ARDHI UNIVERSITY

DETERMINATION OF SOIL MOISTURE CONTENT VARIATION USING GNSS INTERFEROMETRIC REFLECTROMETRY (GNSS-IR) TECHNIQUE

MACHEMBA ABDALLAH H

BSc Geomatics

Dissertation

Ardhi University, Dar es Salaam

July, 2023

DETERMINATION OF SOIL MOISTURE CONTENT VARIATION USING GNSS INTERFEROMETRIC REFLECTROMETRY (GNSS-IR) TECHNIQUE

MACHEMBA ABDALLAH H

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

CERTIFICATION

The undersigned certify that they have proof read and hereby recommend for acceptance by Ardhi University Dissertation entitled "**Determination of Soil Moisture Content Variation Using GNSS Interferometric Reflectometry (GNSS-IR) Technique**" in Partial Fulfillment of the Requirement for the Degree of Bachelor of Science in Geomatics at Ardhi University.

…………………………………	…………………………………
Dr. Elifuraha Saria	**Ms. Valerie Ayubu**
(Main Supervisor)	(Second Supervisor)
Date 03/08/2023	Date 2023/08/04

DECLARATION AND COPYRIGHT

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

....

MACHEMBA ABDALLAH H

22754/T.2019

(Candidate)

ACKNOWLEDGEMENT

I would like to thank God who has been my strength and guidance in every step of my dissertation course. I also extend my sincere appreciation to my supervisors Dr. Elifuraha Saria and Ms. Valerie Ayubu for their constant support and guidance throughout this project.

I would like to extend appreciation to the staff members of Geospatial Science and Technology Department for their moral and academic support especially Mr. Timothy Joseph and Dr. Ahmada. Also, many thanks to Mr. Lameck Mkoy for his time he participated in completion of this research.

All my classmates and friends Johnson Kiluswa, Masatu Masatu, Salma Kodi, Daniel Sylvanus, Jailos Urema and Baraka Ngimbudzi for which we shared ideas concerning our research's this wouldn't have been possible without their support.

DEDICATION

I am thankful to my family, friends and the university staff for motivating me throughout my journey of this dissertation work. Thereby, I dedicate this dissertation work to my Mother, Mwajibu Bakari who has been my greatest support in all ways. My Brothers Salumu Machemba, Said Machemba and Ally Machemba who have been encouraging and cheering me up throughout my dissertation course. And also, my sisters Tatu Machemba and Ashura Machemba who have been my support in so many ways.

ABSTRACT

Soil moisture content plays a critical role in various environmental and agricultural processes, making its measurements and monitoring essential to the society. Traditional techniques for assessing soil moisture content are often limited in their spatial coverage and require extensive ground-based instrumentation. In recent years, Global Navigation Satellite System (GNSS) Interferometric Reflectometry (GNSS-IR) has emerged as a promising remote sensing technique for monitoring soil moisture content over large areas. This study applied GNSS-IR technique to determine soil moisture content variations by using data from Continuous Operating Reference Station (CORS) OLO3 and SNGC for 2017 and 2018. GNSS-IR leverages the signals transmitted by Global Navigation Satellite Systems, such as GPS, to estimate soil moisture content by analyzing the reflected signals from the Earth's surface. The interference between the direct and reflected signals provides valuable information about the soil moisture content along the GNSS signal path.

The research used data of the aforementioned CORS which were downloaded from UNAVCO and were processed using GIRAS software running in MATLAB version 2018b to extract the soil moisture information. Validation of the GNSS-IR measurements were conducted using Surface soil wetness of MERRA-2 data. The results show that the soil moisture over the case study areas have been decreasing over time. For OLO3 station the soil moisture trendline shows it has been decreasing over the years with minimum soil moisture content and for SNGC station the amount of soil wetness is still decreasing but not as fast as that of OLO3 station. GNSS-IR provides valuable insights into the spatial and temporal dynamics of soil moisture, enabling better understanding of hydrological processes and improving water resource management.

The findings of this study have important implications for agriculture, water resource management, and environmental monitoring. The GNSS-IR technique can aid in optimizing irrigation practices, predicting drought conditions, and assessing soil moisture availability for various applications. Further research and development in GNSS-IR can enhance its operational capabilities and enable its integration into existing monitoring networks for comprehensive soil moisture monitoring at regional and global scales.

Keywords: Global Navigation Satellite System (GNSS) Interferometric Reflectometry (GNSS-IR), Soil Moisture

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

CORS	Continuous Operating Reference Station
GIRAS	GNSS-IR analysis software
GNSS	Global Navigational Satellite System
GNSS-IR	GNSS Interferometric Reflectometry
SNR	Signal to Noise Ratio
GPS	Global Positioning System
RINEX	Receiver Independent Exchangeable Format
NGS	National Geodetic Survey
SSM	Surface Soil Moisture
SMC	Soil Moisture Content
TDR	Time Domain Reflectometry
GPR	Ground-Penetrating Radar
FFZ	First Fresnel Zone
TMA	Tanzania Meteorological Agency

CHAPTER ONE

INTRODUCTION

1.0 Overview

This chapter describes the background of the research, the related studies that have been done by other scholars, statement of the problem that influences the study of the research, main and specific objectives of the research, significance, beneficiaries, expected outputs, limitation and the study area of the research

1.1 Background

Tanzania is among many African countries whose people are mainly small-scale farmers that are the main producers of both food and cash crops. About 73% of its people live in rural areas, their main source of livelihood depends solely on subsistence farming where land becomes the most important commodity (Kimaro & Hieronimo, 2014). Due to climatic change variation which is not only associated with the rise in temperature, but also with the change in the global precipitation cycle, leading to variation in spatial and temporal precipitation patterns that affects the quantity and quality of available water resources especially soil moisture content, hence leading in increasing the competition among agriculture, ecosystems, settlements, industry, and energy sectors (Adhikari *et al.*, 2016).

In accordance to hydrological applications Soil moisture has been reported as being an important variable with respect to influencing climate change dynamics over specific area. Also, it is one of the key variables having significant importance for several earth and environmental science applications, which directly impact human society. It is one of the essential climate variables related to earth science applications like land-surface water balance and plays a major role in transporting moisture from land to atmosphere (Madhavi *et al.*, 2022). Apart from agricultural activities soil moisture affects the content of drought as it is coupled with rainfall deficit and poor rainfall distribution in which the recent droughts have led to food shortages, food insecurity, water scarcity, hunger and acute shortage of power (Osima, 2014). Hence this signifies the responsibilities of the country to account for soil moisture variation in climatic change.

The availability of moisture at the surface is of critical importance for plant growth. As such, assessing the long-term changes in soil moisture is important for the carbon cycle and agriculture, also soil moisture influences drought and flooding and plays an important role in climate change (Larson *et al.*, 2010). Thus, it can be used to show the trending and performing prediction on the climatic variation in the benefits of the societies in Tanzania. Currently there is no drought policy in place. However, the government and its various Ministries and Institutions have already made some efforts to address drought issues, in which TMA is the main government authority that provides daily, monthly and seasonal weather forecasts (Osima, 2014). The general purpose of TMA is to provide quality and reliable meteorological services to meet public and stakeholder's expectation thereby contributing to the protection of life and property, environment and national poverty eradication goal. TMA also provides updates of the previous weather/drought outlook which is released through various media of communication. For example, daily weather forecasting, seasonal outlook of rainfall and drought outlook conditions in the country (Osima, 2014). Methods employed in determination of amount of water content in the soil involves points measurements and remote sensing techniques, Point measurements involve the extraction of soil sample from the field and use techniques such as gravity measurements to determine the amount of water content within the soil, also remote sensing techniques involve the use of satellite image to analyses the reflection of active and passive microwaves emitted from the ground (Sharma *et al.*, 2018). The methods used has some challenges such that for point measurements it is time consuming, high cost of equipment purchase, radiation hazard involved in neutron dispersing technique, the method is that repeated sampling destroys the experimental area and for remote sensing technique the accuracy is affected by changing of the color of the soil (Rasheed *et al.*, 2022).

Another method that can be used in determination of soil moisture content is called GNSS Interferometric Reflectometry, this method determines the variation on the amount of water content within the soil over a certain period of time hence leads to the discussions and prediction on the climatic conditions. GNSS interferometric reflectometry (GNSS-IR) refers to the technique which uses reflected GPS signals to estimate environmental parameters around a geodetic-quality GNSS site (Roesler & Larson, 2018). Reflected signals create constructive and destructive interference patterns that cause oscillations in the GPS observations. The frequency of the oscillations is dependent on the GPS frequency and the distance of the reflecting surface from the antenna. Changes in the dielectric properties of the reflecting surface (e.g., changes in soil moisture) also induce changes in these periodic oscillations (Larson, *et al.*, 2010).

The major challenges facing TMA in effective provision and utilization of climate services include communication facilities, inadequate weather and climate forecasting facilities and meteorological infrastructure such as automatic rainfall stations and satellite orbiting receivers (Tanzania Meteorological Agency, 2018). But in the fight against drought and climatic variations, Tanzania has various continuous operating reference stations which are used to collect GPS data over a long period of time for various purpose e.g. GPS Network in Tanzania for Volcano Observatory stations installed on mount Ol Doinyo Lengai, other stations are TANZ located at Ardhi University Dar es salaam, SNGC located at Songea of Malawi rifting valley GPS Network, TNDC located at Tunduru and MBEY located at Mbeya (EartScope Consortium, 2023). The data from these stations can be used to estimate soil moisture using the GNSS- IR technique and then coming up with policies, ways and strategies in account of drought and climatic conditions that contribute to the development of society in Tanzania.

A study on GPS networks in Canada, identifies 12 out of 38 stations located in permafrost areas that are useful for GPS-IR measurements (Zhang, *et al.*,2020). This study focused on the five Canadian Active Control System stations and obtained daily GPS-IR surface elevation changes in such that the ground surface subsided in Alert, Resolute Bay, and Repulse Bay respectively by 0.61 ± 0.04 cm yr−1 (2012–2018), 0.70 ± 0.02 cm yr−1 (2003–2014), and 0.26 ± 0.05 cm yr−1 (2014–2019). In the discussion on the linear trends of surface deformation at the five sites it was found that ground surface deformed differently among the five sites.

A study on the GPS measurements at Marshall over a span of 210 days for the soil moisture calibration and assessment of reflector depth and how it varies through time was conducted (Larson, *et al*., 2010). The study showed that, estimation of signal penetration depth by geodetic-quality GPS receivers has good agreement with in situ soil moisture sensors buried at a depth of 2.5 cm. However, it presented several points of caution that the GPS signal only penetrate the top centimeter or two of soil when this top centimeter is nearly saturated.

A study conducted to retrieve soil moisture from GPS Signal-to-Noise Ratio data of OSOR stations installed in Chile for 213 days from 01 January 2015 to 31 July 2015 (Altuntas & Tunalioglu, 2020). Phase, amplitude, and reflector height, which are SNR-derived interferogram metrics were examined and results were proved with respect to correlation coefficients compared with in-situ measurements. The study validated the estimates recorded of soil moistures from the Oromo Calibration Site in the LAB-net network and the results showed that SMC estimated from SNR-derived metrics shows well agreement with in-situ measurements i.e. as the highest correlation of 95%.

A field experiment on ECH2O soil moisture probes located in the wheat field at 5, 20, and 40 cm, in order to measure the volumetric water content at these depths over a wheat field from January to September 2008 covering different growth stages of the wheat at Palau d'Anglesola, Lleida, Spain was conducted (Alvarez, *et al.*,2009). During analysis it found that retrieved measurements and ground data measurements are similar to 5-cm ECH2O data for September measurements after seasonal rain, but they are more similar to 20 cm ECH2O data for all August measurements and for the first measurements of September before the seasonal rain.

A study on GN-IRI and a Trimble NetR9 GNSS receiver with antennas fixed in upright (zenith-looking) on a horizontal crossbeam used to collect the GNSS data in Xinxiang City, Henan Province, China, from December 26 to 31, 2020 (Li *et al*., 2021). The experimental site is located at 35.020000° N, 114.547738° E. The study involved GNSS IR instruments used to automatically collect, save and transmit received GNSS data and sensor data was developed based on low-cost u-blox M8N positioning chips. The developed instrument was evaluated using a data set collected in Xinxiang City, Henan, China, over 6 days. The results show that there exists good agreement between the instrument-based reflector height estimates and the ground-truth estimates.

