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DETECTING NOISE IN GPS TIME SERIES

A Case Study of Tanzania CORS

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A Case Study of Tanzania CORS

A Dissertation Submitted to The Department of Geospatial Sciences And Technology In Partially Fulfillment of The Requirements for The Award 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 "**Detecting Noise in GPS Time series, a case study of Tanzania CORS**" in partial fulfillment of the requirement for the award degree of bachelor of science in Geomatics at Ardhi University.

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Date ………………………	Date ………………………

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I, SYLVANUS DANIEL S declare that this dissertation is my own original work and that to the best of my knowledge, it has not been presented to any other University for a similar or any other degree award except where due acknowledgements have been made in the text.

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SYLVANUS DANIEL S

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May this dedication serve as a reminder that together we are a family united by love, dreams, and a shared pursuit of knowledge. Thank you for being my pillars of strength and for instilling in me the values of perseverance, dedication, and resilience.

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ABSTRACT

Accurate analysis of Global Positioning System (GPS) time series is crucial for geodetic and geophysical research. Continuous observations using GPS time series enable the observation of standard deviation in repeated measurements. However, even after removing identifiable errors from the measurements, residual noise remains undetected. This residual noise includes time uncorrelated noise, such as white noise, and time-correlated noise, like flicker and brown noise. Understanding and mitigating these noise components are essential to ensure their not affect the results. This research employs the GAMIT/GLOBK software to post-process GPS position data obtained from four Continuous Operating Reference Stations (CORS) in Tanzania, namely ARSH, DODM, MTVE, and MBEY. Initially, the RINEX data is processed using GAMIT/GLOBK to generate daily positions, which are then mapped to create position time series. These time series are carefully examined for deviations from the mean, indicative of the presence of noise. Next, MATLAB is utilized to perform Fourier transformation on the position time series, converting them from the time domain to the frequency domain. Through power spectral density analysis, different noise types, including flicker, white, and brown noise, are identified, and their spectral characteristics are revealed. In conclusion, the accurate analysis of GPS time series is important for geodetic and geophysical studies. This research emphasizes the critical significance of understanding and mitigating noise effects to ensure the precision of measurements. By employing continuous observations and advanced analysis techniques, the study successfully detects residual noise in GPS time series data. This critical method enables researchers to achieve higher levels of precision and dependability in their geodetic and geophysical research endeavors. Ultimately, the ability to identify and mitigate noise ensures the attainment of accurate results, making it an indispensable factor in advancing our understanding of Earth's dynamic processes.

Keywords: Global Positioning System (GPS) Noise, GPS Time Series, Space Geodesy

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ACRONYMS AND ABBREVIATIONS

CORS	Continuously Operating Reference Station
DGPS	Differential GPS
EDM	Electronic Distance Meter
GAMIT	GPS Analysis at MIT
GIS	Geographic Information System
GLOBK	GLOBAL Kalman filtering
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GMT	Generic Mapping Tools
IGS	International GNSS Service
MATLAB	Matrix Laboratory
MLE	Maximum Likelihood Estimation
PSD	Power Spectral Density
RINEX	Receiver Independent Exchange Format
SCIGN	Southern California Integrated GPS Network
SINEX	Solution Independent Exchange Format
SNR	Signal toNoise Ratio
UNAVCO	University NAVSTAR Consortium
WN	White Noise

CHAPTER ONE

INTRODUCTION

1.1. Background to the study

The Global Positioning System (GPS) is a widely used method for gathering geodetic measurements in Earth research (Herring, 1999). GPS provides accurate measurements of the locations and velocities of GPS stations over time, making GPS time series an essential tool in geodetic and geophysical research (Amiri-Simkooei et al., 2007). Time series are vital in various areas of observation and data collection (Le Bail, 2006) and are frequently utilized for monitoring crustal deformation, analyzing tectonic plate motion, and conducting atmospheric investigations (Williams, 2003).

However, the precision and reliability of GPS time series can be affected by several types of noise, such as white noise, flicker noise, and brown noise (Langbein & Johnson, 1997). Noise in this context refers to random variations or disturbances present in the measured geodetic data obtained from GPS stations, which obscure the true underlying signal or movement being studied. Noise in GPS time series can arise from multiple sources, including instrumental errors, environmental factors, and geophysical effects. Instrumental errors may result from imperfections in the GPS receiver's design, calibration, or measurement process. Environmental factors, such as atmospheric disturbances, temperature fluctuations, and ground vibrations, can also introduce noise in GPS measurements. Additionally, geophysical effects, such as tectonic activities and post-glacial rebound, contribute to the noise observed in GPS time series data (Langbein & Johnson, 1997).

These noise components introduce errors and uncertainties into the analysis, undermining the accuracy of the results. Several studies have shown that daily geodetic measurements of position or distance changes exhibit temporal correlations rather than being simply independent observations (Langbein & Johnson, 1997; Zhang et al., 1997; Mao et al., 1999; Williams, 2004; Beavan, 2005). These temporal correlations have significant impacts on the estimations of standard error rates obtained by applying least squares fitting a linear trend in time to the deformation time series (Langbein & Johnson, 1997; Williams, 2003; Langbein, 2004).

The noise present in GPS deformation time series can comprise both white noise and dominant colored noise due to various factors, such as geophysical effects and system defects related to GNSS technology (Ma, 2023). Ignoring colored noise can lead to greater uncertainty in the estimation of deformation parameters. The characterization of noise in geodetic data has been explored using power law noise models in the frequency domain. For instance, some studies have used the power law index, n, to describe the noise process in GPS measurements (Langbein & Johnson, 1997; Mao et al., 1999; Zhang et al., 1997), with flicker noise ($n = 1$) identified as the best fit in certain cases (Mao et al., 1999; Zhang et al., 1997). However, other research has found that power law noise with an index between flicker and random walk ($n = 1$ or $n = 2$) characterizes the noise for sites from regional networks after removing common-mode signals (Williams, 2004).

Moreover, the design of GPS monuments can also influence the noise characteristics in the GPS time series. Williams (2004) investigated the relationship between monument design and noise volume, revealing that deeply braced monuments displayed less temporally correlated noise compared to other monument types used in the Southern California Integrated GPS Network (SCIGN).

To achieve accurate and significant results, it is crucial to detect and reduce noise sources in GPS time series. Different methods, such as maximum likelihood estimation and power spectral density analysis, have been employed for defining the frequency content of time series data and detecting noise. However, more research is still needed to assess the effectiveness of various noise detection techniques and their applicability to GPS time series processed with GAMIT/GLOBK, a widely used software program for processing GPS data, and examined with MATLAB, a powerful numerical computing environment.

Hence, this dissertation aims to address these gaps in knowledge by examining the noise properties of GPS time series from CORS stations and developing a systematic approach to identify different types of noise present in these time series. Data processing in this study involves a series of steps in handling the raw GPS measurements acquired from various stations. The data processing procedures encompass data collection, quality control, error correction, and analysis to obtain meaningful and accurate results. Using GAMIT/GLOBK and MATLAB, this research has processed GPS time series and performed power spectral density analysis to characterize noise components accurately. The findings of this study contribute to the understanding of noise identification in GPS time series, providing valuable information for practitioners and researchers in the fields of geodesy and related disciplines.

1.2. Problem statement

Despite the widespread use of Global Positioning System (GPS) time series in geodetic and geophysical research, the accuracy and reliability of these time series can be compromised by various types of noise, including white noise, flicker noise, and brown noise. The presence of noise in GPS time series can introduce errors and uncertainties in data analysis, leading to inaccurate results and interpretations. Although there are existing methods for noise detection and correction, there is a need for further research to investigate the performance of these methods when applied to GPS time series processed with GAMIT/GLOBK and analyzed using MATLAB.

This research aims to address this problem by developing a systematic approach for detecting and analyzing different types of noise in GPS time series from CORS stations. The research will involve the processing of GPS time series using GAMIT/GLOBK, followed by power spectral density analysis using MATLAB. The research will also explore the characteristics of different types of noise in GPS time series, their impact on the accuracy of GPS measurements, and the effectiveness of different noise detection methods. By addressing this problem, the research seeks to contribute to the existing body of knowledge on noise detection in GPS time series and provide valuable insights for improving the accuracy and reliability of GPS measurements in geodetic and geophysical research.

1.3. Objectives of research

1.3.1. Main Objectives

The main objective of this research is to develop a systematic approach for detecting and analyzing different types of noise in GPS time series from CORS stations, after removing blunders, systematic and random errors in the observation data.

1.3.2. Specific objectives

i) To assess the noise characteristics of GPS time series from CORS stations.
ii) To evaluate the performance of different noise detection methods, including power spectral density analysis, for identifying and quantifying noise in GPS time series.
iii) To investigate the impact of different types of noise on the accuracy and reliability of GPS measurements.
iv) To provide recommendations for improving the accuracy and reliability of GPS measurements by mitigating the effects of noise in time series data.

v) To contribute to the existing body of knowledge on noise detection in GPS time series and provide valuable insights for dissertators and researchers.

1.4 Scope and Limitations

The scope of this research is focused on the analysis of GPS time series data of one year (2015) obtained from CORS stations. It will involve the detection and analysis of different types of noise in the time series data, including white noise, flicker noise, and brown noise. The main method used for noise detection is power spectral density analysis and time series were processed using GAMIT/GLOBK software

Limitations of this research

i) Availability and quality of data

The accuracy and reliability of the research findings may be influenced by the availability and quality of the GPS time series data from CORS stations, which are subject to various factors such as data gaps, outliers, and measurement errors. In some years you may find there is no availability of the data caused by different factors encounter to receiver errors and failure.

ii) Assumptions and simplifications

The research may make certain assumptions and simplifications in the noise detection and correction methods, which may have limitations and uncertainties.

iii) Generalizability of findings

The research findings may be limited in their generalizability to other GPS time series data or other geodetic/geophysical settings, as the research is focused on a specific context and methodology.

1.5. Significance

The significance of this research lies in its aim to improve GPS time series accuracy by detecting and mitigating noise in CORS station data. It can enhance reliability of GPS measurements, contribute to methodological advancements, and have practical applications in geodesy and geophysics.

i) Improved accuracy and reliability of GPS measurements

By developing a systematic approach for detecting and analyzing different types of noise in GPS time series data from CORS stations, this research has the potential to improve the accuracy and reliability of GPS measurements. Identifying and mitigating the effects of noise in the data can lead to more precise and trustworthy results, which can be valuable in various geodetic and geophysical applications.

ii) Enhanced understanding of noise characteristics in GPS data

Through the application of power spectral density analysis and other data analysis techniques, this research can provide insights into the characteristics of different types of noise in GPS time series data. This can contribute to a better understanding of the nature and behavior of noise in GPS measurements, which can be beneficial for future research and development in the field of geodesy and geophysics.

iii) Methodological contributions to noise detection in GPS data

This research can contribute to the existing literature by proposing a systematic approach for detecting and analyzing different types of noise in GPS time series data. This can be valuable for researchers and dissertators in the field of geodesy and geophysics, as it can provide a methodological framework for identifying and mitigating noise in GPS data, particularly from CORS stations.

iv) Practical applications for geodetic and geophysical studies

The findings of this research can have practical applications in various geodetic and geophysical studies, such as geodetic network analysis, crustal deformation monitoring, and geophysical modeling. By improving the accuracy and reliability of GPS measurements, this research can contribute to more robust and accurate results in these areas, which can have implications for geodetic and geophysical research, as well as practical applications in fields such as engineering, geosciences, and environmental sciences.

1.6. Research organization

The research is organized into five chapters to provide a systematic and comprehensive analysis of the topic.

Chapter One serves as the introduction, providing a background to the study. It highlights the significance of accurate analysis of Global Positioning System (GPS) time series in geodetic and geophysical research. The problem statement is presented, emphasizing the challenges posed by various types of noise in GPS measurements. The chapter outlines the objectives of the research, including both the main objectives and specific objectives. Additionally, the scope and limitations of the study are discussed, followed by an explanation of its significance.

