - 5163694.088 = 0.007$

$\Delta Y\_AUSPOS = 3733963.708 - 3733963.688 = 0.02$

$\Delta Z\_AUSPOS = -304475.976 - (-304475.983) = 0.007$

RMSE_AUSPOS = sqrt $((0.007)^{\wedge 2} + (0.02)^{\wedge 2} + (0.007)^{\wedge 2} / 1) = 0.022$

Table 4.5 provides the Root Mean Square Error (RMSE) analysis for AUSPOS and TBC software in relation to OLO 3. The table displays the calculated RMSE values for the ΔX, ΔY, ΔZ coordinates at different time intervals.

Table 4 5 AUSPOS and TBC Root Mean Square Error (RMSE) analysis for OLO 3

Hours	AUSPOS				T			
	ΔX (m)	ΔY (m)	ΔZ (m)	RMSE (m)	Δx (m)	ΔY (m)	ΔZ (m)	RMSE (m)
2 Hrs.	0.007	0.02	0.007	0.022	-0.094	-0.057	0.007	0.110
4 Hrs.	0.002	0.015	0.006	0.016	-0.088	-0.059	0.006	0.106
6 Hrs.	-0.005	0.011	0.007	0.014	-0.089	-0.061	0.007	0.108
8 Hrs.	-0.005	0.012	0.007	0.015	-0.092	-0.06	0.007	0.110
10 Hrs.	-0.008	0.012	0.008	0.016	-0.089	-0.059	0.008	0.107
12 Hrs.	-0.004	0.016	0.006	0.018	-0.088	-0.06	0.006	0.107
24 Hrs.	-0.002	0.015	0.009	0.018	-0.085	-0.061	0.009	0.105

The RMSE values for AUSPOS are consistently lower than those 0f TBC and vary with time, ranging from -0.008 to 0.007 for ΔX, 0.011 to 0.02 for ΔY and from 0.006 to 0.009 for ΔZ.

The RMSE values for TBC vary with time, ranging from -0.085 to -0.094 for ΔX, from -0.059 to -0.061 for ΔY and 0.006 to 0.009 for ΔZ.

Figure 4.2 illustrates the Root Mean Square Error (RMSE) analysis. The graph displays the changes in the RMSE values for the ΔX, ΔY and ΔZ coordinates over different time intervals.

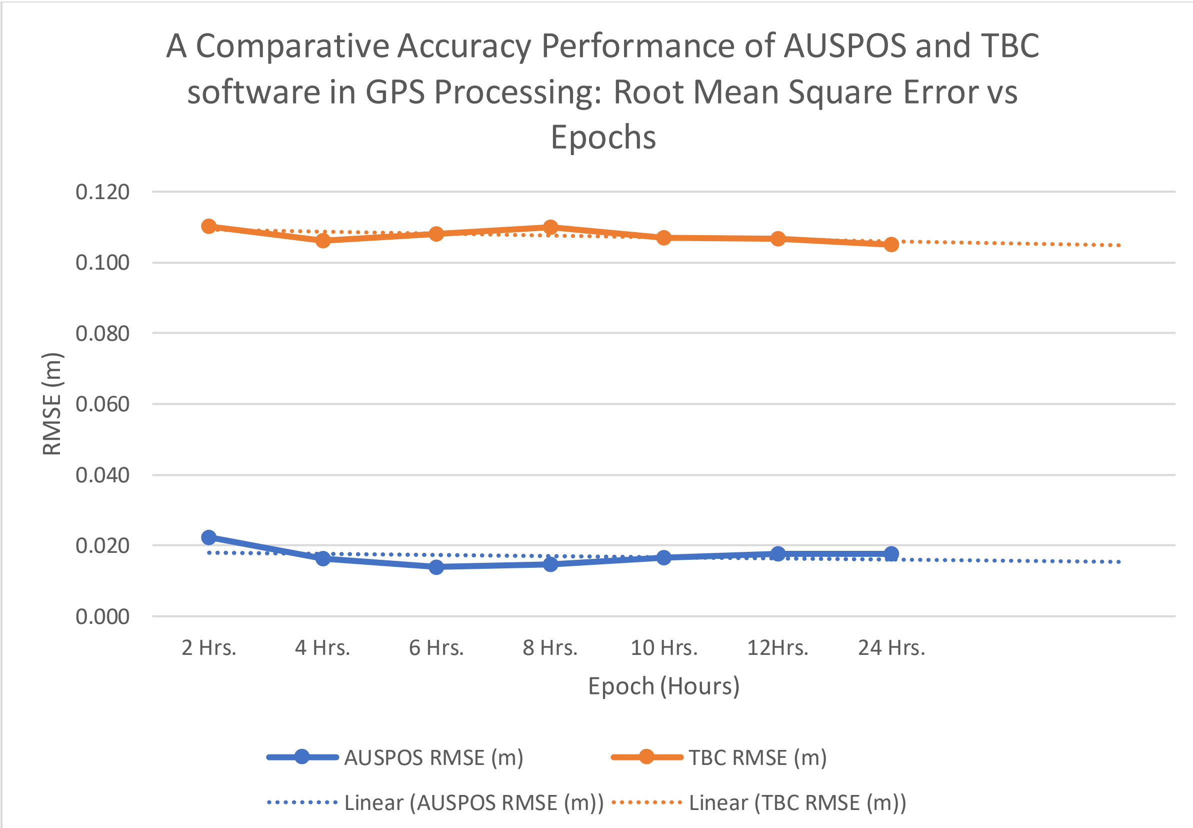


Figure 4 2 Comparison of RMSE Analysis for AUSPOS and TBC software in GPS Processing for OLO 3

The x-axis represents the time intervals in hours, while the y-axis represents the Root Mean Square Error (RMSE) values for the ΔX, ΔY and ΔZ coordinates.

4.1.5 Analysis of Results of AUSPOS vs. TBC: Impact of increasing time for OLO 3

- **Trend Analysis**

By examining the trend of the RMSE values for AUSPOS and TBC, the accuracy improvement or degradation with increasing observation time can be assessed.

For AUSPOS, the RMSE values generally decrease as the observation time increases. This indicates that AUSPOS exhibits improved accuracy with longer observation periods.

Similarly, TBC shows a decreasing trend in RMSE values as the observation time increases. This suggests that TBC also benefits from longer observation periods, resulting in enhanced positional accuracy.

- **Performance Analysis**

Based on the RMSE values and their trends, the performance of AUSPOS and TBC as the observation time increases can be analyzed as follows.

TBC generally demonstrates a decreasing RMSE trend, indicating improved accuracy with longer observation periods. However, the RMSE values for TBC are slightly higher compared to AUSPOS at most time intervals.

AUSPOS also exhibits a decreasing RMSE trend, suggesting improved accuracy with longer observations. The RMSE values are generally lower compared to TBC at most time intervals. As the observation time increases, the RMSE values for both software generally decreases, suggesting improved accuracy.

Table 4.6 presents the UTM coordinates of OLO 5 obtained from AUSPOS and TBC software at different time intervals, allowing for a comparison of their performance. The table serves as a basis for evaluating the accuracy and reliability of the two software packages in GPS processing.

Table 4 6 ECEF Coordinates of OLO 5, in ITRF14 and GRS80 ellipsoid obtained from AUSPOS and TBC software

Hours	AUSPOS			TBC		
	X (m)	Y (m)	Z (m)	X (m)	Y (m)	Z (m)
2 Hrs.	5162364.348	3735464.446	-291147.343	5162364.442	3735464.537	-291147.345
4 Hrs.	5162364.356	3735464.453	-291147.344	5162364.44	3735464.535	-291147.343
6 Hrs.	5162364.360	3735464.455	-291147.344	5162364.441	3735464.534	-291147.343
8 Hrs.	5162364.358	3735464.452	-291147.343	5162364.439	3735464.535	-291147.342
10 Hrs.	5162364.359	3735464.452	-291147.344	5162364.44	3735464.532	-291147.341
12Hrs.	5162364.354	3735464.449	-291147.343	5162364.438	3735464.531	-291147.340
24 Hrs.	5162364.357	3735464.452	-291147.343	5162364.436	3735464.529	-291147.339

Table 4.7 provides the Root Mean Square Error (RMSE) analysis for AUSPOS and TBC software in relation to OLO 5. The table displays the calculated RMSE values for the ΔX, ΔY, ΔZ coordinates at different time intervals.

Table 4 7 AUSPOS and TBC Root Mean Square Error (RMSE) Analysis for OLO 5

Hours	AUSPOS				TBC			
	ΔX (m)	ΔY (m)	ΔZ (m)	RMSE (m)	Δx (m)	ΔY (m)	ΔZ (m)	RMSE (m)
2 Hrs.	0.008	0.022	0.008	0.025	-0.086	-0.069	0.01	0.111
4 Hrs.	0.000	0.015	0.009	0.017	-0.084	-0.067	0.008	0.108
6 Hrs.	-0.004	0.013	0.009	0.016	-0.085	-0.066	0.008	0.108
8 Hrs.	-0.002	0.016	0.008	0.018	-0.083	-0.067	0.007	0.107
10 Hrs.	-0.003	0.016	0.009	0.019	-0.084	-0.064	0.006	0.106
12 Hrs.	0.002	0.019	0.008	0.021	-0.082	-0.063	0.005	0.104
24 Hrs.	-0.001	0.016	0.008	0.018	-0.08	-0.062	0.004	0.101

Figure 4 3 illustrates the Root Mean Square Error (RMSE) analysis. The graph displays the changes in the RMSE values for the ΔX, ΔY and ΔZ coordinates over different time intervals.

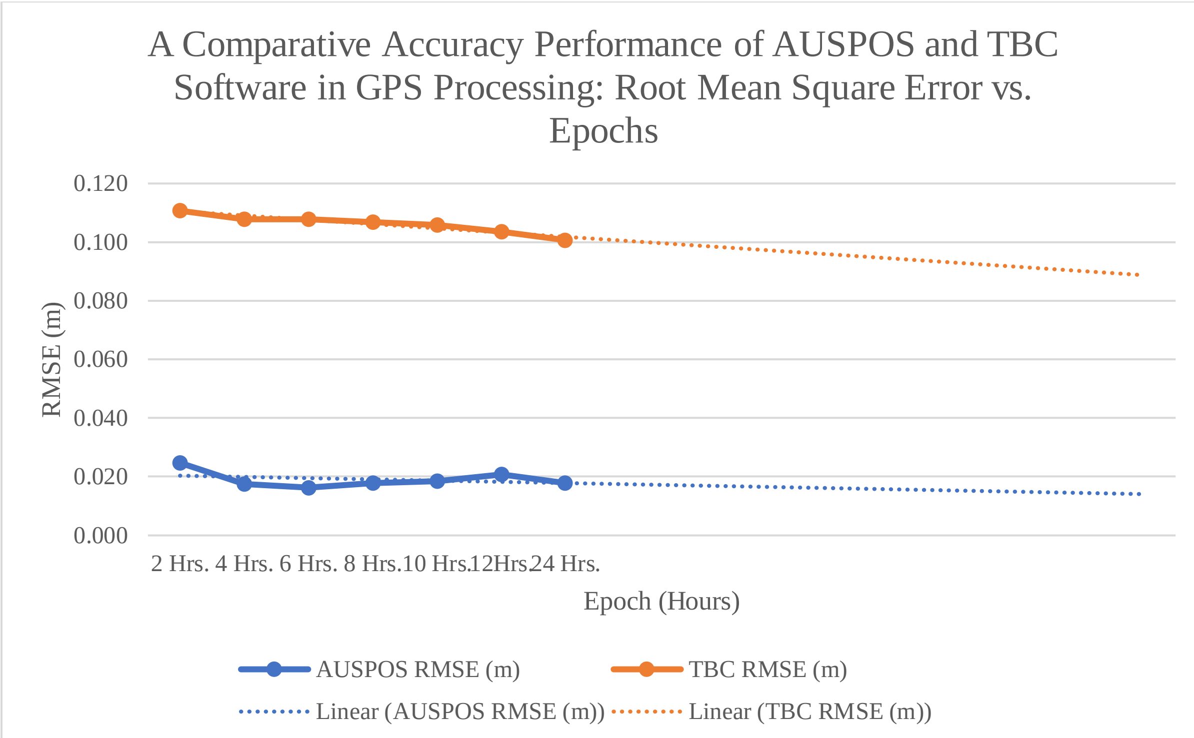


Figure 4 3 Comparison of RMSE Analysis for AUSPOS and TBC software in GPS Processing for OLO 5

4.1.6 Result Analysis of AUSPOS vs. TBC: Impact of increasing time for OLO 5

- **Trend Analysis**

Both AUSPOS and TBC show relatively stable trends in their positional discrepancies and RMSE values as the time interval increases. There is no clear increasing or decreasing trend in the positional discrepancies or RMSE values for either software.

- **Performance Analysis**

As the time interval increases from 2 hours to 24 hours, the ΔX, ΔY and ΔZ values for AUSPOS remain relatively consistent, ranging from -0.004 to 0.008 meters for ΔX, from 0.016 to 0.022 meters for ΔY and from 0.008 to 0.009 for ΔZ. The RMSE values for AUSPOS also show consistency, ranging from 0.016 to 0.025 meters, indicating a stable level of accuracy across the different time intervals.

Similar to AUSPOS, TBC demonstrates consistent performance as the time interval increases. The ΔX values range from -0.086 to -0.08 meters, while the ΔY values range from -0.069 to -0.062 meters. Again, the ΔZ values range from 0.004 to 0.01. The RMSE values for TBC vary between 0.101 and 0.111 meters, indicating a slightly higher level of positional discrepancy compared to AUSPOS. AUSPOS consistently demonstrates lower positional discrepancies and RMSE values compared to TBC throughout the different time intervals. This indicates that AUSPOS generally provides more accurate and precise results.

4.1.7 Results obtained from AUSPOS and GAMIT/GLOBK software: Position Time Series Analysis

In this analysis, the performance of AUSPOS and GAMIT/GLOBK software in GPS processing was evaluated using positional time series analysis. The study aimed to compare and assess the accuracy and reliability of these two software packages over a specified time period. By analysing the time series data, valuable insights into the performance and consistency of AUSPOS and GAMIT software were obtained.