In contrast to the current research, this study uses GNSS data downloaded from UNAVCO saved and collected from Continuous operating reference stations located at Songea (SNGC) and Arusha (OLO3) in Tanzania. The data was used to analyze the variation of soil moisture over two years (2017 to 2018) and determine the trending over the specified area. Also, it involved the use of soil moisture data (Merra-2) from NASA Project power team which provides solar and meteorological data sets for the support of renewable energy, building energy efficiency and agricultural needs to validate with the results obtained and lastly to came up with discussions and prediction on the soil moisture variation in account of climate change.

1.2 Description of the Study Area

The research used the Continuous Operating Reference Stations at Arusha (OLO3) and Songea (SNGC) located at North east and south west of Tanzania respectively. Arusha has two wet seasons and two dry seasons; the long rainy season is from March to May and short rainy season is in November and December (AfricanMecca Safaris, 2023). Also, Songea is characterized with wetness from November to April and the month with the most wetness is January. Rainy season of Songea starts from October to May and the driest month is August (Weather Spark, 2023). Recently Arusha and Songea have been facing rainfall season variation then due to this climatic change there is a need to conduct a study on determining the trending of soil moisture using the GPS sites installed in mount Ol Doinyo Lengai to come up with strategies in overcoming the crisis over the surrounding society. Figure 1-1 below shows a location map of CORS sites used in the research

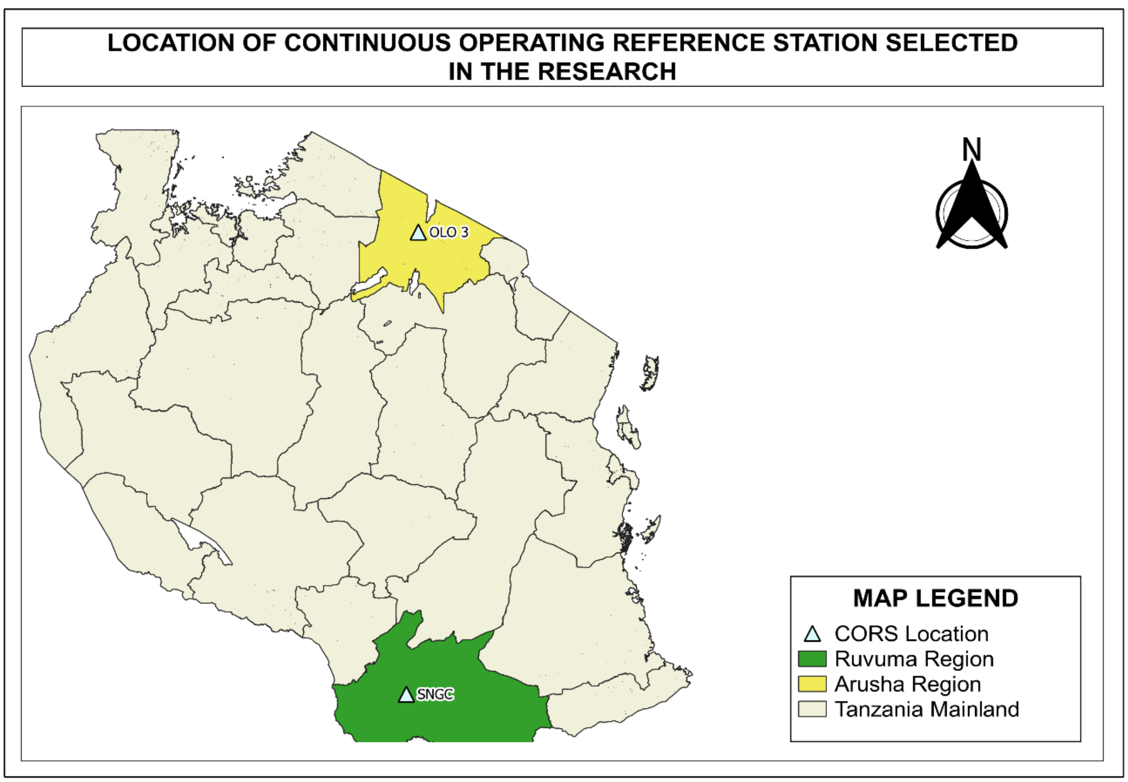

Figure 1-1: A map of Tanzania showing location of CORS sites used in the research

1.3 Research Problem

A reliable weather condition is the most essential factor in the development of the society. Tanzania has been facing natural disasters such as drought, food insecurity and shortage of rainfall which is caused by climatic variations along areas of Arusha, Dodoma, Shinyanga and Simiyu. In the past 5 years the problem of shortage of rainfall has been increasing causing agricultural activities to deteriorate hence leading to food shortage and increasing in life standards of peoples. Since soil moisture affects agricultural activities hence there is a need to monitor and account for the changes that occur within our societies. Various ways and methods have been used to study soil moisture in account for drought and climatic variation which is conducted by the Tanzania Meteorological Agency, but through the Geomatics field there is another method called GNSS IR that can be used to study and monitor soil moisture in our societies. Since Tanzania has various continuous operating reference station in various areas which automatically collect and save GNSS data for various use, these data can be used to assess the trending of variation of soil moisture along different areas of CORS station with minimum budget and hence coming up with ways, solution and strategies that can be used to account for drought and climatic variation for future generations.

1.4 Objectives of the Research

1.4.1 Main Objectives

The main objective of this research is to determine the variation of soil moisture content using GNSS data which is collected and saved by continuous operating reference stations located in Tanzania for the accounting of drought and climatic variations for future generations.

1.4.2 Specific Objectives

1. To collect observation GNSS data from continuous operating station in Tanzania of OLO3 and SGNC in receiver independent exchangeable format from UNAVCO and navigation files from SOPAC archives using GAMIT.

2. To process the collected data using signal to noise ratio frequency for determination of change in reflector height soil moisture estimations.

3 Validating soil moisture variations over time using data from NASA project power on variations of soil moisture over the location of the Continuous operating reference station.

1.5 Significance of the Study

The research provides the following benefits upon its conduction as it brings a new method on how to determine the soil moisture using GPS data in Tanzania and thus easing the work on data collection on soil moisture directly to the field. The study facilitates peoples on the societies to take measures and solutions in order to account for natural hazards such as drought which is directly involved with soil moisture. Also, to facilitate agricultural activities since through the data processed will be used to predict climatic conditions hence determining suitable agricultural activity according to the trending of the soil moisture over the specific period of time. By assessing soil moisture variation, helps to formulate of policies in the conservation of environment in accordance to the trending of water content within the soil. Through the research it also facilitates plantations to use GNSS IR techniques in continuous monitoring of their farms according to the amount of water content on the soil as it may affect the production of crops which later influences the growth of the economy. To add another method that the Tanzania Meteorological Agency can use to make more analysis on drought and climatic variation using the available continuous operating reference stations with minimum budget for the benefit of peoples around the society, and also creating employment opportunities to geomatics professional in using the GNSS data for soil moisture estimation. Moreover, to facilitate other researchers to determine other parameters such as sea surface height change and soil deformation for the benefits of the country.

1.6 Beneficiaries

Tanzania Meteorological Agency is responsible to monitor drought conditions and issue early warning in collaboration with various stakeholders, government institutions and NGO's at a local and national level. Through the study TMA will be able to add another method for monitoring drought caused by climatic variations using GNSS data available in Tanzania with a minimum budget. Also, Surveyors may benefit from this study as it adds another application on GNSS data that can be used in different areas and setups to analyze other environmental parameters around a geodetic GNSS site and hence increases the wide range of new employment opportunities. Lastly, for Ardhi University Geomatics students the study provides them an insight to engage in other studies cornering environmental parameters which can be determined around a quality GNSS site using GNSS-IR technique hence increasing researches that are beneficial to the society.

1.7 Scope and limitations

The study is mainly concentrated with the analyzing of change in reflector depth and how it varies through time by assessing variation of the frequency of the reflected signals over the period of two years (2017 to 2018) since changes in the dielectric properties of the reflecting surface (e.g., changes in soil moisture) also induce changes in these periodic oscillations.

1.8 Chapter Summary

The dissertation report consists of five chapters, arranged systematically to accomplish the preparation and presentation of the research study; - "Determination of Soil Moisture Content Variation Using GNSS Interferometric Reflectometry (GNSS-IR) Technique".

Chapter one, introduces the research by describing relevant background information, the related studies conducted by other scholars, statement of the problem, objectives, significance, scope and limitation and beneficiaries of this study. Chapter two, presents the literature review of the research study, the methodologies adopted in previous researches and approaches taken to reach their objectives and summarizes briefly the difference between this study "Determination of Soil Moisture Content Variation Using GNSS Interferometric Reflectometry (GNSS-IR) Technique" and other studies and what is the expected outcome in comparison to other studies. Chapter three, describes the techniques and methods involved throughout the research in collection of data and in carrying out the research. It also describes some of the software that will be used in order to reach the expected output. Chapter four, presents the results and analysis that clarify the findings of the research objectives. Chapter five, it includes conclusions derived from the results and discussion of the findings. It also includes recommendations for further studies.

CHAPTER TWO

LITERATURE REVIEW

2.0 Overview

This chapter introduces concepts, theories and ideas on soil moisture measurements and methods for retrievals. It also analyzes factors influencing SMC and practical's configuration together with reviews on the previous works on GNSS-IR as the new established technique in soil moisture Estimation.

2.1 Soil Moisture

It refers to the content of water available within the shallow layer of the earth's upper surface, the soil moisture is important in agronomic, hydrological and meteorological processes at all spatial scales. Soil moisture information plays a key role in water stress detection, irrigation management, indicator for the prediction of natural disaster such as drought and flooding, for environmental changes such as dust storms and erosion (Sharma,*et al*., 2018).

2.2 Soil Moisture Measurement

Soil moisture data are appreciated to an extensive variety of administration agencies corporations concerned through meteorological conditions and climate, inundation control and runoff potential, soil erosion, water reservoir controlling, and water quality. Soil moisture is a crucial variable in governing the exchange of water and warmth energy among the land surface and the atmosphere through plant transpiration and soil evaporation. As a consequence, soil moisture shows a vital protagonist in the development of climate patterns and the creation of precipitation (Civeira, 2019).

Climate prediction models have shown that enhanced description of superficial soil moisture and plants can lead to noteworthy estimation enhancements. Likewise, soil moisture intensely disturbs the volume of precipitation that runs off inside proximate rivers and streams. Worldwide, significant landscapes with dry or wet shallow areas have been observed to report positive response on succeeding rainfall patterns. Also, soil moisture data can be used for water reservoir content and managing. Even though the importance of soil moisture data availability, widespread and constant quantifications of soil moisture is negligible. As mentioned before, there is still a deficiency of conclusive methods of soil moisture measurement worldwide (Civeira, 2019).

2.3 Factors Influencing Soil Moisture

Soil moisture is affected by several factors such as terrain, soil properties (physical, chemical and biological), climate and vegetation. From the perspective of restoration ecology, these influencing factors can be classified into two main types: environmental factors and vegetation factors.

2.3.1 Environmental Factors on Soil Moisture

In regions with little vegetation cover, environmental factors (terrain, soil and climate) often control the soil moisture distribution. Multiple terrain factors (e.g., slope position, slope surface, slope gradient, slope type and altitude) have different individual impacts on soil moisture redistribution and consumption. This suggests that the change in soil moisture on a slope after a precipitation event, particularly in the variable layers, is primarily affected by lateral flows that favor the lower parts of the slope, since the amount of solar radiation received by soils on different slopes varies, evaporation rates and the subsequent soil moisture distribution also vary between different sloping surfaces. Therefore, soil moisture variation in the stable layers is determined by the water budget resulting from the long-term regional climate and vegetation characteristics (Zhao, *et al*., 2018).