Chapter Two focuses on the literature review, delving into the relevant concepts and existing knowledge. It provides an overview of GPS reference stations, including the International GNSS Service (IGS) and Continuously Operating Reference Station (CORS). The various types of noise in GPS data, such as white noise, flicker noise, and brown noise, are discussed. The chapter also explores the sources of noise in GPS data and introduces the concept of power spectral density. Furthermore, it examines the processing software used in the research, specifically GAMIT/GLOBK and MATLAB. Finally, related studies in the field are reviewed to provide context and support for the current research.

Chapter Three outlines the methodology employed in the research. It describes the process of data identification and collection. The chapter then explains the data processing steps, such as creating a working directory, tables, and updating site information. It also covers running sh_gamit to generate results, as well as generating time series plots using Xb in GMT. The concept of GPS time series is introduced, followed by a detailed explanation of power spectral density analysis.

Chapter Four presents the results and analysis of the research. It starts with an introduction to the chapter, followed by a detailed examination of power spectral density analysis. The estimated spectral index is discussed, and the results are analyzed. The interpretation of the findings is provided, highlighting the specific characteristics of noise in the Easting, Northing, and Up components of the GPS signals for each station. Finally, a summary of the results is presented.

Chapter Five concludes the research and offers recommendations. The chapter summarizes the main findings of the study and draws conclusions based on the analysis. It also provides recommendations for mitigating the effects of noise in GPS time series analysis.

CHAPTER TWO

LITERATURE REVIEW

This chapter covers various aspects of GPS reference stations and their use in geodetic applications. The International GNSS Service (IGS) and Continuously Operating Reference Stations (CORS) are discussed as important sources of GPS data. The types of GPS noise, including white, flicker, and brown noise, are described along with their sources. Power spectral density and processing software such as GAMIT/GLOBK and MATLAB are also reviewed. Lastly, related studies in this field are briefly introduced. Overall, this literature review provides a comprehensive overview of the relevant concepts and tools in GPS reference station data analysis.

2.1. GPS reference stations

2.1.1. International GNSS Service (IGS)

The International GNSS Service (IGS) station is a network of continuously operating GNSS reference stations located around the world that provide high-precision GNSS data for a wide range of scientific, commercial, and educational applications (Dow et al., 2009). IGS was established in 1992 by the International Association for Geodesy and it officially formally operations in 1994. IGS mainly provided GPS data in the early days of its establishment and it is now beginning to provide orbit and clock data of other GNSS. IGS is composed of more than 300 tracking stations, data analysis and processing centers, and data publishing centers worldwide as shown in Figure 2.1 (Mengshi et al., 2022).

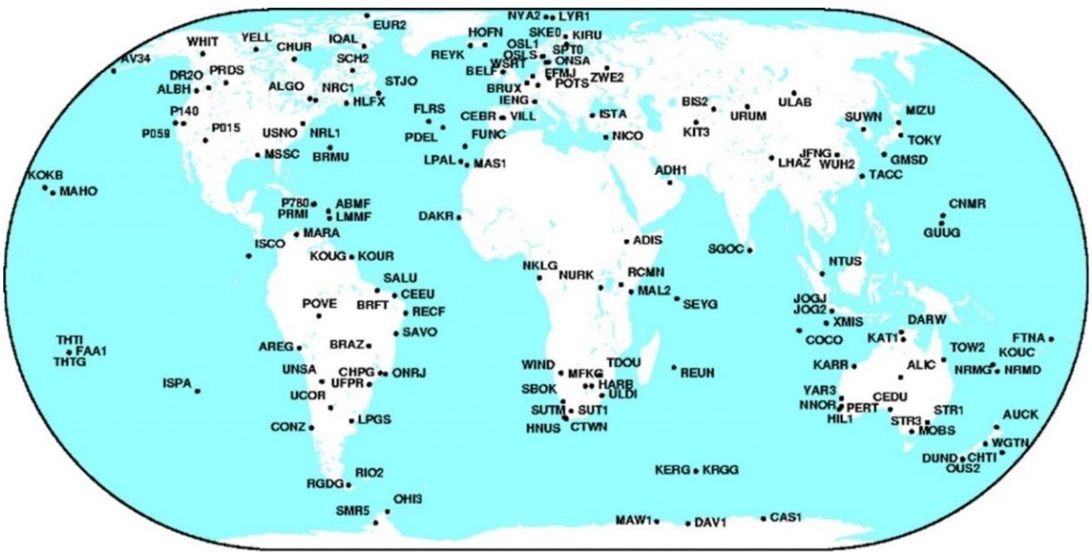


Figure 2.1: Global distribution of stations of the IGS network (google)

The data collected by the IGS stations are used for a variety of applications, including geodesy, geophysics, surveying, navigation, and space weather monitoring (Feltens & Schaer, 1998). The data are freely available to users worldwide and are distributed via the internet in various formats, including RINEX (Receiver Independent Exchange Format) and SINEX (Solution Independent Exchange Format) (Dow et al., 2009).

The IGS stations use state-of-the-art GNSS receivers and antennas to collect high-quality data at a rate of one sample per second or higher (Dow et al., 2009). The data are processed using sophisticated algorithms and software to estimate precise GNSS orbits, clock corrections, and other parameters needed for high-precision positioning and navigation (Dow et al., 2009).

The IGS station network is maintained and operated by a consortium of international organizations, including government agencies, universities, and research institutions (Kouba, 2009). The IGS is funded by these organizations, as well as by user fees and contributions from private sector partners.

2.1.2. Continuously operating reference station (CORS)

Continuously Operating Reference Stations is a network of stations that provide GNSS data consisting of carrier phase and code range measurements in support of 3D positioning, meteorology, space weather, and geophysical applications (Subhalakshmi, 2021). The CORS network is a multi-purpose cooperative endeavor involving government, academic, and private organizations. The sites are independently owned and operated. Each agency shares their data with NGS, and NGS in turn analyzes and distributes the data free of charge. The CORS network contains 2000+ stations, by different organizations, and is expanding.

A CORS comprises a GPS receiver operating continuously and antenna set up in a stable manner at a safe location with a reliable power supply for continuously streaming raw data. The first reference stations were set up along coastlines to transmit DGPS corrections to improve the accuracy of ship navigation (Subhalakshmi, 2021). Today, reference stations are being established all over the world in large numbers to monitor the Earth's crust, provide geodetic control, support surveying, precise positioning, machine control, engineering, GIS data collection, monitor man-made and natural structures etc.

Continuously operating reference station (CORS) GPS networks have increased in number and application over the last decade. Nowadays such high quality GPS networks are also used for ionospheric mapping, precipitable water vapour predictions and to provide correction information for regional differential GPS users (Roberts et al., n.d.).

2.2. GPS noise

In GPS time series, "noise" refers to random fluctuations in the signal that are not related to the underlying signal of interest. These fluctuations can be caused by errors in GPS measurements, atmospheric effects, and other environmental factors. Two techniques used to access the noise characteristics of geodetic time series are the power spectral Method (PSD) and the Maximum likelihood estimation (MLE) which aimed to examine the data in covariance matrix in time (space) domain, using maximum likelihood estimation (MLE) the numerical values of the noise model can be estimated (Bos et al., 2008). CATS software package is an example of the program that uses maximum likelihood estimation (MLE) to find the parameters of the noise model that best fit the residual of time series (King & Williams, 2009).

2.2.1. White noise

It is a random signal with a constant power spectrum across all frequencies shown in Figure 2.2 (Calais, n.d.). White noise can be caused by measurement errors or other random fluctuations in the signal. Random signal with samples uncorrelated in time: e.g., position error at time t does not depend on error at t+dt. The effect of white noise can be greatly reduced through frequent measurement and averaging (Mao et al., 1999)

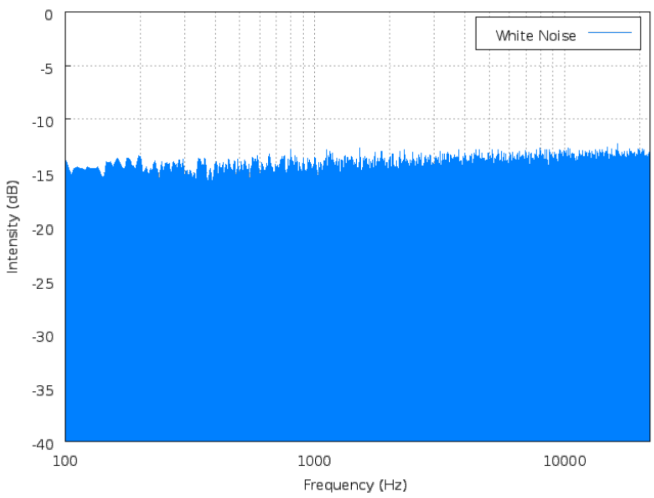


Figure 2.2: White noise (Calais, n.d.)

2.2.2. Flicker noise

Also known as 1/f noise or pink noise, it has a power spectrum that decreases inversely with frequency. In other words, the power in the noise decreases as the frequency increases (time-correlated) as shown in Figure 2.3 (Mao et al., 1999). Flicker power proportional to 1/f (Calais, n.d.).Flicker noise can be a source of error in GPS time series analysis, especially at lower frequencies.

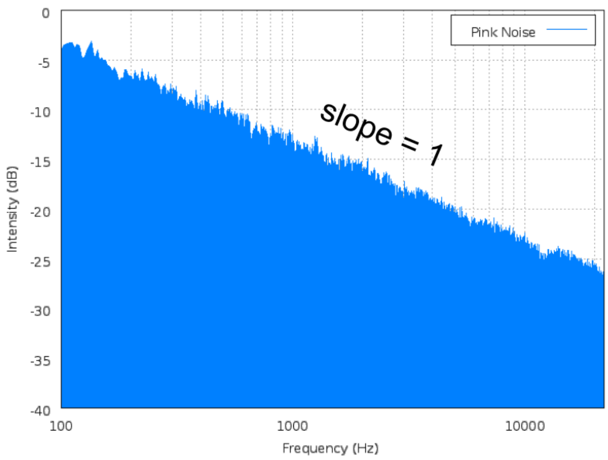


Figure 2.3: Flicker noise (Calais, n.d.)

2.2.3. Brown noise

It is a random signal with a non-constant power spectrum or random signal with samples correlated in time, Random power proportional to 1/f2 as shown in Figure 2.4 (Calais, n.d.). Colored noise can be caused by various sources, such as seasonal variations in the atmosphere or other environmental effects.

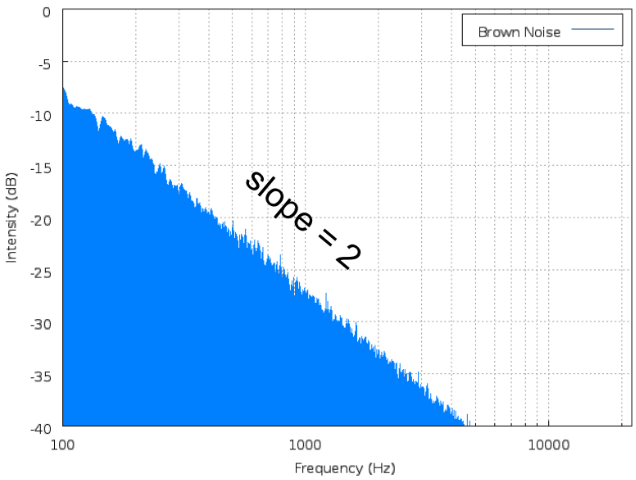


Figure 2.4: Brown noise (Calais, n.d.)