Table 4.8 provides sample data set for the position time series analysis of AUSPOS software. The table has different columns such as Days column, the ECEF coordinates in ITRF14 and GRS80 ellipsoid, ΔX, ΔY, ΔZ and RMSE columns.

Table 4 8 Sample Data Set for Position Time Series Analysis: AUSPOS software

Days	X (m)	Y (m)	Z (m)	ΔX (m)	ΔY (m)	ΔZ (m)	RMSE (m)
1	5158236.923	3740835.135	-302267.448	-0.01	0.007	0.010	0.016
2	5158236.923	3740835.137	-302267.448	-0.01	0.005	0.010	0.015
3	5158236.924	3740835.139	-302267.448	-0.011	0.003	0.010	0.015
4	5158236.918	3740835.132	-302267.447	-0.005	0.01	0.009	0.014
5	5158236.921	3740835.133	-302267.446	-0.008	0.009	0.008	0.014
6	5158236.91	3740835.125	-302267.444	0.003	0.017	0.006	0.018
7	5158236.922	3740835.134	-302267.447	-0.009	0.008	0.009	0.015
8	5158236.923	3740835.137	-302267.448	-0.01	0.005	0.010	0.015
9	5158236.925	3740835.136	-302267.45	-0.012	0.006	0.012	0.018

10	5158236.922	3740835.134	-302267.447	-0.009	0.008	0.009	0.015

(See appendix C for a full Data Set for Position Time Series Analysis of AUSPOS software)

Table 4.9 provides sample data set for the position time series analysis of GAMIT/GLOBK software. The table has different columns such as Days column, the ECEF coordinates in ITRF14 and GRS80 ellipsoid, ΔX, ΔY, ΔZ and RMSE columns.

Table 4 9 Sample Data Set for Position Time Series Analysis: GAMIT/GLOBK software

Days	X (m)	Y (m)	Z (m)	ΔX (m)	ΔY (m)	ΔZ (m)	RMSE (m)
1	5158236.925	3740835.142	-302267.448	-0.012	0.001	0.01	0.016
2	5158236.929	3740835.143	-302267.45	-0.016	-0.001	0.012	0.02
3	5158236.932	3740835.146	-302267.449	-0.02	-0.003	0.01	0.023
4	5158236.923	3740835.141	-302267.449	-0.01	0.002	0.011	0.015
5	5158236.931	3740835.144	-302267.448	-0.019	-0.002	0.01	0.021
6	5158236.916	3740835.132	-302267.446	-0.003	0.01	0.008	0.013
7	5158236.926	3740835.137	-302267.449	-0.013	0.005	0.011	0.018
8	5158236.93	3740835.141	-302267.447	-0.017	0.001	0.009	0.02
9	5158236.925	3740835.14	-302267.45	-0.012	0.003	0.011	0.017
10	5158236.933	3740835.142	-302267.449	-0.021	0.001	0.01	0.023

(See appendix D for a full Data Set for Position Time Series Analysis of GAMIT/GLOBK software)

Figure 4 4 illustrates the Positional time series analysis based on Root Mean Square Error (RMSE) analysis.

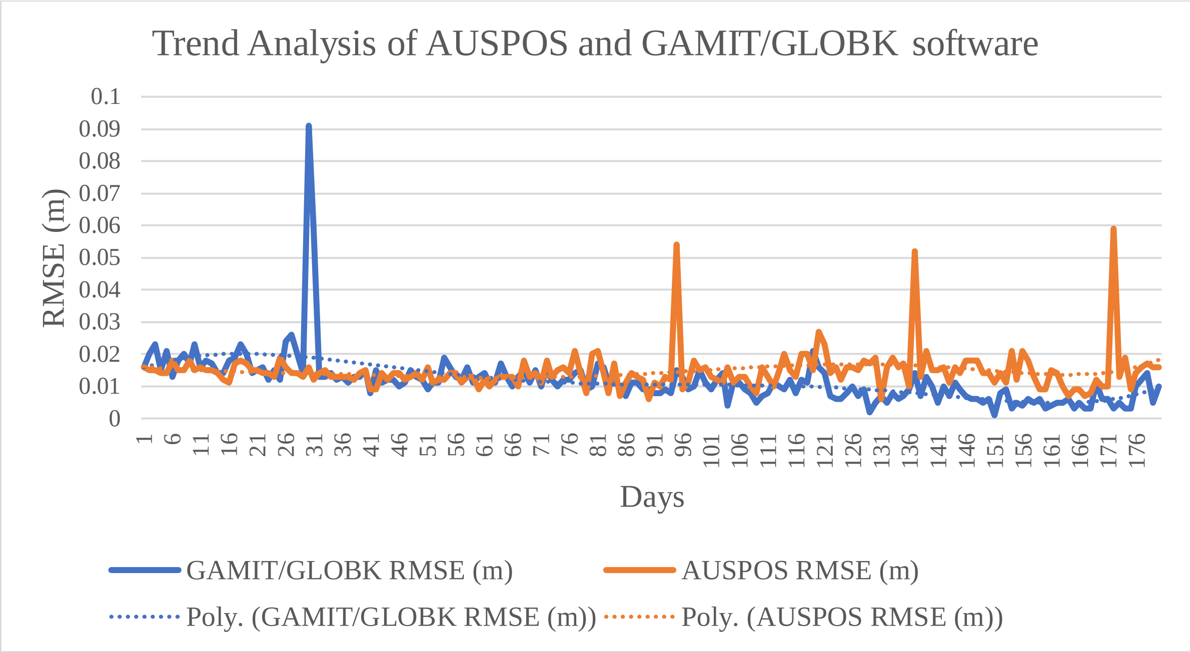
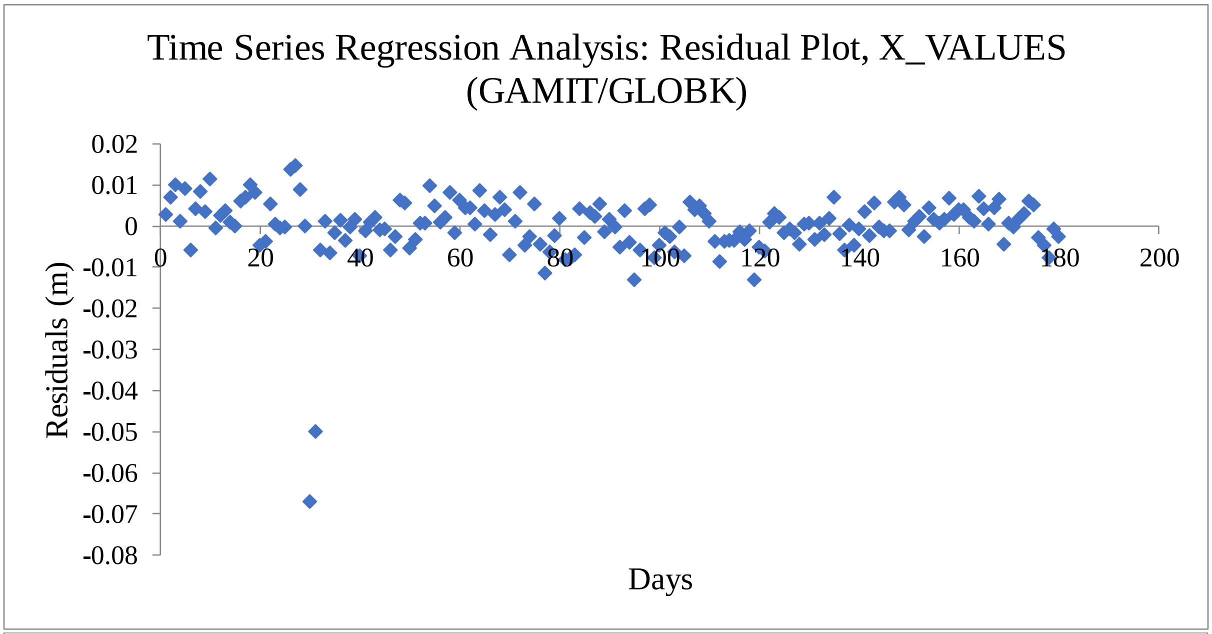


Figure 4 4 Trend Analysis of AUSPOS and GAMIT/GLOBK

Figures 4.5, to figure 4.16 show the plotting of the residuals against the predicted values which are X values, Y values and Z values for both AUSPOS and GAMIT software so that can provide visual insights.

Figure 4 5 Line Fit Plot, X-Values (GAMIT/GLOBK)



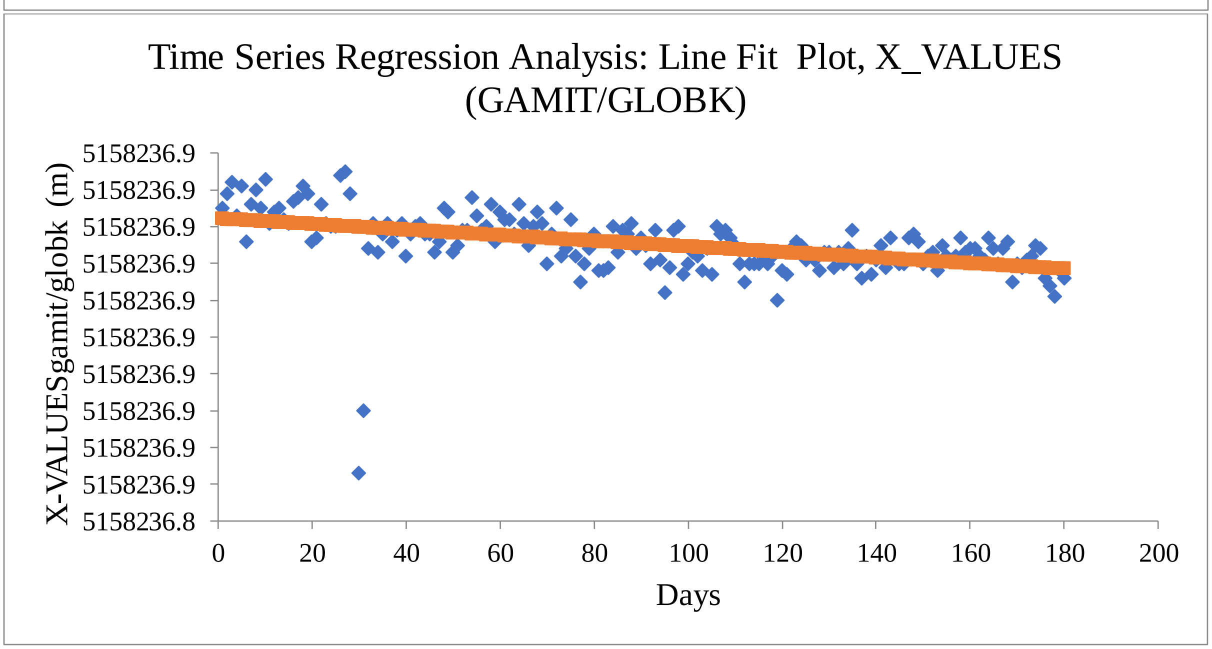
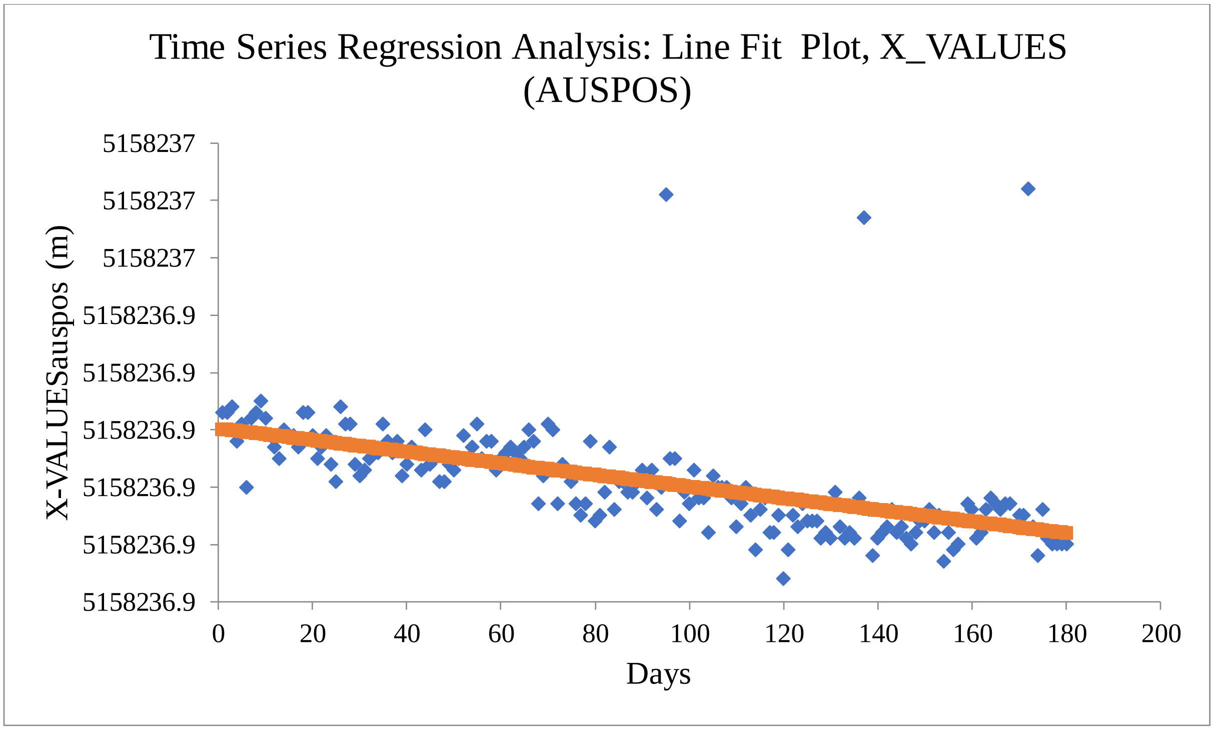


Figure 4 6 Residual Plot X-Values (GAMIT/GLOBK)

Figure 4 7 Line fit plot X-Values (AUSPOS)