In a detailed view, influencing factors vary with the watershed's size. For example, in a small watershed, land use and topographical factors significantly affect the spatial variations in soil moisture, whereas climate primarily controls the soil moisture on a large scale. The probable reason is that climatic conditions are comparatively consistent at a smaller level, and land use and topographical factors are highlighted, while at a larger scale, climatic factors influence the soil properties, land use, and topography (Rasheed *et al.*, 2022).

2.3.2 Vegetation factors on soil moisture

The vegetation affects the soil capacity for storing, transporting and evaporating water through the canopy. Vegetation can redistribute precipitation through canopy interception and stem flow to affect infiltration processes after rainfall. The vegetation can also alter the amount of net radiation through the canopy and reduce soil moisture evaporation from the variable layers by producing litter on the surface. Vegetation systems can further alter the physical and chemical properties of soil and, consequently, its water-conducting and water-retention capacities. Root growth and organic matter decomposition increase soil porosity, prevent the topsoil from hardening, reduce bulk density and promote, in general, well-developed topsoil has a relatively high water-retention capacity, as litter and humus retain more precipitation that will subsequently infiltrate into the soil and replenish soil moisture (Zhao, *et al*., 2018).

2.4 Methods for Soil Moisture Estimations

Due to its applicability and use over various fields, Soil moisture can be estimated using two Techniques which are point measurement technique and retrieval of spatial distribution of soil moisture using remote sensing technique for soil moisture estimation.

2.4.1 Point Measurement Technique

Point measurement technique is the direct measurement of soil done in the field or by analyzing soil samples under laboratory conditions. There are a number of methods available for point measurement, for e.g. gravimetric methods, nuclear methods, scattering, electromagnetic methods, tensiometer techniques, hygrometric techniques and emerging techniques (Sharma, *et al*., 2018).

1. Gravimetric Method

Gravimetric method is the classical and direct method currently used to determine soil moisture which is the most natural and oldest technique, it involves taking a soil sample from the field and determining the weight of water contained in a soil sample, relative to the weight of dry soil. (Sharma, *et al.*, 2018).

2. Neutron Method

The neutron dispersing technique employs a radioactive source that scatters fast neutrons (average energy 5MeV, mega electron volt) into the soil. These fast neutrons slow down with the hydrogen nuclei collision in the soil water molecule. Neutron dispersing is the most accurate non-destructive test with a response time of 1–2 min and is majorly beneficial in measuring a large soil volume at several depths (Rasheed *et al.*, 2022).

3. **Gamma Attenuation**

The gamma ray attenuation technique is a nondestructive technique in which there is no need for direct contact between the material under study and detector assembly. It is capable of determining the moisture content in the upper layer soil layer (up to 1–2 cm). The advantage of this method is that it is capable of providing the average water content for the profile depth. (Sharma, *et al.*, 2018).

4. **Time Domain Reflectometry**

Time domain reflectometer is an electromagnetic technique which is used in soil moisture measurement. This method applies a voltage signal to the transmission line inserted into the soil. The voltage signal requires time to travel from source to the end of the transmission line and back again (Sharma, *et al.*, 2018). The TDR sensor measures the time needed for a transmitted signal to travel from one end to another. TDR is advantageous for long-term in situ measurements and automation due to its high temporal resolution, quickness of achievement, and independence from the soil texture and temperature (Rasheed *et al.*, 2022).

2.4.2 Remote Sensing Technique

Remote sensing of soil moisture is based upon the large sensitivity of the dielectric properties of a soil to its moisture content. The dielectric properties largely influence the interaction between soil and microwave radiation. Passive microwave remote sensing of soil moisture is generally most straightforward because the vegetation effects can be regarded, in most cases, as a simple attenuation of the microwave signal (Oevelen, 1998).

1. **Passive Microwave Remote Sensing of Soil Moisture**

Passive microwave remote sensors can be used to monitor surface soil moisture over land surfaces, these sensors measure the intensity of microwave emission from the soil, which is proportional to the brightness temperature, a product of the surface temperature and emissivity. Current and near future spaceborne passive microwave sensors for soil moisture measurements include the Scanning Multichannel Microwave Radiometer (SMMR) on Nimbus-7, the Special Sensor Microwave/Imager (SSM/I) on Defense Meteorological Satellite Program (DMSP), the Tropical Rainfall Measuring Mission Microwave Imager (TRMM-TMI), the Advanced

Microwave Scanning Radiometer-EOS (AMSR-E) on Aqua, and the upcoming soil moisture and ocean salinity (Wang & Qu, 2009).

2. Active Microwave Remote Sensing of Soil Moisture

The concept of soil moisture retrieval in active microwave remote sensing forms its basis on sensing the backscatter coefficient using radars. Many researchers have retrieved soil moisture using multi-polarized, multi-frequency, multi-incident, and temporal SAR data under the variety of agricultural heterogeneity. However, along with its strong sensitivity towards soil moisture, SAR signals are also sensitive towards other target parameters such as crop cover, surface roughness, and soil texture. Therefore, due to its sensitivity towards other target properties, like soil moisture, sensitivity decreases significantly due to the presence of these noise parameters in a resolution cell (Sharma, *et al*., 2018).

2.5 Global Navigation Satellite System Interferometric Reflectometry (GNSS-IR)

During the 1970s, a new and unique approach to surveying, the global positioning system (GPS), emerged. More recently other countries are developing their own systems. Thus, the entire scope of satellite systems used in positioning is now referred to as global navigation satellite systems (GNSS). Receivers that use GPS satellites and another system such as GLONASS are known as GNSS receivers. These systems provide precise timing and positioning information anywhere on the Earth with high reliability and low cost (Ghilani & Wolf, 2012). GPS is a major navigation technology that has been modified to provide surveying accuracy without downgrading its navigation capabilities, Although GPS was designed as a navigation system, it has a tremendous impact on surveying and is being used more and more as a means of determining position. But in recent years GPS instruments that have been developed for tectonic studies and land surveying (here called geodetic-quality GPS instruments) have shown potentials as an alternative means of observation by measuring their reflected signals on Earth’s surface. In this scheme, GNSS Reflectometry (GNSS-R) has become an unprecedented tool that can monitor Earth’s surface characteristics (Edokossi, *et al.*, 2020).

GNSS-IR is a method for estimating environmental parameters around a geodetic-quality GNSS site. Unlike other reflection techniques, where an antenna is designed to measure reflection signals or a geodetic antenna is rotated to improve its ability to measure reflections, GNSS-IR uses data collected with (nominally) multipath-suppressing geodetic quality GNSS antennas in an upright orientation. GNSS-IR has been demonstrated and validated for measuring surface soil moisture, snow depth, permafrost melt, tides, ice-up, fin density, and vegetation water content (Roesler & Larson, 2018).There are thousands of geodetic-quality GNSS receivers deployed throughout the world, which are used as Continuously Operating Reference Stations (CORS). Geodetic-quality GNSS receivers are not designed for remote sensing, but they can be used to provide a new, cost-effective and high-efficiency method to sense geophysical parameters such as soil moisture and snow depth (Chang *et al.*, 2019).

Experiments and missions based on GNSS reflected signals are commonly known as GNSS reflectometry (GNSS-R). This technique works based on the interference between the direct and reflected signal at the receivers' platforms where they are space borne, airborne or can be installed near the ground or sea surface. This yields an inborn disturbance evident on Signal-to-Noise Ratio (SNR) data, known also as SNR-based GNSS Reflectometry (GNSS-R). Based on the included observables such as SNR or carrier phase, GNSS-R has also been designated in the literature as interference pattern technique (GNSS-IPT), interferometric reflectometry (GNSS-IR) or multipath reflectometry (GNSS-MR). One of the most intriguing Fields that GNSS-IR properly showed its strength is monitoring the sea surface phenomena based on exploiting its accidental radio waves reflected (Farzaneh, *et al.,* 2021).

2.5.1 Mode of Work for GNSS-IR

The direct and reflected signals can be received by a single GNSS receiver antenna and the technique is termed as GNSS interferometric reflectometry (GNSS-IR). The main reason why GNSS-IR works is that the magnitude of the signal-to-noise ratio (SNR) time series recorded by the receiver varies as the water content of the soil around the GNSS antenna changes (Chang *et al.*, 2019). For microwave frequencies, the soil permittivity and signal reflection coefficient are highly dependent on soil moisture. Because of this effect, the SNR or power of ground-reflected GNSS signals are considerably affected by the amount of water contained in the soil (Chang, *et al.*, 2019)

The input of GPS-IR is signal-to-noise ratio (SNR) data of GPS signals, one of the observables recorded by GPS receivers. It represents the strength of the received signal. SNR series at low satellite elevation angles oscillate with respect to the elevation angle due to the interference between direct and reflected signals. The oscillating frequency mainly depends on the vertical distance between the antenna and the reflecting surface (called reflector height and denoted as H). If a GPS station is located above a smooth horizontal surface SNR can be expressed by a sinusoidal function (1.1) of elevation angle e;

$$\mathrm{SNR}(e) = A(e)\sin\left(\frac{4\pi H_R}{\lambda}\sin e + \phi\right) \qquad (1.1)$$

where; e = is the GNSS satellite elevation angle with respect to the horizon

λ= is the GNSS wavelength

ϕ = is a phase constant,

H_R = is the vertical distance between the GNSS antenna phase center and the horizontal reflecting surface

$A(e)$ = represents the amplitude of the SNR data

when taking *sine* as independent variable then the frequency of the oscillation is given by (Zhang, *et al*.,2020);

$$f = \frac{2H}{\lambda} \qquad (1.2)$$

Then if oscillating frequency is determined the value of H_R is obtained by (Zhang, *et al*.,2020):

$$H = \frac{f\lambda}{2} \qquad (1.3)$$

The variation in the distance *H* only depends on the change in surface elevation. The change of *H* is opposite to that of surface elevation; i.e., surface uplift leads to decreasing H and surface subsidence leads to increase *H* (Zhang, *et al*.,2020). Figure 2-1 below shows the geometry of reflecting signals to the GNSS antenna

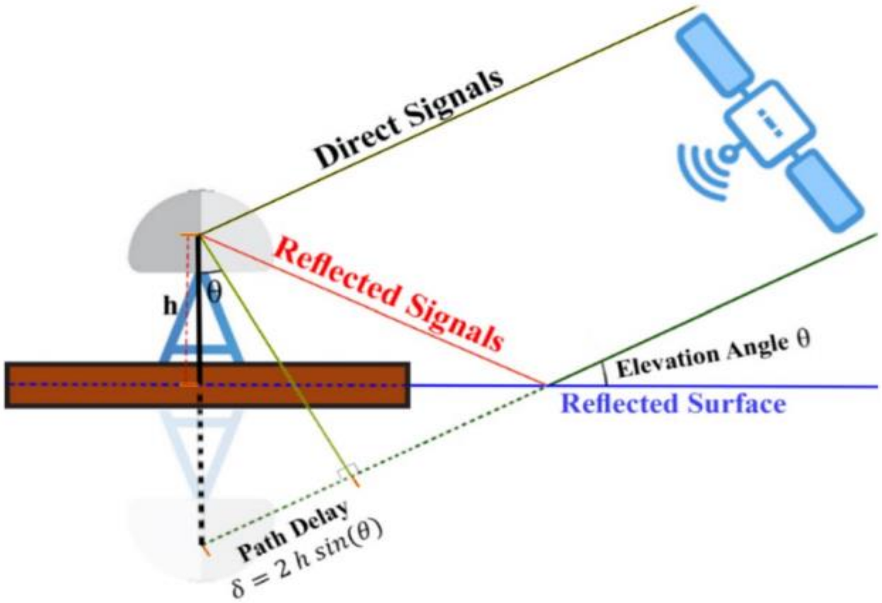

Figure 2-1: Geometry of the GPS antenna, GPS signals, and the ground surface in relation to soil moisture estimation (Farzaneh, *et al.*, 2021).

CHAPTER THREE

METHODOLOGY

3.0 Overview

This chapter describes all the methods, techniques and tools that were used to execute the research. It explains how the research is going to be conducted from data collection, data reading, conversions and data processing until the main objective is met.