2.3. Sources of noise in GPS data

Global Positioning System (GPS) time series data are prone to various sources of noise, which can affect the accuracy and reliability of the analysis. In order to obtain accurate results from GPS time series data, it is crucial to identify and characterize the different sources of noise which are

i) Atmospheric Delays

Atmospheric delays, caused by tropospheric and ionospheric effects, are known sources of noise in GPS time series data (S. Williams et al., 1998). Tropospheric delays are caused by changes in temperature, pressure, and humidity, and can be modeled using meteorological data (S. Williams et al., 1998). Ionospheric delays, caused by solar radiation and ionization of the upper atmosphere, can be eliminated by using dual-frequency receivers (Bilich et al., n.d.).

ii) Multipath Effects

Multipath effects, which occur when GPS signals reflect off surfaces before reaching the receiver antenna, can introduce biases and noise in GPS time series data (King & Williams, 2009). Techniques such as antenna calibration, signal processing filters, and the use of multipath-free receivers or antennas have been proposed to mitigate multipath effects (King & Watson, 2010).

iii) Receiver and Antenna Biases

Receiver and antenna biases, arising from hardware characteristics, can introduce noise in GPS time series data (Richard, 1997). Calibration techniques, empirical or semi-empirical models, and differential techniques have been proposed to estimate and correct for receiver and antenna biases (King & Watson, 2010)

iv) Orbital Errors

Orbital errors, resulting from inaccuracies in satellite orbits, clock modeling, and satellite positioning, can introduce noise in GPS time series data (Amiri-Simkooei et al., 2007). Precise ephemeris data, orbit correction models, and differential techniques have been proposed to mitigate orbital errors (King & Watson, 2010).

v) Geological and Geophysical Signals

GPS time series data can also contain signals related to geological and geophysical processes, such as crustal deformation and tectonic plate motion (Wang et al., 2012). Time series modeling, spectral analysis, and statistical tests have been proposed to identify and characterize these signals in GPS time series data (Wang et al., 2012).

2.4. Power spectral density

Power spectral density (PSD) is a commonly used technique in signal processing for analyzing the frequency content of a signal (Langbein & Johnson, 1997b). It provides information about the distribution of power across different frequencies in a signal, which can be useful for identifying and characterizing the spectral characteristics of a signal. PSD is widely used in various fields, including communication systems, audio processing, vibration analysis, and image processing (Langbein, 2004).

PSD is typically calculated using Fourier transform-based techniques, such as the periodogram, Welch's method, or the multitaper method. These methods transform the signal from the time domain to the frequency domain, allowing for the analysis of signal power at different frequencies (Nourbagheri & Zohdy, 2016).

The power spectra, P_y, of many geophysical phenomena, including the noise in GPS position time series, are well approximated by a power law process (Amiri-Simkooei et al., 2007). The one-dimensional time behavior of the stochastic process is such that its power spectrum has the form

$$P_y(f) = P_0\left(\frac{f}{f_0}\right)^k \quad \text{...2.1}$$

where f is the temporal frequency, P_0 and f_0 are the normalizing constants, and k is the spectral index (Amiri-Simkooei et al., 2007a). Typical spectral index values lie within [-3, 1]; for stationary processes $-1 < k < 1$ and for nonstationary processes $-3 < k < -1$. A smaller spectral index implies a more correlated process and a more relative power at lower frequencies. Special cases within this stochastic process occur at the integer values for k. Classical white noise has a spectral index of 0, flicker noise has a spectral index of -1, and random walk noise has a spectral index of -2. The power spectral method can be employed to assess the noise characteristic of GPS time series.

2.5. Processing software

2.5.1. GAMIT/GLOBK

GAMIT/GLOBK is a software package used for precise GPS data processing. It is widely used in geodetic research and is known for its accuracy and reliability. The GAMIT/GLOBK software package includes several modules, including pre-processing, network adjustment, and post-processing. The pre-processing module includes several steps, including data editing, quality control, and file conversion.

GAMIT (GPS Analysis at MIT) is a widely used GPS data processing software that can be used to estimate precise positions of GPS receivers (Herring T, 1999). It uses a combination of relative and PPP techniques to achieve high accuracy (Teferle et al., 2007). GAMIT is known for its ability to process large datasets and is widely used in the field of geodesy. GLOBK is a Kalman filter whose primary purpose is to combine various geodetic solutions such as GPS, VLBI and SLR experiments (Herring T, 1999).

2.5.2. MATLAB

MATLAB is a widely used numerical computing environment and programming language in scientific and engineering communities (Lanagran-Soler et al., 2015). It provides a user-friendly and interactive environment for data analysis, simplifying the processing of GNSS data and the visualization of results. Moreover, MATLAB includes a large library of functions and toolboxes, enabling various mathematical operations and data processing tasks such as filtering, smoothing, and statistical analysis. Additionally, MATLAB offers a flexible and extensible platform for customizing and automating GNSS data processing, providing an opportunity for integration with other tools and functions (Lanagran-Soler et al., 2015). In the context of this study, MATLAB can be utilized as a powerful tool for processing GNSS data and analyzing the noise characteristics of the data, potentially contributing to the development of more accurate GNSS positioning techniques.

2.6. Related Studies

Wang et al., (2016) proposes a method called singular spectrum analysis (SSA) for reconstructing a reliable model from unevenly sampled GPS time series data with missing data and gross errors. This method allows for simultaneous interpolation and detection of gross errors without requiring prior knowledge of the time series data. Results from simulation and real GPS data testing showed that SSA is an efficient method for interpolation and gross error detection. This study addresses the need for robust detection and interpolation procedures to obtain a uniform time series for various geospatial studies and applications, and highlights the limitations of traditional methods that rely on improper assumptions.

Gazeaux et al., (2013) investigates the effectiveness of methods for detecting and removing offsets in Global Positioning System (GPS) time series, which degrade the accuracy of the data. To assess these methods, they designed and managed the Detection of Offsets in GPS Experiment and simulated time series data with realistic components including velocity, offsets, white and flicker noise. They made the data set available to the GPS analysis community without revealing the offsets, and blind tests were conducted with a range of detection approaches. Results show that manual methods, where offsets are hand picked, provide better results than automated or semi-automated methods. The smallest detectable offset for the best manual and automatic solutions was found to be 5 mm and 8 mm, respectively, and robust geophysical interpretation of individual site velocities lower than 0.2-0.4 mm/yr is not robust. The study concludes that further work is needed to improve offset detection in GPS time series before interpreting sub-mm/yr velocities for single GPS stations can be routinely achieved.

Amiri, (2009)developed a methodology to analyze multivariate GPS coordinate time-series, which is relevant to this research on noise identification in GPS time series. The study applied least-squares variance component estimation (LS-VCE) to estimate full covariance matrices among different series and adopted various stochastic models to assess the noise characteristics of multivariate time-series. The results of the study showed that the correlation between a series of different coordinate components per station is not significant, but the spatial correlation between different stations for individual components is significant. This study's findings provide insights into the noise characteristics of multivariate GPS time series, which can contribute to the development of more accurate noise detection and mitigation techniques.

Williams, (2004) aimed to analyze the noise content in continuous GPS position time series. A total of 954 time series from 414 individual sites in nine different GPS solutions were analyzed using maximum likelihood estimation (MLE). The noise was assumed to be white noise only, a combination of white noise plus flicker noise, or a combination of white noise plus random walk noise. The spectral index and amplitude of the power law noise were estimated simultaneously with the white noise. The results showed that the noise can be best described by a combination of white noise plus flicker noise. The amplitudes of both noise components showed a latitude dependence, with higher values at equatorial sites and a bias to larger values in the Southern Hemisphere. In addition, the study revealed that the noise is significantly lower in regional solutions where a spatially correlated (common mode) signal has been removed. The study also compared the noise amplitudes to different monument types in the Southern California Integrated GPS Network and suggested that the deep drill braced monument is preferred for maximum stability. Overall, the study provided valuable insights into the noise characteristics of continuous GPS position time series and highlighted the importance of proper monument selection for maximum stability.

CHAPTER THREE

METHODOLOGY

This chapter provides an overview of the methods and procedures which were used to analyze noise in GPS time series. It covers data identification, collection, data pre-processing and actual processing to the final output. The chapter also highlights the data processing procedures and various softwares used in this study.

3.1. Data identification

The study area for this research encompasses CORS stations located in various parts of Tanzania, including Mbeya, Dodoma, Geita, Arusha, and Mtwara. Additionally, IGS (International GNSS Service) stations from different parts of the world, such as ADIS, ASRG, DEAR, HARB, MAL2, MAS1, MBAR, NKLG, REUN, SBOK, SEY1, SUTH, TDOU, WIND, YKRO, and ZAMB, are also included in the study, as shown in Figure 3.1. These stations have been selected for their availability of GPS time series data, which will be processed and analyzed to investigate the noise characteristics and improve the accuracy of the measurements.

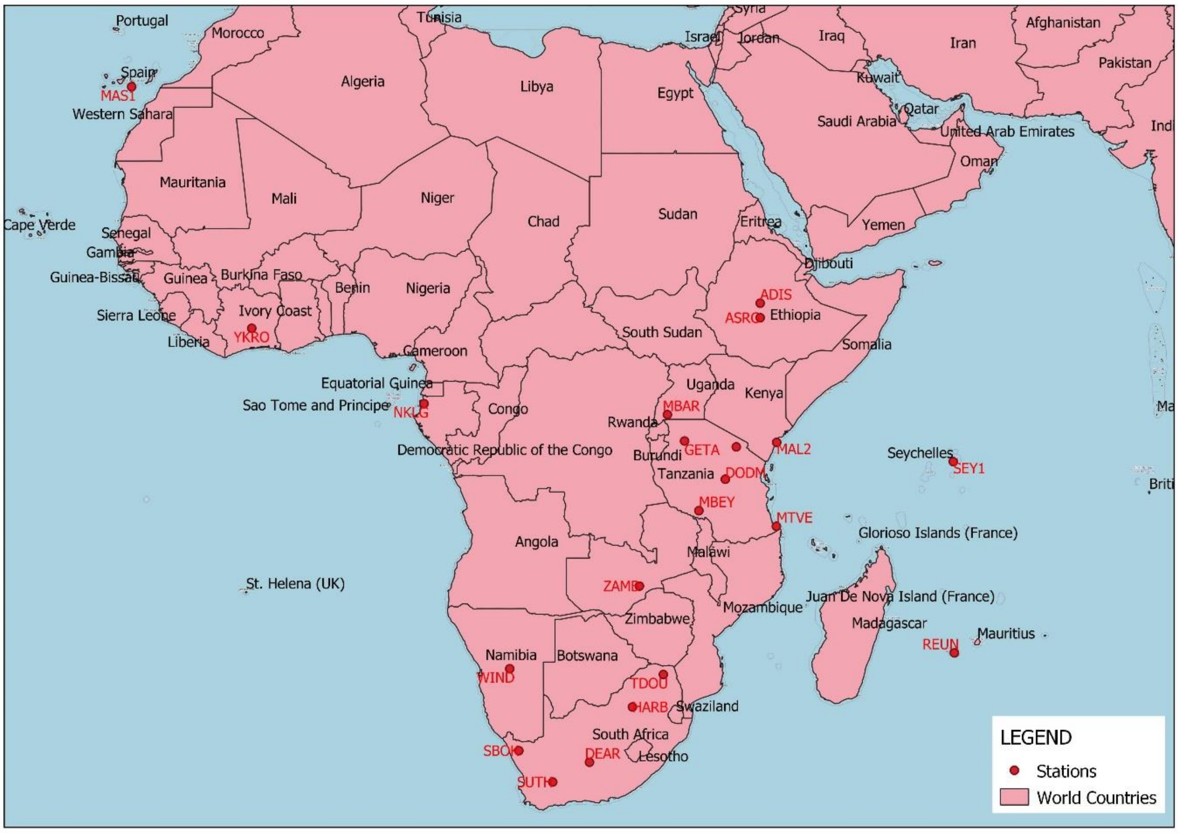


Figure 3.1: Distribution of IGS and CORS stations around the world used for this research

For IGS and CORS stations the informations and data were downloaded from various sources, such as the IGS and UNAVCO websites. Table 3.1 presents the positions of the sites used in this research, along with additional information on the IGS and CORS stations. The data for this table has been sourced from UNAVCO (https://www.unavco.org/), a reliable and reputable data provider in the field of geodesy and geophysics

Table 3.1: IGS and CORS station informations (https://www.unavco.org/)