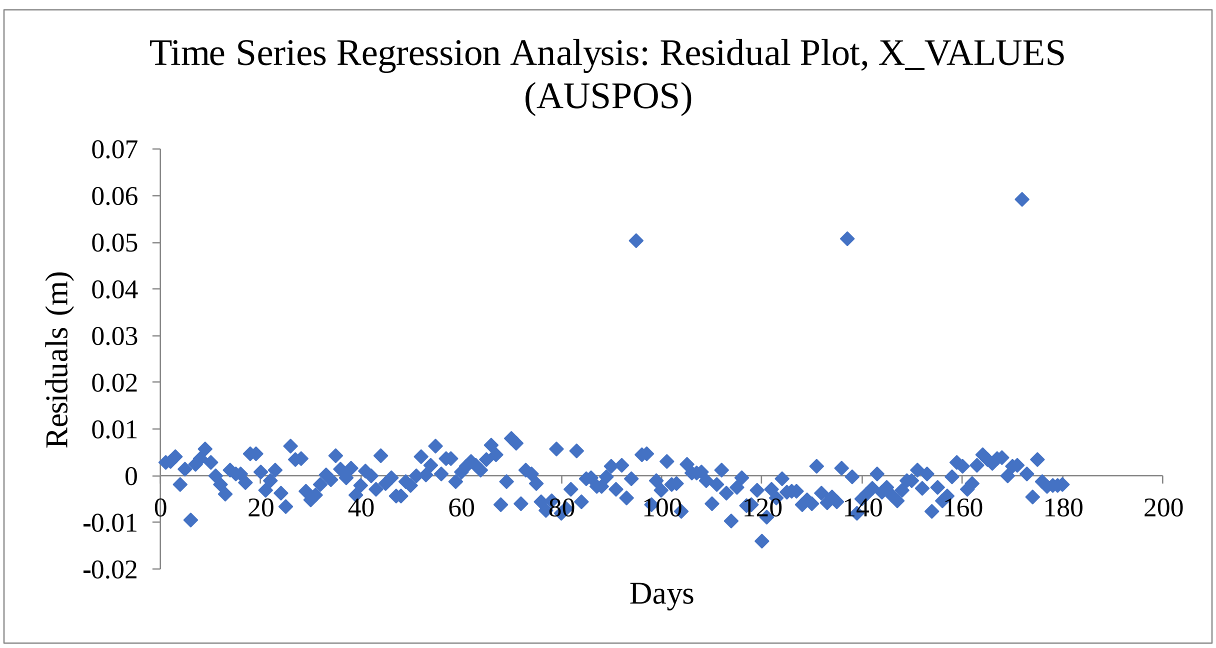
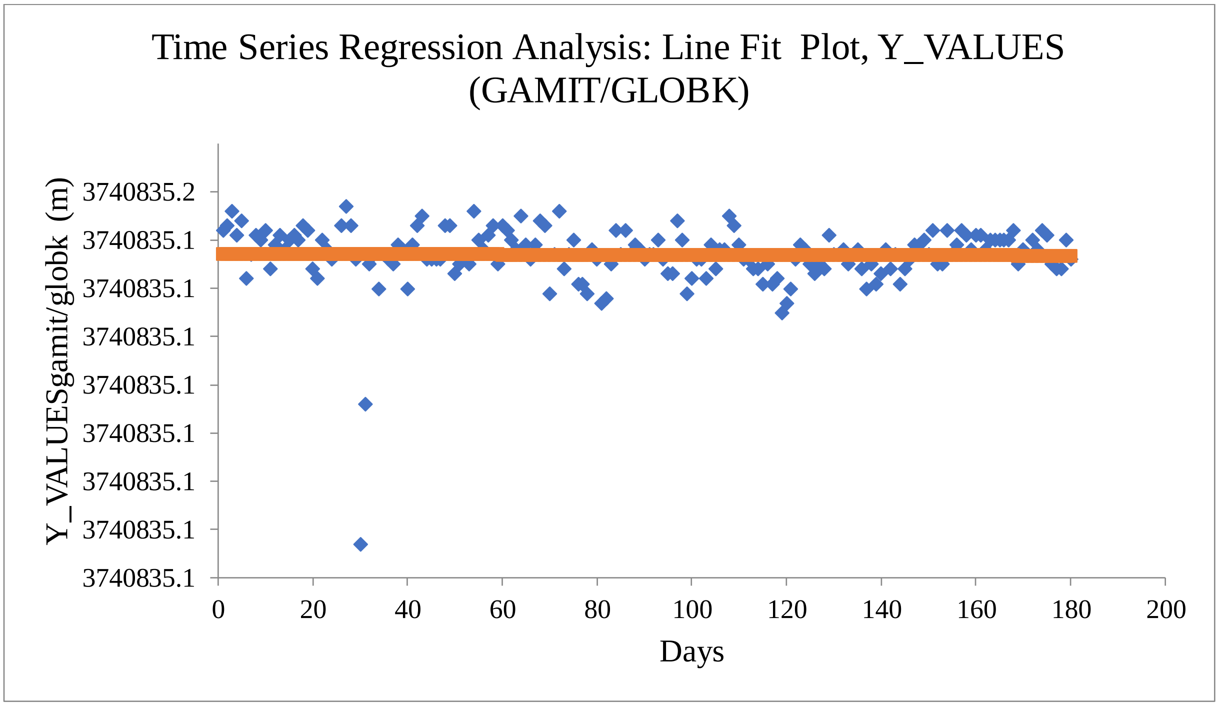


Figure 4 8 Residual Plot, X-Values (AUSPOS)

Figure 4 9 Line Fit Plot, Y-Values (GAMIT/GLOBK)



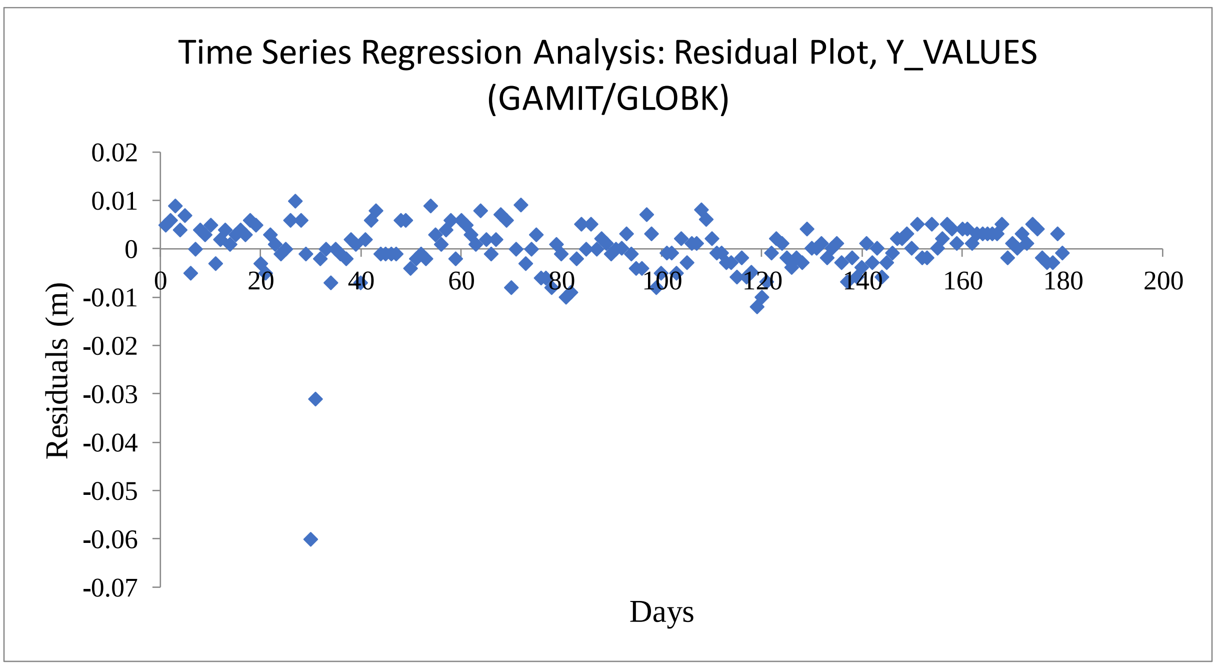
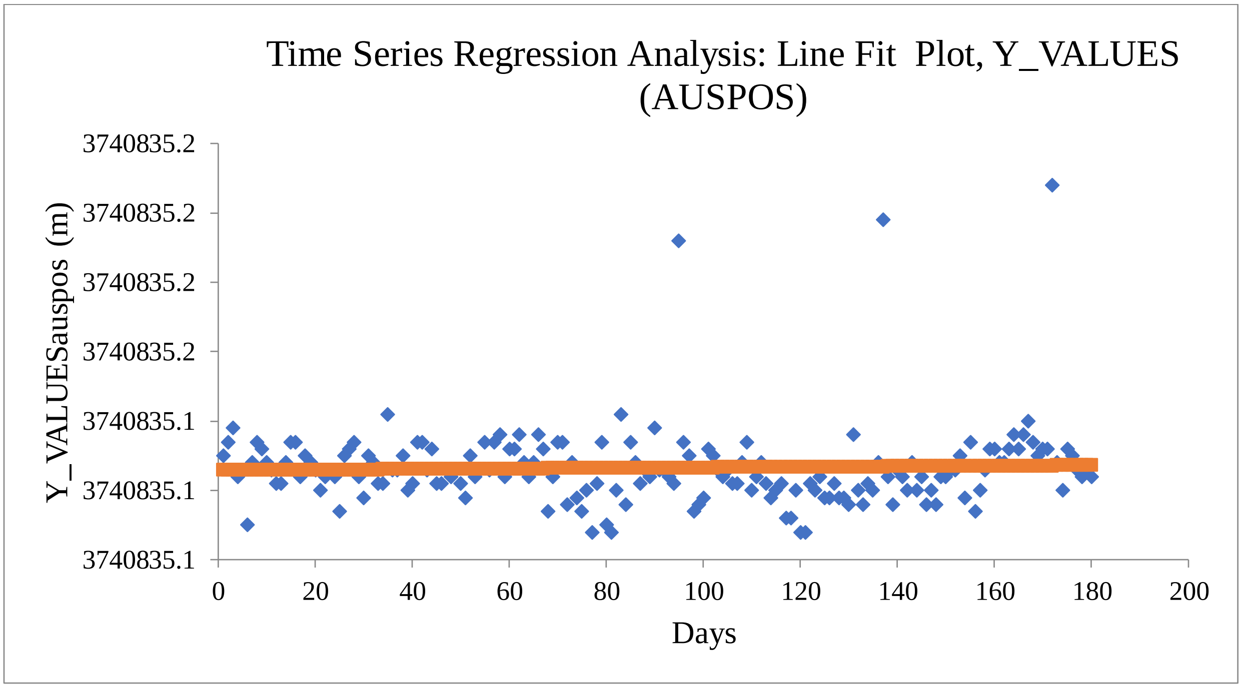


Figure 4 10 Residual Plot, Y-Values (GAMIT/GLOBK)

Figure 4 11 Line Fit Plot, Y-Values (AUSPOS)



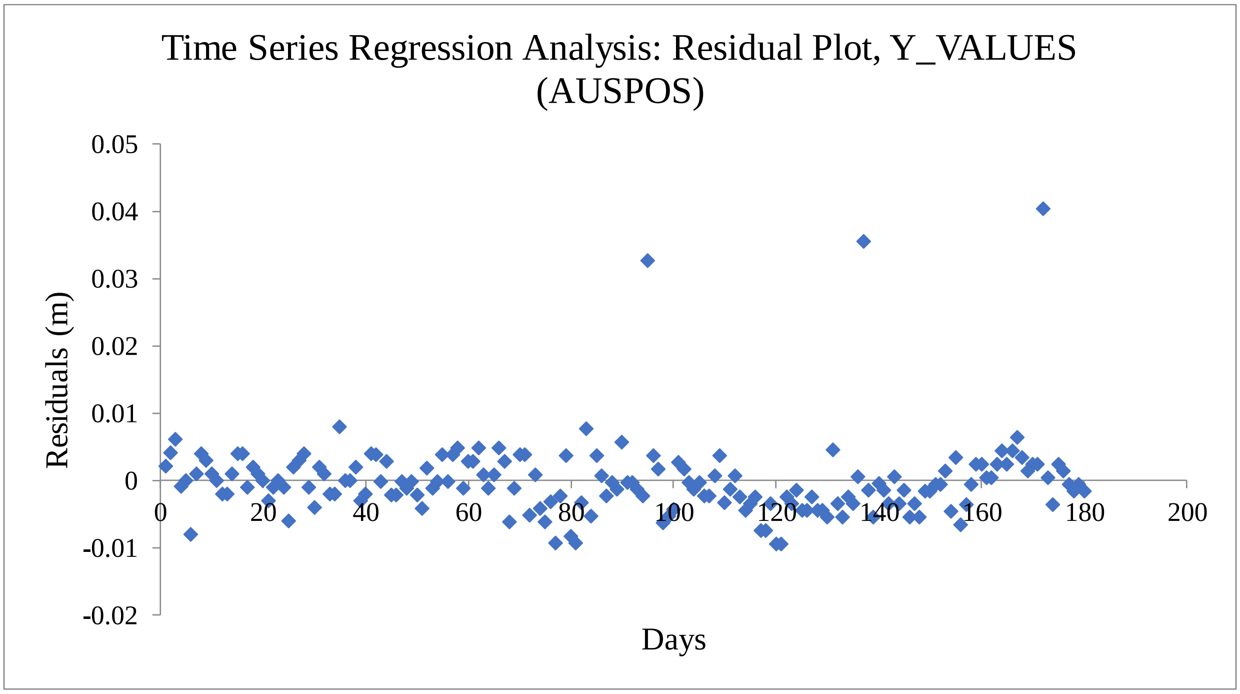
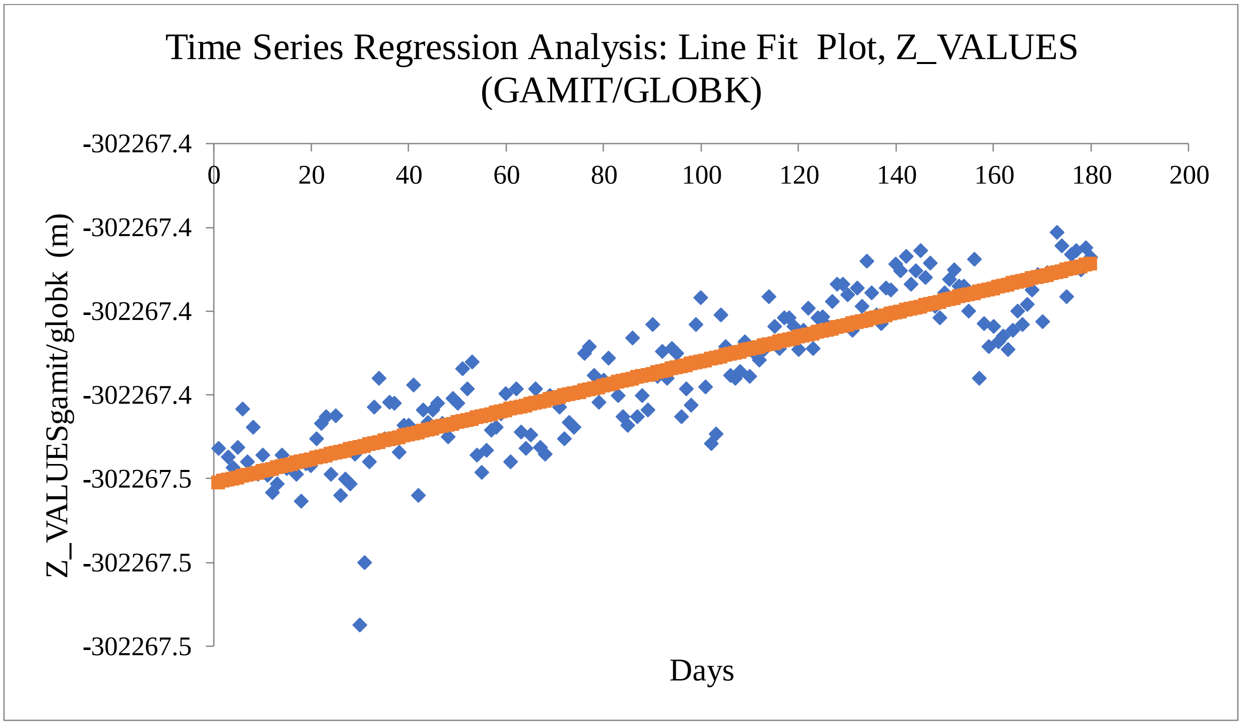