3.1 Data Search

This study used CORS data installed around the flank of Mountain. Ol Doinyo Lengai in Ngorongoro district Arusha region. The stations are installed under TZVOLCANO. (Stamps, *et al*., 2016). The network has 6 continuous observing sites, however for this study only one site was chosen which is OLO3. The reason for the choice of this site is its location and the surrounding ground in order to determine the surrounding soil moisture. The second site used in this study is SNGC, it is located in Songea district Ruvuma region that was installed for Rift valley monitoring to analyzing soil moisture trends. The data required for analysis was observation file and ephemeris file that was downloaded from UNAVCO in RINEX format for the 2017 and 2018 year.

3.2 Data Translation

Data reading involved two processes, Conversion of rinex data format of observation and precise ephemeris file to MAT files and Conversion of MAT data format of observation and precise ephemeris to SNRMAT format. All of the tasks were performed in GIRAS as it is capable of reading and evaluating multi-GNSS (GPS, GLONASS, GALILEO AND BEIDOU) data. Precise ephemeris and observation files were inserted into GIRAS software in order to obtain orbit information and then it was saved as MAT files. Data was saved in MAT files so that it can be compatible with MATLAB version R2018b to read and process the files, also to allow data reading and processing separately at different times and then combined. Table 3-1 shows the process involved in data translation of observation files and precise ephemeris files.

Table 3- 1: Steps on data translation of observation files and precise ephemeris files

Input File path	Input File(s)	Process	Output File Path	Output file(s)
\data\inp_files\obs\	RINEX 2 observation files	Read Observation files	\data\mat_files\obs\	OBSMAT files
\data\inp_files\eph\	Precise Ephemeris files	Read Ephemeris files	\data\mat_files\eph\	EPHMAT files

Data reading was done in the interval of 60 days in consideration of the computer ability on converting rinex format to MAT files. Figure 3-1 shows the process of data reading for 60 days of 2017 observation file using GIRAS software running on MATLAB R2018b version.

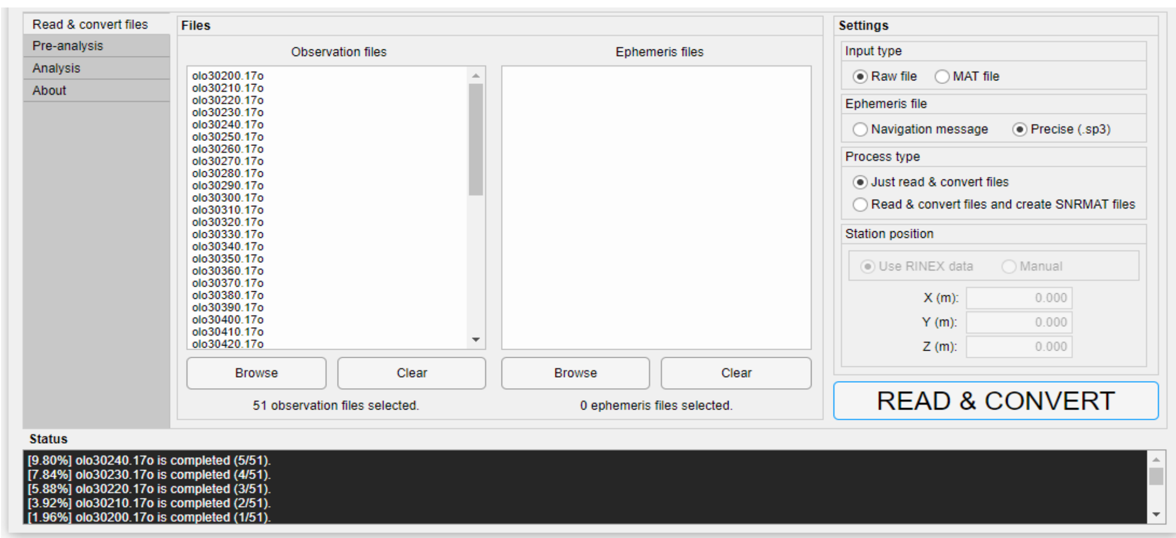

Figure 3- 1: Data reading and conversion of OLO3 observation files

A total of 341 observation files for 2017 and 365 observation files for 2018 of OLO3 station were converted from RINEX format to MAT format. And for SNGC a total of 365 observation files for 2017 and 2018 respectively were converted into MAT format. Shortage in the number of observations processed to be less than the required days 365 is due to the defaults which occur in the continuous operating reference station which causes some days data not being saved. Apart from observation files, also ephemeris files were converted in MAT format. The data that was supposed to be used was navigation files but due to some errors occurring during the data conversion, Precise ephemeris files were used instead. Figure 3-2 shows the data conversion of SP3 files into MAT files.

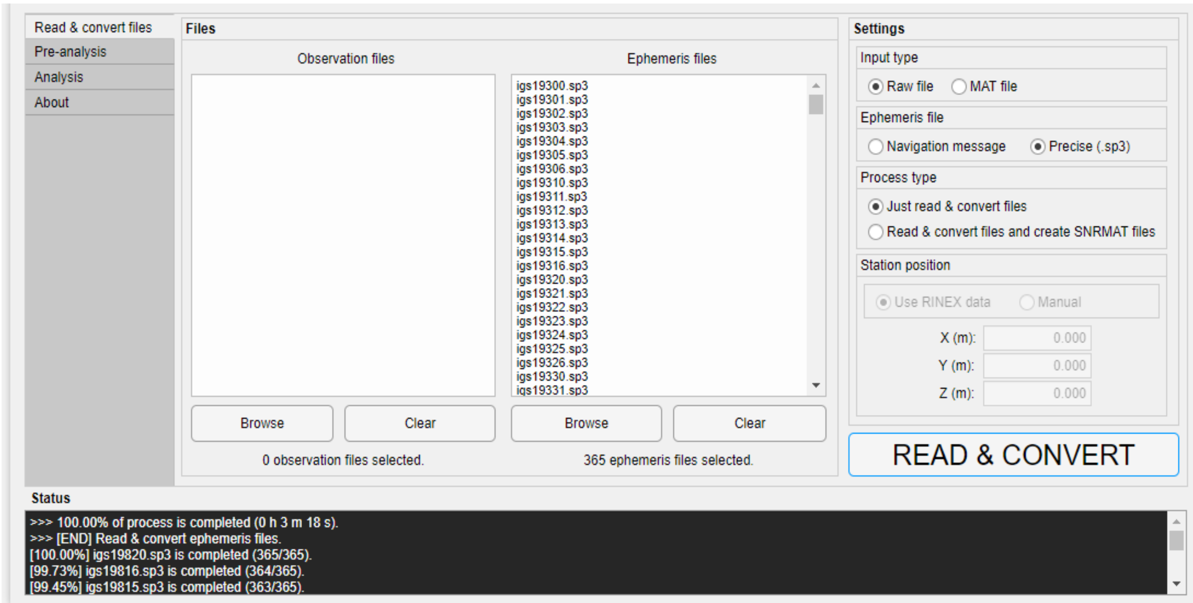

Figure 3- 2: Data conversion of SP3 files into MAT files

3.2.1 Conversion of MAT data format to SNRMAT format

To make soil moisture estimation, Signal to noise ratio data is required. The observation and Precise ephemeris MAT files were inserted at the same time into the GIRAS software processed and then SNRMAT files were created. During the conversion of the MAT files into SNRMAT files the position was required in which the software had two options of either using the position indicated on the RINEX files or manually inserting the position (X, Y, Z). Option used was to allow the software to use the position indicated on the RINEX.

Table 3- 2: Steps on Conversion of MAT files to SNRMAT files

Input File path	Input File(s)	Process	Output File Path	Output file(s)
\data\mat_files\obs\ or \data\mat_files\nav\	(a) OBSMAT files (b) EPHMAT files	Read MAT files and create SNRMAT files	\data\mat_files\snr\	SNRMAT files

The conversion of observation and SP3 MAT files to SNRMAT files was done for 2017 and 2018 separately in both stations OLO3 and SNGC. Figure 3-3 shows the conversion of OBSMAT and EPHMAT to SNRMAT in which later it is then used in soil moisture data estimations. Also, the SNRMAT comes as the final output in the process of data reading and conversion.

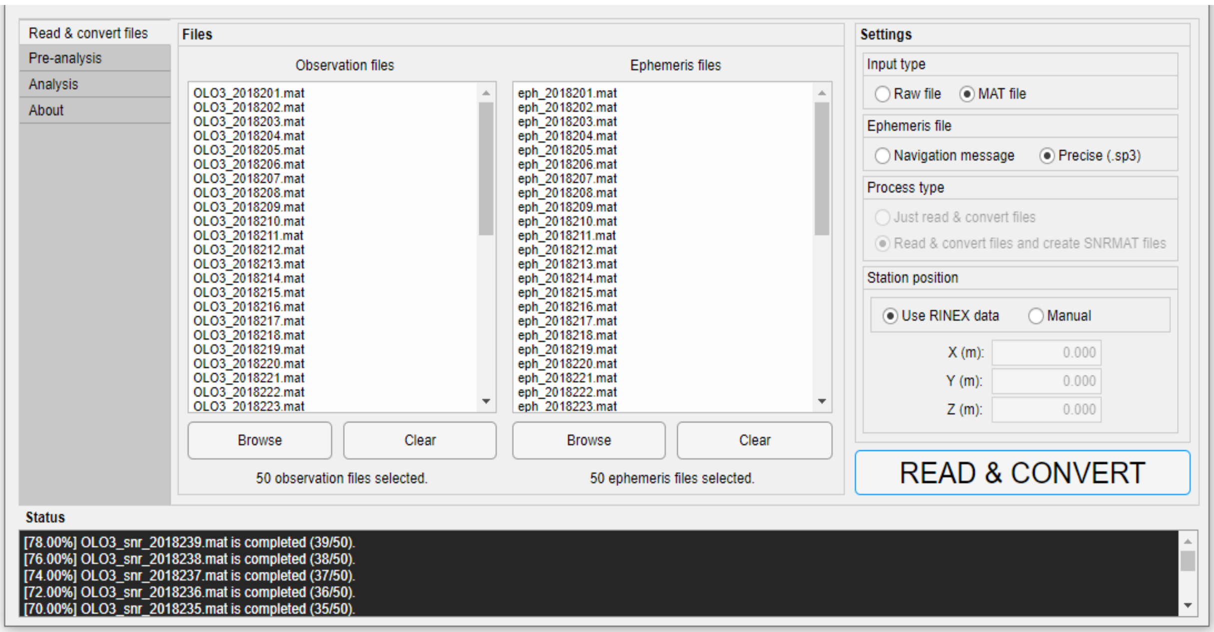

Figure 3- 3: Conversion of OBSMAT and EPHMAT to SNRMAT

3.3 Pre-analysis

Pre-analysis involved the use of the SNRMAT files to map the signal to noise ratio variation, sky view and the First Fresnel zone around the study area. For both year 2017 and 2018 in station OLO3 and SNGC. This was done using the GIRAS software.

3.3.1 Signal to Noise Ratio variation

SNR refers to the power of the strength of a signal to the background noise. In this study SNR was analyzed in G1 satellite to assess the variation on the amount of background noise received on the stations which was highly influenced by reflected signals. In determination of SNR an elevation angle of 0° to 90° was selected in order to obtain information at which elevation angle has a high influence of background noise in 2017 and 2018 for both OLO3 and SNGC. The process was done by using a dataset of the SNR files for various days as indicated on table 3-3.