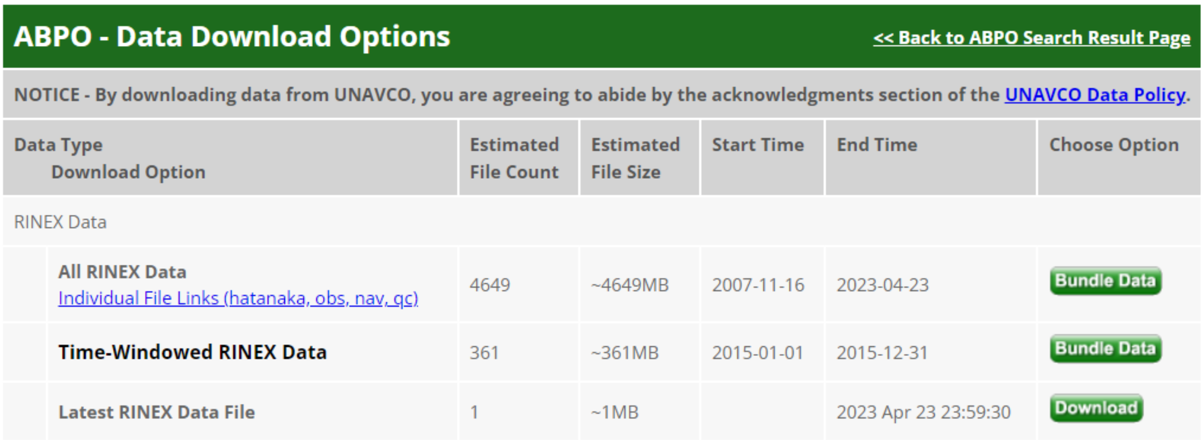
Station code	**Latitude**	**Longitude**	**Station name**	**Station type**
ADIS	9.035° N	38.766° E	Addis Ababa University	IGS
ARSH	3.387° S	36.698° E	Arusha Ministry of Energy and Minerals	CORS
ASRG	7.780° N	38.767° E	Southern Rim	IGS
DEAR	30.665° S	23.993° E	DE AAR	IGS
DODM	6.186° S	35.748° E	Dodoma	CORS
GETA	2.881° S	32.217° E	GEITA	CORS
HARB	25.887° S	27.707° E	Hartebeesthoek	IGS
MAL2	2.996° S	40.194° E	Malindi	IGS
MAS1	27.764° N	15.633° W	Maspalomas	IGS
MBAR	0.601° S	30.738° E	Mbarara	IGS
MBEY	8.912° S	33.459° E	Mbeya Ministry of Energy and Minerals	CORS
MTVE	10.260° S	40.166° E	MTWARA	CORS
NKLG	0.354° N	9.672° E	N'KOLTANG (GABON)	IGS
REUN	21.208° S	55.572° E	La Reunion - Observatoire Volcanologique	IGS
SBOK	29.669° S	17.879° E	SPRINGBOK	IGS
SEY1	4.674° S	55.479° E	SEY1	IGS
SUTH	32.380° S	20.810° E	Sutherland	IGS
TDOU	23.080° S	30.384° E	THOHOYANDOU	IGS
WIND	22.575° S	17.089° E	Windhoek	IGS
YKRO	6.871° N	5.240° W	Yamoussoukro	IGS
ZAMB	15.426° S	28.311° E	Lusaka – Zambia	IGS

3.2. Data collection

The accurate and reliable collection of data is critical in any scientific research, including Global Navigation Satellite System (GNSS) time series analysis. In this study, data from CORS stations located in Tanzania and IGS stations worldwide were utilized to improve the accuracy of GNSS time series analysis by addressing noise issues. This section describes the methods used to obtain the data from these sources in detail.

To obtain the required data, the GAMIT software was used, which allows for precise positioning and processing of GNSS data. A script was created with specified parameters, including the year (2015), day of the year (1 to 365), and station location, to download the Rinex files for the named stations. The script was executed to retrieve the data from GAMIT, which was then processed further for analysis. This method ensured that the data obtained was precise and aligned with the specific requirements of the research.

An alternative method to obtain data was through the UNAVCO website, which provides access to GNSS data via the Data Access Interface version 1 (DAIv1). The DAIv1 allows for filtering and searching of permanent station data based on various criteria, such as station code, network, region, operational status, data rate, temporal and spatial constraints, and monument/equipment types (Consortium, 2021). The data download option is available after selecting the desired station, and the data is retrieved in Rinex format for further analysis. Once the desired station is selected, the data download options are displayed, as shown in Figure 3.2 for station ABPO.



ABPO - Data Download Options << Back to ABPO Search Result Page

NOTICE - By downloading data from UNAVCO, you are agreeing to abide by the acknowledgments section of the UNAVCO Data Policy.

Data Type / Download Option	Estimated File Count	Estimated File Size	Start Time	End Time	Choose Option
RINEX Data					
All RINEX Data Individual File Links (hatanaka, obs, nav, qc)	4649	~4649MB	2007-11-16	2023-04-23	Bundle Data
Time-Windowed RINEX Data	361	~361MB	2015-01-01	2015-12-31	Bundle Data
Latest RINEX Data File	1	~1MB		2023 Apr 23 23:59:30	Download

Figure 3.2: the data download options for the IGS/CORS stations (UNAVCO)

The combination of data obtained from CORS and IGS stations, using both GAMIT scripts and UNAVCO website, ensured the availability of precise and reliable data for the analysis of GNSS time series in this research. The rigorous data collection process enhanced the accuracy and validity of the findings, enabling robust conclusions to be drawn from the research findings.

3.3. Data processing

Prior to processing the time series data using GAMIT/GLOBK, thorough preparations were made, and the data was organized into respective folders for the specific year 2015. GAMIT/GLOBK is a comprehensive GPS analysis package developed by MIT, the Harvard Smithsonian Center for Astrophysics (CfA), Scripps Institution of Oceanography (SIO), and Australian National University. It is utilized for estimating station coordinates and velocities, post-seismic deformation, atmospheric delays, satellite orbits, and Earth orientation parameters (Herring et al., 2015).

3.3.1 Creation of the Working Directory

To facilitate the processing of the data for the year 2015, a mother directory named "2015" was created. Within this directory, several subdirectories were established, including "rinex," "igs," "brdc," and "gsoln as shown in Figure 3.3." The "rinex" directory contains data for the experiment sites and reference control stations (IGS stations). The rinex data for 2015 was placed in this directory, and the "station.info" file was reviewed and edited to ensure accuracy. Additionally, the rinex folder serves as a location to download rinex data using the GAMIT script.

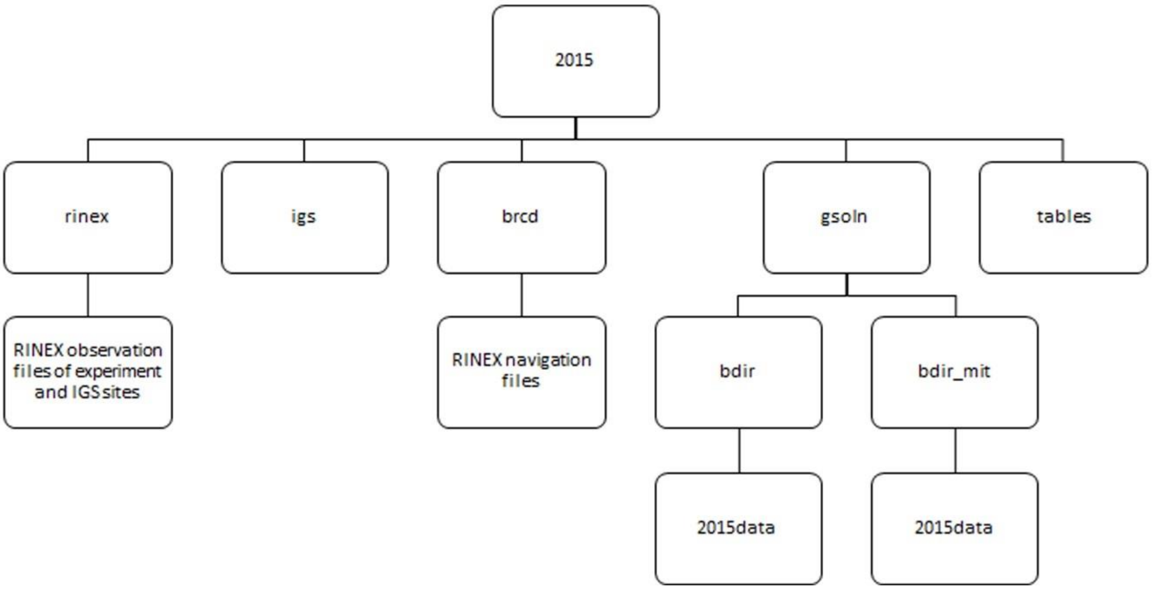


Figure 3. 3: Workflow for processing GNSS data by using GAMIT/GLOBK software

To download the precise orbital data and satellite lock corrections information, a directory named "igs" was created. The required data were obtained from various archieves such as garner.ucsd.edu/pub/rinex/WEEK by executing the “get_orb”.

The "brdc" directory holds the satellite navigation information, which were downloaded from garner.ucsd.edu/pub/rinex/YEAR/DAY using the "get_e" command.

The "gsoln" directory is used for running solutions and contains command files, a list of binary h files, experiment list files, and GLOBK output files. Within the "gsoln" directory, four subdirectories are created: "bdir," "bdir_mit," "globk," and "glred."

The "bdir" directory is used to store the gamit output which are loosely constrained daily least squares adjustment for the station coordinates (h files) for the specific year. It is recommended to create a subdirectory within "bdir" named after the corresponding year to organize the output files effectively.

The "bdir_mit" directory holds the loosely constrained solutions (h) files downloaded from MIT.

The "globk" directory is used to run globk commands to obtain position and velocity estimates.

The "glred" directory is utilized for running glred, which uses combined h-files as input to generate position time series.

3.3.2 Creation of Tables

The gamit tables directory was set up within the year directory by executing "2015> sh_setup -yr." This command copies the default tables folder from "~/gg/" to initialize gamit. The tables directory contains setup and metadata information of each station for the year 2015. Several files related to station information, such as "lfile," "lfile.old," "igs14_comb.apr," and "station.info," are included in the created tables directory (Valerie, 2020).

3.3.3 Updating Site Information in the station.info File

Before updating the station information, it is essential to ensure that the rinex files for all sites intended for processing are present in the rinex directory. To create the "station.info" tables, the following command was executed: "sh_upd_stnfo -l sd." The output file was named "station.info.new" and subsequently renamed to "station.info." The "station.info" file was then updated using the experiment and IGS sites from the rinex directory through the command "sh_upd_stnfo –files /rinex/*.15o." This command extracts information from the RINEX header for each site in the respective year.

3.3.4 Running sh_gamit to Generate O-files and h-files

Once the table directory setup and update were completed, the "sh_gamit" tool, which encompasses several GAMIT processes to create daily constrained and loosely constrained estimates, was executed at the year level directory as the script show in Figure 3.4. Before running the "sh_gamit" command, it is important to verify that the orbital information (final orbit) and satellite navigation data are located in the "igs" and "brdc" directories, respectively.

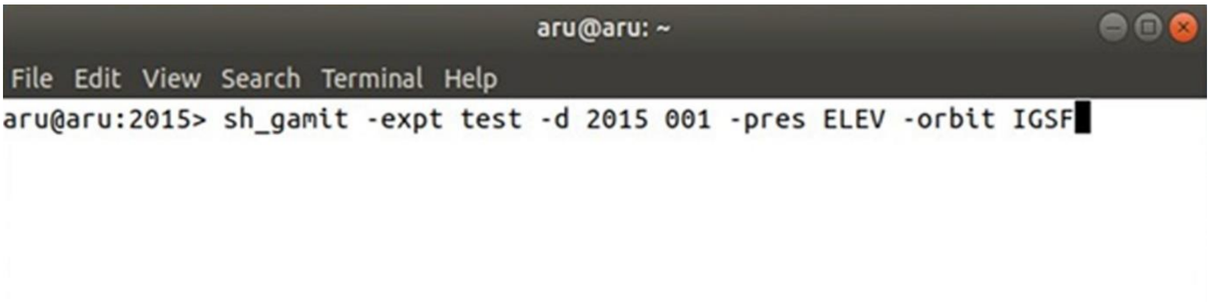


Figure 3. 4: Sh_gamit command for processing day 001

The following steps were performed during the execution of "sh_gamit":

i) Assign parameters of the program flow, giving precedence to command-line arguments, parameters set in process.Defaults and sites.Defaults, and default assignments within "sh_gamit" itself.

ii) Create the day directory and/or standard directories if they do not exist.

iii) Link the standard tables using script links (day) and the RINEX files containing data at 24-hour intervals into the day directory.

iv) Run "makexp" to create input files for "makex" (scal.makex.Batch) and "fixdrv."

v) Run "sh_check_sess" to ensure that all satellites included in the RINEX observation files are present in the navigation file and the g-file (created previously at MIT from an IGS sp3 file).

vi) Run "sh_make" to create a j-file of satellite clock estimates from the sp3 file.

vii) Run "makex" to create x-files (observations) and k-files (receiver clock estimates) using phase and pseudorange data from RINEX obs, nav, and j-file.

viii) Run "fixdrv" to generate the batch file for GAMIT processing.

ix) Execute the batch run to generate a tabular orbital ephemeris (arc), model the phase observations (model), edit the data (autcln), estimate parameters (solve), and save the cleaning summary.

x) Create sky plots of phase residuals and plots of phase vs. elevation angle using the DPH files written by "autcln."

xi) Invoke "sh_cleanup" to delete or compress files as specified by "-dopt" and "-copt."