Figure 4 12 Residual Plot, Y-Values (AUSPOS)

Figure 4 13 Line Fit Plot, Z-Values (GAMIT/GLOBK)



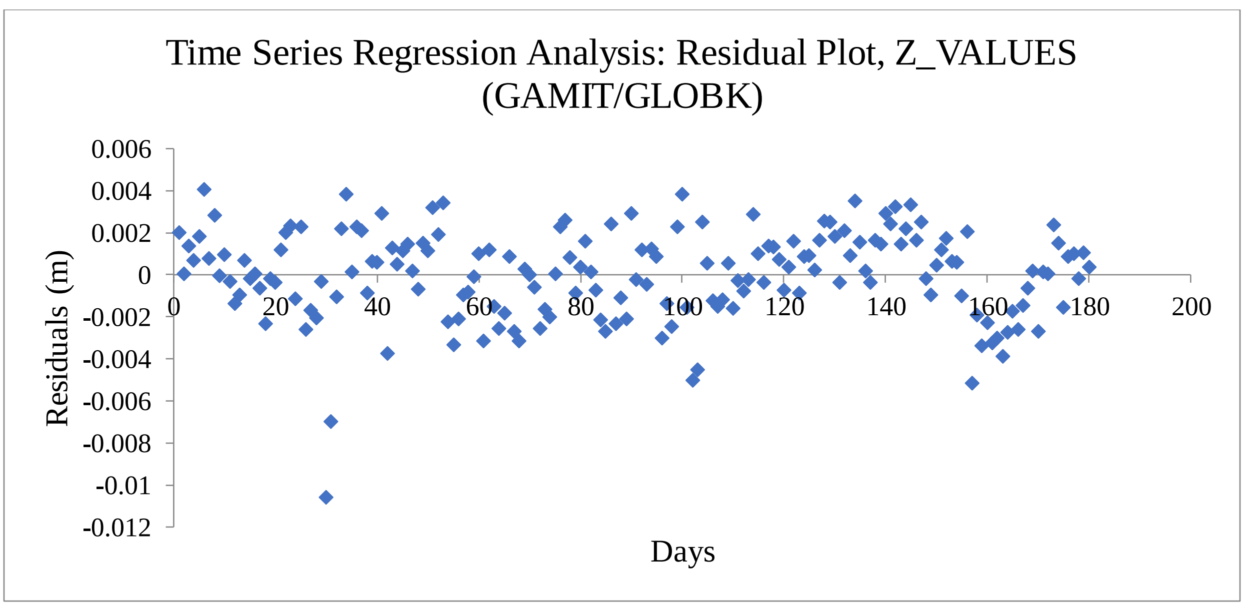
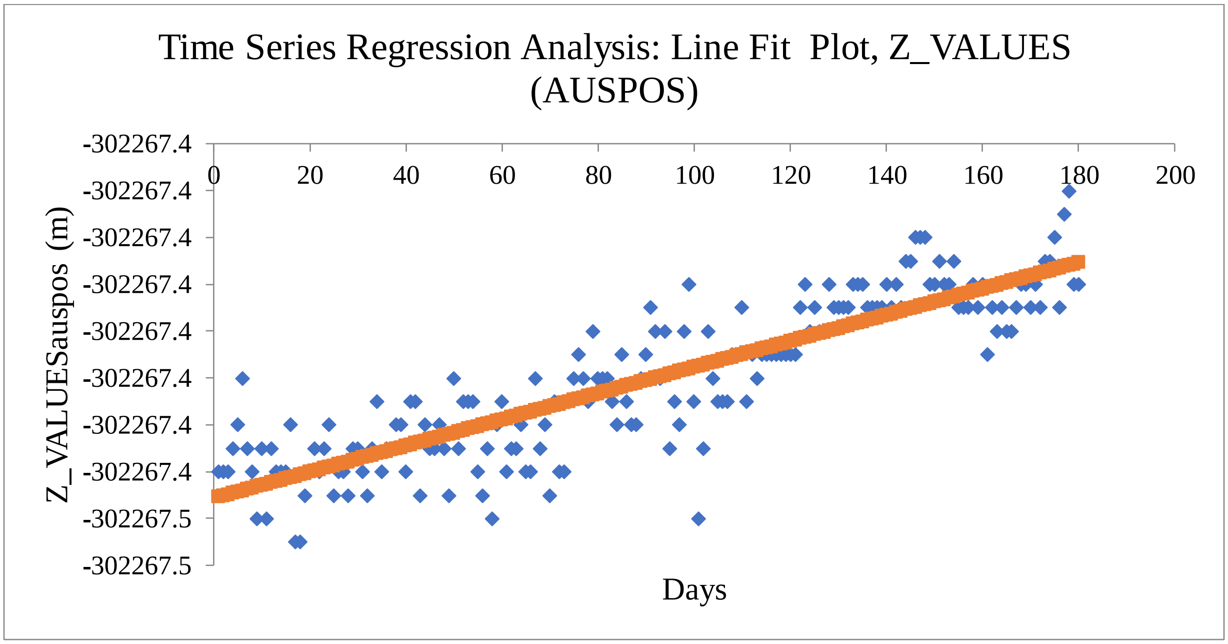


Figure 4 14 Residual Plot, Z-Values (GAMIT/GLOBK)

Figure 4 15 Line Fit Plot, Z-Values (AUSPOS)



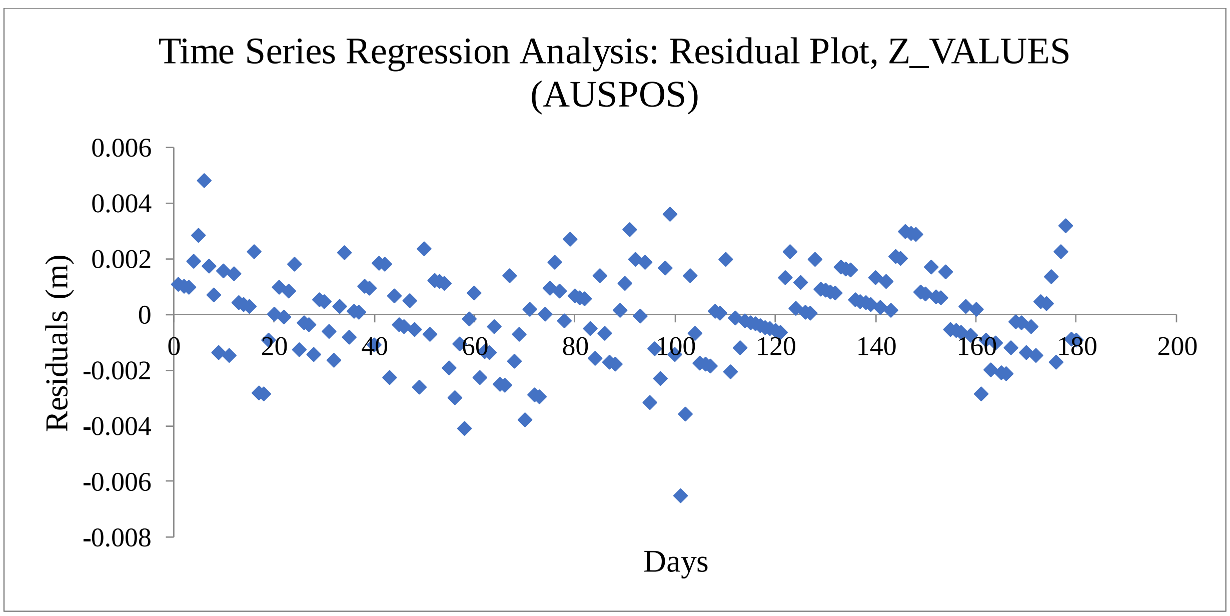


Figure 4 16 Residual Plot, Z-Values (AUSPOS)

4.1.8 Analysis of the Result: AUSPOS vs. GAMIT/GLOBK

Considering the provided RMSE values for both AUSPOS and GAMIT/GLOBK software in surveying applications, we can analyse their performance.

For AUSPOS, the RMSE values range from 0.006 to 0.027. The majority of values fall between 0.009 and 0.021, indicating relatively stable and consistent performance. Lower RMSE values suggest higher accuracy and precision in the positioning solutions provided by AUSPOS. The performance initially shows stability (0.014-0.019), followed by some spikes on the day 95 (0.033), 137 (0.036), 172 (0.040). This may be due to some errors in observation done on these days.

Regarding GAMIT/GLOBK, the RMSE values range from 0.001 to 0.063. The performance initially shows stability (0.008 to 0.017), followed by a spike on day 30 (0.063) and day 31 (0.034) and subsequent stabilization at lower levels (0.008 to 0.017). This indicates some fluctuations in performance over time. The sudden spike in RMSE values on day 30 and 31 may indicate an anomaly or outlier in the positioning solution provided by GAMIT/GLOBK. This anomaly could be caused by various factors, such as data corruption, equipment malfunction, or other environmental influences.

Comparing the two software, GAMIT/GLOBK demonstrates more consistent and stable results with generally lower RMSE values in the surveying applications. This suggests that GAMIT/GLOBK may offer more reliable and accurate positioning solutions compared to AUSPOS. However, it is essential to consider specific requirements of the surveying project, such as the desired level of accuracy, surveying techniques, and the specific tasks involved. Factors like cost, ease of use, and support availability should also be considered when selecting between AUSPOS and GAMIT/GLOBK or any other software for surveying applications.

Additionally, examining the residual plot for AUSPOS and GAMIT/GLOBK can provide further insights. The residuals represent the differences between the observed values and the predicted values obtained from the regression model. Upon examining the residuals, several key observations were made. It was observed that the residuals exhibited relatively small magnitudes for both AUSPOS and GAMIT/GLOBK, indicating that both software exhibits consistency and stability over a given period of time.

4.2 Discussion of the Results

The research successfully achieved its objectives which included comparing the accuracy of AUSPOS and TBC, analysing the performance of AUSPOS at different hourly intervals, and evaluating the consistency and stability of positioning solutions provided by AUSPOS and GAMIT/GLOBK. The research findings provide valuable insights into the accuracy and performance of these software packages.

The comparison of AUSPOS and TBC accuracy revealed that both solutions exhibited small positional discrepancies compared to the reference coordinates, indicating their capability to achieve accurate results. However, TBC consistently demonstrated lower RMSE values and positional discrepancies compared to AUSPOS at most time intervals. This suggests that TBC offers a higher level of accuracy and reliability.

Furthermore, the time series analysis provided insights into the consistency and stability of positioning solutions provided by AUSPOS and GAMIT/GLOBK over the duration of dataset. The analysis revealed trends, variations, and anomalies in the calculated positions over time. While both software packages demonstrated overall stability and accuracy, the specific patterns identified through the time series analysis provided a deeper understanding of their long-term reliability. This information is particularly valuable for surveying professionals and researchers who require consistent and stable positioning solutions for extended periods.

The findings of this research have practical implications for surveying professionals and researchers, as they can now make informed decisions when selecting the most suitable software for their specific needs. Factors such as accuracy, performance at different time intervals, and long-term consistency, as revealed through the positional time series analysis, should be carefully considered. This will ensure the optimal choice of software for achieving accurate and reliable surveying results.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

This chapter concludes the study, summarizing the main findings, making recommendations for future research, and providing conclusions.