Table 3- 3: Dataset for Signal to Noise Ratio variation

Data	Format	Day
OLO3_2017001	SNRMAT	First day of the year
OLO3_2018001		
SNGC_2017001		
SNGC_2018001		
OLO3_2017182	SNRMAT	Mid-year.
OLO3_2018182		
SNGC_2017182		
SNGC_2018182		
OLO3_2020365	SNRMAT	Last day of the year
OLO3_2021365		
SNGC_2017365		
SNGC_2018365		

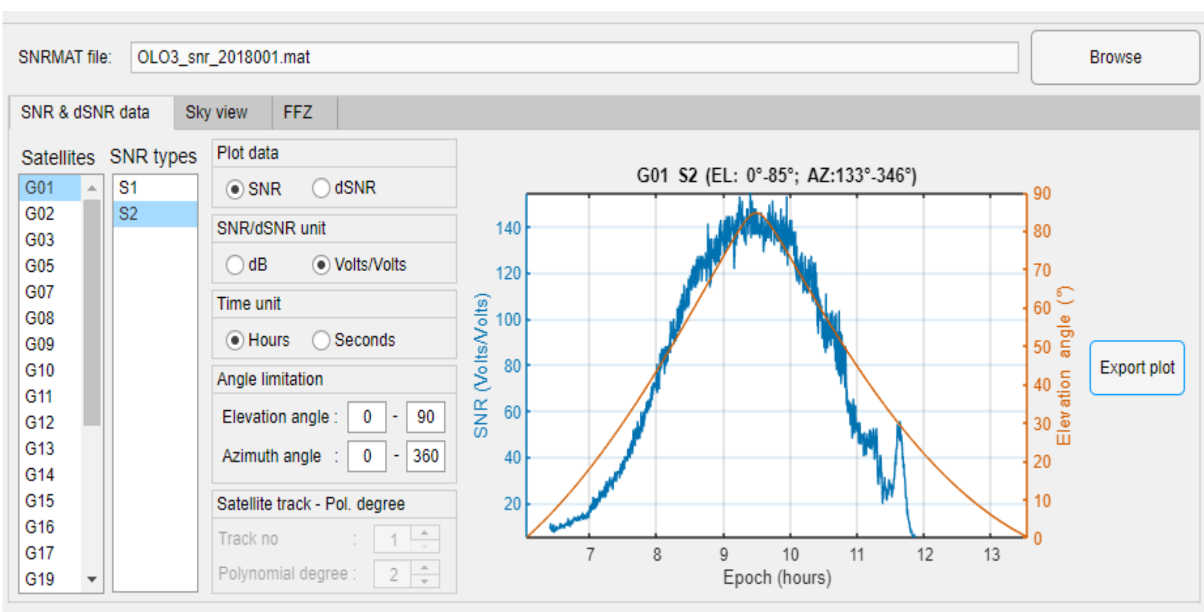

Figure 3- 4: Analysis of SNR variation of station OLO3

3.3.2 Sky View

It is used to determine the number of satellites available around the CORS location. Using the SNRMAT files created a single file was used to determine the position of the satellite over the station. 4 satellites were selected which were G01, G11, G17 and G31. The aim of assessing the availability of satellites over the specified stations is to know which area on stations receives satellite signals which then can be helpful in soil moisture estimations. Also, the plot of the sky view was done in four satellite systems that included GPS, GLONASS, GALILEO and BEIDOU.

3.3.3 First Fresnel Zone

FFZ defines the region with most of the signal reflection. The Fresnel zone was plotted using S2 data of SNR at which the reflector height was set at 2m and elevation angle of 5° in order to determine at certified conditions which areas have high reflection of signals. The Fresnel zone was plotted for both OLO3 and SNGC. Figure 3-5 shows the process on the mapping of the Fresnel zone of OLO3 station.

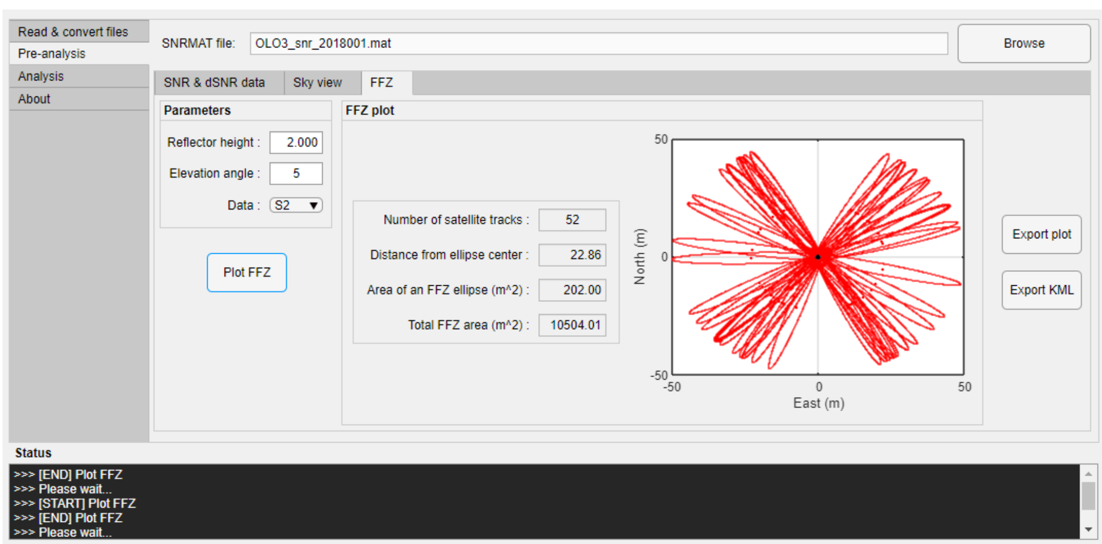

Figure 3- 5: Process on plotting of First Fresnel Zone plot

3.4 Soil Moisture Estimation

From the product of conversion to SNRMAT, the files were inserted into GIRAS and then processed at the same time to obtain variations of oscillating frequency and other parameters and then saved independently in text and MAT format. During the processing the data used was both

S1 and S2 of SNR in which the maximum reflector height used was 2m in order to prevent other signals from other features above the reflector height to be neglected. Also, the elevation angle chosen was 0° to 90°, azimuth angle 0° to 360° and a precision that was required was 0.001m. Figure 3-6 shows the SNR data processing to obtain soil moisture trending variation of 363 days which was done in 2 hrs 31 min and 2 sec in one station.

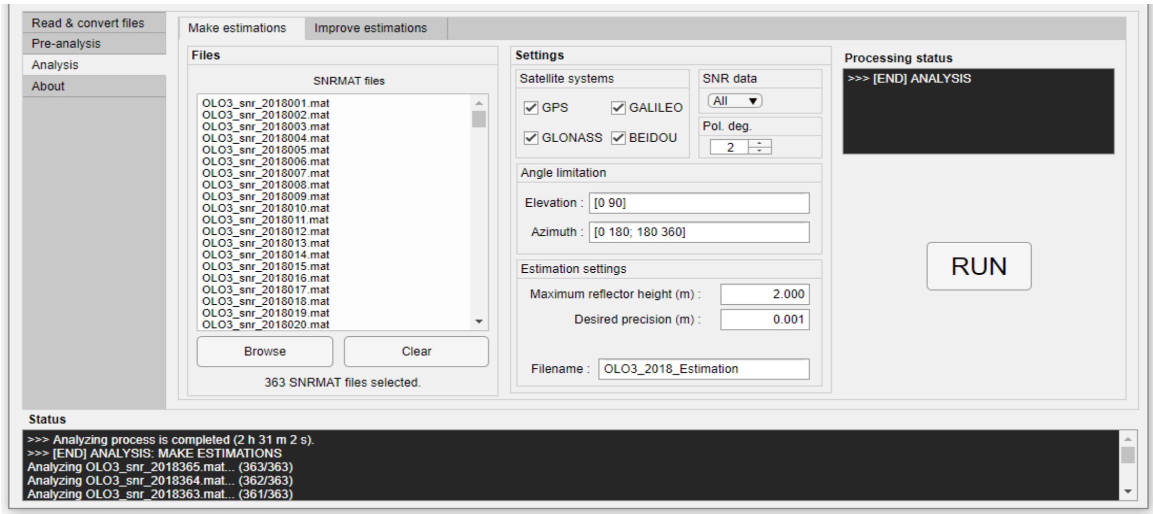

Figure 3- 6: SNR data processing to obtain soil moisture trending variation

After processing the data then it followed with making estimation using the file saved from the above process. The file had the following parameters year, day of year, satellite RPN, SNR type, satellite track number, satellite track type, oscillating frequency, amplitude, phase, first epoch, last epoch, number of epochs, minimum elevation angle, maximum elevation angle, minimum azimuth angle, maximum azimuth angle, max (p) and background noise. To make estimation, oscillating frequency and day of year was used to plot a graph on the soil moisture content variation for 2017 and 2018 for both OLO3 and SNGC stations.

The Vertical height of the reflecting signals to the GPS antenna was computed using equation (1.3) which shows the relation between oscillating frequency, wavelength of GPS signal and vertical reflecting height.

$$H_R = \frac{f\lambda}{2} \qquad (1.3)$$

The wavelength of the GPS signal was categorized into two, for S1 signals and S2 signals which their values were 0.1903m and 0.2442m respectively.

3.5 Data validation

In order to check the validity of the method in soil moisture estimation, data from the NASA power project team was used to validate the results. The data was downloaded from NASA power project website for both OLO3 and SNGC in 2017 and 2018 in which a total of 365 days of soil wetness data was accessed respectively. The data downloaded was then plotted to see the validation on the results obtained from GNSS-IR technique. Figure 3-7 shows the configuration on downloading soil moisture data from NASA power project website.

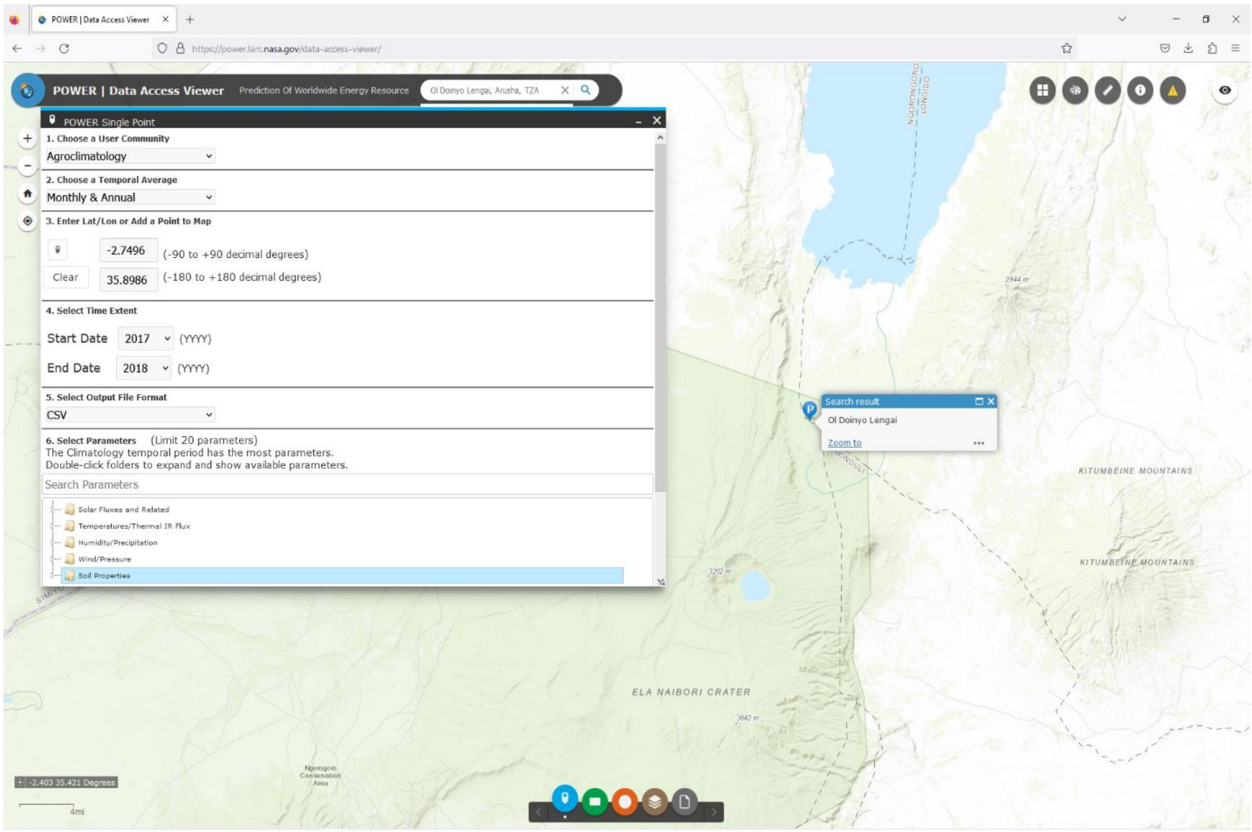

Figure 3- 7: Merra-2 Surface soil wetness data downloading from NASA power project

CHAPTER FOUR

RESULTS AND ANALYSIS

4.0 Overview

This chapter describes all the outcome of the findings and the goal that is achieved in determining the soil moisture content variation using GNSS data. The results and analysis are described and discussed in this chapter, and all the outputs for the variation in soil moisture are presented in graphs and plots.

