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ACCURACY ASSESEMENT OF PRIDE PPP-AR AGAINST TBC AND GAMIT/GLOBK GNSS DATA PROCESSING SOFTWARE

EMMANUEL ANNA S

BSc Geomatics

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ACCURACY ASSESMENT OF PRIDE PPP-AR AGAINST TBC AND GAMIT/GLOBK GNSS DATA PROCESSING

EMMANUAEL ANNA S

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

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The undersigned certify that, they have proof read and here by recommend for acceptance by the Ardhi University a dissertation entitled **"ACCURACY ASSESSMENT OF PRIDE PPP-AR AGAINST TBC AND GAMIT/GLOBK GNSS DATA PROCESSING SOFTWARE.",** in fulfillment of the requirements for the Award of Bachelor of Science (B.Sc.) in Geomatics of the Ardhi University.

....	....
Dr. Elifuraha Saria	Ms. Valerie Ayubu
(Main Supervisor)	(Second Supervisor)
Date………………	Date………………….

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EMMANUEL ANNA S

(candidate)

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Date ………………………

DEDICATION

I dedicated this dissertation to my lovely father and mother Mr. Samwel Emmanuel and Ms.Paulina Samwel, all my brothers Frank, Joel and Emmanuel for their endless prayers for my successful end , I recognize and appreciate their contribution which help me in one way or another to the way of success in my study.

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ABSTRACT

The precise point positioning method has become more popular post processing method due to powerful online data processing services, such as the Canadian Spatial Reference System- PPP (CSRS-PPP).Recently has been advancement in technology that made a lot of precise point position processing software to be discovered which may have comparable capabilities with relative software. In 2019 Pride PPP-AR was introduced with an ambiguity resolution feature for the global positioning system. Ambiguity resolution is the technology that helps to speed up convergence time and increase positioning accuracy for precise point positioning. Pride PPP-AR integrates the advantages of GNSS Standard Point Position and GNSS relative positioning and overcomes their disadvantage to some extent. In this study the performance of Pride PPP-AR was comparatively assessed in terms of static positioning. Data for 24 hours in the year of 2021 and 2022 and data for 37 days in the year of 2022 from the permanent volcanic monitoring network (TZVOLCANO) in Tanzania were processed. This study processed the data using PRIDE PPP-AR, TBC and GAMIT/GLOBK as the base software which give true positions. The results after processing were Geocentric Coordinates System (X.Y,Z). The results were analyzed in terms of position accuracy and difference in coordinates. From the analysis AR features greatly improve the accuracy of precise point positioning method compare to previous year. According to the analysis Pride PPP-AR can be used as alternative method for relative method. For Pride PPP-AR to be used in high precision like geodetic surveys , Further investigation covering longer timespan e.g., one year or more is recommended to assess the software accuracy.

ACRONYMS AND ABBREVIATIONS

GAMIT	GPS Analysis at Massachusetts Institute of Technology
GNSS	Global Navigation Satellite System
RTKLIB	Real Time Kinematic Library
TBC	Trimble Business Centre
TGO	Trimble Geomatics Office
AUSPOS	AUSLIG Online GPS Processing Service
GPS	Global Positioning System
IGS	International GNSS Services
BDS	BeiDou Navigation Satellite System
CORS	Continuous Operating Reference Stations
RINEX	Receiver Independent Exchange Format
3D	Three Dimension
CSRS	Canadian Spatial Reference System

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CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Geodetic positioning is the accurate determination of coordinates or position of points on the earth's surface with respect to the reference system. Geodetic positioning involves both space and terrestrial positioning techniques. There are three techniques for terrestrial geodetic positioning (Triangulation, Trilateration and Traversing). Triangulation is the method that determines the position of a point by measuring the angle of a series of joined or overlapping triangles. It differs from plane surveys that are concerned with surveys of small areas while local gravity is not taken into consideration. Trilateration is another technique in which only distances are measured, and each side is measured repeatedly to ensure that precision and accuracy are attained. The angles are computed through distances so the geodetic positions are obtained as in triangulation. Traversing is the process which involves the determination of position from bearing and distances. Horizontal angles between inter-stations are measured from which bearings are derived to compute the station position.

Satellite positioning, especially Global Navigation Satellite System (GNSS) is the modern space technology which has profoundly influenced the profession of surveying as well as a plethora of modern society's economic, scientific and social activities. It is a geodetic method that precisely determines the position of a point in 3-dimensional space. GNSS consists of different satellite systems such as GPS (US), GALILEO (Europe Union) , GLONASS (Russia) and BeiDou (China) each with its own satellite constellations arranged in orbits to provide the desired coverage. GNSS uses pseudo range data and carrier phase as observables to position a point. Static positioning is used for high precision surveying applications associated with control establishments, crustal deformation studies (Larson and Agnew,1991, Nocquet *et al*., 2006; Calais *et al.,* 2006; Stamps *et al.*, 2008; Saria *et al*., 2013; 2014) and volcanic monitoring (Dzurisin, 2006, Segall, 2013, Daud *et al.,* 2023).

There are two main processing approaches when GNSS data is measured in static mode. Relative technique determines unknown position with respect to a reference station with known position. Error budgets in this technique are minimized, applying corrections and has shown to offer precise and accurate position results in mm level (Williams *et al.,* 2004; Bos *et al.,* 2008).

Relative method computes the position of points by applying single differencing phase or code measurement, double differencing model and triple differencing model. Single differencing model involves single receiver observing two satellites and receivers observing single satellite in which satellite and clock errors cancel out. Double differencing model involves the combination of two types of single differencing enabling to eliminate receiver clock errors and satellite clock errors. Triple differencing model combines two double differences. The Triple difference is the two double differences of two different epochs. In this model, the ambiguity parameter is eliminated. The code and phase measurements are required to be processed so as to determine position of a point (Wells *et al.*, 1987).

Another method for GNSS processing is known as Precise Point Positioning (PPP) that directly determines the position of a point in relation to the satellites. The positioning uncertainty in PPP can be relatively large, as it normally does not include any differencing with reference stations . In order to reduce the effect of sources of errors in positioning external information such as satellite products (ultra rapid, the rapid and final products) are added during processing. PPP has many advantages over relative, only one receiver configuration as well as its flexible operation and wide-area application. Efforts to improve PPP positioning accuracy have been increasing, thanks to its powerful and cost-effective technique (Li *et al.*, 2015; Labib *et al.*, 2019; Geng *et al*., 2019; 2022). To achieve centimeter-level positioning, PPP requires a convergence time of around 30 min, which makes it challenging to meet user demands in real time and severely restricts the marketing of PPP technology applications. Therefore, PPP ambiguity resolution (AR) technology has been advocated as a solution to the PPP convergence problem (Geng *et al*., 2019; 2022). Ambiguity resolution (AR) is a core technology that helps to accomplish the convergence criteria (10min) and the performance of PPP AR is based on the quality of ambiguity resolution products (Geng *et al*., 2022).

R elative and PPP processing strategies requires a processing software capable of producing the desired position based on the clients' applications. Many of the available software are commercial with limited licenses. For example, Bernese, Trimble Business Centre (TBC), Trimble Geo Office (TGO) are relatively commercially limited with authorizations. GAMIT-GLOBK (Herring *et al*., 2010) is a double differencing research software with free access not suited for surveys with short observations time of less than 8 hours. Many of the relative software provide capability for the user to design and set up the experiment. For PPP software, many of them are online services requiring the user to upload the observational files. The use of any software in various applications requires knowing its accuracy performance. Numerous studies have been conducted to assess the performance of different GNSS data processing software before use. For example, Muki (2017) assessed the applications of an open source RTKLIB software package in comparison with GAMIT-GLOBK. The analysis of statistical data suggested that RTKLIB is capable of producing position at centimeter level of precision. Mabhuye and Mbilinyi. (2018) assessed free against commercial GNSS data processing software on 3D position. The results indicated that TBC had a good comparable accuracy with respect to GAMIT-GLOBK. A 3D positional assessment of GNSS software TBC and Leica geo-office against GAMIT-GLOBK suggested that the two software (TBC and Leica geo-office) provide the same level of accuracy but not suitable for surveys requiring mm level of precision (Kihinga , 2017).

Recently, Atiz and Kalayci. (2021) assessed the performance of Pride PPP-AR positioning and zenith total delay estimation with modernized CSRS-PPP. The results suggested that Pride PPP-AR improves the positioning accuracy level to at least by about 10% and the performance of tropospheric and the modernized CSRS solution is less than 6 mm .An investigation of IGS GPS/Galileo/BDS-3 phase bias products with PridePPP-AR show that all GPS/Galileo phase biases from WUM, COM, GRG and SGG can enable static and kinematic PPP-AR in an efficient manner (Geng *et al*., 2021). Glaner *et al*. (2020) reported a big difference when evaluating Pride zPPP-AR using different satellite products to reduce convergence time between them. This study assesses the performance of Pride PPP-AR software as PPP technique proposed to improve the positional accuracy and can be used as an alternative for relative methods.

1.2 Problem Statement

For many decades, PPP technique has suffered from challenges in having an efficient processing software capable of producing comparable results with relative methods. It has seldom been used in surveying practices (control establishment, plate motions) and just relies only on an online service such as the Canadian Spatial Reference System-PPP (CSRS-PPP), Automatic Precise Positioning Service (APPS) by Jet Propulsion Laboratory (JPL), GPS

Analysis and Positioning Software (GAPS) by University of New Brunswick (UNB) to process GNSS data for less accuracy surveying applications. Recently, a new PPP software called PRIDE PPP-AR that applies ambiguity resolution (AR) technology to improve the position accuracy has been released for the public use. The software is an open source providing both graphical user interface and command line. Ambiguity resolution (AR) technique helps to speed up convergence time that is proposed to increase positioning accuracy and has been suggested as a solution to the PPP convergence problem However, the performance of PRIDE PPP-AR software in producing positions comparable with double differencing software is less known. The use of this software in various surveying applications requires knowledge of its accuracy and performance. This research assesses the PRIDE PPP-AR performance in comparison with relative methods. For this purpose, the static observations of GNSS from the volcano monitoring network (TZVOLCANO Network) in Tanzania at different timespan are processed by Pride PPP-AR and double difference relative solutions using GAMIT-GLOBK and Trimble Business Centre (TBC) software.

1.3 Research hypothesis

This study hypothesizes that the use of PPP-AR model in GNSS data processing offers an opportunity to investigate the improvement of position accuracy in surveying industries. The study uses Pride PPP-AR software to address the hypothesis by evaluating the GNSS position differences and accuracy of the TZVOLCANO Network processed by double differencing GAMIT-GLOBK and TBC software.

1.4 Objectives of the research

1.4.1 Main Objective

The main focus of this work is to assess the accuracy performance of Pride PPP-AR against other GNSS relative processing software. The investigation aims to understand the level of position improvement through PPP-AR techniques as an alternative for relative methods.

1.4.2 Specific Objectives

i) To evaluate the positional differences of GNSS data processing software (GAMIT-GLOBK, TBC and Pride PPP-AR) at different observation timespan (e.g., 1 hour, 2 hours, 3 hours, 6 hours 12 hours and 24 hours) based on normal surveying applications.

ii) To assess the time series of the positional differences

iii) To assess positional accuracy obtained from GAMIT-GLOBK, TBC and Pride PPP-AR at various data time lengths.

1.5 Significance of the research

This study provides an understanding of PPP-AR performance as an alternative to relative techniques. The geosciences community gets a wide option of selecting GNSS data processing software depending on their need and intended surveying applications, accuracy with cost effectiveness.

1.6 Study Area

This work uses the Continuous volcano monitoring network (Figure 1.1 ,TZVOLCANO Network) the active volcano Ol Doinyo Lengai, northern part of Tanzania in the magma-rich, Eastern Branch of the East African Rift System. Ol Doinyo Lengai is located some 240 kilometers to the northwest of Arusha region, along the western escarpment of the Great Rift Valley, overlooking Lake Natron on the border with Kenya. The network operates with six stations OLO1, OLO5, OLO6, OLO7, OLO8 and OLO9 installed on the flanks of the volcano Ol Doinyo Lengai while OLE3 is an episodic site (Daud *et al*., 2023). It observes and transmits low latency and near real-time data to the UNAVCO archive with open access. All other data were downloaded from the EarthScope Consortium, Inc.