Following these steps, numerous output files are generated, with the O-files and h-files being of particular interest. These files represent the results of the processing operation.

The script used to process all data in "sh_gamit" for both experiment and IGS sites is presented in Figure 3.5 as a sample for day 301 to 367.

3.3.5 Generating Time Series Plots using Xb in GMT

To plot the time series of GPS stations, the operational tool "Xb" in GMT was utilized. Xb is the tool that extracts baseline and positional components from O files and plot time series. The following script was employed to plot the time series:

xb -m y -st 1 -ps y

After executing the script, the generated files were arranged using the "awk" program with the command:

*ls *.ps | awk '{ print "ps2pdf", $1 }'*

This command converts the time series outputs from PS format to PDF format for easier presentation and documentation.

3.4. GPS time series

The processing of GPS time series data using the results from GAMIT/GLOBK software was done by xb tool in GMT for four stations: ARSH, DODM, MBEY, and MTVE. The results of the time series analysis are presented, focusing on the plots of the processed data using the GMT module in GAMIT.

Each time series plot represents the observed displacements of the GPS station in three components: Easting, Northing, and Up. These plots provide a visual representation of the variations and trends in the GPS measurements over time. It should be noted that due to missing data, not all time series plots cover a full year of data. The available data ranges from December 2014 to December 2015 for ARSH, December 2014 to September 2015 for DODM, December 2014 to October 2015 for MBEY, and December 2014 to June 2015 for MTVE.

The time series plots serve as a valuable tool for understanding the behavior of the GPS stations. They enable researchers to observe any notable patterns, trends, or irregularities in the data. Additionally, the plots provide insights into the presence of noise and disturbances that can affect the accuracy and reliability of the GPS measurements.

ARSH station:

The time series plot for the ARSH station represents the observed displacements of the GPS station in three components: Easting, Northing, and Up. The plot covers the period from December 2014 to December 2015. The plot provides a visual representation of the variations and trends in the GPS measurements over time for ARSH as shown in Figure 3.5. It allows us to observe any notable patterns, trends, or irregularities in the data and provides insights into the presence of noise and disturbances that can affect the accuracy and reliability of the GPS measurements.

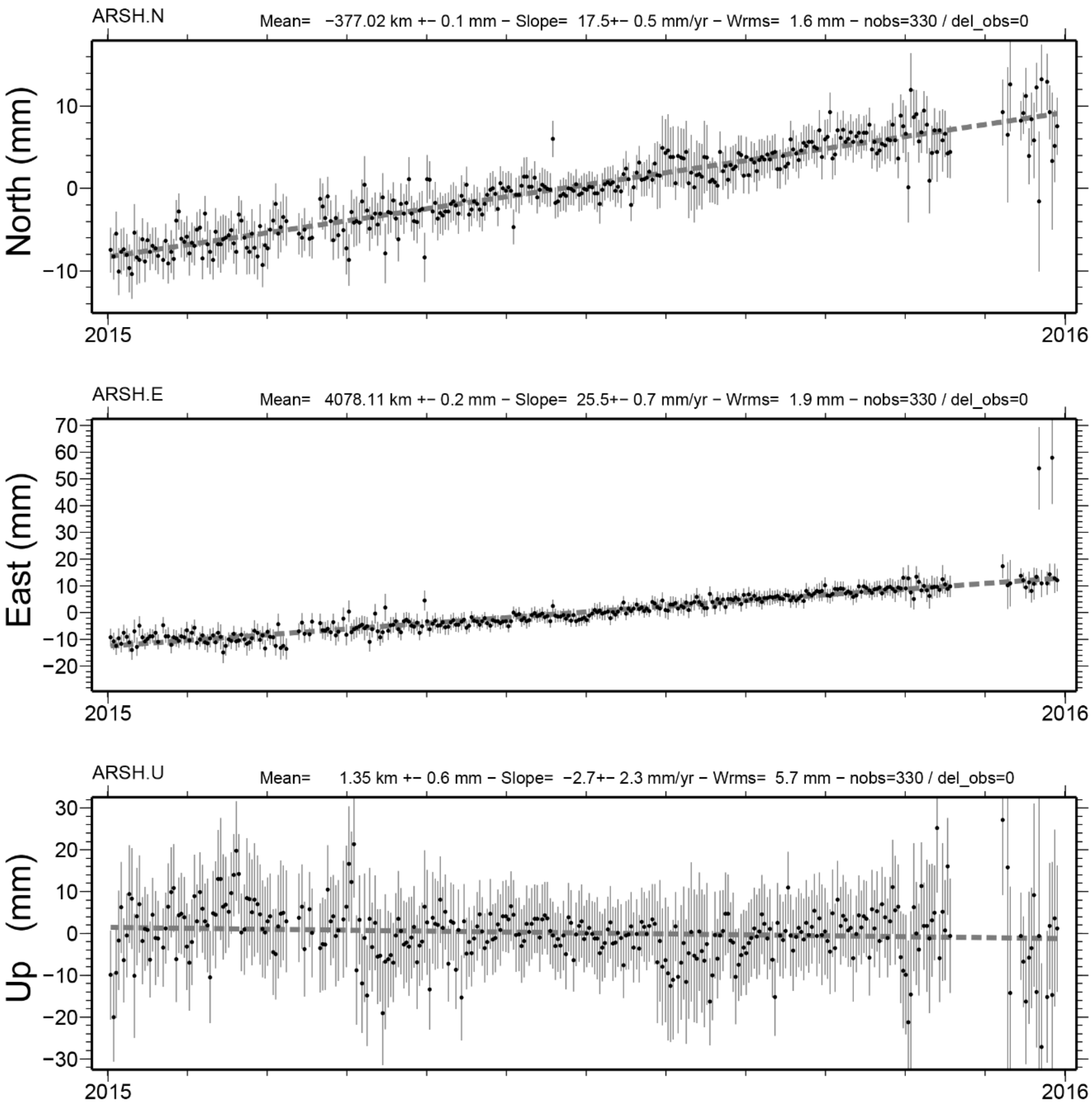


Figure 3.5: Time series plot of the observed displacements for the ARSH GPS station

DODM station:

The time series plot for the DODM station displays the observed displacements of the GPS station in the Easting, Northing, and Up components. The plot covers the period from December 2014 to March 2015 and then skips to June 2015, ending in September 2015 as shown in Figure 3.6. By analyzing this plot, researchers can gain insights into the variations and trends in the GPS measurements over time for DODM within this limited time frame. Although the plot does not cover a full year of data due to missing data points, it still provides valuable information about the behavior of the DODM station during the available time period.

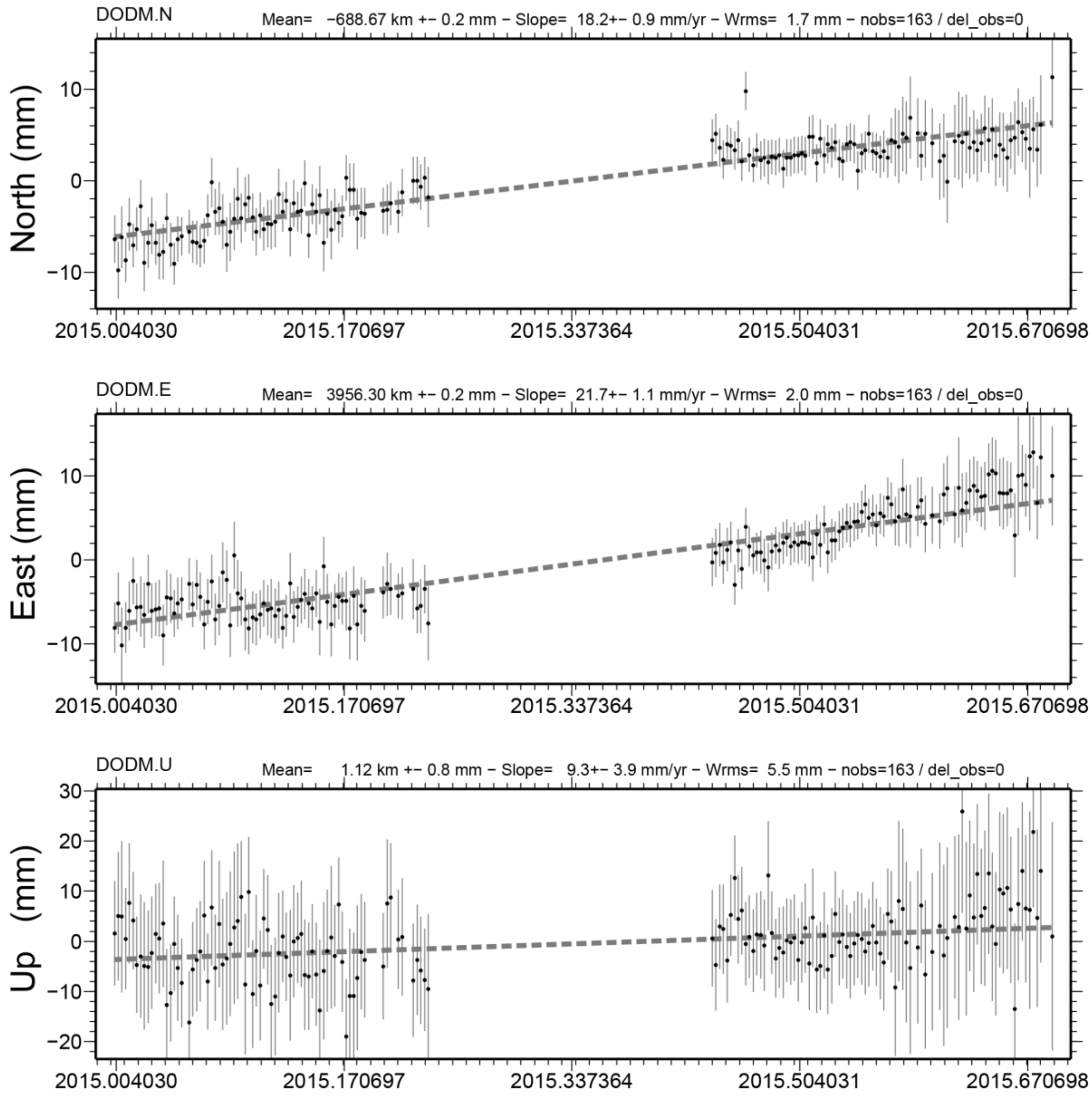


Figure 3.6: Time series plot of the observed displacements for the DODM GPS station

MBEY station:

The time series plot for the MBEY station depicts the observed displacements of the GPS station in the Easting, Northing, and Up components. The plot covers the period from December 2014 to October 2015 as shown in Figure 3.7. By examining this plot, researchers can gain insights into the variations and trends in the GPS measurements over time for MBEY. The plot enables the identification of significant patterns, trends, or irregularities in the data, including the presence of noise or disturbances that could impact the accuracy of the GPS measurements.