4.1 Pre-analysis plots

The pre-analysis in the above chapter involved the processing of the data for the first day of year, middle day and the last to acquire information of signal to noise ratio analysis, sky view and Fresnel zone that will be useful in soil moisture estimation.

4.1.1 Signal to Noise Ratio variation

Below are the plots on the variation of signal to noise ratio by elevation angle of the satellite from the horizontal plane of the GNSS receiver of OLO3 and SNGC station for 2017 and 2018 in which the satellite used for analysis was G01.

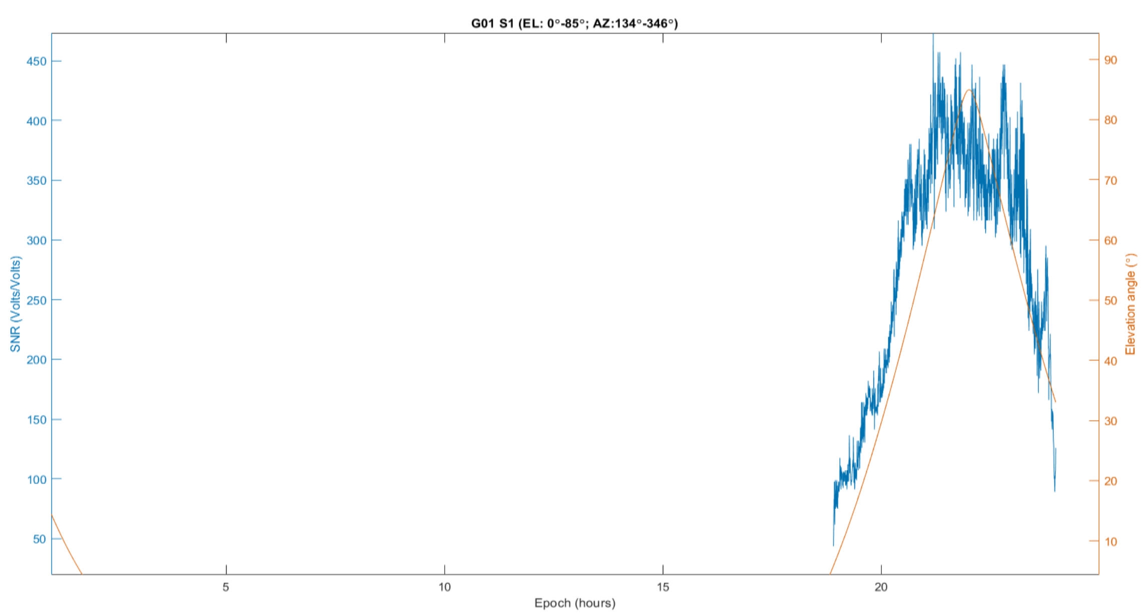

Figure 4- 1: SNR against Elevation angle of dataset OLO3_20171820

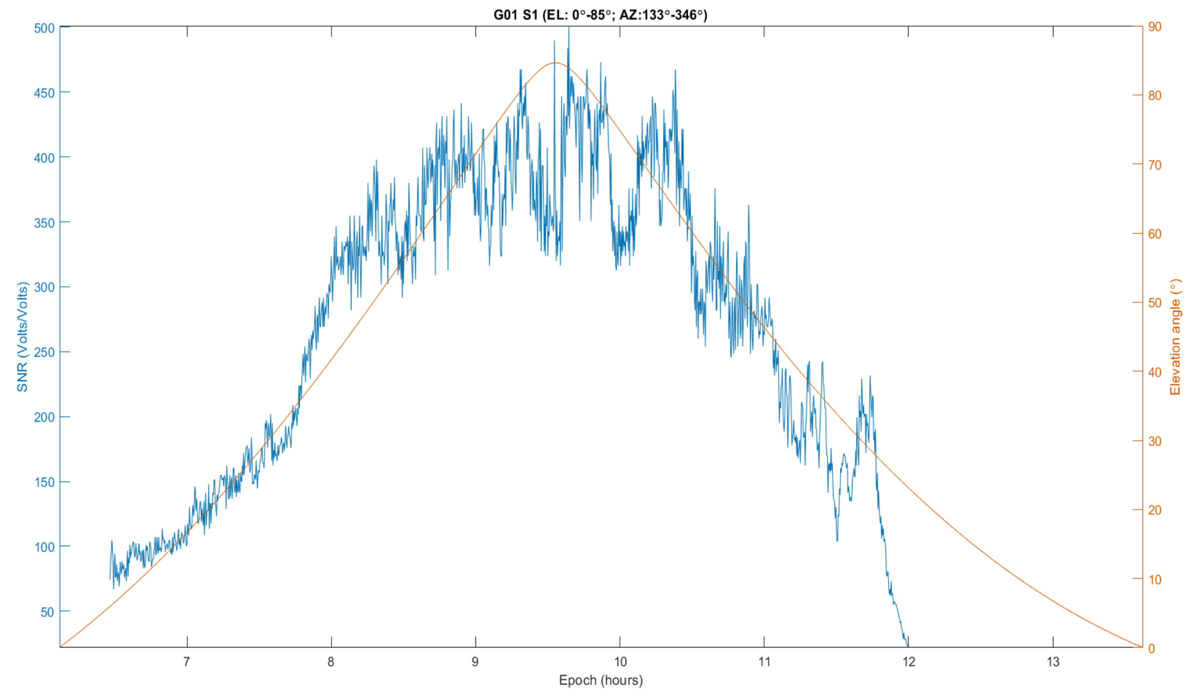

Figure 4- 2: SNR against Elevation angle of dataset OLO3_20173650

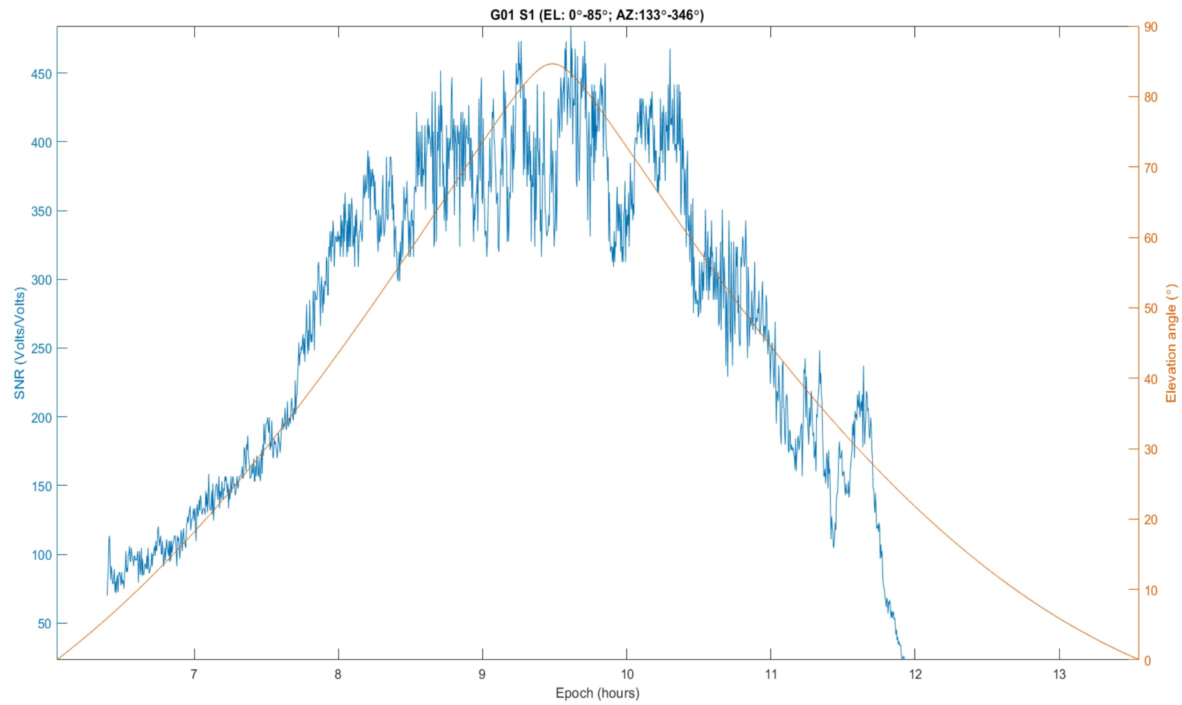

Figure 4- 3: SNR against Elevation angle of dataset OLO3_20180010

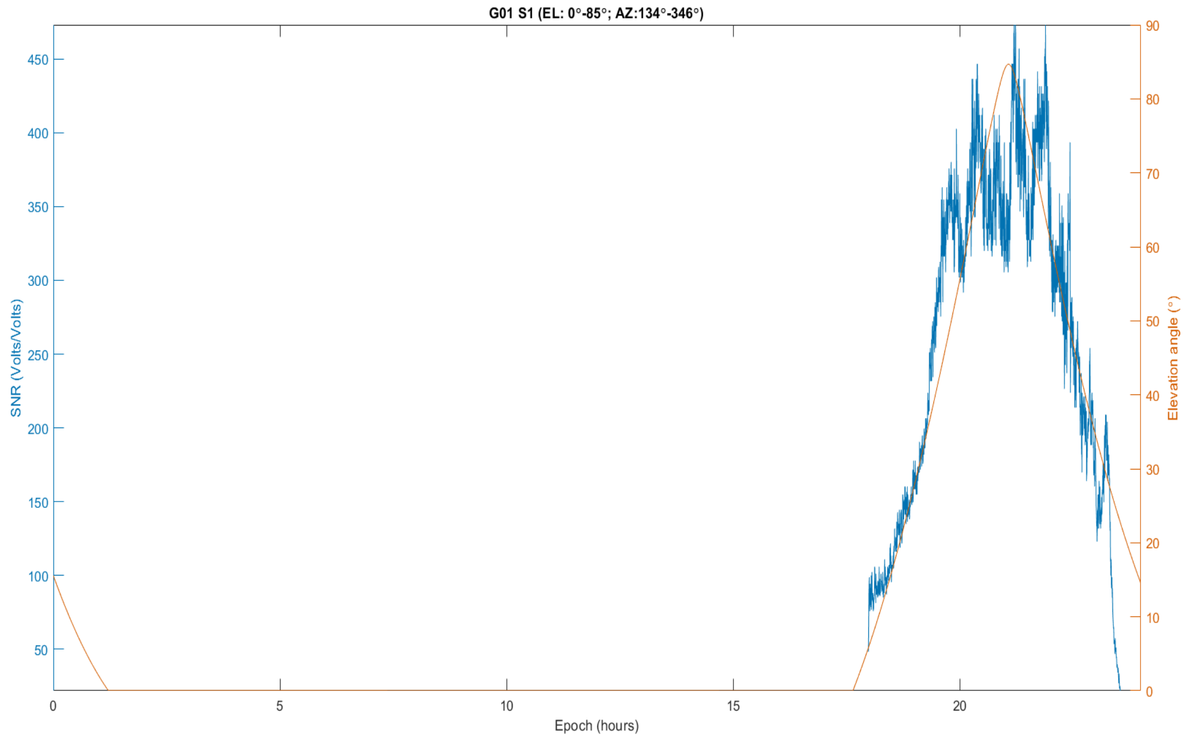

Figure 4- 4: SNR against Elevation angle of dataset OLO3_20181820

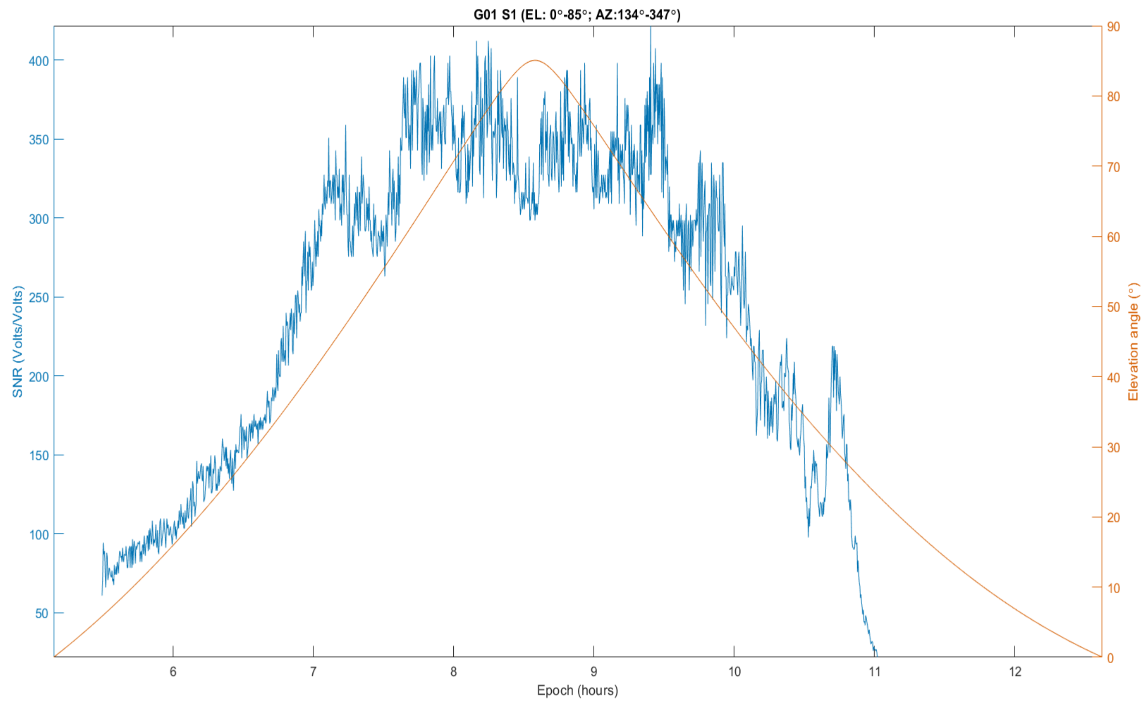

Figure 4- 5: SNR against Elevation angle of dataset OLO3_20183650

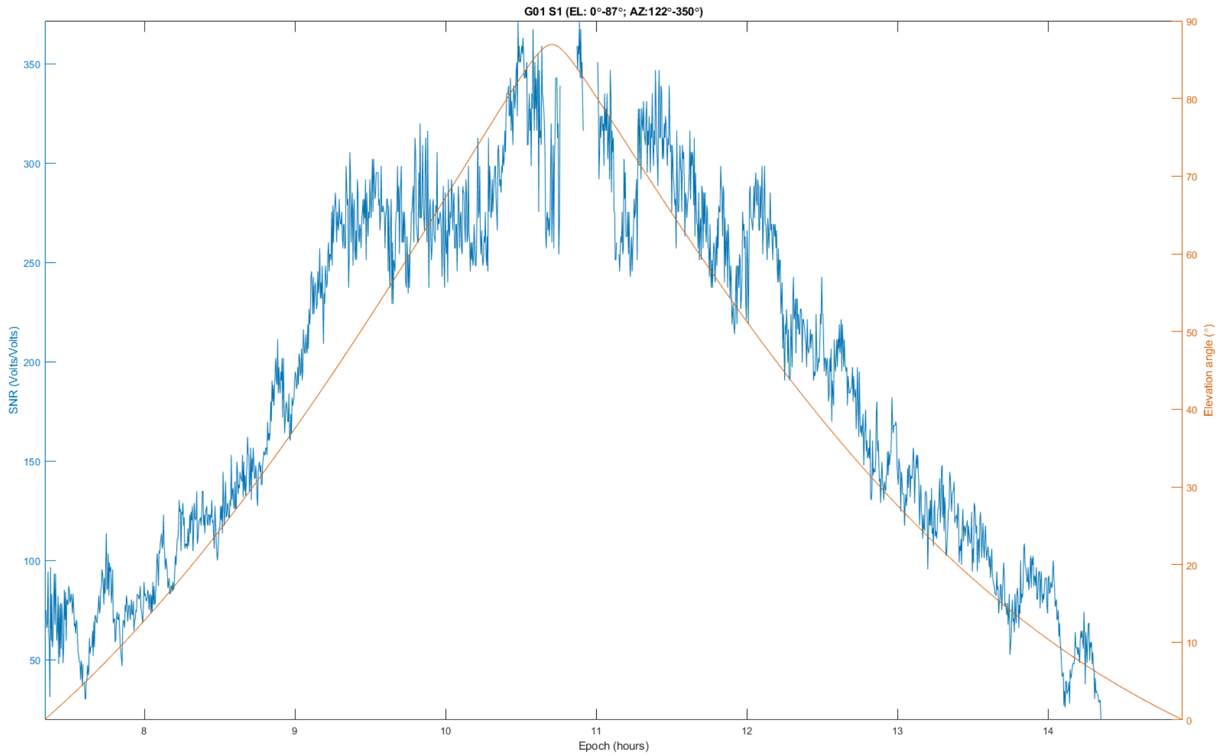

Figure 4- 6: SNR against Elevation angle of dataset SNGC_20170010

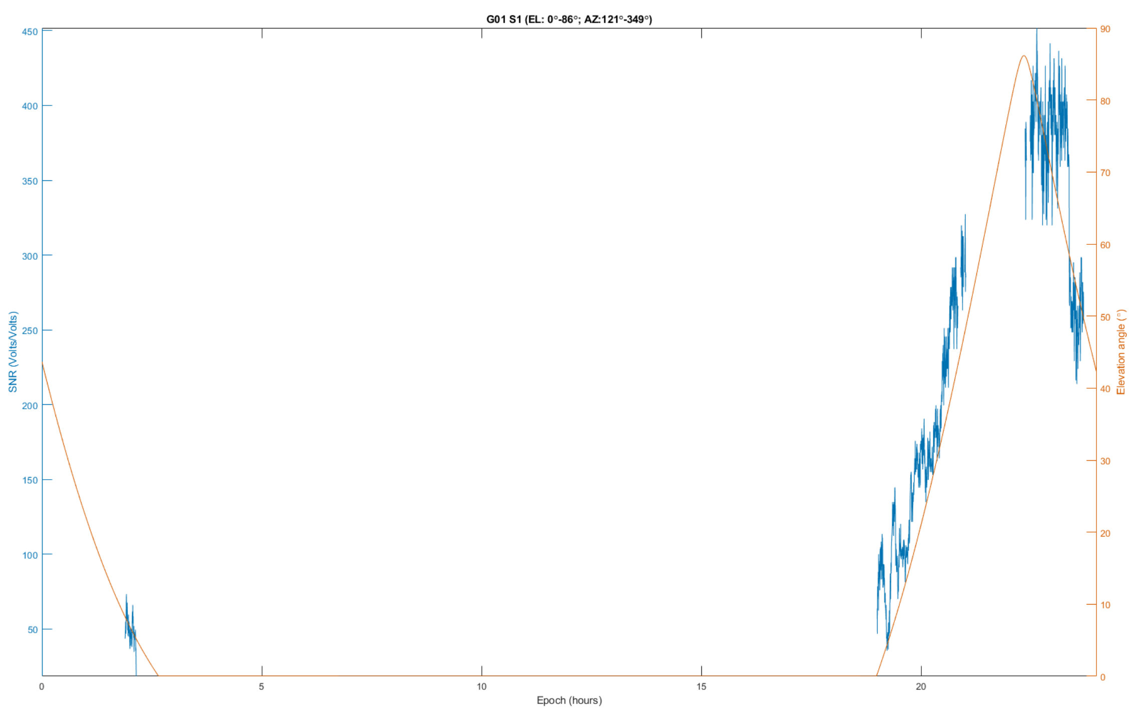