5.1 Conclusion

The comparative analysis between AUSPOS, TBC, and GAMIT/GLOBK in terms of accuracy performance in surveying applications has provided valuable insights. In terms of Positional Accuracy AUSPOS exhibits small positional discrepancies compared to the reference coordinates. Comparing AUSPOS and TBC, TBC generally exhibits higher RMSE. The RMSE values for AUSPOS range from 0.016 to 0.021 meters, while for TBC, they range from 0.092 to 0.116 meters. AUSPOS demonstrates consistent and stable performance, with relatively low RMSE values, suggesting its reliability in providing accurate positioning solutions. AUSPOS and GAMIT/GLOBK exhibit similar trends in RMSE values over time. Both show a decreasing trend, indicating improved accuracy with longer observation periods. AUSPOS demonstrates overall stability and accuracy, with RMSE values ranging from 0.006 to 0.027 meters while, for GAMIT/GLOBK RMSE range from 0.001 to 0.021. These findings suggest that AUSPOS, an online GNSS processing service provided by Geoscience Australia, can be used as an alternative in geodetic surveying when high accuracy is not immediately required. It offers quick and reasonably accurate positioning solutions, making it suitable for preliminary surveys, rapid field checks, and for scenarios requiring immediate result, AUSPOS can be beneficial. While GAMIT/GLOBK outperform AUSPOS in terms of accuracy, AUSPOS remains a cost-effective and accessible option. It can serve as a valuable tool for independent validation of survey data, and establishment of control points. However, for critical projects demanding the highest precision, specialized software like GAMIT/GLOBK may still be preferable.

5.2 Recommendation

Based on the findings and conclusions of this research on the accuracy performance of AUSPOS compared to TBC and GAMIT, the following recommendations can be made for future research and practical applications:

a) Field Validation and Case Studies: Validate the accuracy of AUSPOS through field validation studies, comparing its results with ground truth measurements obtained using conventional surveying methods. Additionally, conduct case studies in diverse environments and challenging conditions to assess AUSPOS' performance in real-world scenarios. This will help identify any limitations or specific conditions where AUSPOS may excel or face challenges, enabling surveying professionals to make informed decisions about its use in practical applications.

b) Further Comparative Studies: Conduct more extensive comparative studies involving a larger dataset and additional software solutions. This will provide a broader perspective on the performance of AUSPOS in relation to other GNSS postprocessing software. Comparisons can include different commercial software packages as well as open-source alternatives to assess their accuracy, consistency, and suitability for various surveying applications.

c) Long-Term Stability Analysis: Perform long-term stability analysis of AUSPOS and other software solutions by analyzing positioning solutions over extended periods of time. This will help identify any potential variations or trends in accuracy and stability, providing insights into the long-term reliability of these software packages.

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APPENDICIES

APPENDIX - A	AUSPOS Processing Report
APPENDIX - B	Network Adjustment Report
APPENDIX - C	Data Set Positional Time Series Analysis in ITRF14, GRS80 Ellipsoid (AUSPOS)
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APPENDIX - A

AUSPOS GPS Processing Report

May 2, 2023

This document is a report of the GPS data processing undertaken by the AUSPOS Online GPS Processing Service (version: AUSPOS 2.4). The AUSPOS Online GPS Processing Service uses International GNSS Service (IGS) products (final, rapid, ultra-rapid depending on availability) to compute precise coordinates in International Terrestrial Reference Frame (ITRF) anywhere on Earth and Geocentric Datum of Australia (GDA) 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.

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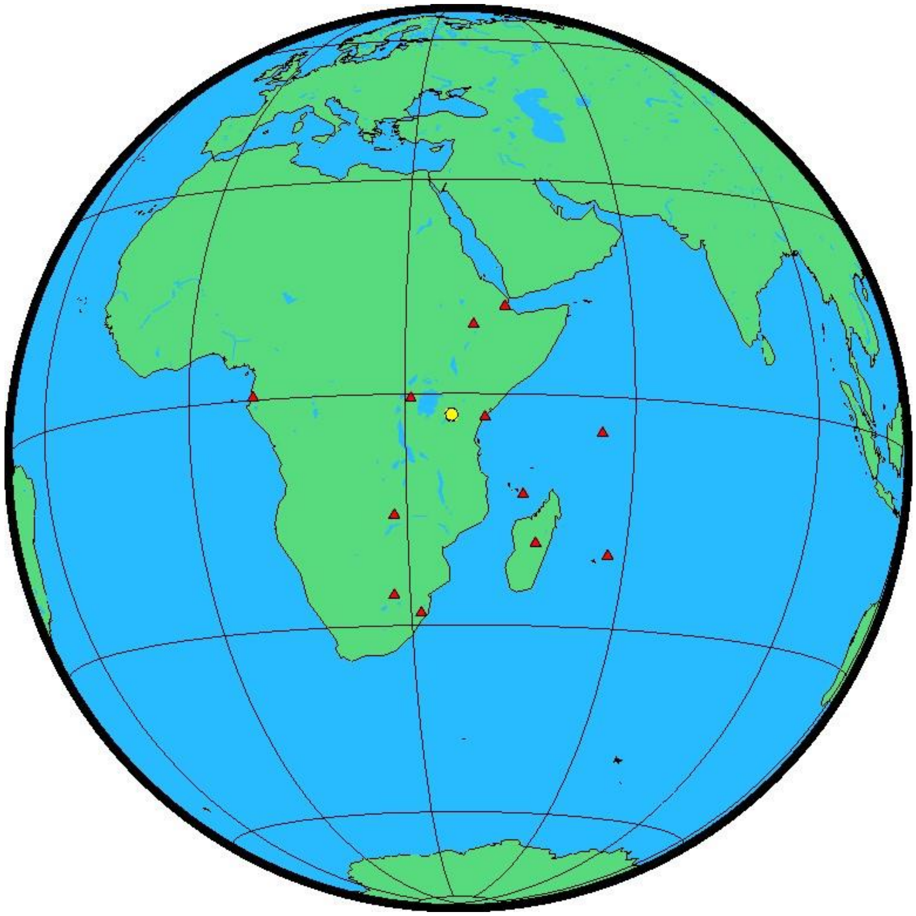
1 User Data

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
OLO1	olo10010.20o	TRM57971.00 NONE	0.000	2020/01/01 00:00:00	2020/01/01 23:59:30
OLO3	olo30010.20o	TRM57971.00 NONE	0.000	2020/01/01 00:00:00	2020/01/01 23:59:30
OLO5	olo50010.20o	TRM57971.00 NONE	0.000	2020/01/01 00:00:00	2020/01/01 23:59:30
OLO6	olo60010.20o	TRM115000.00 NONE	0.000	2020/01/01 00:00:00	2020/01/01 23:59:30
OLO7	olo70010.20o	TRM57971.00 NONE	0.000	2020/01/01 00:00:00	2020/01/01 23:59:30

2 Processing Summary



Date	User Stations	Reference Stations	Orbit Type
2020/01/01 00:00:00	OLO1, OLO3 OLO5, OLO6 OLO7.	ABPO ADIS DJIG HARB HRAO MAL2 MAYG MBAR NKLG SEYG ULDI VACS ZAMB	IGS final

3 Computed Coordinates, ITRF2014

All coordinates are based on the IGS realisation of the ITRF2014 reference frame. All the given ITRF2014 coordinates refer to a mean epoch of the site observation data. All coordinates refer to the Ground Mark.

3.1 Cartesian, ITRF2014

Station	X (m)	Y (m)	Z (m)	ITRF2014 @
OLO1	5158236.923	3740835.135	-302267.448	01/01/2020
OLO3	5163694.097	3733963.693	-304475.985	01/01/2020
OLO5	5162364.357	3735464.452	-291147.343	01/01/2020
OLO6	5161197.875	3736841.295	-299447.244	01/01/2020
OLO7	5160792.461	3737529.456	-309142.625	01/01/2020
ABPO	4097216.541	4429119.203	-2065771.182	01/01/2020
ADIS	4913652.568	3945922.837	995383.517	01/01/2020
DJIG	4583085.943	4250982.661	1266243.202	01/01/2020
HARB	5084657.606	2670325.401	-2768480.899	01/01/2020
HRAO	5085352.439	2668396.128	-2768731.291	01/01/2020
MAL2	4865385.437	4110717.484	-331137.379	01/01/2020
MAYG	4379104.227	4418744.612	-1401897.796	01/01/2020
MBAR	5482951.121	3260442.866	-66519.612	01/01/2020
NKLG	6287385.696	1071574.857	39133.196	01/01/2020
SEYG	3597835.884	5240884.102	-516780.953	01/01/2020
ULDI	4796680.890	2930311.696	-3005435.624	01/01/2020
VACS	3215946.907	5047449.762	-2198718.156	01/01/2020
ZAMB	5415352.959	2917210.200	-1685888.606	01/01/2020

3.2 Geodetic, GRS80 Ellipsoid, ITRF2014

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)
OLO1	-2 44 03.13831	35 57 00.78166	988.092	1006.921
OLO3	-2 45 14.33699	35 52 17.02131	1483.040	1501.272
OLO5	-2 38 01.25736	35 53 21.60916	659.001	678.116
OLO6	-2 42 31.35569	35 54 19.85265	908.325	927.089
OLO7	-2 47 46.46344	35 54 45.59206	1449.066	1467.297

ABPO	-19 01 05.89563	47 13 45.16965	1552.964	1553.754
ADIS	9 02 06.49476	38 45 58.70253	2439.133	2446.192
DJIG	11 31 34.63991	42 50 49.44029	711.399	724.125
HARB	-25 53 13.05763	27 42 26.08999	1558.079	1532.768
HRAO	-25 53 24.36893	27 41 13.13962	1414.151	1388.795
MAL2	-2 59 45.79109	40 11 38.92664	-20.927	9.488
MAYG	-12 46 55.38799	45 15 29.35912	-16.548	4.043
MBAR	-0 36 05.28089	30 44 16.36493	1337.536	1349.483
NKLG	0 21 14.07284	9 40 19.66055	31.491	21.505
SEYG	-4 40 43.43142	55 31 50.27638	-37.624	3.378
ULDI	-28 17 35.21629	31 25 15.33435	607.949	583.454
VACS	-20 17 49.46776	57 29 49.33915	421.155	424.067
ZAMB	-15 25 31.93802	28 18 39.65373	1324.932	1324.504

3.3 UTM Grid, GRS80 Ellipsoid, ITRF2014

Station	East (m)	North (m)	Zone	Ellipsoidal Height (m)	Derived Above Geoid Height(m)
OLO1	828059.381	9697382.712	36	988.092	1006.921
OLO3	819281.750	9695215.188	36	1483.040	1501.272
OLO5	821309.962	9708524.373	36	659.001	678.116
OLO6	823091.029	9700216.532	36	908.325	927.089
OLO7	823863.101	9690527.169	36	1449.066	1467.297
ABPO	734645.791	7895659.182	38	1552.964	1553.754
ADIS	474316.204	998745.103	37	2439.133	2446.192
DJIG	265181.190	1275054.312	38	711.399	724.125
HARB	570848.375	7136643.562	35	1558.079	1532.768
HRAO	568816.550	7136306.376	35	1414.151	1388.795
MAL2	632707.791	9668770.796	37	-20.927	9.488
MAYG	528019.027	8586952.136	38	-16.548	4.043
MBAR	248230.518	9933467.616	36	1337.536	1349.483
NKLG	574791.320	39120.307	32	31.491	21.505
SEYG	337019.629	9482677.631	40	-37.624	3.378
ULDI	345152.753	6869315.467	36	607.949	583.454

VACS	551895.105	7755565.803	40	421.155	424.067
ZAMB	640671.904	8294178.563	35	1324.932	1324.504

3.4 Positional Uncertainty (95% C.L.) - Geodetic, ITRF2014

Station	Longitude (East) (m)	Latitude (North) (m)	Ellipsoidal Height (Up) (m)
OLO1	0.006	0.004	0.011
OLO3	0.006	0.004	0.013
OLO5	0.006	0.004	0.011
OLO6	0.006	0.004	0.011
OLO7	0.006	0.004	0.011
ABPO	0.006	0.003	0.009
ADIS	0.006	0.005	0.011
DJIG	0.006	0.005	0.012
HARB	0.006	0.004	0.010
HRAO	0.006	0.004	0.011
MAL2	0.005	0.003	0.009
MAYG	0.006	0.003	0.011
MBAR	0.006	0.004	0.010
NKLG	0.007	0.004	0.012
SEYG	0.006	0.004	0.010
ULDI	0.006	0.005	0.012
VACS	0.006	0.003	0.011
ZAMB	0.006	0.004	0.011

4 Ambiguity Resolution - Per Baseline

Baseline	Ambiguities Resolved	Baseline Length (km)
DJIG - MAL2	85.2%	1628.187
OLO5 - OLO6	100.0%	8.494
OLO1 - OLO6	100.0%	5.716
ABPO - MAYG	89.6%	721.316
OLO7 - OLO6	97.9%	9.728
MAL2 - OLO5	86.3%	480.219
HARB - ULDI	88.0%	454.611
HARB -	100.0%	2.066
MAL2 - MAYG	78.0%	1215.680
ABPO - HARB	88.0%	2135.930
MBAR - NKLG	44.9%	2334.399
MAYG - SEYG	87.5%	1438.654
HARB - ZAMB	75.7%	1158.584
MAL2 - MBAR	75.0%	1083.687
ADIS - DJIG	90.5%	525.072
ABPO - VACS	83.7%	1084.732
OLO3 - OLO6	100.0%	6.309
AVERAGE	86.5%	840.787

Please note for a regional solution, such as used by AUSPOS, ambiguity resolution success rate of 50% or better for a baseline formed by a user site indicates a reliable solution.

5 Computation Standards

5.1 Computation System

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

5.2 Data Pre-processing and Measurement Modelling

Data pre-processing	Phase pre-processing is undertaken in a baseline by baseline mode using triple-difference. 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 post-fit residuals is also performed, and outliers are removed.

Basic observable	Carrier phase with an elevation angle cut-off 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	IGS14 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 WETGMF 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	IGS14 phase-centre variation model applied
Satellite phase centre calibration	IGS14 phase-centre variation model applied
Satellite trajectories	Best available IGS products.
Earth Orientation	Best available IGS products.

5.3 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 200-6000km baselines, the Phase-Based L5/L3 strategy for 20-200km baselines, the Quasi-Ionosphere-Free (QIF) strategy for 20-2000km baselines and the Direct L1/L2 strategy for 0-20km baselines.