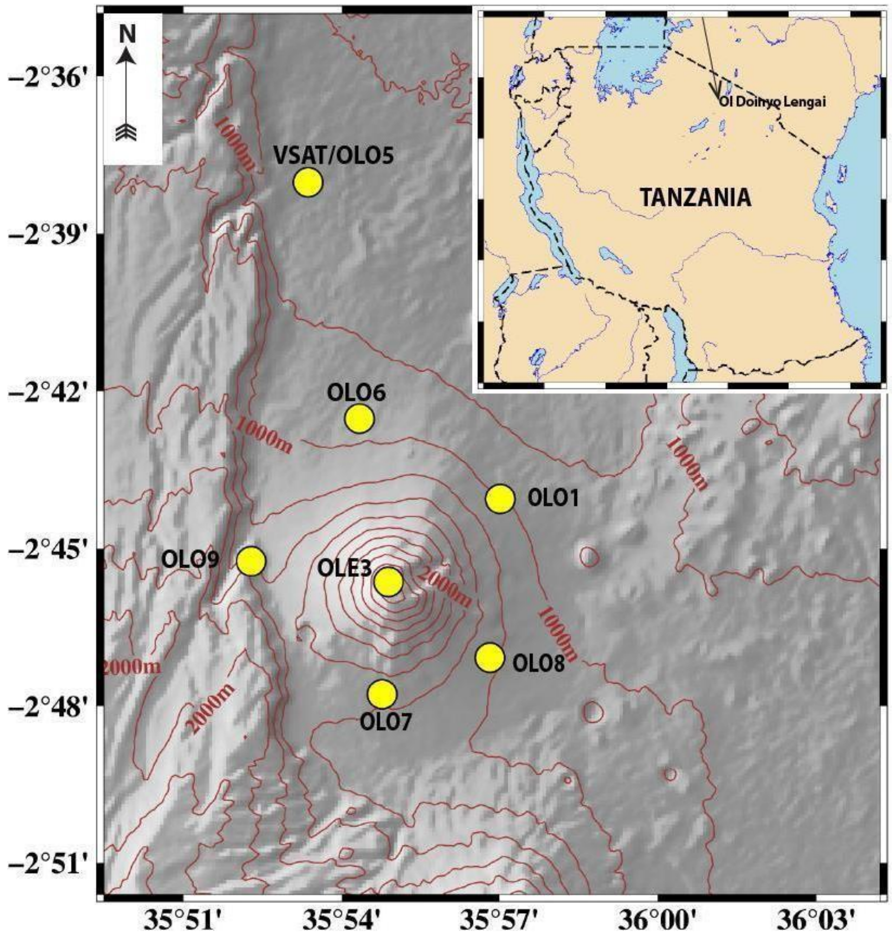

Figure 1. 1 Tanzania Volcano Monitoring Network (TZVOLCANO)

1.7 Organization of the Research

This study contains the following chapter; Chapter one contains introduction of the research. This chapter briefly describes the research by giving background information related to this research, statement of the problem, objectives of the research, significance of the research and study area of the research. Chapter two contains literature review; This chapter provides an overview of space positioning techniques mainly GNSS positioning technique and explains the GNSS satellites system such as GPS, GLONASS, Galileo, and BeiDou. It also explains the GNSS positioning techniques such as Precise point positioning and Relative positioning and all sources of error in GNSS position and how they are mitigated to obtain accurate position. Finally it explains the overview of GNSS Data processing software such as GAMIT/GLOBK, TBC and PRIDE PPP-AR ,and also explains the previous GNSS related research of GNSS data processing software. Chapter three explains about methods and procedures which were used to achieve the research objectives. It also includes data sources and acquisitions, preparation and processing to the final output. Chapter four; This represents the output/result obtained after processing the data from GAMIT-GLOBK, TBC and Pride PPP-AR software . It also shows the assessment by statistical analysis. Chapter five contains the conclusion and recommendation of the research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter provides an overview of space positioning techniques mainly GNSS positioning techniques and explains the GNSS satellites systems such as GPS, GLONASS, Galileo, and BeiDou. It also explains the GNSS positioning techniques such as Precise point positioning and Relative positioning and all sources of error in GNSS position and how they are mitigated to obtain accurate position. Finally it explains the overview of GNSS Data processing software such as GAMIT-GLOBK , TBC and Pride PPP-AR ,and also explains the previous GNSS related research of GNSS data processing software.

2.2 Space Geodesy

Is a field of study that uses techniques from astronomy, geophysics, and engineering to precisely measure the shape, orientation, and motion of the Earth, as well as its gravitational field and its interaction with other celestial bodies. Space geodesy involves the use of satellite-based instruments and ground-based observatories to measure various parameters related to the Earth's position and movement. Some of the key techniques used in space geodesy include; Global Navigation Satellite Systems (GNSS); These systems use satellite signals to precisely measure the position and velocity of object the Earth's surface. Very Long Baseline Interferometry (VLBI) a technique involves combining data from multiple radio telescopes to measure the precise position and motion of objects in space. Satellite Laser Ranging (SLR): This technique involves measuring the time it takes for a laser beam to bounce off a satellite and return to Earth, allowing researchers to precisely measure the satellite's distance from the Earth's surfaces. Gravity Recovery and Climate Experiment (GRACE): This mission uses twin satellites to precisely measure variations in the Earth's gravity field, which can be used to study changes in the planet's water resources and climate. GNSS is a geodetic method that uses satellites to determine precisely the position of a point in 3-dimensional space. GNSS consists of different satellite systems such as GPS (US), GALILEO (Europe Union), GLONASS (Russia) and BeiDou (China) (Hofmann-Wellenhof *et al.*, 2001.

2.2.1 GPS

Global Positioning System (United States) is operated by the U.S Space force. GPS was launched in the late 1970s by the United States Department of Defense. It uses the constellation of 27 satellites and global coverage. GPS has made a considerable impact on almost all positioning, navigation, timing and monitoring applications. It provides particularly coded satellite signals that can be processed in a GPS receiver, allowing the receiver to estimate position, velocity and time (Hofmann-Wellenhof *et al*., 2001). GPS comprises three main components; The Space segment: The space segment consists of 24 satellites circling the earth at 12,000 miles in altitude. This height of 2256 altitude allows the signals to cover a greater area. The Control segment: The control segment tracks the satellites and then provides them with corrected orbital and time information. The control segment consists of four unmanned control stations and one master control station. The four unmanned stations receive data from the satellites and then send that information to the master control station where it is corrected and sent back to the GPS satellites. The User segment: The user segment consists of the users and their GPS receivers. The number of simultaneous users is limitless.

2.2.2 GLONASS

The GLONASS (GLObal NAvigation Satellite System or "GLObalnaya NAvigatsionnaya Sputnikovaya Sistema") is nearly identical to GPS. Glonass satellite-based radio-navigation 9 system provides the positioning and timing information to users. It is operated by the Ministry of Defense of the Russian Federation (GLONASS-ICD, 2002). Glonass space segment consists of 24 satellites, equally distributed in 3 orbit separated by o 120 in the equatorial plane. The main difference between GPS and GLONASS is that GLONASS uses Frequency Division Multiple Access (FDMA) technology to discriminate the signals of different satellites, but GPS and Galileo use (Code Division Multiple Access, CDMA) to distinguish between the satellites (Hofmann-Wellenhof *et al*., 2001).

2.2.3 GALILEO

GALILEO is Europe's initiative for a state-of-the-art global navigation satellite system, providing a highly accurate, guaranteed global positioning service under civilian control. Galileo will be not too different from the other GNSS parts (modernized GPs and (Hofmann-Wellenhof *et al*., 2001. It will provide autonomous navigation and positioning services, but at the same time will be interoperable with the two other global satellite navigation systems; the GPS and GLONASSGalileo segments Galileo segments are almost similar to GPS, but with some modification. The Galileo ground segment is responsible for managing the constellation of navigation satellites, controlling core functions of the navigation mission such as orbit determination of satellites, and clock synchronization, and determining and disseminating (via the MEO satellites) the integrity information, such as the warning alerts within time-to-alarm requirements, at global level.. User Segment;The user segment consists of different types of user receivers, with different capabilities related to the different GALILEO signals in order to fulfill the various GALILEO services

2.2.4 BeiDou

BeiDou (China) first launched in 2000, BeiDou operates out of China by the China National Space Administration. In the 20 years since, BeiDou has had 48 satellites in orbit. Beidou consist of three system components; BDS-3 space segment consist of 3 GEO satellites, 3 IGSO satellites AND 24 MEO satellites, Ground segment consist of various ground stations, including master control stations, time synchronization/uplink stations, monitoring stations as wells as operation and management facilities of inter-satellite link, User segment consist of various kinds of BDS products, systems and services as well as those compatible with other navigation systems including basic products such as chips, modules and antennae, terminals, application system and applications(Hofmann-Wellenhof *et al.*, 2001).

2.3 GNSS positioning techniques

The positions can be determined; With respect to a well coordinate system usually three coordinate values and With respect to another point, taking one point as the origin of a local coordinate system. There are two modes of positioning techniques in GNSS measurements; single point positioning (precise point positioning) and Relative positioning (Differential positioning).If the object to be positioned is stationary, we speak of static positioning and if the object is moving we speak of kinematic positioning. Both positioning techniques can be either static or kinematic positioning.

2.3.1 Precise Point Positioning (PPP)

This is a modeling and processing method with which one can compute positions with high accuracy anywhere on the globe using a single GNSS receiver . It is a logical extension of GNSS pseudorange navigation, whereby the broadcast satellite orbits and clocks are replaced with precise estimates, and the pseudorange data is complemented with the very precise carrier-phase observations, usually on two or more frequencies so as to be able to either eliminate or estimate the ionospheric delays. The precise orbits and clocks are downloaded or obtained in real time from a number of service providers, using either the Internet or satellite links. PPP provides in addition to accurate positioning solutions, tropospheric and ionospheric delays, as well as accurate receiver clocks. To facilitate the high PPP accuracy, careful modeling of local stations and environmental effects is required. As PPP does not rely, as with relative baseline positioning, on combining observations with simultaneous measurements from reference stations, it offers greater operational flexibility and is suited for areas that lack dense GNSS network infrastructures. Although PPP was originally developed as a dual-frequency technique, it can also be used with multiple frequencies or even with only a single frequency. There are different single-frequency (SF-) PPP formulations possible; ionosphere-corrected SF-PPP and ionosphere-free SF-PPP. Both make use of externally provided precise orbit and clock information, but in the case of ionosphere-corrected SF-PPP, the single-frequency data are corrected for the frequency dependent clock and the ionospheric delay. PPP has many advantages over relative, only one receiver configuration as well as its flexible operation and wide-area application. Efforts to improve PPP positioning accuracy have been increasing, thanks to its powerful and cost-effective technique (Li *et al*., 2015; Labib *et al*., 2019; Geng *et al*., 2019; 2022).

2.3.2 Relative positioning

Is the technique that determines unknown position with respect to a reference station with known position. Error budgets in this technique are minimized, applying corrections and has shown to offer precise and accurate position results in mm level (Williams *et al*., 2004; Bos *et al*., 2008). Relative method computes the position of points by applying single differencing phase or code 2 measurement, double differencing model and triple differencing model. Single differencing model involves single receiver observing two satellites and receivers observing single satellite in which satellite and clock errors cancel out. Double differencing model involves the combination of two types of single differencing enabling to eliminate receiver clock errors and satellite clock errors. Triple differencing model combines two double differences. The Triple difference is the two double differences of two different epochs. In this model, the ambiguity parameter is eliminated.

2.4 General overview of GNSS software

In this study, three GNSS processing software are investigated which include GAMIT-GLOBK, Pride PPP-AR and TBC.

2.4.1 GAMIT /GLOBK software

GAMIT (GNSS at MIT) developed at Massachusetts Institute of Technology(Herring *et al*., 2010) . is a collection of programs used for the analysis of GNSS data. It uses the GNSS broadcast carrier phase and pseudorange observables to estimate three-dimensional relative positions of ground stations and satellite orbits, atmospheric zenith delays, and earth orientation parameters. GAMIT is the double differencing technique. The software is designed to run under any UNIX operating system supporting X Windows; we have implemented thus far versions for Sun (OS/4 and Solaris 2), HP, IBM/RISC, DEC and LINUX on Intel-based workstations. GAMIT is composed of distinct programs which perform the functions of preparing the data for processing (*makexp and makex*), generating reference orbit and rotation values for the satellites (arc, yawtab), interpolating time- and location-specific values of atmospheric and loading models *(grdtab*), 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 by a driver module (*fixdrv*) for modeling, editing, and estimation. Though the data editing is almost always performed automatically, the solution residuals can be displayed or plotted so that problematic data can be identified *(cview).* GAMIT is the double differencing technique which produces quasi observation which is not tied with reference frames.

GLOBK is a Kalman filter whose primary purpose is to combine various geodetic solutions such as GPS, VLBI, and SLR experiments. It accepts as data, or "quasi-observations' ' the estimates and covariance matrices for station coordinates, earth-orientation parameters, orbital parameters, and source positions generated from the analysis of the primary observations. The input solutions are generally performed with loose a priori uncertainties assigned to all global parameters, so that constraints can be uniformly applied in the combined solution). 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.

2.4.2 Overview of TBC software

TBC (Trimble Business Centre has replaced Trimble Geomatics Office (TGO) as Trimble’s GNSS data processing softaware. TBC is the commercial software applied for processing and managing optical, GNSS and imaging survey data, for post processing of static or kinematic survey requires a licence to enable full functionality including GPS baseline processing. A license is not needed to view and export processed results from RTK surveys.

Features of TBC:

- d-on modules (Photogrammetry).

TBC has the following procedure during processing of GNSS data, Importing of GNSS data into your project, Before processing baseline , ensure your project is configured correctly in the Baseline section of the Project Setting dialog. Use the Time-Based View to review how occupations and sessions relate to each other and disable any baselines that should not be processed. Use the Plan View to select the baselines you want to process If you do not select any baselines. Use Process Baselines dialog to process the baselines, To see more information about any specific processed baseline, select it in the Process Baselines and click Report button. To see the resultant coordinates for any point after saving the processed baselines, select the point in Project Explorer or one of the graphic or spreadsheet views. If you need to edit a session associated with a processed baselines, select the baseline in the Plan View. To view additional baseline processing information select Point Derivation Report and Vector List Report in the Report menu. After all this network adjustment follows, Before performing a network adjustment ensure your project is configured correctly . Display the Adjust Network pane to begin the network adjustment process. On the Fixed Coordinates tab , select the minimum number of constraints required then adjust he network. In the Adjust Network pane click the Report icon to view the Network Adjustment Report. If the Chi Square test fails use Weighting tab to apply a weighting strategy to the processed vectors to improve the initial a prior error estimates for the observation, repeat the procedure until the test passes.

2.4.3 Overview of PRIDE PPP-AR software

Pride PPP –AR is an open source developed by Wuhan University, China (2019). It uses pseudorange data and precise satellite products to compute position. It is a research software but does not require longer observation time to compute position compare to other research software. PPP ambiguity resolution (AR) technology has been advocated as a solution to the PPP convergence problem (Geng *et al.*, 2019; 2022). Ambiguity resolution (AR) is a core technology that helps to accomplish the convergence criteria and the performance of PPP-AR is based on the quality of ambiguity resolution products.