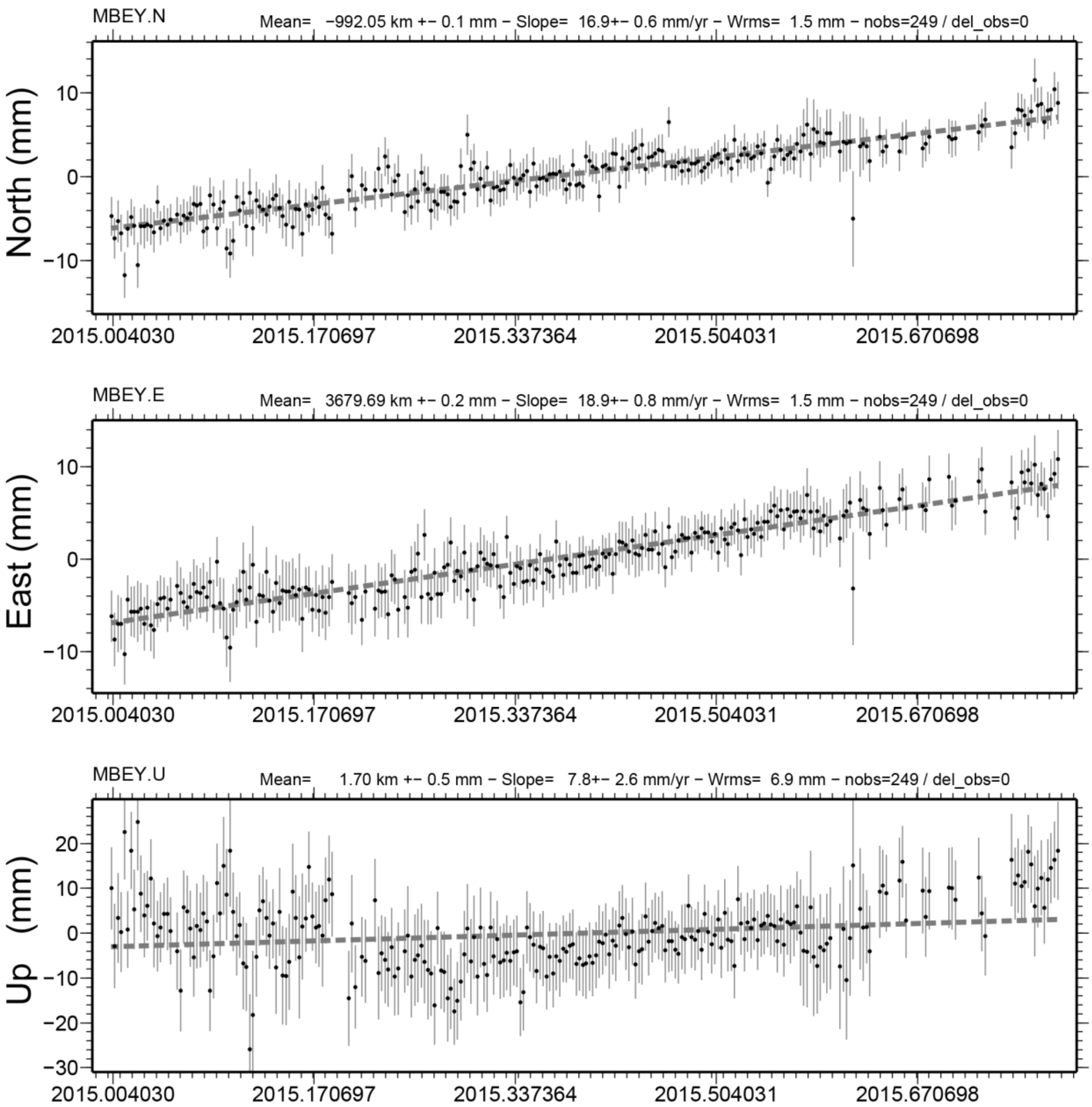


Figure 3.7: Time series plot of the observed displacements for the MBEY GPS station

MTVE station:

The time series plot for the MTVE station illustrates the observed displacements of the GPS station in the Easting, Northing, and Up components. The plot covers the period from December 2014 to June 2015 as shown in Figure 3.8. Analyzing this plot allows researchers to understand the variations and trends in the GPS measurements over time for MTVE. The plot facilitates the identification of significant patterns, trends, or irregularities in the data, including the presence of noise or disturbances that might affect the accuracy of the GPS measurements.

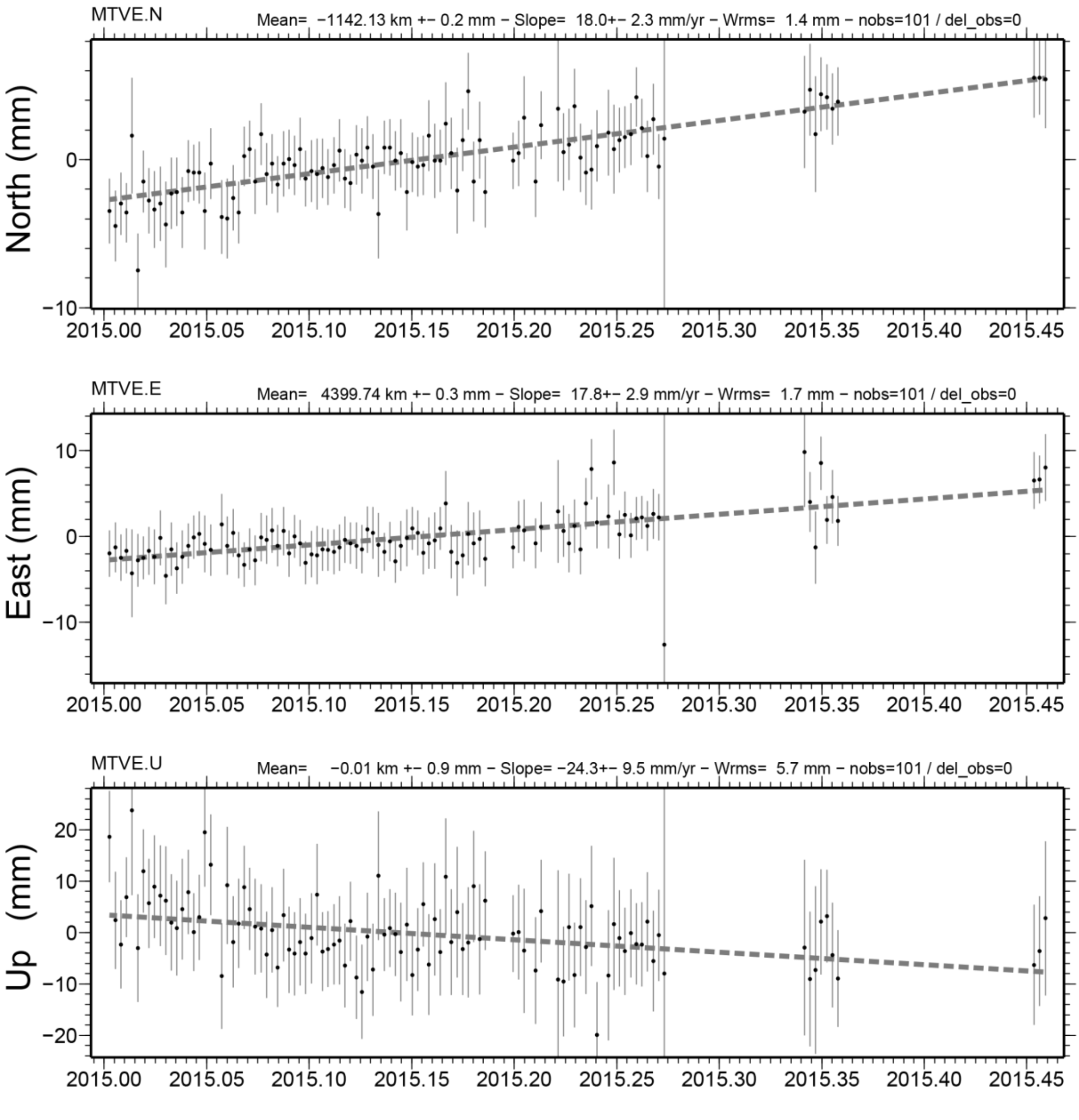


Figure 3.8: Time series plot of the observed displacements for the MTVE GPS station

3.5. Power spectral density

Power spectral density plotted in MATLAB 2018b to detect noise in four GPS stations follow the following procedures

1. Load the data from the CSV file:

```
data = readtable('MTWARA.csv');
```

This code reads the data from the CSV file named 'MTWARA.csv' using the readtable function and stores it in the variable data.

2. Extract the relevant columns from the data:

```
time = table2array(data(:, 1));
easting = table2array(data(:, 2));
northing = table2array(data(:, 3));
up = table2array(data(:, 4));
```

These lines extract the columns containing time, easting, northing, and up values from the data table and store them in separate variables.

3. Convert time to numeric representation:

```
time_num = datenum(time);
```

This code converts the time values to a numeric representation using the datenum function and stores the result in the time_num variable.

4. Calculate the time difference in seconds:

```
time_diff = seconds(diff(time_num));
```

This line calculates the time difference between consecutive time values in seconds using the diff function and the seconds function. The result is stored in the time_diff variable.

5. Calculate the sampling frequency:

```
Fs = 1 / mean(time_diff);
```

This code calculates the sampling frequency by taking the reciprocal of the mean of the time_diff values. The sampling frequency is stored in the variable Fs.

6. Resample the data at a constant time step:

```
t_new = linspace(time_num(1), time_num(end), numel(time_num));
% New time vector
```

```
easting_new = interp1(time_num, easting, t_new);
northing_new = interp1(time_num, northing, t_new);
up_new = interp1(time_num, up, t_new);
```

These lines resample the easting, northing, and up data to have a constant time step. The linspace function is used to generate a new time vector t_new with the same number of elements as the original time vector. The interp1 function is then used to interpolate the easting, northing, and up values at the new time points.

7. Perform the Fourier transform and calculate the power spectral density:

```
N = length(easting_new); % Length of resampled data
% Fast Fourier Transform for Easting component
Y_easting = fft(easting_new);
P2_easting = abs(Y_easting) / N;
P1_easting = P2_easting(1:round(N/2)+1);
P1_easting(2:end-1) = 2 * P1_easting(2:end-1);
f_easting = Fs * (0:round(N/2)) / N;
psd_easting = P1_easting.^2;
```

These lines perform the Fourier transform on the resampled easting data using the fft function. The resulting complex values are then converted to the power spectral density (PSD) by taking the absolute value and dividing by the length of the data (N). The PSD is further processed to eliminate duplicate values and calculate the corresponding frequency vector.

The same process is repeated for the northing and up components, resulting in the variables P1_northing, f_northing, psd_northing, P1_up, f_up, and psd_up.

8. Plot the power spectral density:

```
figure;
subplot(3, 1, 1);
plot(log10(f_easting), log10(psd_easting), 'b');
xlabel('Frequency (Hz)');
ylabel('Power/Frequency (dB/Hz)');
title('Easting Power Spectral Density');
```

These lines create a figure with three subplots, each representing the power spectral density for the easting, northing, and up components. The plot function is used to plot the PSD values against the corresponding frequencies. The axes labels and titles are also set.

10. Perform linear regression to estimate the spectral indexes:

```
% Find indices of non-zero power
nonzero_easting = psd_easting > 0;
nonzero_northing = psd_northing > 0;
nonzero_up = psd_up > 0;
% Perform linear regression on log-log scale
fit_easting = polyfit(log10(f_easting(nonzero_easting)), log10(psd_easting(nonzero_easting)), 1);
fit_northing = polyfit(log10(f_northing(nonzero_northing)), log10(psd_northing(nonzero_northing)), 1);
fit_up = polyfit(log10(f_up(nonzero_up)), log10(psd_up(nonzero_up)), 1);
% Get the spectral indexes (slope of the linear fit)
spectral_index_easting = fit_easting(1);
spectral_index_northing = fit_northing(1);
spectral_index_up = fit_up(1);
```

These lines perform linear regression on the log-log scale using the polyfit function. The regression is applied to the frequencies and PSD values with non-zero power. The resulting coefficients are stored in the fit_easting, fit_northing, and fit_up variables. The spectral indexes are obtained by extracting the slope (fit_easting(1), fit_northing(1), fit_up(1)).

11. Display the estimated spectral indexes:

```
disp(['Easting Spectral Index: ' num2str(spectral_index_easting)]);
disp(['Northing Spectral Index: ' num2str(spectral_index_northing)]);
disp(['Up Spectral Index: ' num2str(spectral_index_up)]);
```

These lines display the estimated spectral indexes in the command window using the disp function.