5.4 Reference Frame and Coordinate Uncertainty

Terrestrial reference frame	IGS14 station coordinates and velocities mapped to the mean epoch of observation.
Australian datums	GDA2020 and GDA94.
Derived AHD	For stations within Australia, AUSGeoid2020 (V20180201) is used to compute AHD. AUSGeoid2020 is the Australia-wide gravimetric quasi-geoid model that has been posteriori fitted to the AHD. For reference, derived AHD is always determined from the GDA2020 coordinates. In the GDA94 section of the report, AHD values are assumed to be identical to those derived from GDA2020.
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 GDA94, GDA2020 and ITRF2014. Uncertainties are scaled using an empirically derived model which is a function of data span, quality and geographical location.

APPENDIX - B

NETWORK ADJUSTMENT REPORT

pProject File Data		**Coordinate System**	
Name:		Name:	World wide/UTM
Size:		Datum:	ITRF2014
Modified:		Zone:	36 South
Time zone:		Geoid:	EGM96 (Global)
Reference number:		Vertical datum:	
Description:		Calibrated site:	
Comment 1:			
Comment 2:			
Comment 3:			

Network Adjustment Report

Adjustment Settings

Set-Up Errors

GNSS

Error in Height of Antenna: 0.003 m

Centering Error: 0.000 m

Covariance Display

Horizontal:

Propagated Linear Error [E]: U.S.

Constant Term [C]: 0.000 m

Scale on Linear Error [S]: 1.960

Three-Dimensional

Propagated Linear Error [E]: U.S.

Constant Term [C]: 0.000 m

Scale on Linear Error [S]: 1.960

Adjustment Statistics

Number of Iterations for Successful Adjustment:	2
Network Reference Factor:	1.01
Chi Square Test (95%):	Passed
Precision Confidence Level:	95%
Degrees of Freedom:	18

Post Processed Vector Statistics

Reference Factor:	1.01
Redundancy Number:	18.00
A Priori Scalar:	0.24

Control Point Constraints

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
OLO1	Grid	Fixed	Fixed		
Fixed = 0.000001(Meter)					

Adjusted Grid Coordinates

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
OLO1	828059.394	?	9697382.721	?	1007.033	0.002	EN
OLO3	819281.763	0.001	9695215.198	0.000	1501.754	0.002	
OLO5	821309.977	0.001	9708524.382	0.000	678.093	0.002	
OLO6	823091.042	0.001	9700216.544	0.000	927.247	0.002	
OLO7	823863.118	0.001	9690527.178	0.000	1467.760	0.002	

Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Constraint
OLO1	S2°44'03.13801"	E35°57'00.78206"	988.201	0.002	EN
OLO3	S2°45'14.33665"	E35°52'17.02173"	1483.152	0.002	
OLO5	S2°38'01.25706"	E35°53'21.60967"	659.111	0.002	
OLO6	S2°42'31.35531"	E35°54'19.85309"	908.438	0.002	
OLO7	S2°47'46.46315"	E35°54'45.59258"	1449.181	0.002	

Adjusted ECEF Coordinates

Point ID	X (Meter)	X Error (Meter)	Y (Meter)	Y Error (Meter)	Z (Meter)	Z Error (Meter)	3D Error (Meter)	Constraint
OLO1	5158237.005	?	3740835.210	?	-302267.444	?	?	EN
OLO3	5163694.180	0.002	3733963.769	0.001	-304475.980	0.000	0.002	
OLO5	5162364.436	0.002	3735464.529	0.001	-291147.339	0.000	0.002	
OLO6	5161197.959	0.002	3736841.373	0.001	-299447.238	0.000	0.002	
OLO7	5160792.545	0.002	3737529.537	0.001	-309142.622	0.001	0.002	

Error Ellipse Components

Point ID	Semi-major axis (Meter)	Semi-minor axis (Meter)	Azimuth
OLO3	0.001	0.001	83°
OLO5	0.001	0.001	86°
OLO6	0.001	0.001	85°
OLO7	0.001	0.001	86°

Adjusted GNSS Observations

Observation ID		Observation	A-posteriori Error	Residual	Standardized Residual
OLO6 --> OLO7 (PV7)	**Az.**	175°18'16"	0.011 sec	-0.006 sec	-0.830
	ΔHt.	540.743 m	0.003 m	0.001 m	0.223
	Ellip Dist.	9711.381 m	0.000 m	0.001 m	1.955
OLO5 --> OLO7 (PV8)	**Az.**	171°47'19"	0.006 sec	0.007 sec	1.797
	ΔHt.	790.070 m	0.003 m	-0.003 m	-1.452
	Ellip Dist.	18161.266 m	0.000 m	0.000 m	-1.105
OLO6 --> OLO5 (PV4)	**Az.**	347°45'52"	0.012 sec	-0.008 sec	-1.131
	ΔHt.	-249.327 m	0.003 m	-0.003 m	-1.642
	Ellip Dist.	8489.094 m	0.000 m	0.000 m	1.646
OLO1 --> OLO3 (PV1)	**Az.**	255°59'16"	0.011 sec	0.010 sec	1.564
	ΔHt.	494.951 m	0.003 m	0.001 m	0.471

	Ellip Dist.	9033.188 m	0.001 m	0.000 m	-0.814
OLO3 --> OLO7 (PV9)	**Az.**	135°31'13"	0.016 sec	-0.005 sec	-0.478
	ΔHt.	-33.971 m	0.003 m	0.003 m	1.361
	Ellip Dist.	6549.107 m	0.000 m	0.000 m	-0.714
OLO1 --> OLO6 (PV6)	**Az.**	299°33'33"	0.017 sec	-0.012 sec	-1.093
	ΔHt.	-79.764 m	0.003 m	-0.001 m	-0.620
	Ellip Dist.	5714.495 m	0.001 m	0.000 m	0.756
OLO1 --> OLO7 (PV10)	**Az.**	211°19'42"	0.014 sec	-0.008 sec	-0.945
	ΔHt.	460.980 m	0.004 m	0.000 m	-0.132
	Ellip Dist.	8030.509 m	0.001 m	0.000 m	-0.663
OLO6 --> OLO3 (PV5)	**Az.**	217°09'22"	0.016 sec	0.003 sec	0.312
	ΔHt.	574.714 m	0.003 m	0.002 m	0.908
	Ellip Dist.	6281.307 m	0.000 m	0.000 m	0.624
OLO1 --> OLO5 (PV3)	**Az.**	328°39'18"	0.008 sec	-0.004 sec	-0.810
	ΔHt.	-329.091 m	0.003 m	0.000 m	0.230
	Ellip Dist.	13014.777 m	0.000 m	0.000 m	-0.739
OLO3 --> OLO5 (PV2)	**Az.**	8°31'47"	0.008 sec	-0.001 sec	-0.124

	ΔHt.	-824.041 m	0.003 m	0.000 m	0.121
	Ellip Dist.	13451.134 m	0.000 m	0.000 m	0.542

Covariance Terms

From Point	To Point		Components	A-posteriori Error	Horiz. Precision (Ratio)	3D Precision (Ratio)
OLO1	OLO3	**Az.**	255°59'16"	0.011 sec	1: 17373899	1: 16073655
		ΔHt.	494.951 m	0.003 m		
		ΔElev.	494.721 m	0.003 m		
		Ellip Dist.	9033.188 m	0.001 m		
OLO1	OLO5	**Az.**	328°39'18"	0.008 sec	1: 27378966	1: 26819873
		ΔHt.	-329.091 m	0.003 m		
		ΔElev.	-328.940 m	0.003 m		
		Ellip Dist.	13014.777 m	0.000 m		
OLO1	OLO6	**Az.**	299°33'33"	0.017 sec	1: 11306518	1: 11267199
		ΔHt.	-79.764 m	0.003 m		
		ΔElev.	-79.786 m	0.003 m		
		Ellip Dist.	5714.495 m	0.001 m		
OLO1	OLO7	**Az.**	211°19'42"	0.014 sec	1: 15759734	1: 14264162
		ΔHt.	460.980 m	0.004 m		
		ΔElev.	460.727 m	0.004 m		
		Ellip Dist.	8030.509 m	0.001 m		
OLO3	OLO5	**Az.**	8°31'47"	0.008 sec	1: 28778769	1: 25717439
		ΔHt.	-824.041 m	0.003 m		
		ΔElev.	-823.661 m	0.003 m		

		Ellip Dist.	13451.134 m	0.000 m		
OLO3	OLO6	**Az.**	37°09'28"	0.016 sec	1: 13030817	1: 10719911
		ΔHt.	-574.714 m	0.003 m		
		ΔElev.	-574.507 m	0.003 m		
		Ellip Dist.	6281.307 m	0.000 m		
OLO3	OLO7	**Az.**	135°31'13"	0.016 sec	1: 13084001	1: 13082315
		ΔHt.	-33.971 m	0.003 m		
		ΔElev.	-33.994 m	0.003 m		
		Ellip Dist.	6549.107 m	0.001 m		
OLO5	OLO6	**Az.**	167°45'54"	0.012 sec	1: 19222967	1: 18639043
		ΔHt.	249.327 m	0.003 m		
		ΔElev.	249.154 m	0.003 m		
		Ellip Dist.	8489.094 m	0.000 m		
OLO5	OLO7	**Az.**	171°47'19"	0.006 sec	1: 38011178	1: 35934665
		ΔHt.	790.070 m	0.003 m		
		ΔElev.	789.667 m	0.003 m		
		Ellip Dist.	18161.266 m	0.000 m		
OLO6	OLO7	**Az.**	175°18'16"	0.011 sec	1: 20195727	1: 18458029
		ΔHt.	540.743 m	0.003 m		
		ΔElev.	540.513 m	0.003 m		
		Ellip Dist.	9711.381 m	0.000 m		

APPENDIX - C

Data Set Positional Time Series Analysis in ITRF14, GRS80 Ellipsoid (AUSPOS)

Days	X (m)	Y (m)	Z (m)	ΔX (m)	ΔY (m)	ΔZ (m)	RMSE (m)
1	5158236.923	3740835.135	-302267.448	-0.01	0.007	0.010	0.016
2	5158236.923	3740835.137	-302267.448	-0.01	0.005	0.010	0.015
3	5158236.924	3740835.139	-302267.448	-0.011	0.003	0.010	0.015
4	5158236.918	3740835.132	-302267.447	-0.005	0.01	0.009	0.014
5	5158236.921	3740835.133	-302267.446	-0.008	0.009	0.008	0.014
6	5158236.91	3740835.125	-302267.444	0.003	0.017	0.006	0.018
7	5158236.922	3740835.134	-302267.447	-0.009	0.008	0.009	0.015
8	5158236.923	3740835.137	-302267.448	-0.01	0.005	0.010	0.015
9	5158236.925	3740835.136	-302267.45	-0.012	0.006	0.012	0.018
10	5158236.922	3740835.134	-302267.447	-0.009	0.008	0.009	0.015
11	5158236.919	3740835.133	-302267.45	-0.006	0.009	0.012	0.016
12	5158236.917	3740835.131	-302267.447	-0.004	0.011	0.009	0.015
13	5158236.915	3740835.131	-302267.448	-0.002	0.011	0.010	0.015
14	5158236.92	3740835.134	-302267.448	-0.007	0.008	0.010	0.014
15	5158236.919	3740835.137	-302267.448	-0.006	0.005	0.010	0.012
16	5158236.919	3740835.137	-302267.446	-0.006	0.005	0.008	0.011
17	5158236.917	3740835.132	-302267.451	-0.004	0.01	0.013	0.017
18	5158236.923	3740835.135	-302267.451	-0.01	0.007	0.013	0.018
19	5158236.923	3740835.134	-302267.449	-0.01	0.008	0.011	0.017
20	5158236.919	3740835.133	-302267.448	-0.006	0.009	0.010	0.015
21	5158236.915	3740835.13	-302267.447	-0.002	0.012	0.009	0.015
22	5158236.917	3740835.132	-302267.448	-0.004	0.01	0.010	0.014
23	5158236.919	3740835.133	-302267.447	-0.006	0.009	0.009	0.014
24	5158236.914	3740835.132	-302267.446	-0.001	0.01	0.008	0.013
25	5158236.911	3740835.127	-302267.449	0.002	0.015	0.011	0.019
26	5158236.924	3740835.135	-302267.448	-0.011	0.007	0.010	0.016
27	5158236.921	3740835.136	-302267.448	-0.008	0.006	0.010	0.014
28	5158236.921	3740835.137	-302267.449	-0.008	0.005	0.011	0.014
29	5158236.914	3740835.132	-302267.447	-0.001	0.01	0.009	0.013
30	5158236.912	3740835.129	-302267.447	0.001	0.013	0.009	0.016
31	5158236.913	3740835.135	-302267.448	0	0.007	0.010	0.012
32	5158236.915	3740835.134	-302267.449	-0.002	0.008	0.011	0.014
33	5158236.917	3740835.131	-302267.447	-0.004	0.011	0.009	0.015
34	5158236.916	3740835.131	-302267.445	-0.003	0.011	0.007	0.013
35	5158236.921	3740835.141	-302267.448	-0.008	0.001	0.010	0.013