Pride PPP-AR has the following features:

- High rate GNSS data processing of ip to 50Hz
- Second order uonispheric correction
- Receiver clock jump mitigation
- Multiday processing
- Adopt both rapid products and real time products for more timeliness etc.
- Satellite attitude quaternions
- It uses only single receiver

Pride PPP-AR has three modules for processing. The first part, data preparation and pre-processing, prepare table file and precise products for the following process .The *ssp* (standard point positioning) module will be used to calculate the prior positions of station. The function of *sp3orb* (SP3 orbit) is to transform SP3 orbit into a self-defined binary format, then the software can efficiently access the precise orbit products. In least square estimator module , *tedit*(turboedit) is used to make data tentative pre –processing and generate the log-file to record the RINEX health diagnosis information. Once got the log-file *lsq* (least square adjustment) module can realize the parameter estimation and outputs results. The third module *redig(a* posterior residual diagnosis) , the residuals can be processed and new log-file can be generated .If the data is not fixed the ambiguity-float solution can be obtained otherwise the module named *arsig* (ambiguity resolution at a single receiver).

2.5 Previous related research of GNSS processing software

i. (Kihinga,2017) conducted the research on 3D- positional assessment of GNSS software TBC and Leica geo-office against GAMIT/GLOBK software using differential method by post processing GPS survey data of the same study area. Data from two networks were used during this study. According to the results obtained, the commercial software both can be used in processing GNSS data for surveying for accuracy in mm and cm level but not for survey which needs accurate system (X,Y,Z) shown by each software when compared to the results of GAMIT/GLOBK.

ii. (Muki, 2017) conducted research 0n application of an open source GNSS processing software package RTKLIB and its comparison to GAMIT software . The research was based on introducing post processing software RTKLIB and it possibility to use in precise positioning in comparison to GAMIT. S RTKLIB is free open source open software package containing applications designed for real time navigation and post processing. The evaluation of data based on statistical analysis of the discrepancies between the two software packages for the output results in ECEF coordinate system (WGS84). The analysis of these statistical data showed that RTKLIB is capable of centimeter level of precision, this make it to be applicable in surveying work which does nor require high accuracy like cadastral and detail survey.

iii. (Mabhuye and Mbilinyi,2018) assessed free against commercial GNSS data processing software on 3D position. This aim to assess the results in 3D positional coordinate obtained from TBC, RTKLIB and Track from GAMIT/GLOBK coordinates as the base in order to determine which of these packages can process GPS data depending on availability of time, environment, cost and accuracy required. The results indicated that TBC had a good comparable accuracy with respect to GAMIT-GLOBK. A 3D positional assessment of GNSS software TBC and Leica geo-office against GAMIT-GLOBK suggested that the two software (TBC and Leica geo-office) provide the same level of accuracy but not suitable for surveys requiring mm level of precision.

iv. (Atiz and Kalayci2021) assessed the performance of Pride PPP-AR positioning and zenith total delay estimation with modernized CSRS-PPP. In these study the performance of mordenized CSRS-PPP with AR was investigated from different aspect. In this study, the performance of modernized CSRS-PPP with AR was investigated from different aspects. The data of geographically distributed 47 IGS stations were processed before and after the software transition to PPP-AR. The new software provided an accuracy level of 1.7 mm, 1.4 mm, and 4.6 mm for the north, east, and up components only using GPS satellites. The results of this study showed that the AR feature improves the positioning accuracy at least by about 10%. For the east component, the improvement on using AR is >45% in both GPS-only and GPS–GLO cases. In addition to accuracy analysis, the static PPP convergence times were evaluated. Accordingly, while the GPS + GLO combination has an undeniable contribution over GPS-only PPP, AR does not improve the convergence time. Moreover, the performance of tropospheric delay estimation was analyzed by comparing CSRS-PPP ZTD solutions with IGS final ZTDs. The results indicate that the difference between the IGS final product and the modernized CSRS-PPP solution is <6mm. It can be concluded that the new CSRS-PPP software can successfully be used for troposphere estimation. In conclusion, it is stated that the modernized CSRS-PPP service is a beneficial tool to achieve PPP-AR positioning and troposphere estimation.

v. (Geng, Yang and Guo,2021) assess IGS GPS/Galileo/BDS-3 phase bias products with Pride PPP-AR .This aim at making a detailed assessment on their quality and analyzing the PPP-AR performance. In this study, we carry out PPP-AR at 300 globally-distributed stations using seven sorts of phase bias products. Generally, all GPS/Galileo phase biases from WUM, COM, GRG and SGG can enable static and kinematic PPP-AR in an efficient manner. For the GPS/Galileo daily solutions, all phase bias products are able to improve the positioning precision for the east component by more than 30% after ambiguity fixing. In particular, the phase bias products based on GBM satellite orbits and clocks (i.e., GRG-gbm and SGG-gbm) deliver the lowest improvement rates after PPP-AR. In the case of hourly static GPS/Galileo solutions, both east and north components can have more than 30% improvement in terms of positioning precisions, while again the GRG-gbm and SGG-gbm products show inferior performance compared to others. In the case of BDS-2 or BDS-3 only daily solutions, insufficient satellite number (5 for BDS-2 and 3 for BDS-3 on average observed by an Asia-Oceania station) limits the performance of PPP-AR using the BDS-2/ BDS-3 phase bias products from WUM, GRG-gbm and SGG-gbm in the year of 2019. We argue that BDS-2/ BDS-3 PPP-AR was unreliable even though a decent fixing rate might be achieved over the year of 2019. Fortunately, the BDS-3 constellation has been fully operational since July 31, 2020, and BDS-2/BDS-3 phase biases are more reliable and precise to enable PPP-AR where the horizontal coordinate components can achieve about 5 mm precision.

vi. (Glaner and Weber, 2021) evaluate PPP with integer ambiguity resolution for GPS and Galileo using satellite products from different analysis centers. In this study the different modern satellite products were tested in a combined GPS and Galileo PPP-AR solution. The result have shown that the convergence behavior varies significantly between stations. Besides multipath and other potential error sources, Galileo observation type and the receiver type influence the convergence performance.

This study aim to assess the precise point positioning software PRIDE PPP-AR using GAMIT and TBC so as it can be used as alternative technique for relative positioning.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter explains methods and procedures which were used to achieve the research objectives. It includes data sources and acquisitions, preparation and processing to the final output.

3.2. Baseline Design

Trimble Business Center (TBC) is a short line processing software. Therefore, it is recommended to consider the baseline configuration when processing using TBC. GAMIT-GLOBK and Pride PPP-AR, baseline configuration is not necessary. For that case OLE3 and OLO6 are selected as reference stations where other stations (OLO1, OLO7, OLO8 and OLO9) will refer. This requires that the triangles formed are strong.

3.3 Data Source

The GNSS data used for this study were obtained from the permanent volcanic monitoring network (Figure 1.1, TZVOLCANO) in Tanzania. The TZVOLCANO GNSS sites observe low latency data at 15 seconds and high-rate data at 1Hz and 5Hz (Daud *et al*., 2023). This study uses low latency data with a sampling rate of 15 seconds. The research include incorporated some more data obtained freely from the EarthScope Consortium, Inc and the Crustal Dynamics Data Information System (CDDIS) archives to constrain and enable the solution to be tied to global reference frame and make the final solution consistent with the International Terrestrial Reference Frame of 2014.

3.4 Data Format

Usually data from GNSS or GPS receiver can be of two formats, Receiver dependent format or Receiver independent exchange format. The receiver dependent format, is the format that all observables, navigational messages as well as additional stored in the receivers after observation and they can only be processed using the software of the same manufacturer of the receiver (Bernhard Hofmann-Wellenhof *et al*., 2007). This was a limiting factor mainly in the geodesy community since sometimes the software from the same manufacturer can be very expensive and in the other case it may not have high-end processing capability. In addition, most high end processing software examples (GAMIT-GLOBK, GIPSY-OASIS and BERNESE) do not have their respective receivers, which could have made them useless in the geodesy community. With that respect the receiver dependent format is not much used due to its limitation on data sharing and processing.

The Receiver Independent Exchange Format (RINEX) is the widely used format which allows exchange of raw observation and navigation data to be processed by any type of software (Gurtner and Estey 2009). The proposal for development of RINEX format was introduced by the Astronomical Institute of the University of Berne during the European Reference Frame (EUREF) campaign in 1989. The reason for its introduction was to solve a problem aroused in this campaign, which used 60 GNSS receivers from four different manufacturers, and it was hard to combine the data (Gurtner and Mader 1990; Gurtner and Estey 2009). Since its introduction it has been published in successive versions which has some improvement from older versions (Gurtner and Mader 1990; Gurtner and Estey 2009). In any raw observation, three observation files can be retrieved which are Observational file data, Navigational file data and Meteorological data file. Each observation file must have a header section which contains metadata information and a data section which contains blocks of observations. format for observation file has been explained in many literatures (Gurtner and Estey 2009; Bernhard Hofmann-Wellenhof *et al*., 2007), which is also documented on IGS site standards. RINEX observation files containing information such as L1 and L2 for carrier phases and pseudo-ranges, signal amplitudes, initial station coordinates, antenna offsets, time at starting and stopping observation, and the identification of the satellites tracked in each receiver channel. Some instrument manufacturers have developed software embedded in the receiver which can convert data directly as they are downloaded.

Due to increased understanding with the geodesy community, there has been increased GNSS installation and therefore lots of data is archived on remote servers worldwide. To save space on data archives the RINEX data is usually compressed. Although there are many other standards for compression a file, there is a special or specific file compression mainly for RINEX data called hatanaka compression. These compressions use the specific features of the stored data inside the file to compress, which follows the sequence principle inside the file. This is the example on the compressed RINEX file sometimes called CRINEX file format, which is made by an effective and powerful algorithm for compressing observation data (Hatanaka, 1996). This compression format was developed in 1996 and a further version in 2008 (Hatanaka

2008). The hatanaka compression is capable of compressing an observation file to approximately one third of its original size.

In this study the GNSS data were translated to RINEX format using an open source software called Translating, Editing and Quality Check (TEQC). This tool is capable of performing different GNSS data exchange however the main capability is related to translating the data (from receiver dependent to receiver independent format), editing and quality check hence the name TEQC. TEQC is an open source software freely downloaded from UNAVCO website (Estey L. H & C. M. Meertens, 1999). The quality of all GNSS data in this study were analyzed in the following section.

3.5 GNSS Data Quality Check

GNSS sites are installed in a selected location with a great sky-view above horizon. This is because the quality of the collected GNSS observation depends mainly on the actual observed data by each satellite relative to theoretical data that could have been collected if no obstruction. The data collected also depend on observation rates set to collect data in the instrument. The TZVOLCANO GNSS sites observe low latency data at 15 seconds. The observations are collected to all locked satellites every 15 seconds and are recorded as one block. Theoretically a full day observation (24 hours), usually the expected observation epochs are determined from 24 hours x 60 minutes x 60 seconds / 15 seconds) x number of satellites. This means that, for the Global Positioning System (GPS) where a maximum of 12 satellites are usually above horizon, the maximum expected epochs in one day are 518,400. The actual observed data for a full day are usually the same or below this value depending on the number of satellites observed. The quality of measurement is calculated using an open source and unified tool for solving many pre-processing problems with GPS, GLONASS, Galileo, SBAS, Beidou, QZSS, and IRNSS data, especially in RINEX or BINEX format TEQC (Estey and Meertens 1999).

Before data processing commenced data quality checks for all GNSS observation files were examined. However instead of using the broadcasting ephemerides observed with the observation data, this study used precise ephemerides freely downloaded from IGS servers (example ftp garner.ucsd.edu). The precise ephemeris data are related to the corrections that have been conducted on the data compared to the broadcasting ephemerides. Table 1 presents data quality results obtained from the analysis in 2021 and 2022. In practice the data quality is assessed by the percentage ratio of data collected which should not be less than 80%. The quality check results obtained from this study has a minimum of 95% (95 percent) indicating that the data were collected at open sky and minimum sky obstruction indicating good quality of the estimate obtained which qualifies for data processing.

Table 3. 1 Sample of GNSS data quality of the TZVOLCANO network for the year 2021 and 2022

File name	First epoch	last epoch	hrs	Δt	#expt	#have	%	mp1	mp2	c/slps
ole31940.21o	21 7 13 07:10	21 7 13 23:59	16.83	15	20368	20347	100	0.43	0.35	2035
olo61970.21o	21 7 16 00:00	21 7 16 23:59	24.00	15	57444	57401	100	0.50	0.48	5740
olo71940.21o	21 7 13 00:00	21 7 13 23:59	24.00	15	57621	55067	96	0.54	0.35	1147
olo91940.21o	21 7 13 00:00	21 7 13 23:59	24.00	15	57613	55836	97	0.52	0.42	18612
olo91970.21o	21 7 16 00:00	21 7 16 23:59	24.00	15	57622	55829	97	0.55	0.43	5075
ole32140.22o	22 8 2 00:00	22 8 2 23:59	24.00	15	29383	29371	100	0.44	0.36	2259
olo12140.22o	22 8 2 00:00	22 8 2 23:59	24.00	15	58807	56818	97	0.40	0.43	11364
olo62140.22o	22 8 2 00:00	22 8 2 23:59	24.00	15	58765	58691	100	0.59	0.51	6521
olo72140.22o	22 8 2 04:16	22 8 2 15:25	11.08	15	25899	24638	95	0.64	0.41	684
olo82140.22o	22 8 2 00:00	22 8 2 23:59	24.00	15	58788	56460.	96	0.68	0.54	3764

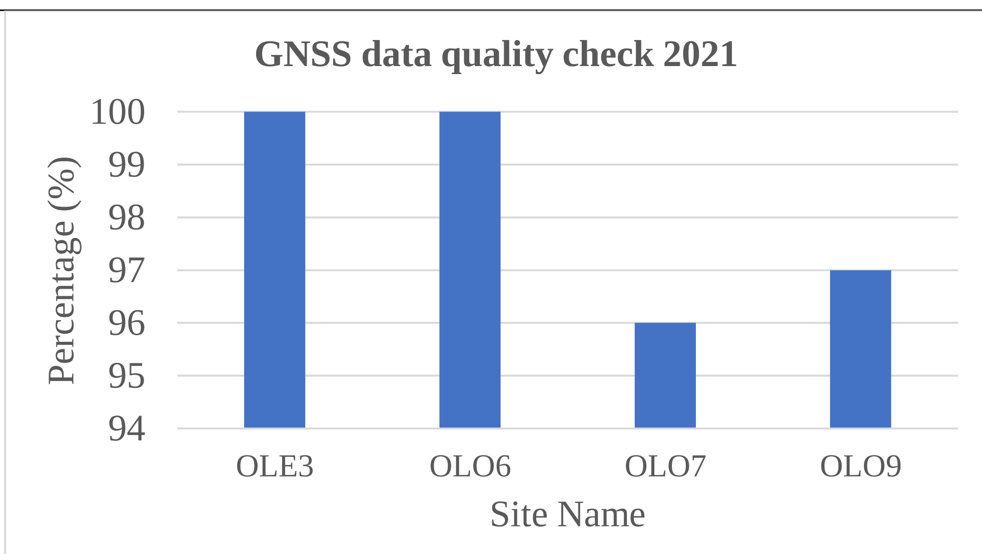

Figure 3. 1 Data quality statistics for observed data for the 2021

All the sites show good data quality 96% and above.