Figure 4- 7: SNR against Elevation angle of dataset SNGC_20171820

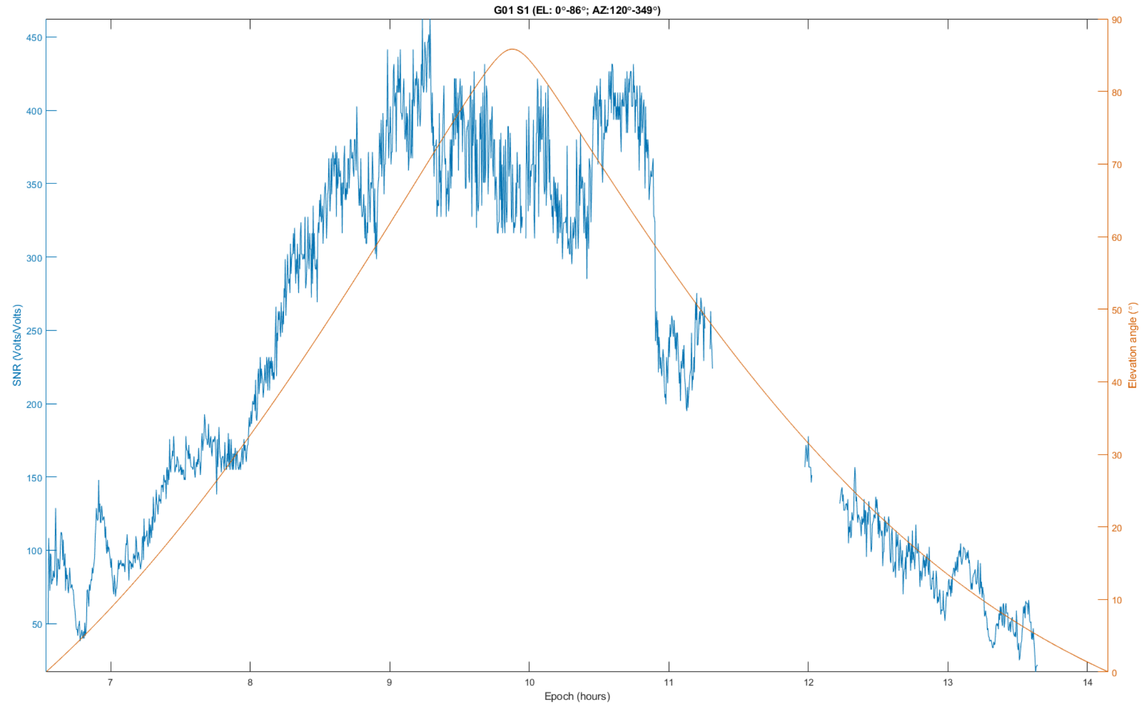

Figure 4- 8: SNR against Elevation angle of dataset SNGC_20173650

From the above plots it can be shown that signals coming from the satellite to the receiver (OLO3 and SNGC) has high strength when the elevation angle increases. It can be analyzed that at a higher elevation angle there is minimum noise and multipath interference in the signal and hence making the signal to noise ratio higher in which it results in good quality of observation. Also, from the plot it shows that the receiver received reflected signals at low elevation angle in relation to the signal to noise ratio and hence due to that estimation on the soil moisture variation is eligible as the station contained reflected signals which was then used in estimating SMC.

4.1.2 Sky View

Sky view enables the determination of the satellite available over the continuous operating reference station. Below are the plots of the satellite path of G1, G11, G17 and G31 that shows the path of the specified satellite over OLO3 and SNGC station. From the diagrams the red concentric circles indicate other GPS satellites which are visible and the black line shows the path of the specified satellite.