36	5158236.918	3740835.133	-302267.447	-0.005	0.009	0.009	0.013
37	5158236.916	3740835.133	-302267.447	-0.003	0.009	0.009	0.013
38	5158236.918	3740835.135	-302267.446	-0.005	0.007	0.008	0.012
39	5158236.912	3740835.13	-302267.446	0.001	0.012	0.008	0.014
40	5158236.914	3740835.131	-302267.448	-0.001	0.011	0.010	0.015
41	5158236.917	3740835.137	-302267.445	-0.004	0.005	0.007	0.009
42	5158236.916	3740835.137	-302267.445	-0.003	0.005	0.007	0.009
43	5158236.913	3740835.133	-302267.449	0	0.009	0.011	0.014
44	5158236.92	3740835.136	-302267.446	-0.007	0.006	0.008	0.012
45	5158236.914	3740835.131	-302267.447	-0.001	0.011	0.009	0.014
46	5158236.915	3740835.131	-302267.447	-0.002	0.011	0.009	0.014
47	5158236.911	3740835.133	-302267.446	0.002	0.009	0.008	0.012
48	5158236.911	3740835.132	-302267.447	0.002	0.01	0.009	0.013
49	5158236.914	3740835.133	-302267.449	-0.001	0.009	0.011	0.014
50	5158236.913	3740835.131	-302267.444	0	0.011	0.006	0.012
51	5158236.915	3740835.129	-302267.447	-0.002	0.013	0.009	0.016
52	5158236.919	3740835.135	-302267.445	-0.006	0.007	0.007	0.011
53	5158236.915	3740835.132	-302267.445	-0.002	0.01	0.007	0.012
54	5158236.917	3740835.133	-302267.445	-0.004	0.009	0.007	0.012
55	5158236.921	3740835.137	-302267.448	-0.008	0.005	0.010	0.014
56	5158236.915	3740835.133	-302267.449	-0.002	0.009	0.011	0.014
57	5158236.918	3740835.137	-302267.447	-0.005	0.005	0.009	0.011
58	5158236.918	3740835.138	-302267.45	-0.005	0.004	0.012	0.013
59	5158236.913	3740835.132	-302267.446	0	0.01	0.008	0.013
60	5158236.915	3740835.136	-302267.445	-0.002	0.006	0.007	0.009
61	5158236.916	3740835.136	-302267.448	-0.003	0.006	0.010	0.012
62	5158236.917	3740835.138	-302267.447	-0.004	0.004	0.009	0.010
63	5158236.916	3740835.134	-302267.447	-0.003	0.008	0.009	0.012
64	5158236.915	3740835.132	-302267.446	-0.002	0.01	0.008	0.013
65	5158236.917	3740835.134	-302267.448	-0.004	0.008	0.010	0.013
66	5158236.92	3740835.138	-302267.448	-0.007	0.004	0.010	0.013
67	5158236.918	3740835.136	-302267.444	-0.005	0.006	0.006	0.010
68	5158236.907	3740835.127	-302267.447	0.006	0.015	0.009	0.018
69	5158236.912	3740835.132	-302267.446	0.001	0.01	0.008	0.013
70	5158236.921	3740835.137	-302267.449	-0.008	0.005	0.011	0.014
71	5158236.92	3740835.137	-302267.445	-0.007	0.005	0.007	0.011
72	5158236.907	3740835.128	-302267.448	0.006	0.014	0.010	0.018
73	5158236.914	3740835.134	-302267.448	-0.001	0.008	0.010	0.013
74	5158236.913	3740835.129	-302267.445	0	0.013	0.007	0.015

75	5158236.911	3740835.127	-302267.444	0.002	0.015	0.006	0.016
76	5158236.907	3740835.13	-302267.443	0.006	0.012	0.005	0.014
77	5158236.905	3740835.124	-302267.444	0.008	0.018	0.006	0.021
78	5158236.907	3740835.131	-302267.445	0.006	0.011	0.007	0.014
79	5158236.918	3740835.137	-302267.442	-0.005	0.005	0.004	0.008
80	5158236.904	3740835.125	-302267.444	0.009	0.017	0.006	0.020
81	5158236.905	3740835.124	-302267.444	0.008	0.018	0.006	0.021
82	5158236.909	3740835.13	-302267.444	0.004	0.012	0.006	0.014
83	5158236.917	3740835.141	-302267.445	-0.004	0.001	0.007	0.008
84	5158236.906	3740835.128	-302267.446	0.007	0.014	0.008	0.017
85	5158236.911	3740835.137	-302267.443	0.002	0.005	0.005	0.007
86	5158236.911	3740835.134	-302267.445	0.002	0.008	0.007	0.011
87	5158236.909	3740835.131	-302267.446	0.004	0.011	0.008	0.014
88	5158236.909	3740835.133	-302267.446	0.004	0.009	0.008	0.013
89	5158236.911	3740835.132	-302267.444	0.002	0.01	0.006	0.012
90	5158236.913	3740835.139	-302267.443	0	0.003	0.005	0.006
91	5158236.908	3740835.133	-302267.441	0.005	0.009	0.003	0.011
92	5158236.913	3740835.133	-302267.442	0	0.009	0.004	0.010
93	5158236.906	3740835.132	-302267.444	0.007	0.01	0.006	0.013
94	5158236.91	3740835.131	-302267.442	0.003	0.011	0.004	0.012
95	5158236.961	3740835.166	-302267.447	-0.048	-0.024	0.009	0.054
96	5158236.915	3740835.137	-302267.445	-0.002	0.005	0.007	0.009
97	5158236.915	3740835.135	-302267.446	-0.002	0.007	0.008	0.011
98	5158236.904	3740835.127	-302267.442	0.009	0.015	0.004	0.018
99	5158236.909	3740835.128	-302267.44	0.004	0.014	0.002	0.015
100	5158236.907	3740835.129	-302267.445	0.006	0.013	0.007	0.016
101	5158236.913	3740835.136	-302267.45	0	0.006	0.012	0.013
102	5158236.908	3740835.135	-302267.447	0.005	0.007	0.009	0.012
103	5158236.908	3740835.133	-302267.442	0.005	0.009	0.004	0.011
104	5158236.902	3740835.132	-302267.444	0.011	0.01	0.006	0.016
105	5158236.912	3740835.133	-302267.445	0.001	0.009	0.007	0.011
106	5158236.91	3740835.131	-302267.445	0.003	0.011	0.007	0.013
107	5158236.91	3740835.131	-302267.445	0.003	0.011	0.007	0.013
108	5158236.91	3740835.134	-302267.443	0.003	0.008	0.005	0.010
109	5158236.908	3740835.137	-302267.443	0.005	0.005	0.005	0.008
110	5158236.903	3740835.13	-302267.441	0.01	0.012	0.003	0.016
111	5158236.907	3740835.132	-302267.445	0.006	0.01	0.007	0.013
112	5158236.91	3740835.134	-302267.443	0.003	0.008	0.005	0.010
113	5158236.905	3740835.131	-302267.444	0.008	0.011	0.006	0.015

114	5158236.899	3740835.129	-302267.443	0.014	0.013	0.005	0.020
115	5158236.906	3740835.13	-302267.443	0.007	0.012	0.005	0.015
116	5158236.908	3740835.131	-302267.443	0.005	0.011	0.005	0.013
117	5158236.902	3740835.126	-302267.443	0.011	0.016	0.005	0.020
118	5158236.902	3740835.126	-302267.443	0.011	0.016	0.005	0.020
119	5158236.905	3740835.13	-302267.443	0.008	0.012	0.005	0.015
120	5158236.894	3740835.124	-302267.443	0.019	0.018	0.005	0.027
121	5158236.899	3740835.124	-302267.443	0.014	0.018	0.005	0.023
122	5158236.905	3740835.131	-302267.441	0.008	0.011	0.003	0.014
123	5158236.903	3740835.13	-302267.44	0.01	0.012	0.002	0.016
124	5158236.907	3740835.132	-302267.442	0.006	0.01	0.004	0.012
125	5158236.904	3740835.129	-302267.441	0.009	0.013	0.003	0.016
126	5158236.904	3740835.129	-302267.442	0.009	0.013	0.004	0.016
127	5158236.904	3740835.131	-302267.442	0.009	0.011	0.004	0.015
128	5158236.901	3740835.129	-302267.44	0.012	0.013	0.002	0.018
129	5158236.902	3740835.129	-302267.441	0.011	0.013	0.003	0.017
130	5158236.901	3740835.128	-302267.441	0.012	0.014	0.003	0.019
131	5158236.909	3740835.138	-302267.441	0.004	0.004	0.003	0.006
132	5158236.903	3740835.13	-302267.441	0.01	0.012	0.003	0.016
133	5158236.901	3740835.128	-302267.44	0.012	0.014	0.002	0.019
134	5158236.902	3740835.131	-302267.44	0.011	0.011	0.002	0.016
135	5158236.901	3740835.13	-302267.44	0.012	0.012	0.002	0.017
136	5158236.908	3740835.134	-302267.441	0.005	0.008	0.003	0.010
137	5158236.957	3740835.169	-302267.441	-0.044	-0.027	0.003	0.052
138	5158236.906	3740835.132	-302267.441	0.007	0.01	0.003	0.013
139	5158236.898	3740835.128	-302267.441	0.015	0.014	0.003	0.021
140	5158236.901	3740835.133	-302267.44	0.012	0.009	0.002	0.015
141	5158236.902	3740835.132	-302267.441	0.011	0.01	0.003	0.015
142	5158236.903	3740835.13	-302267.44	0.01	0.012	0.002	0.016
143	5158236.906	3740835.134	-302267.441	0.007	0.008	0.003	0.011
144	5158236.902	3740835.13	-302267.439	0.011	0.012	0.001	0.016
145	5158236.903	3740835.132	-302267.439	0.01	0.01	0.001	0.014
146	5158236.901	3740835.128	-302267.438	0.012	0.014	0.000	0.018
147	5158236.9	3740835.13	-302267.438	0.013	0.012	0.000	0.018
148	5158236.902	3740835.128	-302267.438	0.011	0.014	0.000	0.018
149	5158236.904	3740835.132	-302267.44	0.009	0.01	0.002	0.014
150	5158236.904	3740835.132	-302267.44	0.009	0.01	0.002	0.014
151	5158236.906	3740835.133	-302267.439	0.007	0.009	0.001	0.011
152	5158236.902	3740835.133	-302267.44	0.011	0.009	0.002	0.014

153	5158236.905	3740835.135	-302267.44	0.008	0.007	0.002	0.011
154	5158236.897	3740835.129	-302267.439	0.016	0.013	0.001	0.021
155	5158236.902	3740835.137	-302267.441	0.011	0.005	0.003	0.012
156	5158236.899	3740835.127	-302267.441	0.014	0.015	0.003	0.021
157	5158236.9	3740835.13	-302267.441	0.013	0.012	0.003	0.018
158	5158236.904	3740835.133	-302267.44	0.009	0.009	0.002	0.013
159	5158236.907	3740835.136	-302267.441	0.006	0.006	0.003	0.009
160	5158236.906	3740835.136	-302267.44	0.007	0.006	0.002	0.009
161	5158236.901	3740835.134	-302267.443	0.012	0.008	0.005	0.015
162	5158236.902	3740835.134	-302267.441	0.011	0.008	0.003	0.014
163	5158236.906	3740835.136	-302267.442	0.007	0.006	0.004	0.010
164	5158236.908	3740835.138	-302267.441	0.005	0.004	0.003	0.007
165	5158236.907	3740835.136	-302267.442	0.006	0.006	0.004	0.009
166	5158236.906	3740835.138	-302267.442	0.007	0.004	0.004	0.009
167	5158236.907	3740835.14	-302267.441	0.006	0.002	0.003	0.007
168	5158236.907	3740835.137	-302267.44	0.006	0.005	0.002	0.008
169	5158236.903	3740835.135	-302267.44	0.01	0.007	0.002	0.012
170	5158236.905	3740835.136	-302267.441	0.008	0.006	0.003	0.010
171	5158236.905	3740835.136	-302267.44	0.008	0.006	0.002	0.010
172	5158236.962	3740835.174	-302267.441	-0.049	-0.032	0.003	0.059
173	5158236.903	3740835.134	-302267.439	0.01	0.008	0.001	0.013
174	5158236.898	3740835.13	-302267.439	0.015	0.012	0.001	0.019
175	5158236.906	3740835.136	-302267.438	0.007	0.006	0.000	0.009
176	5158236.901	3740835.135	-302267.441	0.012	0.007	0.003	0.014
177	5158236.9	3740835.133	-302267.437	0.013	0.009	-0.001	0.016
178	5158236.9	3740835.132	-302267.436	0.013	0.01	-0.002	0.017
179	5158236.9	3740835.133	-302267.44	0.013	0.009	0.002	0.016
180	5158236.9	3740835.132	-302267.44	0.013	0.01	0.002	0.016

APPENDIX - D

Data Set Positional Time Series Analysis in ITRF14, GRS80 Ellipsoid (GAMIT/GLOBK)

Days	X (m)	Y (m)	Z (m)	ΔX (m)	ΔY (m)	ΔZ (m)	RMSE (m)
1	5158236.925	3740835.142	-302267.448	-0.012	0.001	0.01	0.016
2	5158236.929	3740835.143	-302267.45	-0.016	-0.001	0.012	0.02
3	5158236.932	3740835.146	-302267.449	-0.02	-0.003	0.01	0.023
4	5158236.923	3740835.141	-302267.449	-0.01	0.002	0.011	0.015
5	5158236.931	3740835.144	-302267.448	-0.019	-0.002	0.01	0.021
6	5158236.916	3740835.132	-302267.446	-0.003	0.01	0.008	0.013
7	5158236.926	3740835.137	-302267.449	-0.013	0.005	0.011	0.018
8	5158236.93	3740835.141	-302267.447	-0.017	0.001	0.009	0.02
9	5158236.925	3740835.14	-302267.45	-0.012	0.003	0.011	0.017
10	5158236.933	3740835.142	-302267.449	-0.021	0.001	0.01	0.023
11	5158236.921	3740835.134	-302267.45	-0.008	0.008	0.012	0.016
12	5158236.924	3740835.139	-302267.451	-0.012	0.003	0.013	0.018
13	5158236.925	3740835.141	-302267.45	-0.012	0.001	0.012	0.017
14	5158236.922	3740835.138	-302267.449	-0.009	0.004	0.01	0.014
15	5158236.921	3740835.14	-302267.449	-0.009	0.003	0.011	0.014
16	5158236.927	3740835.141	-302267.449	-0.014	0.002	0.011	0.018
17	5158236.928	3740835.14	-302267.45	-0.015	0.002	0.011	0.019
18	5158236.931	3740835.143	-302267.451	-0.019	0	0.013	0.023
19	5158236.929	3740835.142	-302267.449	-0.016	0.001	0.011	0.02
20	5158236.916	3740835.134	-302267.449	-0.004	0.008	0.011	0.014
21	5158236.917	3740835.132	-302267.448	-0.004	0.011	0.009	0.015
22	5158236.926	3740835.14	-302267.447	-0.013	0.003	0.008	0.016
23	5158236.921	3740835.138	-302267.446	-0.008	0.005	0.008	0.012
24	5158236.92	3740835.136	-302267.45	-0.007	0.006	0.011	0.015
25	5158236.92	3740835.137	-302267.446	-0.007	0.006	0.008	0.012
26	5158236.934	3740835.143	-302267.451	-0.021	0	0.013	0.024
27	5158236.935	3740835.147	-302267.45	-0.023	-0.004	0.012	0.026
28	5158236.929	3740835.143	-302267.45	-0.016	0	0.012	0.02
29	5158236.92	3740835.136	-302267.449	-0.007	0.007	0.01	0.014
30	5158236.853	3740835.077	-302267.459	0.06	0.066	0.02	0.091
31	5158236.87	3740835.106	-302267.455	0.043	0.037	0.017	0.059
32	5158236.914	3740835.135	-302267.449	-0.002	0.007	0.011	0.013
33	5158236.921	3740835.137	-302267.446	-0.008	0.006	0.007	0.013
34	5158236.913	3740835.13	-302267.444	-0.001	0.012	0.006	0.014
35	5158236.918	3740835.137	-302267.448	-0.005	0.006	0.009	0.012