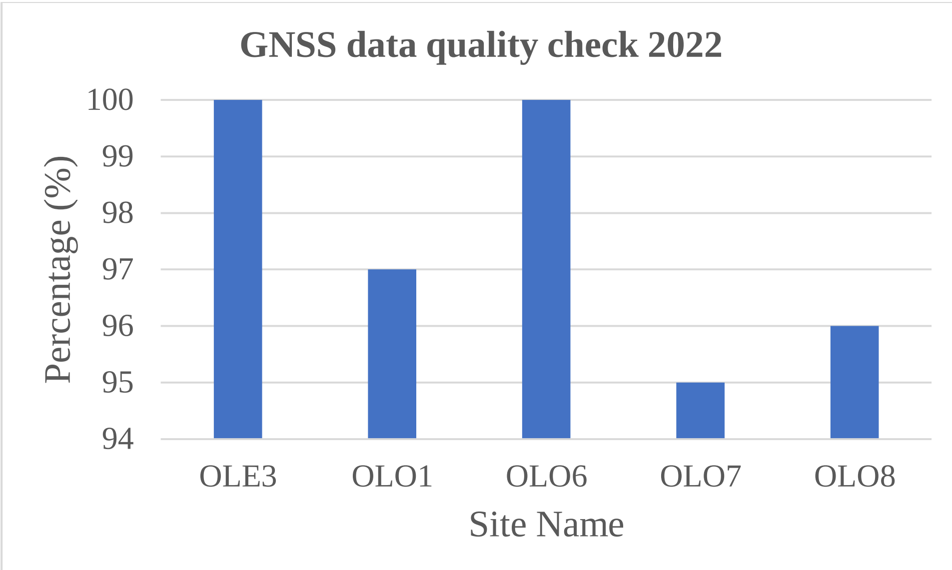

Figure 3. 2 Data quality statistics for observed data of the year 2022

All the sites show good data quality 95% and above.

3.6 Data Processing

In this study GNSS data was processed using GAMIT-GLOBK, TBC and Pride PPP-AR GNSS data processing software.

3.6.1 GAMIT-GLOBK processing

The GNSS data processing for the final output was categorized into two stages. The first stage was GAMIT-GLOBK processing to produce quasi observables (loose solution), the h files which are input for the second stage. The second stage was the combination of loose observables and reference frame application to obtain the final solution.

GAMIT processing

In this study the main input data were raw phase and pseudorange (observation and navigation file) in ASCII format (the RINEX files) obtained from different archives in Tanzania, Africa and around the world. The RINEX files are the actual observables recorded at each site whether for some hours of occupation or full day occupation. These files were processed for each day and therefore the span by which each file contains does not exceed 24 hours. The other input in the processing was the precise satellite navigation file (ephemerides file). These files contained the

Keplerian elements which provide the location of a satellite at a certain time. This study uses the precise satellite navigation file which has been corrected for satellite clock correction and satellite position. The third main input file was satellite position file or orbit file. There are three available satellite position files at IGS archives around the world namely Rapid, Ultra-rapid and Final orbit. This study uses final orbit which has been corrected for satellite state vectors, seven tropospheric delay parameters per site per day and phase ambiguities. The GNSS processing software uses double-differenced of carrier-phase measurements to estimate daily station coordinates, satellite state vectors, seven tropospheric delay parameters per site and per day, two horizontal tropospheric gradients and carrier-phase ambiguities using IGS final orbits routinely analyzed at IGS analysis centers. The results from this process are the least squares adjustment vectors and their corresponding variance covariance (VCV) matrix for station position and orbital elements estimated daily independently. These were termed as regional or Africa wide loose daily solutions, which are later converted to binary format and become input in GLOBK combination.

GLOBK combination

GLOBK combination was the second phase after estimating the least squares adjustment vectors and their corresponding variance covariance (VCV) matrix for station position and orbital elements (The loose solution). In order to obtain global coverage for the Reference Frame application, the global daily loose solution files from IGS routinely processed at the Massachusetts Institute of technology (MIT) were downloaded to be combined with regional GAMIT solutions. The reason for combining the global loose solution with the regional loose solution is to increase the number of globally distributed common sites and optimally tie our solution to the latest ITRF which eventually strengthens the minimal constraint solution. During this phase two combination stages are considered. In the first combination stage the individual daily regional loose solutions are combined with daily global loose solutions using common GNSS sites on the two solutions. This process is handled by a small program in GLOBK software called Global parameter REDUCING program (GLRED) and the second phase is GLOBK for stacking multiple epochs to obtain a mean position and/or velocity. The output from this process is the adjusted coordinates and their uncertainties.

3.6.2 Data processing by Trimble Business Centre (TBC)

Is the ideal office software for processing and analysing GNSS and terrestrial survey data recorded in the field. It is suitable for baseline processing

- **Data arrangement and organization**

After data acquisition data was arranged in a format that can be processed by TBC. The folder of data was in RINEX format and contained observation and navigation data.

- **Project setting**

Before data processing the project setting must start first. After opening TBC software, the project setting includes general information, coordinate system (datum transformation, geoidal model, projection, units (coordinate, distance, GPS time) and baseline processing settings.

- **Importing GNSS data**

After project setting then data were imported starting with control data then data for other points. The control point for the network was OLO3 and OLO6

- **Processing GNSS baselines**

  Before processing baselines we checked the baselines processing settings to ensure they are appropriate for our project. Then after imported the data the baseline was processed and the triangle observed at the same time where connected and the baselines processing report were display.

  - **Adjustment of the network**

  TBC uses relative positioning technique on determination of position. The network(Figure 3.1) was adjusted by control point which was OLO3 and OLO6 for daily solutions .

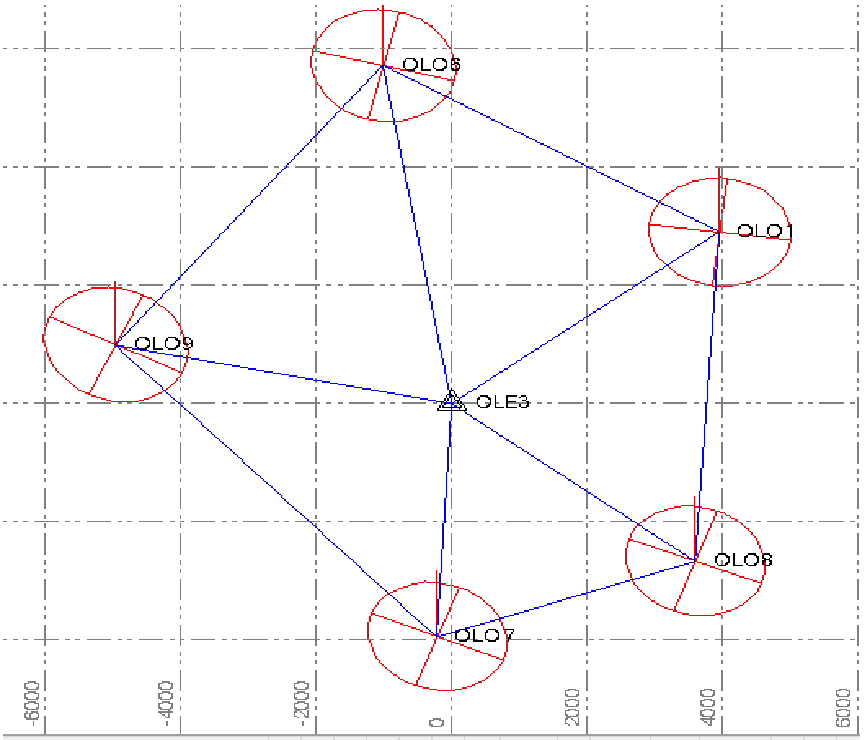

Figure 3. 3 Network Adjustment

- **The output obtained**

After baselines processing and network adjustment, the output was adjusted coordinates, adjusted geodetic coordinates, adjusted ECEF coordinate and error ellipse.

3.6.3 Pride PPP-AR processing

Pride PPP-AR (Precise Point Positioning with Ambiguity Resolution) originates in Maorong Ge's efforts on PPP-AR and leter developed by Dr Jianghui Geng's team. It is an open source software package which is based on many GNSS professionals' collective work in GNSS Research Center, Wuhan University.

- **Data arrangement and organization**

The observation data are arranged in the format that can be processed by Pride PPP-AR.

The GNSS data observed must be in RINEX format

- **Project setting**

Before data processing, project setting must start first including general information and coordinates .

- **Importing of GNSS data**

After project setting data was imported.

- **Data processing**

The processing procedures of Pride PPP-AR were divided into three modules, The first part was; Data preparation and Pre-processing which check the original observation file, construct the test volume to identify the outliers . Second part was Least Square Estimator which used to make data tentative pre-processing and generate a log-file to record the RINEX health diagnosis information and can realize the parameter estimation and outputs results. The third part was posterior residual diagnosis which processes residuals and new log-files can be generated.

CHAPTER FOUR

RESULTS AND ANALYSIS OF RESULTS

This chapter represents analysis and discussion of the results obtained after processing data by using GAMIT-GLOBK, TBC and Pride PPP-AR software. It shows the statistical and graphical representation of the results.

4.1 Results

The difference in coordinates and positional accuracy were the results estimated from this research

4.1.1 Difference of coordinate between GAMIT-GLOBK, Pride PPP-AR and TBC

Figure 4.1 to 4.14 presents the difference of coordinates and positional accuracy of coordinates between GAMIT-GLOBK with Pride PPP-AR and TBC software with timespan at of 37 days from 300 to 337 in the year of 2022.

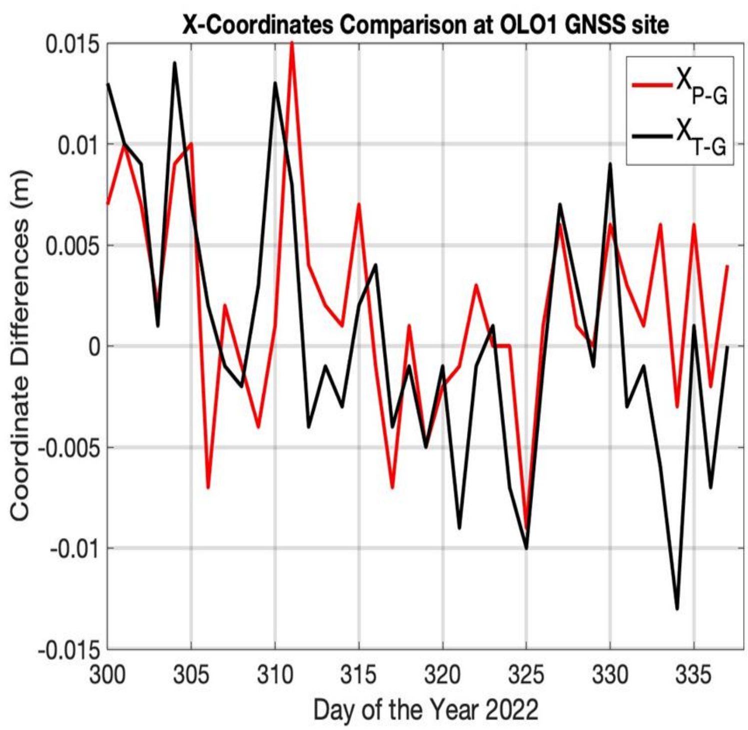

Figure 4. 1 Time series of X position differences for OLO1 GNSS site

Where X_{P-G} is the difference of X coordinates between Pride PPP-AR and GAMIT/GLOBK

X_{T-G} is the difference of X coordinates between TBC and GAMIT/GLOBK

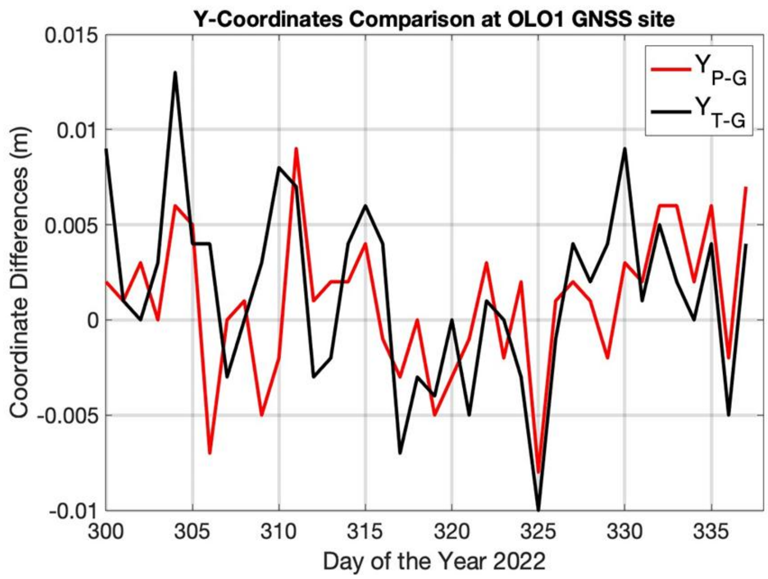

Figure 4. 2 Time series of the Y position differences for OLO1 GNSS site

Where Y_{P-G} is the difference of Y coordinates between Pride PPP-AR and GAMIT/GLOBK