That's a summary of the processes and codes in the script. The script reads the GPS time series data, resamples it, calculates the power spectral density, removes specific frequency components if needed, plots the PSDs, performs linear regression, and displays the estimated spectral indexes, it also shown in Figure 3.9.

Figure 3.9: The procedures for plotting PSD to detect the noise in Time series

CHAPTER FOUR

RESULTS AND ANALYSIS

In this chapter, the results obtained from the analysis of power spectral density (PSD) of four GPS stations in Tanzania are presented and analyzed. The aim of this analysis was to detect the presence of GPS noise and determine its spectral characteristics. The spectral index, which represents the slope of the linear fit on a log-log scale, was used to identify the type of noise present in each station. This chapter provides an interpretation of the results to determine the type of noise observed in each GPS station.

4.1 Power Spectral Density Analysis

The analysis of power spectral density (PSD) is a fundamental technique for investigating the spectral characteristics of time series data. In this study, the PSD analysis was applied to the recorded GPS data from the four selected stations: ARSH, DODM, MBEY, and MTVE. The analysis involved calculating the power/frequency distribution across different frequencies in the GPS signals.

By examining the PSD plots, it becomes possible to detect the presence of noise and determine its spectral characteristics. Noise in GPS signals can arise from various sources, such as atmospheric disturbances, multipath reflections, receiver electronics, and environmental factors. Each noise source introduces specific spectral properties, which can be discerned through the analysis of PSD.

The analysis was conducted over a period of one year, providing a comprehensive overview of the noise characteristics in the GPS signals. The time series data were sampled at a consistent time step, ensuring accurate frequency representation in the PSD analysis. This allowed for the identification of noise components with different spectral indices, shedding light on the nature of the noise affecting each GPS station.

By combining the PSD analysis with further statistical techniques, such as linear regression, it becomes possible to estimate the spectral index and determine the type of noise present in each GPS station. This information is valuable for understanding the sources and characteristics of noise, as well as for developing appropriate noise mitigation strategies.

ARSH station:

Figure 4.1 shows the power spectral density (PSD) plot for the ARSH GPS station in Tanzania. The PSD provides information about the distribution of power across different frequencies in the GPS signal. The x-axis represents the frequency in Hz, while the y-axis represents the power/frequency in dB/Hz.

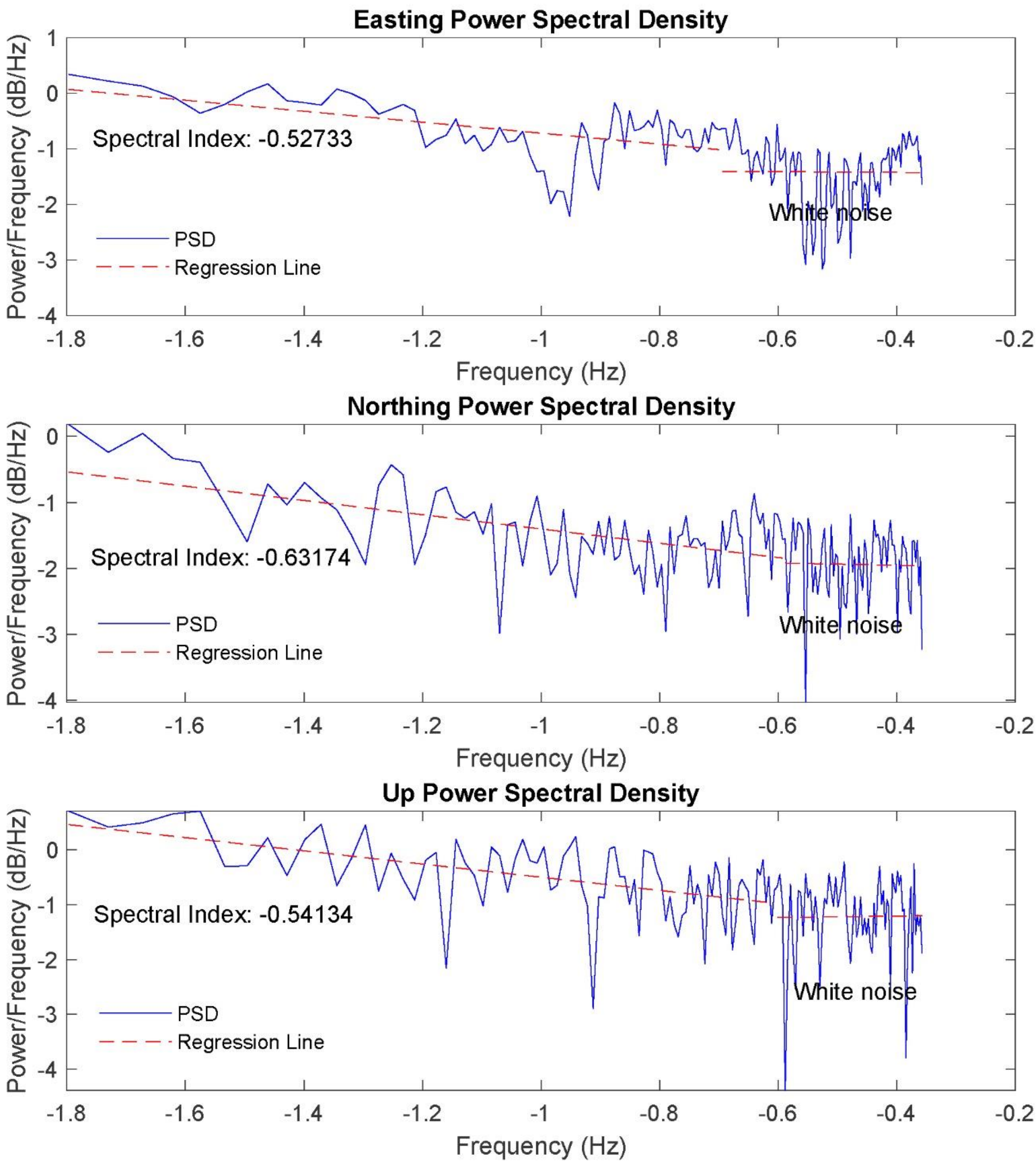


Figure 4.1: Power Spectral Density of ARSH GPS Station

DODM station:

Figure 4.2 displays the power spectral density (PSD) plot for the DODM GPS station in Tanzania. The PSD analysis helps in understanding the power distribution across various frequencies in the GPS signal. The x-axis represents the frequency in Hz, while the y-axis represents the power/frequency in dB/Hz.

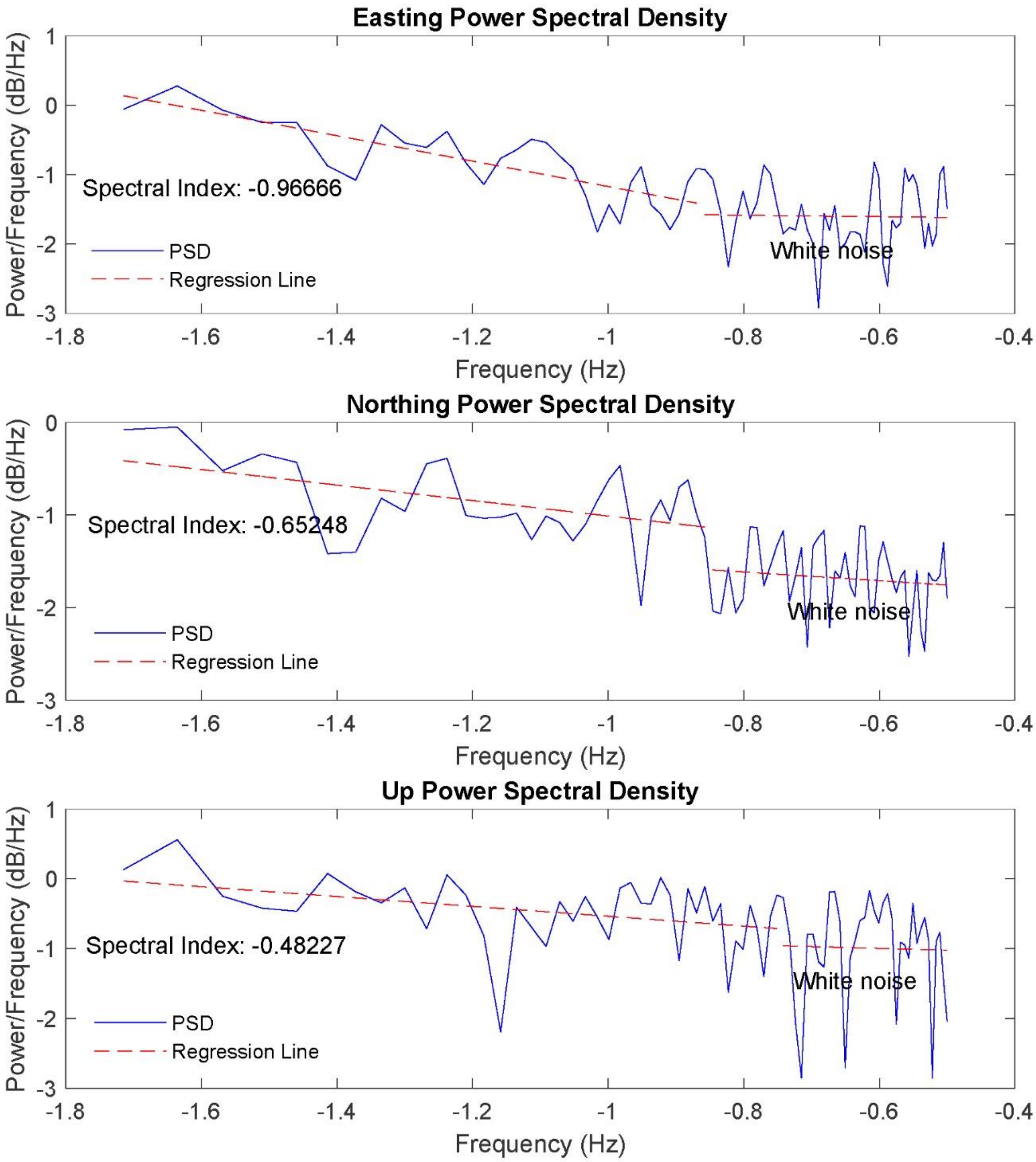


Figure 4.2: Power Spectral Density of DODM GPS Station

MBEY station:

Figure 4.3 illustrates the power spectral density (PSD) plot for the MBEY GPS station in Tanzania. The PSD analysis provides insights into the power distribution across different frequencies in the GPS signal. The x-axis represents the frequency in Hz, while the y-axis represents the power/frequency in dB/Hz.