36	5158236.921	3740835.136	-302267.445	-0.008	0.006	0.007	0.013
37	5158236.916	3740835.135	-302267.446	-0.004	0.008	0.007	0.011
38	5158236.919	3740835.139	-302267.448	-0.007	0.004	0.01	0.013
39	5158236.921	3740835.138	-302267.447	-0.008	0.005	0.009	0.013
40	5158236.912	3740835.13	-302267.447	0.001	0.012	0.009	0.015
41	5158236.918	3740835.139	-302267.444	-0.005	0.003	0.006	0.008
42	5158236.92	3740835.143	-302267.451	-0.007	0	0.013	0.015
43	5158236.921	3740835.145	-302267.446	-0.008	-0.002	0.008	0.011
44	5158236.918	3740835.136	-302267.447	-0.005	0.007	0.008	0.012
45	5158236.918	3740835.136	-302267.446	-0.005	0.007	0.008	0.012
46	5158236.913	3740835.136	-302267.446	-0.001	0.006	0.007	0.01
47	5158236.916	3740835.136	-302267.447	-0.003	0.007	0.008	0.011
48	5158236.925	3740835.143	-302267.448	-0.012	0	0.009	0.015
49	5158236.924	3740835.143	-302267.445	-0.011	0	0.007	0.013
50	5158236.913	3740835.133	-302267.446	-0.001	0.009	0.007	0.012
51	5158236.915	3740835.135	-302267.443	-0.002	0.008	0.005	0.009
52	5158236.919	3740835.136	-302267.445	-0.006	0.006	0.006	0.011
53	5158236.919	3740835.135	-302267.443	-0.006	0.007	0.005	0.011
54	5158236.928	3740835.146	-302267.449	-0.016	-0.003	0.01	0.019
55	5158236.923	3740835.14	-302267.45	-0.011	0.003	0.011	0.016
56	5158236.919	3740835.138	-302267.448	-0.006	0.005	0.01	0.013
57	5158236.92	3740835.141	-302267.447	-0.008	0.002	0.009	0.012
58	5158236.926	3740835.143	-302267.447	-0.013	-0.001	0.009	0.016
59	5158236.916	3740835.135	-302267.446	-0.003	0.007	0.008	0.011
60	5158236.924	3740835.143	-302267.445	-0.011	-0.001	0.007	0.013
61	5158236.922	3740835.142	-302267.449	-0.009	0.001	0.011	0.014
62	5158236.922	3740835.14	-302267.445	-0.009	0.003	0.006	0.011
63	5158236.918	3740835.138	-302267.447	-0.005	0.004	0.009	0.011
64	5158236.926	3740835.145	-302267.448	-0.013	-0.003	0.01	0.017
65	5158236.921	3740835.139	-302267.447	-0.009	0.003	0.009	0.013
66	5158236.915	3740835.136	-302267.445	-0.003	0.007	0.006	0.01
67	5158236.92	3740835.139	-302267.448	-0.007	0.004	0.01	0.013
68	5158236.924	3740835.144	-302267.449	-0.011	-0.001	0.01	0.015
69	5158236.921	3740835.143	-302267.445	-0.008	0	0.007	0.011
70	5158236.91	3740835.129	-302267.445	0.003	0.013	0.007	0.015
71	5158236.918	3740835.137	-302267.446	-0.005	0.005	0.007	0.01
72	5158236.925	3740835.146	-302267.448	-0.012	-0.003	0.009	0.016
73	5158236.912	3740835.134	-302267.447	0.001	0.008	0.008	0.012
74	5158236.914	3740835.137	-302267.447	-0.001	0.006	0.009	0.01

75	5158236.922	3740835.14	-302267.445	-0.009	0.002	0.007	0.012
76	5158236.912	3740835.131	-302267.443	0.001	0.011	0.004	0.012
77	5158236.905	3740835.131	-302267.442	0.008	0.012	0.004	0.014
78	5158236.91	3740835.129	-302267.444	0.003	0.014	0.006	0.015
79	5158236.914	3740835.138	-302267.445	-0.001	0.005	0.007	0.009
80	5158236.918	3740835.136	-302267.444	-0.005	0.006	0.006	0.01
81	5158236.908	3740835.127	-302267.443	0.005	0.015	0.005	0.017
82	5158236.908	3740835.128	-302267.444	0.005	0.014	0.006	0.016
83	5158236.909	3740835.135	-302267.445	0.004	0.007	0.007	0.011
84	5158236.92	3740835.142	-302267.446	-0.007	0.001	0.008	0.011
85	5158236.913	3740835.137	-302267.447	0	0.006	0.009	0.01
86	5158236.919	3740835.142	-302267.442	-0.006	0.001	0.003	0.007
87	5158236.918	3740835.137	-302267.446	-0.005	0.005	0.008	0.011
88	5158236.921	3740835.139	-302267.445	-0.008	0.004	0.007	0.011
89	5158236.914	3740835.138	-302267.446	-0.001	0.004	0.008	0.009
90	5158236.917	3740835.136	-302267.441	-0.004	0.007	0.003	0.009
91	5158236.915	3740835.137	-302267.444	-0.002	0.005	0.006	0.008
92	5158236.91	3740835.137	-302267.442	0.003	0.006	0.004	0.008
93	5158236.919	3740835.14	-302267.444	-0.006	0.003	0.006	0.009
94	5158236.911	3740835.136	-302267.442	0.002	0.007	0.004	0.008
95	5158236.902	3740835.133	-302267.443	0.01	0.01	0.004	0.015
96	5158236.909	3740835.133	-302267.446	0.004	0.009	0.008	0.013
97	5158236.919	3740835.144	-302267.445	-0.006	-0.001	0.006	0.009
98	5158236.92	3740835.14	-302267.446	-0.007	0.002	0.007	0.01
99	5158236.907	3740835.129	-302267.441	0.006	0.014	0.003	0.015
100	5158236.91	3740835.132	-302267.439	0.003	0.01	0.001	0.011
101	5158236.913	3740835.136	-302267.445	-0.001	0.006	0.006	0.009
102	5158236.912	3740835.136	-302267.448	0.001	0.007	0.01	0.012
103	5158236.908	3740835.132	-302267.447	0.005	0.01	0.009	0.014
104	5158236.914	3740835.139	-302267.44	-0.001	0.003	0.002	0.004
105	5158236.907	3740835.134	-302267.442	0.005	0.008	0.004	0.011
106	5158236.92	3740835.138	-302267.444	-0.008	0.005	0.006	0.011
107	5158236.918	3740835.138	-302267.444	-0.005	0.004	0.006	0.009
108	5158236.919	3740835.145	-302267.444	-0.006	-0.003	0.005	0.008
109	5158236.917	3740835.143	-302267.442	-0.004	0	0.004	0.005
110	5158236.915	3740835.139	-302267.444	-0.002	0.004	0.006	0.007
111	5158236.91	3740835.136	-302267.443	0.002	0.006	0.004	0.008
112	5158236.905	3740835.136	-302267.443	0.008	0.007	0.005	0.011
113	5158236.91	3740835.134	-302267.442	0.002	0.009	0.004	0.01

114	5158236.91	3740835.134	-302267.439	0.002	0.008	0.001	0.009
115	5158236.91	3740835.131	-302267.441	0.003	0.011	0.003	0.012
116	5158236.912	3740835.135	-302267.442	0	0.007	0.004	0.008
117	5158236.91	3740835.131	-302267.44	0.003	0.011	0.002	0.012
118	5158236.912	3740835.132	-302267.44	0.001	0.01	0.002	0.011
119	5158236.9	3740835.125	-302267.441	0.013	0.017	0.003	0.021
120	5158236.908	3740835.127	-302267.442	0.004	0.015	0.004	0.016
121	5158236.907	3740835.13	-302267.441	0.005	0.013	0.003	0.014
122	5158236.914	3740835.136	-302267.44	-0.001	0.007	0.002	0.007
123	5158236.916	3740835.139	-302267.442	-0.003	0.004	0.004	0.006
124	5158236.915	3740835.138	-302267.44	-0.002	0.005	0.002	0.006
125	5158236.911	3740835.135	-302267.44	0.002	0.008	0.002	0.008
126	5158236.912	3740835.133	-302267.441	0.001	0.01	0.003	0.01
127	5158236.911	3740835.135	-302267.439	0.002	0.007	0.001	0.007
128	5158236.908	3740835.134	-302267.438	0.004	0.008	0	0.009
129	5158236.913	3740835.141	-302267.438	0	0.002	0	0.002
130	5158236.913	3740835.137	-302267.439	-0.001	0.005	0.001	0.005
131	5158236.909	3740835.137	-302267.441	0.003	0.006	0.003	0.007
132	5158236.913	3740835.138	-302267.439	0	0.005	0	0.005
133	5158236.91	3740835.135	-302267.44	0.003	0.007	0.001	0.008
134	5158236.914	3740835.137	-302267.437	-0.001	0.005	-0.001	0.006
135	5158236.919	3740835.138	-302267.439	-0.006	0.004	0.001	0.007
136	5158236.91	3740835.134	-302267.44	0.003	0.008	0.002	0.009
137	5158236.906	3740835.13	-302267.441	0.007	0.012	0.002	0.014
138	5158236.912	3740835.135	-302267.439	0.001	0.007	0	0.007
139	5158236.907	3740835.131	-302267.439	0.005	0.012	0	0.013
140	5158236.911	3740835.133	-302267.437	0.002	0.01	-0.001	0.01
141	5158236.915	3740835.138	-302267.438	-0.002	0.004	-0.001	0.005
142	5158236.909	3740835.134	-302267.437	0.004	0.009	-0.002	0.01
143	5158236.917	3740835.137	-302267.438	-0.004	0.006	0	0.007
144	5158236.911	3740835.131	-302267.438	0.002	0.011	-0.001	0.011
145	5158236.91	3740835.134	-302267.436	0.003	0.008	-0.002	0.009
146	5158236.91	3740835.136	-302267.438	0.003	0.006	0	0.007
147	5158236.917	3740835.139	-302267.437	-0.004	0.003	-0.001	0.006
148	5158236.918	3740835.139	-302267.44	-0.005	0.003	0.001	0.006
149	5158236.916	3740835.14	-302267.44	-0.003	0.002	0.002	0.005
150	5158236.91	3740835.137	-302267.439	0.003	0.006	0.001	0.006
151	5158236.912	3740835.142	-302267.438	0.001	0.001	0	0.001
152	5158236.913	3740835.135	-302267.438	0	0.007	-0.001	0.008

153	5158236.908	3740835.135	-302267.439	0.005	0.007	0	0.009
154	5158236.915	3740835.142	-302267.439	-0.002	0.001	0	0.003
155	5158236.912	3740835.137	-302267.44	0	0.005	0.002	0.005
156	5158236.911	3740835.139	-302267.437	0.002	0.004	-0.001	0.004
157	5158236.912	3740835.142	-302267.444	0	0.001	0.006	0.006
158	5158236.917	3740835.141	-302267.441	-0.004	0.001	0.002	0.005
159	5158236.913	3740835.138	-302267.442	0	0.005	0.004	0.006
160	5158236.914	3740835.141	-302267.441	-0.001	0.001	0.003	0.003
161	5158236.914	3740835.141	-302267.442	-0.001	0.002	0.004	0.004
162	5158236.912	3740835.138	-302267.442	0.001	0.004	0.003	0.005
163	5158236.911	3740835.14	-302267.442	0.002	0.002	0.004	0.005
164	5158236.917	3740835.14	-302267.441	-0.004	0.002	0.003	0.006
165	5158236.914	3740835.14	-302267.44	-0.001	0.003	0.002	0.003
166	5158236.91	3740835.14	-302267.441	0.003	0.003	0.003	0.005
167	5158236.914	3740835.14	-302267.44	-0.001	0.002	0.001	0.003
168	5158236.916	3740835.142	-302267.439	-0.003	0.001	0	0.003
169	5158236.905	3740835.135	-302267.438	0.007	0.008	0	0.011
170	5158236.91	3740835.138	-302267.441	0.003	0.004	0.002	0.006
171	5158236.909	3740835.137	-302267.438	0.003	0.005	-0.001	0.006
172	5158236.911	3740835.14	-302267.438	0.002	0.003	-0.001	0.003
173	5158236.912	3740835.138	-302267.435	0.001	0.004	-0.003	0.005
174	5158236.915	3740835.142	-302267.436	-0.002	0.001	-0.002	0.003
175	5158236.914	3740835.141	-302267.439	-0.001	0.002	0.001	0.003
176	5158236.906	3740835.135	-302267.437	0.006	0.008	-0.002	0.01
177	5158236.904	3740835.134	-302267.436	0.009	0.009	-0.002	0.012
178	5158236.901	3740835.134	-302267.438	0.012	0.008	-0.001	0.014
179	5158236.908	3740835.14	-302267.436	0.004	0.002	-0.002	0.005
180	5158236.906	3740835.136	-302267.437	0.007	0.007	-0.001	0.01