Y_{T-G} is the difference of Y coordinates between TBC and GAMIT/GLOBK

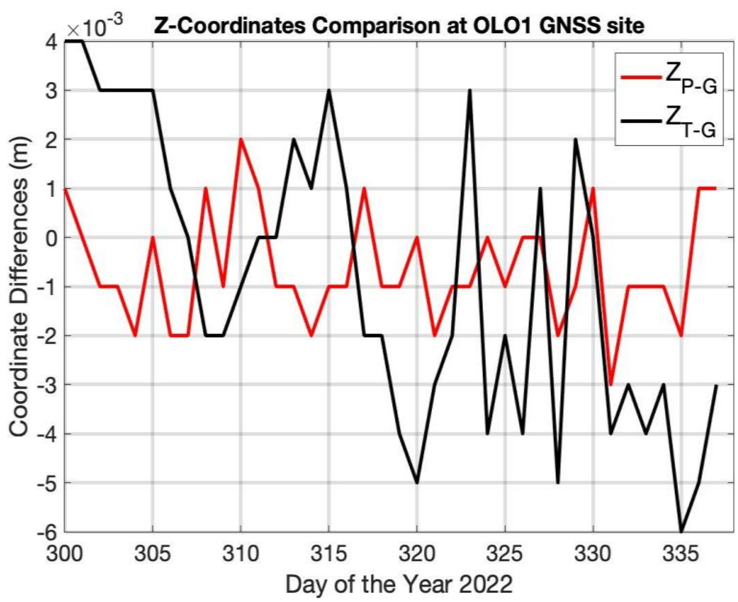

Figure 4. 3 Time series of the Z position differences for OLO1 GNSS site

Where Z_{P-G} is the difference of Z coordinates between Pride PPP-AR and GAMIT/GLOBK

Z_{T-G} is the difference of Z coordinates between TBC and GAMIT/GLOBK

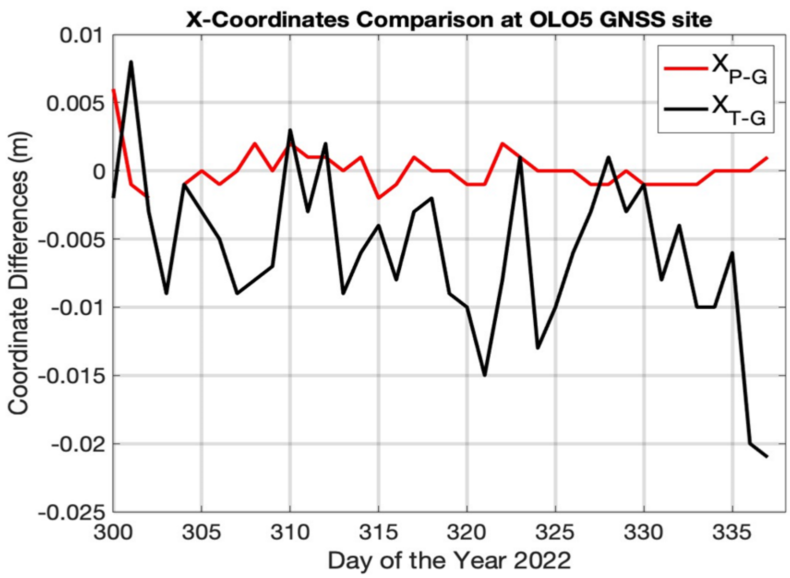

Figure 4. 4 Time series of the X position differences for OLO5 GNSS site

Where X_{P-G} is the difference of X coordinates between Pride PPP-AR and GAMIT/GLOBK

X_{T-G} is the difference of X coordinates between TBC and GAMIT/GLOBK

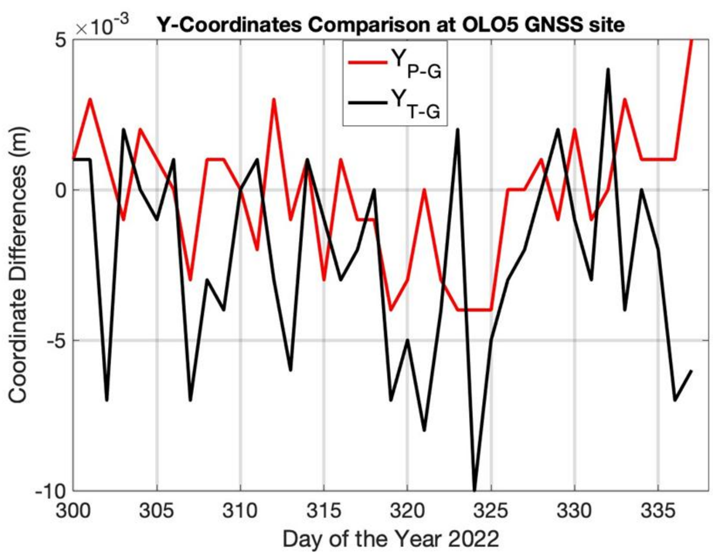

Figure 4. 5 Time series of the Y position differences for OLO5 GNSS site

Where Y_{P-G} is the difference of Y coordinates between Pride PPP-AR and GAMIT/GLOBK

Y_{T-G} is the difference of Y coordinates between TBC and GAMIT/GLOBK

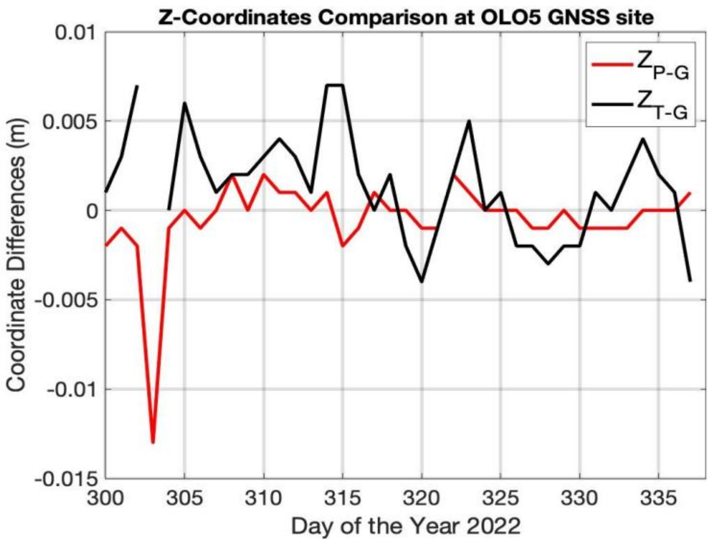

Figure 4. 6 Time series of the Z position differences for OLO5 GNSS site

Where Z_{P-G} is the difference of Z coordinates between Pride PPP-AR and GAMIT/GLOBK

Z_{T-G} is the difference of Z coordinates between TBC and GAMIT/GLOBK

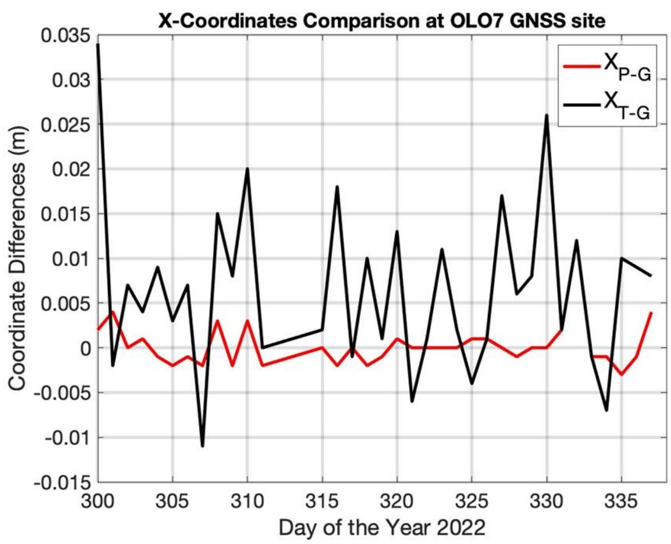

Figure 4. 7 Time series of the X position differences for OLO7 GNSS site

Where X_{P-G} is the difference of X coordinates between Pride PPP-AR and GAMIT/GLOBK

X_{T-G} is the difference of X coordinates between TBC and GAMIT/GLOBK

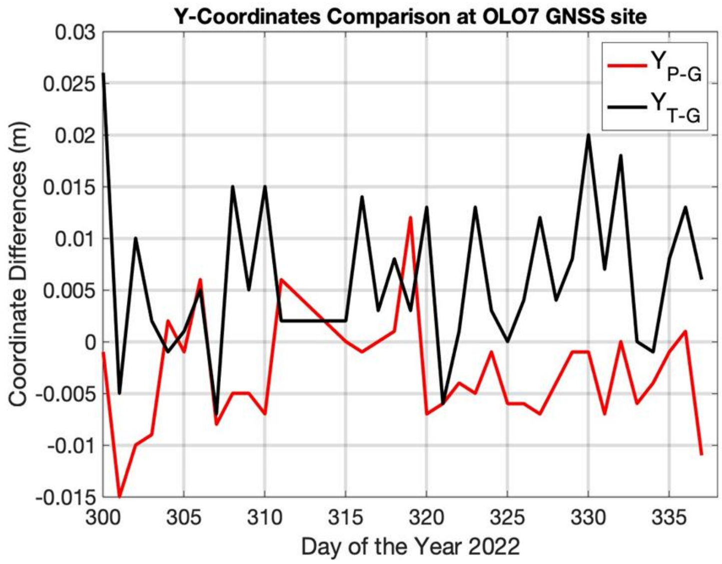

Figure 4. 8 Time series of the Y position differences for OLO7 GNSS site

Where Y_{P-G} is the difference of Y coordinates between Pride PPP-AR and GAMIT/GLOBK

Y_{T-G} is the difference of Y coordinates between TBC and GAMIT/GLOBK

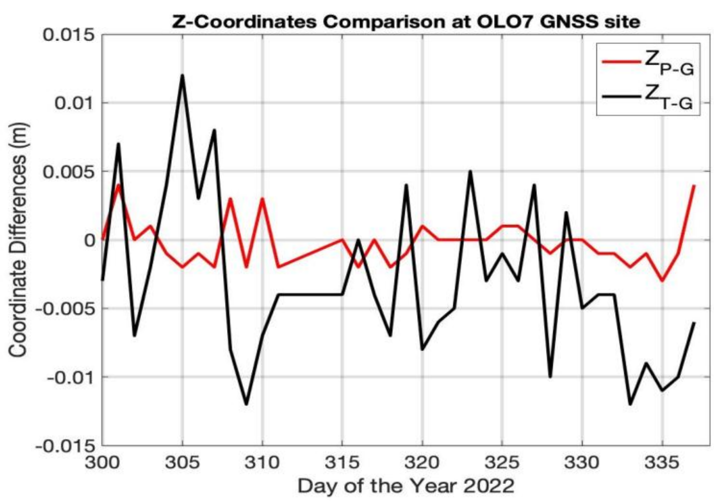

Figure 4. 9 Time series of the Z position differences for OLO7 GNSS site

Where Z_{P-G} is the difference of Z coordinates between Pride PPP-AR and GAMIT/GLOBK

Z_{T-G} is the difference of Z coordinates between TBC and GAMIT/GLOBK

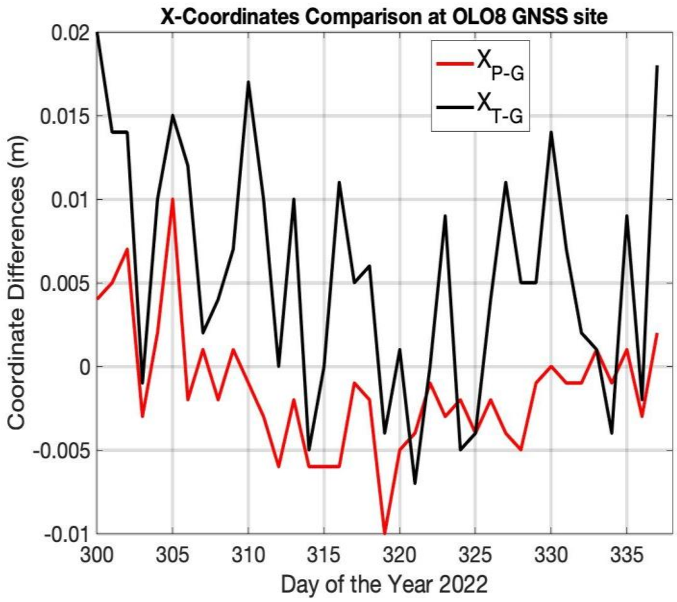

Figure 4. 10 Time series of the X position differences for OLO8 GNSS site

Where X_{P-G} is the difference of X coordinates between Pride PPP-AR and GAMIT/GLOBK