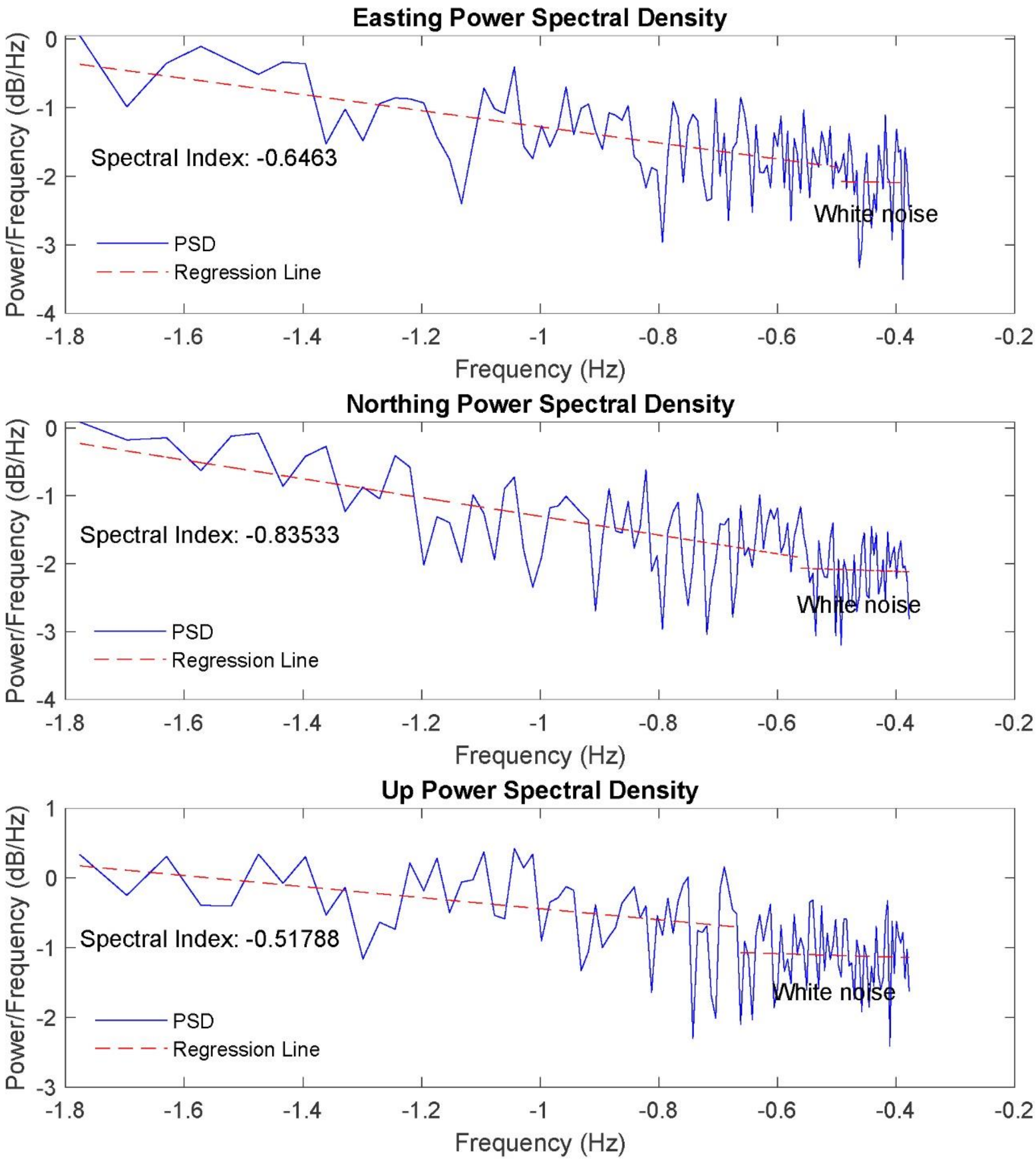


Figure 4.3: Power Spectral Density of MBEY GPS Station

MTVE station

Figure 4.4 exhibits the power spectral density (PSD) plot for the MTVE GPS station in Tanzania. The PSD plot helps visualize the power distribution across various frequencies in the GPS signal. The x-axis represents the frequency in Hz, while the y-axis represents the power/frequency in dB/Hz.

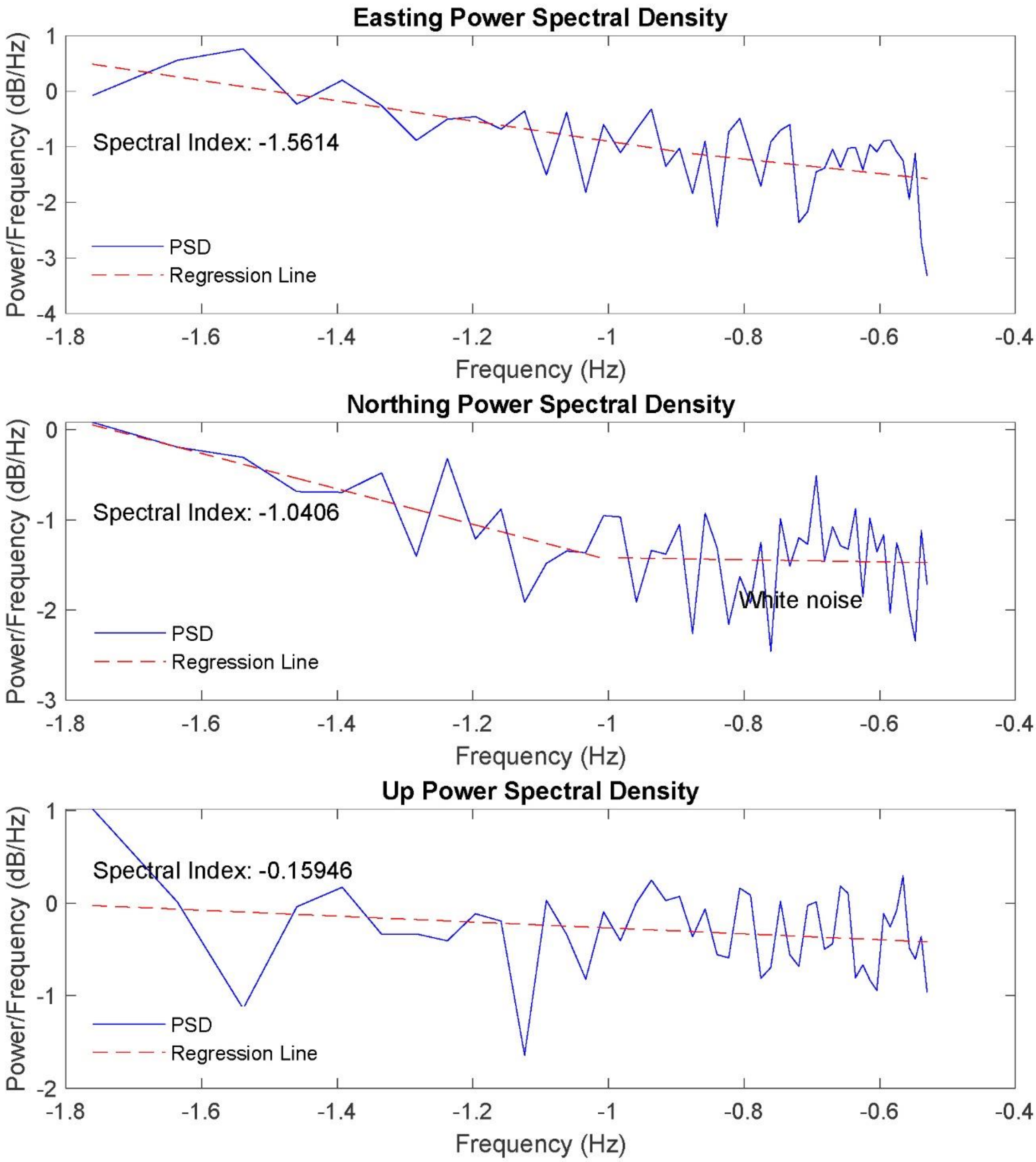


Figure 4.4: Power Spectral Density of MTVE GPS Station

4.2 Estimated Spectral Index

The estimated spectral indexes Table 4.1 for each GPS station were calculated based on the linear regression performed on the log-log scale of the PSD plots. It provides insights into the type of noise present in the GPS signal.

Table 4.1: Estimated spectral index

STATION	EASTING	NORTHING	UP
ARSH	-0.52733	-0.63174	-0.54134
DODM	-0.96666	-0.65248	-0.48227
MBEY	-0.6463	-0.83533	-0.51788
MTVE	-1.5614	-1.0406	-0.15946

4.3 Interpretation of Results

Based on the estimated spectral indexes, the type of noise present in each GPS station can be determined. The spectral index values can be compared with the known spectral characteristics of different types of noise.

In the case of the ARSH station, the estimated spectral indexes indicate that the noise in the Easting, Northing, and Up components of the GPS signal exhibits flicker-like characteristics. Not only flicker noise there is also presence of white noise in both components of ARSH GPS station. Flicker noise is characterized by a spectral index close to -1, indicating a decrease in power with increasing frequency.

For the DODM station, the estimated spectral indexes suggest that the noise in the Easting, Northing and UP components follows a flicker-like pattern, also there is the presence of white noise in which is the noise due to instrument. White noise has the spectral index of 0, Flicker noise has the spectral index of -1.

In the MBEY station, the estimated spectral indexes indicate that the noise in the Easting, Northing and Up components follows a flicker-like pattern, hence there is presence of white noise.

Lastly, for the MTVE station, the estimated spectral indexes suggest that the noise in the Easting component exhibits brown-like noise characteristics. Brown noise has a spectral index of -2, indicating a more pronounced decrease in power with increasing frequency compared to flicker noise. The Northing and Up shows characteristics similar to white noise. White noise has a spectral index of 0, indicating a constant power distribution across all frequencies

These findings indicate that different types of noise, including flicker, white, and brown noise, are present in the GPS signals from the analyzed stations. The presence of noise with specific spectral characteristics can impact the accuracy and reliability of GPS measurements, and further analysis and mitigation strategies may be required to minimize its effects.

4.4 Summary

The results obtained from the analysis of power spectral density for the four GPS stations in Tanzania were presented and interpreted. The estimated spectral indexes provided insights into the type of noise present in each station, including flicker, white, and brown noise. These noises are caused by different factors such as Atmospheric Delays, Multipath Effects, Receiver and Antenna Biases, Orbital Errors, Geological and Geophysical Signals, hence white noise is caused by the instrumental errors. These findings highlight the importance of understanding the spectral characteristics of GPS noise to improve the accuracy and reliability of GPS measurements. Further analysis and mitigation strategies can be explored based on these results to minimize the impact of noise on GPS signals.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this research, a systematic approach was developed to detect and analyze different types of noise in GPS time series from CORS stations. The analysis involved processing the GPS time series using GAMIT/GLOBK and performing power spectral density (PSD) analysis using MATLAB. The estimated spectral indexes provided valuable insights into the characteristics of noise in the GPS signals, allowing for the identification of different types of noise, including flicker, white, and brown noise.

The results obtained from the analysis indicate that the presence of noise with specific spectral characteristics can have a significant impact on the accuracy and reliability of GPS measurements. The estimated spectral indexes revealed that the noise in the Easting, Northing, and Up components of the GPS signals from different stations exhibited varying characteristics, suggesting the presence of different types of noise in each component.

For the ARSH station, the Easting, Northing, and Up components exhibited flicker characteristics, indicating a decrease in power with increasing frequency. Also there is the presence of white noise in all components. The DODM station showed flicker noise in the Easting, Northing and Up component. In the MBEY station, the Easting, Northing and Up components exhibited flicker characteristics. Lastly, for the MTVE station, the Easting component displayed characteristics similar to brown noise with a more pronounced decrease in power with increasing frequency, Easting and Up displayed characteristics similar to white noise with a constant power distribution across all frequencies.

These findings emphasize the importance of understanding and mitigating the effects of noise in GPS time series analysis. The identified noise characteristics provide insights into the sources and impact of noise in GPS signals, enabling researchers and practitioners to develop strategies for minimizing its effects and improving the accuracy and reliability of GPS measurements.

5.2 Recommendations

Based on the research findings, several recommendations can be made for further investigation and improvement in the field of GPS time series analysis:

1. Develop Noise Mitigation Strategies: The identified noise characteristics can guide the development of effective noise mitigation strategies. Further research can focus on investigating and implementing advanced filtering and signal processing techniques tailored to specific noise types and characteristics.
2. Explore Additional Noise Sources: While this research focused on commonly known noise sources, it is important to consider and investigate other potential noise sources that may impact GPS time series. Environmental factors, receiver biases, and atmospheric effects are among the areas that warrant further exploration.
3. Enhance Data Collection and Processing Techniques: Continuously improve data collection methodologies, including receiver calibration, antenna selection, and data quality control procedures. Additionally, explore advancements in data processing algorithms and software tools to enhance the accuracy and reliability of GPS time series analysis.

By following these recommendations, future research in the field of GPS time series analysis can further advance our understanding of noise characteristics and contribute to the development of improved techniques for accurate and reliable GPS measurements.

In conclusion, this research has provided valuable insights into the presence and characteristics of noise in GPS time series from CORS stations. The analysis of power spectral density and estimation of spectral indexes revealed the existence of different noise types, including flicker, white, and brown noise, in the GPS signals. The findings emphasize the need for noise detection and mitigation strategies to enhance the accuracy and reliability of GPS measurements in geodetic and geophysical research. By implementing the recommendations outlined above, researchers and practitioners can contribute to the ongoing efforts to improve the quality of GPS time series analysis and its applications in various fields.

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