X_{T-G} is the difference of X coordinates between TBC and GAMIT/GLOBK

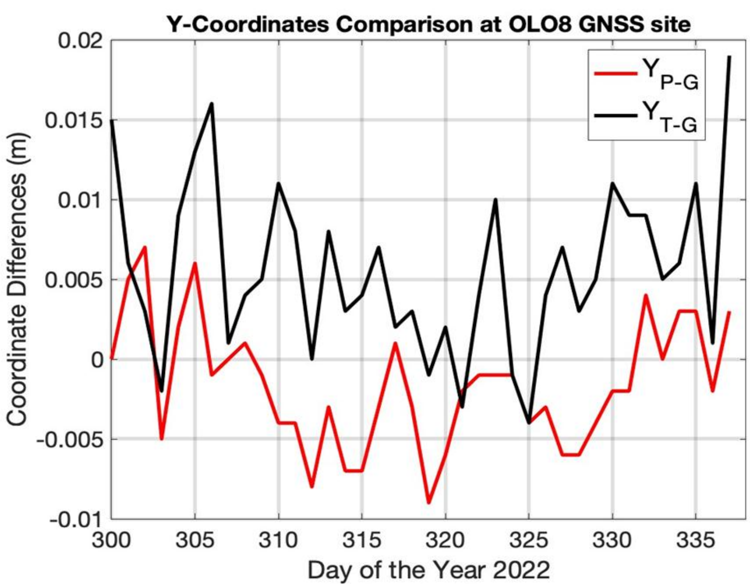

Figure 4. 11 Time series of the Y position differences for OLO8 GNSS site

Where Y_{P-G} is the difference of Y coordinates between Pride PPP-AR and GAMIT/GLOBK

Y_{T-G} is the difference of Y coordinates between TBC and GAMIT/GLOBK

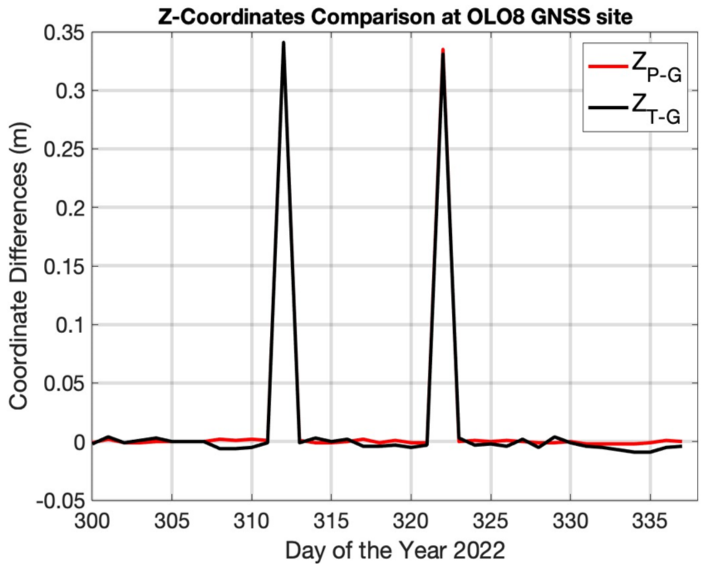

Figure 4. 12 Time series of the Z position differences for OLO8 GNSS site

Where Z_{P-G} is the difference of Z coordinates between Pride PPP-AR and GAMIT/GLOBK

Z_{T-G} is the difference of Z coordinates between TBC and GAMIT/GLOBK

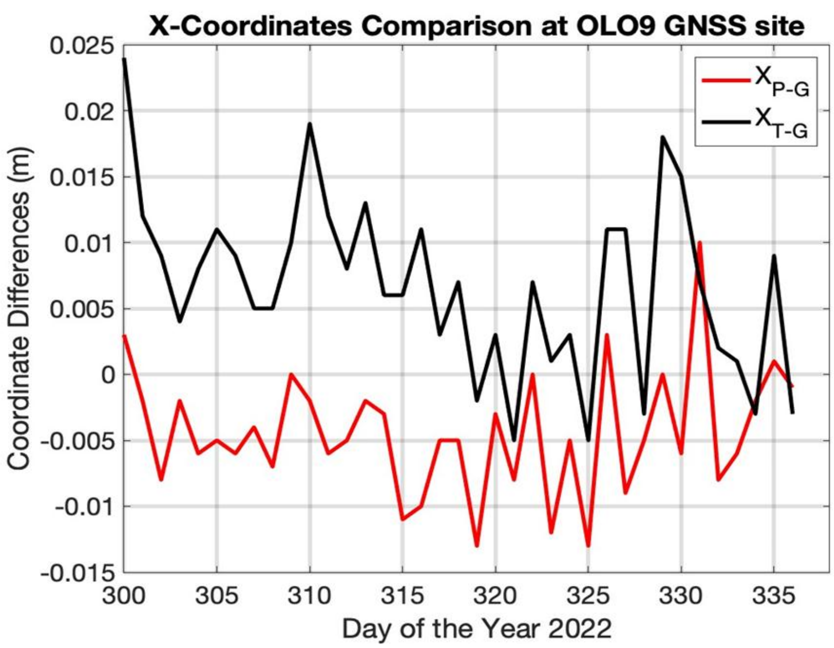

Figure 4. 13 Time series of the X position differences for OLO9 GNSS site

Where X_{P-G} is the difference of X coordinates between Pride PPP-AR and GAMIT/GLOBK

X_{T-G} is the difference of X coordinates between TBC and GAMIT/GLOBK

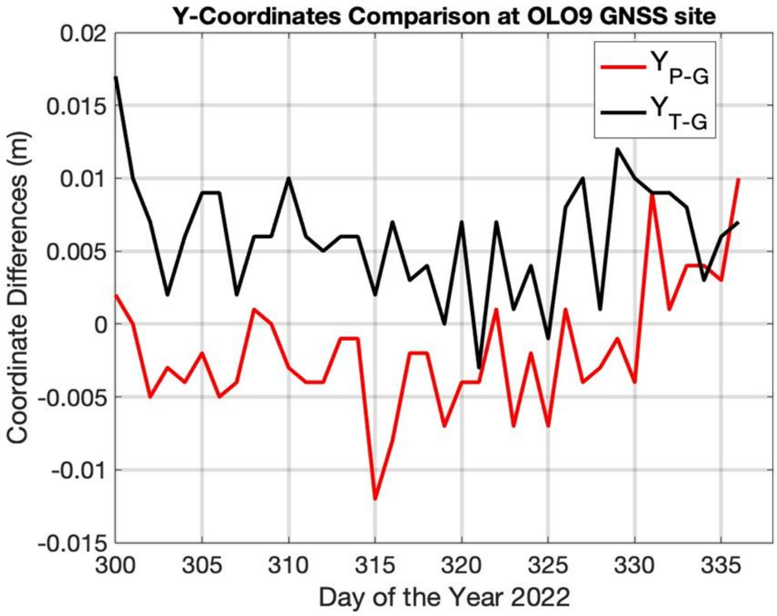

Figure 4. 14 Time series of the Y position differences for OLO9 GNSS site

Where Y_{P-G} is the difference of Y coordinates between Pride PPP-AR and GAMIT/GLOBK

Y_{T-G} is the difference of Y coordinates between TBC and GAMIT/GLOBK

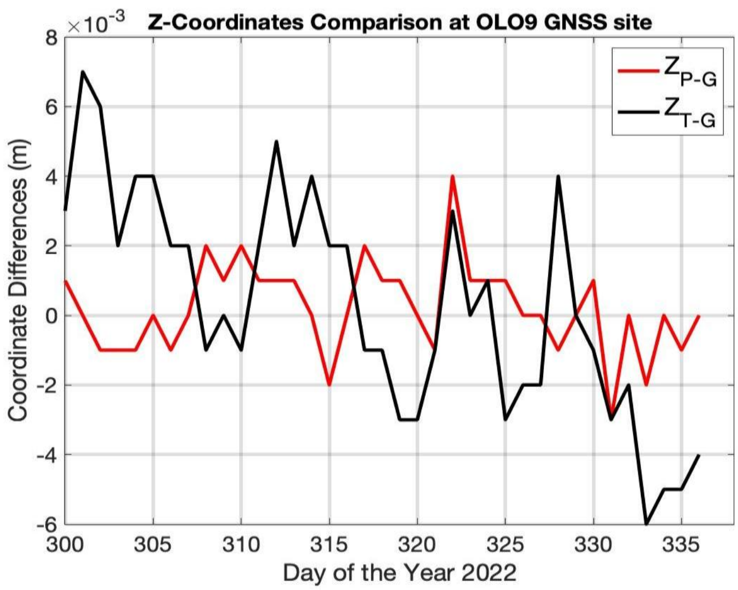

Figure 4. 15 Time series of the Z position differences for OLO9 GNSS site

Where Z_{P-G} is the difference of Z coordinates between Pride PPP-AR and GAMIT/GLOBK

Z_{T-G} is the difference of Z coordinates between TBC and GAMIT/GLOBK

4.1.2 Position accuracy of coordinates obtained from GAMIT-GLOBK, PRIDE PPP-AR and TBC.

Table 4.1 to 4.4 and Figure 4.15 to 4.19 Presents the positional accuracy of coordinates between GAMIT-GLOBK with Pride PPP-AR and TBC software with timespan at 1 hour, 2 hours, 3 hours and 6 hours.

Table 4. 1 Positional accuracy between Pride PPP-AR and TBC from GAMIT-GLOBK at OLO1 GNSS site

TIME (hours)	Pride PPP-AR – GAMIT/GLOBK (m)	TBC – GAMIT/GLOBK (m)
1	0.023	0.046
2	0.020	0.047
3	0.018	0.059
6	0.017	0.066

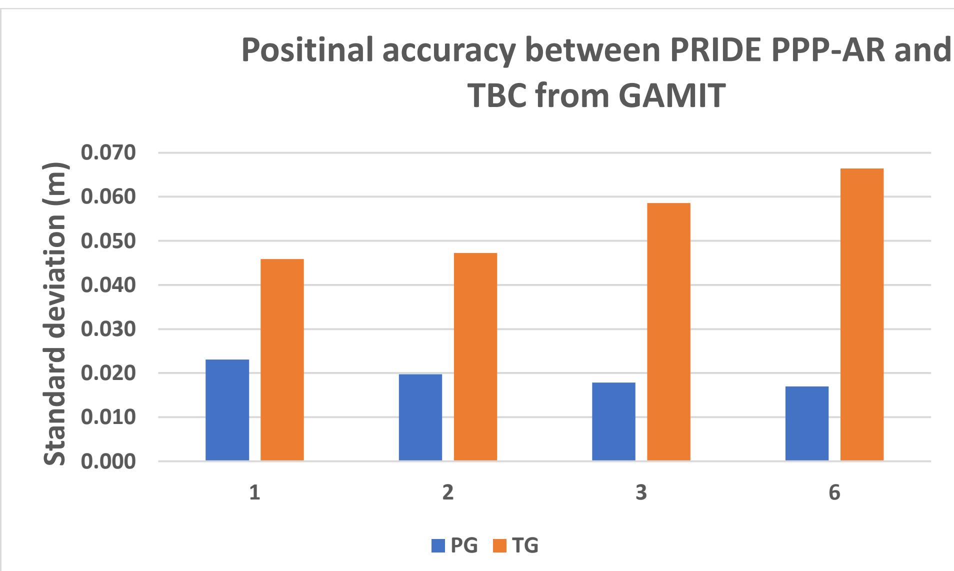

Figure 4. 16 Positional accuracy between Pride PPP-AR and TBC from GAMIT-GLOBK at OLO1 GNSS site

Where PG is the positional accuracy from Pride PP-AR and GAMIT/GLOBK

TG is the positional accuracy from TBC and GAMIT/GLOBK

Table 4. 2 Positional accuracy between Pride PPP-AR and TBC from GAMIT-GLOBK at OLO6 GNSS site

TIME (hours)	Pride PPP-AR – GAMIT/GLOBK (m)	TBC – GAMIT/GLOBK (m)
1	0.006	0.081
2	0.051	0.063
3	0.014	0.059
6	0.007	0.061

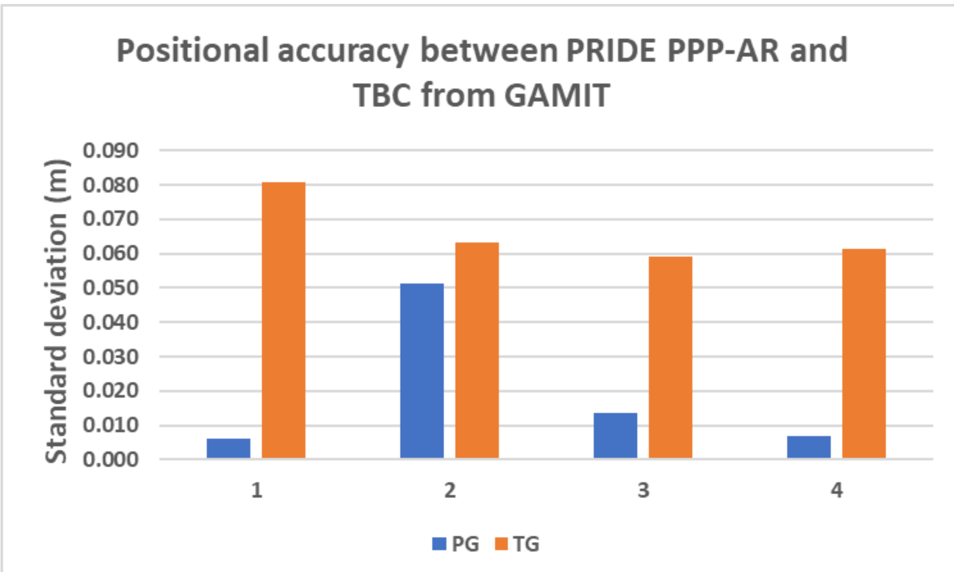

Figure 4. 17 Positional accuracy between Pride PPP-AR and TBC from GAMIT/GLOBK at OLO6 GNSS site

Where PG is the positional accuracy from Pride PP-AR and GAMIT/GLOBK

TG is the positional accuracy from TBC and GAMIT/GLOBK

Table 4. 3 Positional accuracy between Pride PPP-AR and TBC from GAMIT-GLOBK at OLO7 GNSS site

TIME (hours)	Pride PPP-AR – GAMIT/GLOBK (m)	TBC – GAMIT/GLOBK (m)
1	0.030	0.061
2	0.016	0.069
3	0.005	0.068
6	0.013	0.060

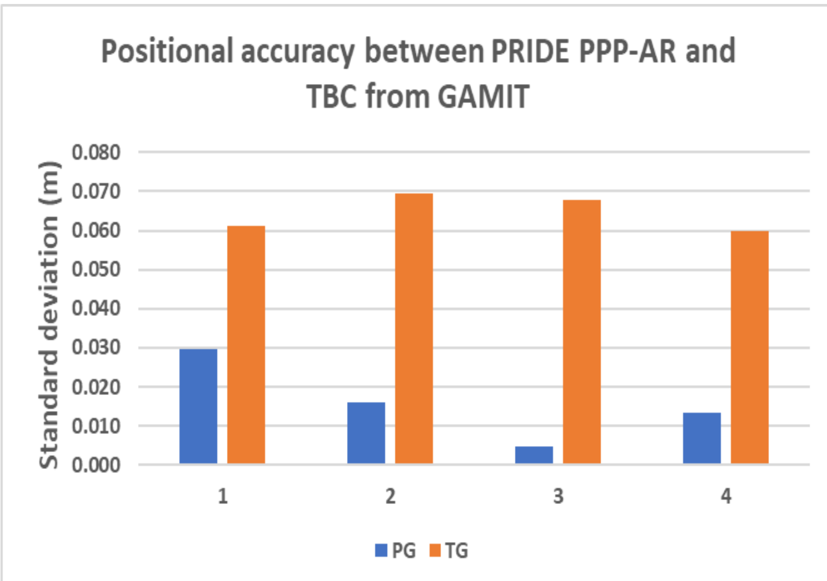

Figure 4. 18 Positional accuracy between Pride PPP-AR and TBC from GAMIT/GLOBK at OLO7 GNSS sit

Where PG is the positional accuracy from Pride PP-AR and GAMIT/GLOBK

TG is the positional accuracy from TBC and GAMIT/GLOBK

Table 4. 4 Positional accuracy between Pride PPP-AR and TBC from GAMIT-GLOBK at OLO8 GNSS site

TIME (hours)	Pride PPP-AR – GAMIT/GLOBK (m)	TBC – GAMIT/GLOBK (m)
1	0.012	0.017
2	0.017	0.047
3	0.008	0.059
6	0.025	0.047

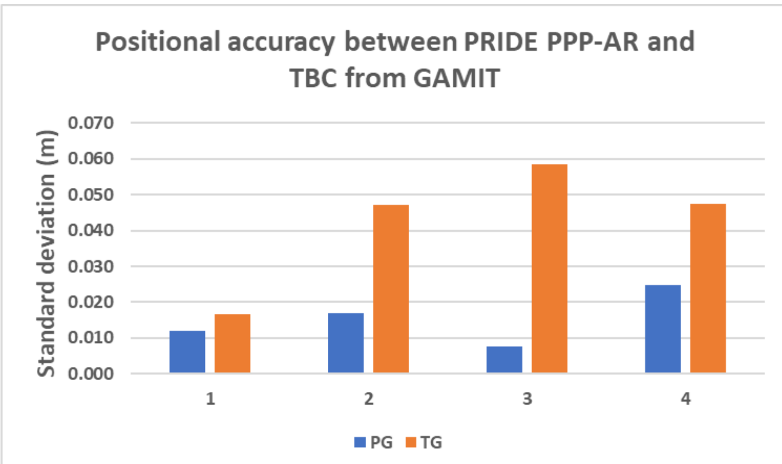

Figure 4. 19 Positional accuracy between Pride PPP-AR and TBC from GAMIT/GLOBK at OLO8 GNSS site

Where PG is the positional accuracy from Pride PP-AR and GAMIT/GLOBK

TG is the positional accuracy from TBC and GAMIT/GLOBK

4.1.3 Daily Positional accuracy of coordinates differences.

Table 4.5 and Figure 4.18 present the daily positional accuracies of the coordinates for 37 days of the year 2022 between Pride PPP-AR and TBC from GAMIT/GLOBK GNSS processing software.

Table 4. 5 Daily position accuracy of coordinates

SITE	Pride PPP-AR – GAMIT/GLOBK (m)	TBC – GAMIT/GLOBK (m)
OLO1	0.002	0.002
OLO5	0.001	0.007
OLO7	0.003	0.009
OLO8	0.002	0.008
OLO9	0.005	0.009

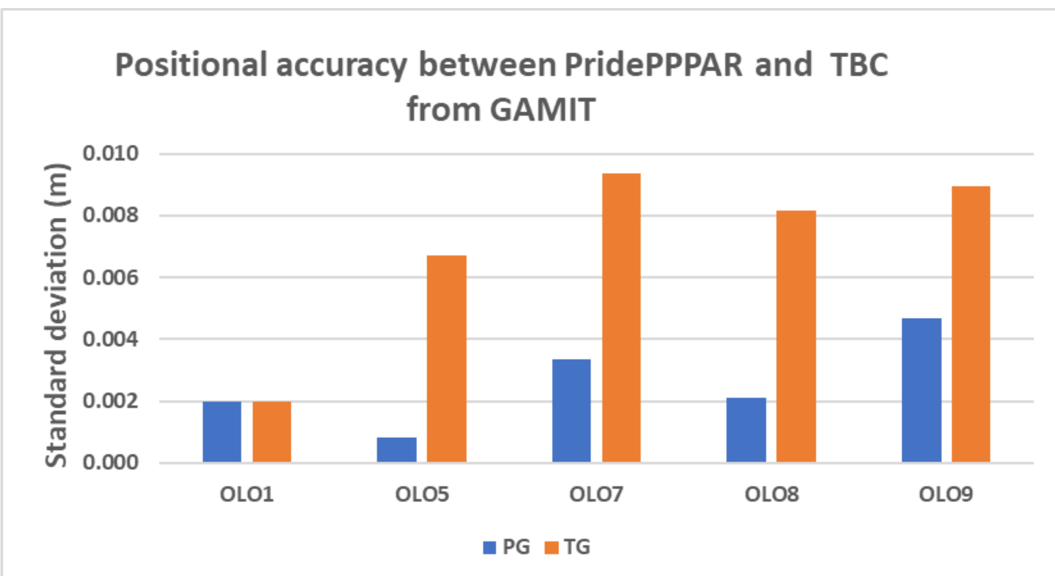

Figure 4. 20 Daily positional accuracy between Pride PPP-AR and TBC from GAMIT/GLOBK

Where PG is the positional accuracy from Pride PP-AR and GAMIT/GLOBK

TG is the positional accuracy from TBC and GAMIT/GLOBK

4.2 Analysis of the results

The coordinates obtained from GAMIT/GLOBK were considered to be the true value of the positions, because GAMIT/GLOBK considered to be the accurate software on GNSS data processing. The difference of coordinate of a position in a geocentric system (X,Y,Z) obtained from TBC and PRIDE PPP-AR from the position given by GAMIT/GLOBK used on calculating positional accuracy(standard deviation) of a point. The following formulas were used to find the position accuracy of a point

Difference in coordinate

Difference= GAMIT/GLOBK solution – other software solution (TBC and PRIDE PPP-AR).

Position accuracy

Position accuracy (standard deviation) was obtained from the difference of coordinates between GAMIT and other software ; TBC and PRIDE PPP-AR. The formula used was

Positional accuracy = $\sqrt{(\Delta x^2 + \Delta y^2 + \Delta z^2)}$ ……………………i

Where ΔX is the difference in X coordinate between GAMIT/GLOBK and other software.

ΔY is the difference in Y coordinate between GAMIT/GLOBK and other software.

ΔZ is the difference in Z coordinate between GAMIT/GLOBK and other software.

4.3 Discussion of the results

As shown from tables and figures(Table 4.4,table 4.5, figure 4.18 and figure 4.19) from this chapter, the results were obtained and its shows that, the position accuracy (standard deviation) from

i) GAMIT and PRIDE PPP-AR were 0.002 OLO1, 0.001 OLO5, 0.003 OLO7, 0.002 OLO8, 0.005 OLO9.

ii) GAMIT and TBC were 0.002 OLO1, 0.007 OLO5, 0.009 OLO7, 0.008 OLO8, 0.009 OLO9.

and for 1, 2, 3, 6 hours the position accuracy from

i) GAMIT and PRIDE PPP-AR for OLO1 were 0.023 (1h), 0.020 (2h), 0.018 (3h), 0.017 (6h), for OLO6 were 0.006 (1h), 0.051 (2h), 0.014 (3h), 0.007 (6h), for OLO7 were 0.030 (1h), 0.016 (2h), 0.005 (3h), 0.013 (6h), for OLO8 were 0.012 (1h), 0.017 (2h), 0.008 (3h), 0.025 (6h).

ii) GAMIT and TBC for OLO1 were 0.046 (1h), 0.047 (2h), 0.059 (3h), 0.066 (6h), for OLO6 were 0.081 (1h), 0.061 (2h), 0.059 (3h), 0.061 (6h), for OLO7 were 0.061 (1h), 0.069 (2h), 0.068 (3h), 0.060(6h), for OLO8 were 0.017 (1h), 0.047 (2h), 0.059 (3h), 0.047 (6h).

Figures (figure 4.18 and figure 4.19) above show a significant variation in positional error which might be caused by differences in mathematical models used in the software. PRIDE PPP-AR has displayed smaller positional error than TBC, this is enough to say PRIDE PPP-AR is more accurate than TBC and therefore can be used in surveying works which require high accuracy.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

In this study the main objective was to assess the accuracy performance of Pride PPP-AR against TBC from GAMIT/GLOBK GNSS data processing software. The output from GAMIT/GLOBK and Pride PPP-AR and TBC were statistically compared and analyzed. The assessment of these statistical results show that Pride PPP-AR preforms better than TBC. Its position coordinates are very closer to that of GAMT/GLOBK. Therefore, Pride PPP-AR is capable of producing positions at millimeter level of accuracy and precision allowing it to be applicable in any surveying works that require high accuracy. Generally, Pride PPP-AR can be used as an alternative for relative technique in survey activities such as control establishment, plate motions and surveying activities since its accuracy is very closer to GAMIT/GLOBK and cost effective than relative technique.

5.2 Recommendations

Based on the findings, the following recommendations are made.

i) Further investigation covering longer timespan e.g., one year or more is recommended to assess the software accuracy.

ii) Assessing the software for the datasets collected in areas covering multipath such as forestry canopy and buildings.

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APPENDICES

1. Coordinates from GAMIT/GLOBK, TBC and Pride PPP-AR
2. Network Adjustment Report

APPENDIX 1

Sample of coordinates (Adjusted ECEF Coordinates,WGS84,ITRF 14) from GAMIT/GLOBK, TBC and Pride PPP-AR.

	OLO1								
	GAMIT/GLOBK			PRIDE PPP-AR			TBC		
	X	Y	Z	X	Y	Z	X	Y	Z
300	5158236.890	3740835.200	-302267.396	5158236.897	3740835.202	-302267.394	5158236.903	3740835.209	-302267.392
301	5158236.884	3740835.194	-302267.394	5158236.894	3740835.195	-302267.395	5158236.894	3740835.195	-302267.390
302	5158236.885	3740835.195	-302267.392	5158236.892	3740835.198	-302267.393	5158236.894	3740835.195	-302267.389
303	5158236.899	3740835.205	-302267.397	5158236.901	3740835.205	-302267.399	5158236.900	3740835.208	-302267.394
304	5158236.888	3740835.195	-302267.395	5158236.897	3740835.201	-302267.396	5158236.902	3740835.208	-302267.392
305	5158236.892	3740835.201	-302267.396	5158236.902	3740835.205	-302267.396	5158236.899	3740835.205	-302267.393
306	5158236.901	3740835.205	-302267.394	5158236.894	3740835.198	-302267.396	5158236.903	3740835.209	-302267.393
307	5158236.897	3740835.207	-302267.395	5158236.899	3740835.207	-302267.397	5158236.896	3740835.204	-302267.395
308	5158236.894	3740835.200	-302267.394	5158236.893	3740835.201	-302267.393	5158236.892	3740835.200	-302267.396
309	5158236.893	3740835.203	-302267.393	5158236.889	3740835.198	-302267.394	5158236.896	3740835.206	-302267.394
310	5158236.895	3740835.206	-302267.393	5158236.896	3740835.204	-302267.391	5158236.908	3740835.214	-302267.394
311	5158236.885	3740835.198	-302267.395	5158236.900	3740835.207	-302267.394	5158236.893	3740835.205	-302267.395
312	5158236.897	3740835.208	-302267.395	5158236.900	3740835.209	-302267.396	5158236.893	3740835.205	-302267.395
313	5158236.893	3740835.202	-302267.393	5158236.895	3740835.204	-302267.393	5158236.892	3740835.200	-302267.391
314	5158236.896	3740835.202	-302267.394	5158236.896	3740835.204	-302267.396	5158236.893	3740835.206	-302267.393
315	5158236.893	3740835.202	-302267.393	5158236.900	3740835.206	-302267.394	5158236.895	3740835.208	-302267.390
316	5158236.893	3740835.202	-302267.393	5158236.893	3740835.201	-302267.394	5158236.897	3740835.206	-302267.392
317	5158236.898	3740835.207	-302267.395	5158236.891	3740835.204	-302267.394	5158236.894	3740835.200	-302267.397
318	5158236.896	3740835.206	-302267.396	5158236.897	3740835.205	-302267.397	5158236.895	3740835.203	-302267.398
319	5158236.895	3740835.205	-302267.395	5158236.890	3740835.200	-302267.396	5158236.890	3740835.201	-302267.399
320	5158236.902	3740835.210	-302267.393	5158236.901	3740835.207	-302267.393	5158236.901	3740835.210	-302267.398
321	5158236.898	3740835.204	-302267.395	5158236.897	3740835.203	-302267.396	5158236.889	3740835.199	-302267.398
322	5158236.897	3740835.205	-302267.395	5158236.901	3740835.208	-302267.396	5158236.896	3740835.206	-302267.397
323	5158236.891	3740835.201	-302267.396	5158236.890	3740835.199	-302267.397	5158236.892	3740835.201	-302267.393
324	5158236.897	3740835.204	-302267.395	5158236.896	3740835.206	-302267.395	5158236.890	3740835.201	-302267.399
325	5158236.902	3740835.212	-302267.393	5158236.892	3740835.203	-302267.394	5158236.892	3740835.202	-302267.395
326	5158236.896	3740835.205	-302267.393	5158236.897	3740835.206	-302267.393	5158236.895	3740835.204	-302267.398
327	5158236.886	3740835.197	-302267.395	5158236.892	3740835.199	-302267.396	5158236.893	3740835.201	-302267.394
328	5158236.890	3740835.202	-302267.390	5158236.891	3740835.203	-302267.392	5158236.893	3740835.204	-302267.395
329	5158236.902	3740835.206	-302267.392	5158236.902	3740835.205	-302267.393	5158236.901	3740835.210	-302267.390
330	5158236.890	3740835.200	-302267.392	5158236.896	3740835.203	-302267.391	5158236.899	3740835.209	-302267.392
331	5158236.897	3740835.206	-302267.392	5158236.900	3740835.207	-302267.395	5158236.894	3740835.207	-302267.396
332	5158236.896	3740835.199	-302267.395	5158236.897	3740835.206	-302267.396	5158236.895	3740835.204	-302267.398
333	5158236.895	3740835.200	-302267.392	5158236.901	3740835.206	-302267.393	5158236.889	3740835.202	-302267.396
334	5158236.897	3740835.200	-302267.394	5158236.894	3740835.203	-302267.395	5158236.884	3740835.200	-302267.397
335	5158236.890	3740835.202	-302267.392	5158236.896	3740835.208	-302267.394	5158236.891	3740835.206	-302267.398
336	5158236.895	3740835.206	-302267.391	5158236.893	3740835.204	-302267.391	5158236.888	3740835.201	-302267.396
337	5158236.892	3740835.201	-302267.392	5158236.897	3740835.207	-302267.391	5158236.892	3740835.205	-302267.395

	OLO5								
	GAMIT/GLOBK			PRIDE PPP-AR			TBC		
	X	Y	Z	X	Y	Z	X	Y	Z
300	5162364.319	3735464.515	-291147.289	5162364.325	3735464.516	-291147.290	5162364.317	3735464.516	-291147.288
301	5162364.315	3735464.512	-291147.291	5162364.322	3735464.515	-291147.292	5162364.323	3735464.513	-291147.288
302	5162364.325	3735464.523	-291147.293	5162364.329	3735464.524	-291147.295	5162364.322	3735464.516	-291147.286
303	5162364.336	3735464.528	-291147.294	5162364.335	3735464.526	-291147.295	5162364.323	3735464.519	-291147.292
304	5162364.323	3735464.519	-291147.291	5162364.326	3735464.521	-291147.292	5162364.322	3735464.519	-291147.291
305	5162364.322	3735464.517	-291147.292	5162364.327	3735464.519	-291147.292	5162364.319	3735464.516	-291147.285
306	5162364.325	3735464.519	-291147.292	5162364.326	3735464.519	-291147.294	5162364.320	3735464.520	-291147.289
307	5162364.330	3735464.527	-291147.290	5162364.329	3735464.525	-291147.291	5162364.321	3735464.520	-291147.289
308	5162364.327	3735464.518	-291147.292	5162364.323	3735464.518	-291147.290	5162364.319	3735464.515	-291147.290
309	5162364.327	3735464.521	-291147.290	5162364.330	3735464.522	-291147.290	5162364.320	3735464.517	-291147.288
310	5162364.320	3735464.518	-291147.292	5162364.321	3735464.518	-291147.290	5162364.323	3735464.518	-291147.289
311	5162364.327	3735464.517	-291147.291	5162364.321	3735464.516	-291147.291	5162364.324	3735464.518	-291147.287
312	5162364.323	3735464.521	-291147.290	5162364.328	3735464.524	-291147.289	5162364.325	3735464.518	-291147.287
313	5162364.323	3735464.518	-291147.290	5162364.323	3735464.517	-291147.290	5162364.314	3735464.512	-291147.289
314	5162364.323	3735464.516	-291147.291	5162364.323	3735464.517	-291147.290	5162364.317	3735464.517	-291147.284
315	5162364.331	3735464.523	-291147.290	5162364.327	3735464.520	-291147.291	5162364.327	3735464.522	-291147.283
316	5162364.334	3735464.524	-291147.291	5162364.335	3735464.525	-291147.293	5162364.326	3735464.521	-291147.289
317	5162364.321	3735464.518	-291147.292	5162364.321	3735464.517	-291147.291	5162364.318	3735464.516	-291147.292
318	5162364.324	3735464.517	-291147.291	5162364.324	3735464.517	-291147.291	5162364.322	3735464.517	-291147.289
319	5162364.329	3735464.522	-291147.293	5162364.325	3735464.518	-291147.293	5162364.320	3735464.515	-291147.295
320	5162364.334	3735464.525	-291147.289	5162364.329	3735464.522	-291147.290	5162364.324	3735464.520	-291147.293
321	5162364.335	3735464.524	-291147.292	5162364.333	3735464.524	-291147.293	5162364.320	3735464.516	-291147.293
322	5162364.329	3735464.523	-291147.293	5162364.325	3735464.520	-291147.291	5162364.321	3735464.519	-291147.291
323	5162364.327	3735464.520	-291147.293	5162364.320	3735464.517	-291147.292	5162364.328	3735464.522	-291147.288
324	5162364.329	3735464.523	-291147.290	5162364.326	3735464.519	-291147.290	5162364.316	3735464.513	-291147.290
325	5162364.327	3735464.520	-291147.290	5162364.319	3735464.516	-291147.290	5162364.317	3735464.515	-291147.289
326	5162364.324	3735464.519	-291147.291	5162364.324	3735464.520	-291147.291	5162364.318	3735464.516	-291147.293
327	5162364.322	3735464.519	-291147.289	5162364.321	3735464.519	-291147.291	5162364.319	3735464.517	-291147.291
328	5162364.326	3735464.521	-291147.290	5162364.326	3735464.521	-291147.291	5162364.327	3735464.521	-291147.293
329	5162364.328	3735464.520	-291147.290	5162364.328	3735464.520	-291147.290	5162364.325	3735464.522	-291147.292
330	5162364.325	3735464.521	-291147.290	5162364.328	3735464.523	-291147.291	5162364.324	3735464.520	-291147.292
331	5162364.328	3735464.522	-291147.290	5162364.328	3735464.521	-291147.291	5162364.320	3735464.519	-291147.289
332	5162364.329	3735464.517	-291147.288	5162364.322	3735464.517	-291147.289	5162364.325	3735464.521	-291147.288
333	5162364.337	3735464.525	-291147.288	5162364.340	3735464.528	-291147.289	5162364.327	3735464.521	-291147.286
334	5162364.332	3735464.520	-291147.290	5162364.327	3735464.520	-291147.291	5162364.322	3735464.520	-291147.286
335	5162364.328	3735464.517	-291147.290	5162364.327	3735464.518	-291147.290	5162364.322	3735464.515	-291147.288
336	5162364.336	3735464.522	-291147.289	5162364.326	3735464.523	-291147.289	5162364.316	3735464.515	-291147.288
337	5162364.325	3735464.515	-291147.289	5162364.326	3735464.520	-291147.289	5162364.304	3735464.509	-291147.293

APPENDIX 2

Samples of Network Adjustment Report (300 and 301days)

Network Adjustment Report (300 day)

Adjustment Settings

Set-Up Errors
GNSS

Error in Height of Antenna:	0.00000 m
Centering Error:	0.00000 m

Covariance Display
Horizontal:

Propagated Linear Error [E]:	U.S.
Constant Term [C]:	0.00000 m
Scale on Linear Error [S]:	1.960

Three-Dimensional

Propagated Linear Error [E]:	U.S.
Constant Term [C]:	0.00000 m
Scale on Linear Error [S]:	1.960

Adjustment Statistics

Number of Iterations for Successful Adjustment:	2
Network Reference Factor:	1.00
Chi Square Test (95%):	Passed
Precision Confidence Level:	95%
Degrees of Freedom:	24

Post Processed Vector Statistics

Reference Factor:	1.00
Redundancy Number:	24.00
A Priori Scalar:	0.59

Control Point Constraints

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
OLO6	Global	Fixed	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	160858.82279	0.00134	9697355.06385	0.00117	1006.94755	0.00740	
OLO5	154053.79809	0.00144	9708465.09926	0.00124	677.98647	0.00776	
OLO6	155875.77049	?	9700164.49493	?	927.13937	?	LLh
OLO7	156696.74425	0.00212	9690477.50613	0.00183	1467.70126	0.01220	
OLO8	160513.63051	0.00138	9691773.20665	0.00117	1255.81964	0.00755	
OLO9	151928.30550	0.00131	9695410.10781	0.00112	1467.82215	0.00721	

Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Constraint
OLO1	S2°44'03.13646"	E35°57'00.78399"	988.11552	0.00740	
OLO5	S2°38'01.25557"	E35°53'21.61157"	659.00397	0.00776	
OLO6	S2°42'31.35384"	E35°54'19.85507"	908.32970	?	LLh
OLO7	S2°47'46.46212"	E35°54'45.59457"	1449.12217	0.01220	
OLO8	S2°47'04.64686"	E35°56'49.15598"	1237.13465	0.00755	
OLO9	S2°45'05.63985"	E35°52'11.79299"	1449.21695	0.00721	

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	5158236.90256	0.00608	3740835.20865	0.00440	-302267.39190	0.00126	0.00761	
OLO5	5162364.31730	0.00635	3735464.51551	0.00465	-291147.28795	0.00132	0.00799	
OLO6	5161197.83722	?	3736841.36009	?	-299447.18774	?	?	LLh
OLO7	5160792.46319	0.00990	3737529.55330	0.00742	-309142.58790	0.00191	0.01251	
OLO8	5158431.81537	0.00620	3740532.83438	0.00451	-307849.12896	0.00126	0.00777	
OLO9	5163771.76431	0.00591	3733820.52827	0.00431	-304207.46735	0.00120	0.00741	

Error Ellipse Components

Point ID	Semi-major axis (Meter)	Semi-minor axis (Meter)	Azimuth
OLO1	0.00168	0.00146	85°
OLO5	0.00179	0.00155	88°
OLO7	0.00266	0.00227	84°
OLO8	0.00172	0.00146	89°
OLO9	0.00164	0.00140	88°

Network Adjustment Report (301day)

Adjustment Settings

Set-Up Errors	
GNSS	
Error in Height of Antenna:	0.00000 m
Centering Error:	0.00000 m
Covariance Display	
Horizontal:	
Propagated Linear Error [E]:	U.S.
Constant Term [C]:	0.00000 m
Scale on Linear Error [S]:	1.960
Three-Dimensional	
Propagated Linear Error [E]:	U.S.
Constant Term [C]:	0.00000 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:	30

Post Processed Vector Statistics	
Reference Factor:	1.01
Redundancy Number:	30.00
A Priori Scalar:	0.52

Control Point Constraints

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
OLO6	Global	Fixed	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	160858.81666	0.00119	9697355.06497	0.00103	1006.93277	0.00666	
OLO5	154053.79268	0.00123	9708465.09904	0.00104	677.98924	0.00667	
OLO6	155875.77049	?	9700164.49493	?	927.13937	?	LLh
OLO7	156696.74212	0.00136	9690477.51686	0.00117	1467.68047	0.00775	
OLO8	160513.62658	0.00117	9691773.21144	0.00099	1255.80547	0.00639	
OLO9	151928.30769	0.00116	9695410.11515	0.00099	1467.81751	0.00647	

Adjusted Geodetic Coordinates

Point ID	Latitude	Longitude	Height (Meter)	Height Error (Meter)	Constraint
OLO1	S2°44'03.13642"	E35°57'00.78379"	988.10074	0.00666	
OLO5	S2°38'01.25557"	E35°53'21.61140"	659.00674	0.00667	
OLO6	S2°42'31.35384"	E35°54'19.85507"	908.32970	?	LLh
OLO7	S2°47'46.46177"	E35°54'45.59450"	1449.10137	0.00775	
OLO8	S2°47'04.64670"	E35°56'49.15585"	1237.12048	0.00639	
OLO9	S2°45'05.63961"	E35°52'11.79306"	1449.21231	0.00647	

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	5158236.89425	0.00548	3740835.19506	0.00394	-302267.39006	0.00111	0.00684	
OLO5	5162364.32271	0.00547	3735464.51274	0.00399	-291147.28828	0.00111	0.00686	
OLO6	5161197.83722	?	3736841.36009	?	-299447.18774	?	?	LLh
OLO7	5160792.44802	0.00633	3737529.53972	0.00467	-309142.57617	0.00124	0.00796	
OLO8	5158431.80640	0.00525	3740532.82304	0.00381	-307849.12348	0.00105	0.00657	
OLO9	5163771.75955	0.00531	3733820.52755	0.00385	-304207.45981	0.00106	0.00664	

Error Ellipse Components

Point ID	Semi-major axis (Meter)	Semi-minor axis (Meter)	Azimuth
OLO1	0.00149	0.00128	85°
OLO5	0.00153	0.00130	87°
OLO7	0.00170	0.00146	83°
OLO8	0.00146	0.00123	89°
OLO9	0.00145	0.00123	87°