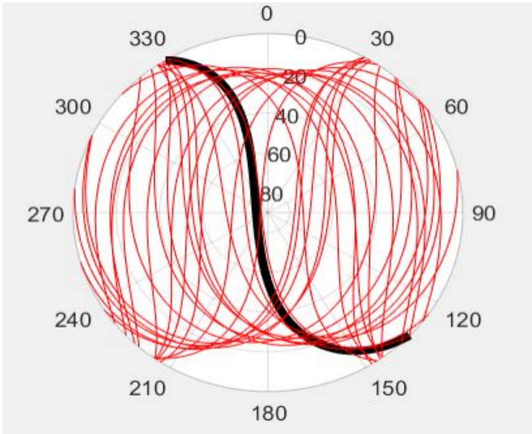

Figure 4- 9: G01 Satellite visible at Azimuth of 133° to 347° for OLO3

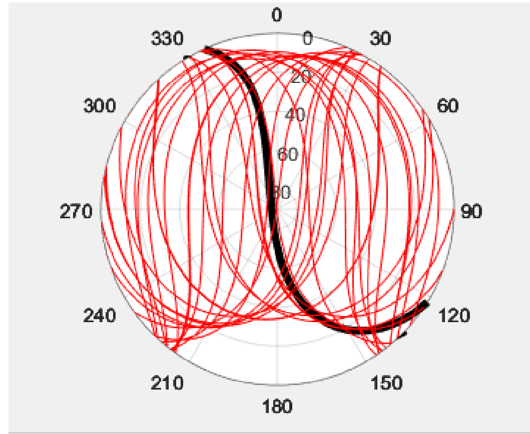

Figure 4- 10: G01 Satellite visible at Azimuth of 122° to 350° for SNGC

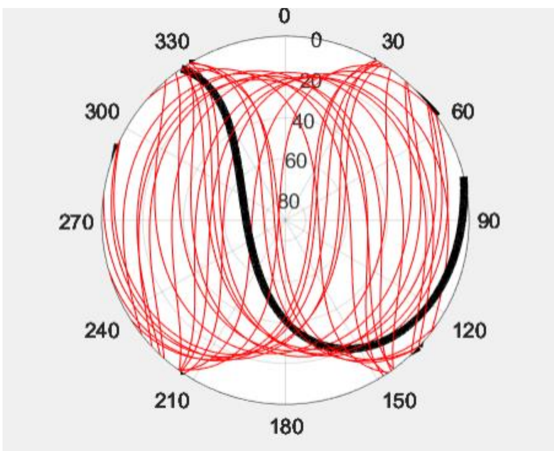

Figure 4- 11: G11 Satellite visible at Azimuth of Azimuth of 76° to 331° for OLO3

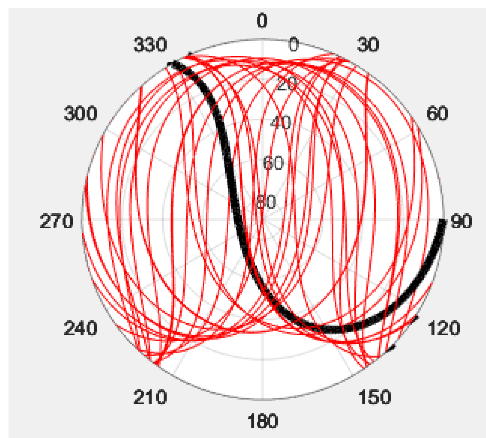

Figure 4- 12: G11 Satellite visible at Azimuth of Azimuth of 80° to 334° for SNGC

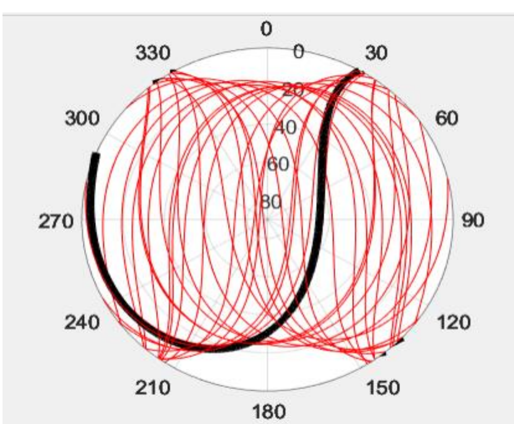

Figure 4- 13: G17 Satellite visible at Azimuth of 27° to 294° for SNGC

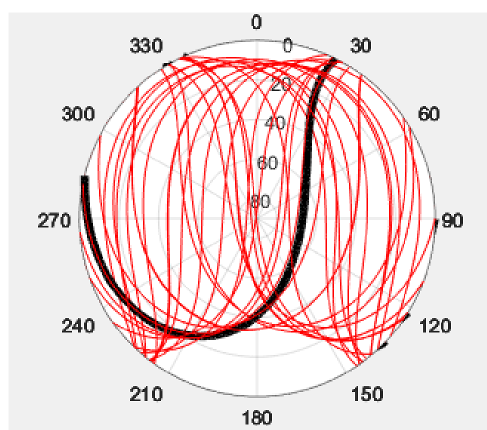

Figure 4- 14: G17 Satellite visible at Azimuth of 25° to 289° for SNGC

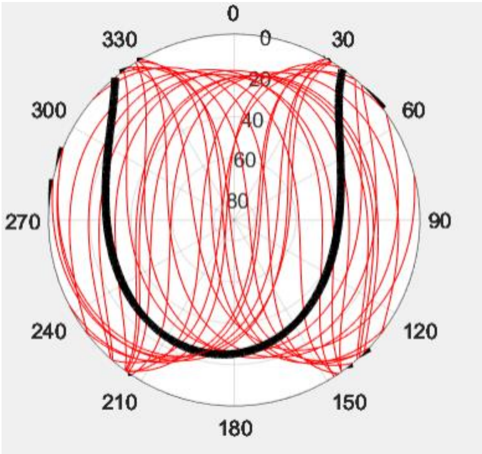

Figure 4- 15: G31 Satellite visible at Azimuth of 35° to 319°

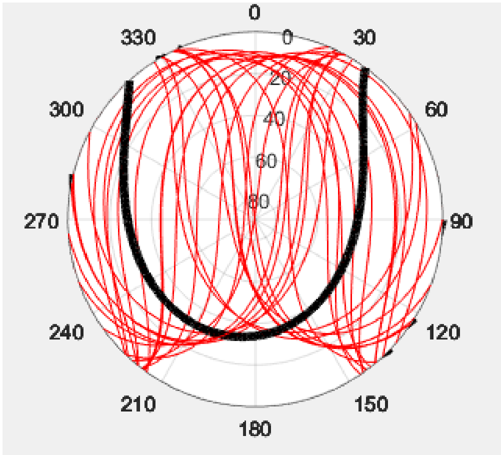

Figure 4- 16: G31 Satellite visible at Azimuth of 36° to 317°

From the plot it can be seen that most of the satellites were visible to the station at various azimuth angle, in accordance to soil moisture estimation the above information on satellites is useful in estimating the variation of SMC over the West, East, North and South Region of the OLO3 and SNGC station. Hence making the results obtained for soil moisture variation to be acceptable as there were many satellites available at different azimuth angles.

4.1.3 First Fresnel Zone

For OLO3 station the FFZ was plotted in which the area of each FFZ ellipse was 202 m^2 and the total area of the all FFZ ellipse was 10504.01 m^2. Below is the plot of the FFZ and the google earth image of the station showing an area which experienced high reflection.

From the diagram below, it shows that reflected signals were mostly occurring at the East and West of the station. The possible reason at which most of the reflected signals occur at the west and East is due to the fact, most of the satellite at low elevation angle originate from west and east of the station and hence making the areas having most of the reflected signals. The information above describes that soil moisture is mostly estimated from East and West of the station.

2018.

Figure 4- 17: A google earth image of First Fresnel Zone of SNGC station

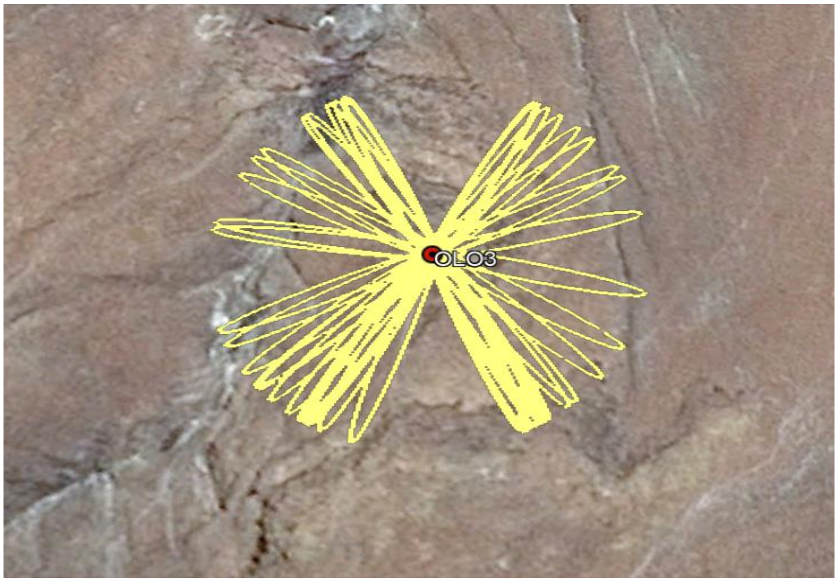

Figure 4- 18: A google earth image showing First Fresnel Zone of OLO3 station

4.2 Soil Moisture Estimation

In soil moisture estimation it involves two parts, the data obtained from processing SNRMAT files and the time series plots which shows the trend of the soil moisture for 2017 and 2018.

4.2.1 Estimated Soil Moisture Data

The data of SNRMAT for both 2017 and 2018 of OLO3 and SNGC were processed and then a single file in txt format was obtained which had the following information; Year, day of year, satellite RPN, SNR type, satellite track number, satellite track type, oscillating frequency, amplitude, phase, first epoch, last epoch, number of epochs, minimum elevation angle, maximum elevation angle, minimum azimuth angle, maximum azimuth angle, max (p) and background noise. Table 4-1 below shows the final data from the processed SNRMAT files which was then used to plot the SMC variation using Frequency and Epoch (doy).

Table 4- 1: A google earth image showing First Fresnel Zone of OLO3 station

Year	doy	S. RPN	SNR type	S. track no.	S. track type	F	A	Phase	1st Epoch	Last epoch	No. of epochs	Min elevation angle	Max Elevation angle	in azimuth ang	Max azimuth angle
2018	1	G01	S1	1	A	1.5029	28.6869	130.71	23025	34125	741	5.9241	84.6316	267.5616	346.2356
2018	1	G01	S1	2	D	7.315	29.3438	167.3	34140	42900	585	23.4162	84.6345	162.9518	266.1257
2018	1	G01	S2	1	A	1.5397	3.3669	108.41	23040	34125	740	5.9999	84.6316	267.5616	346.2356
2018	1	G01	S2	2	D	6.7647	6.1914	66.301	34140	42645	568	24.8472	84.6345	163.9692	266.1257
2018	1	G02	S1	1	A	3.3842	26.9171	154.89	61230	68880	511	30.2756	61.8673	97.4131	181.9879
2018	1	G02	S1	2	D	2.3753	8.5957	57.778	68895	80295	758	0.2452	61.8674	29.7275	97.1382
2018	1	G02	S2	1	A	3.456	2.8663	129.11	61455	68880	496	31.2708	61.8673	97.4131	180.4701
2018	1	G02	S2	2	D	1.7444	1.9366	110.85	68895	80040	743	1.631	61.8674	29.7275	97.1382
2018	1	G03	S1	1	A	21.0201	11.4104	43.189	25140	29130	266	9.8034	13.6106	311.7941	338.6129
2018	1	G03	S1	2	A	21.0201	0.5879	11.027	39840	41235	94	56.2055	58.3336	63.2641	85.4218
2018	1	G03	S1	3	D	7.8615	31.6268	161.34	41250	49005	518	18.3148	58.3339	85.6706	147.7965
2018	1	G03	S2	1	A	16.3793	0.1719	179.88	25395	29130	249	9.8471	13.6106	313.5781	338.6129
2018	1	G03	S2	2	A	16.3793	0.0249	166.06	39840	41235	94	56.2055	58.3336	63.2641	85.4218
2018	1	G03	S2	3	D	2.7108	3.2498	21.952	41250	48765	502	19.8983	58.3339	85.6706	147.5547
2018	1	G05	S1	1	A	17.762	13.9532	48.055	49380	57810	563	8.2108	39.1477	259.2446	320.381
2018	1	G05	S1	2	D	10.1948	36.9427	110.33	57825	68700	552	25.5781	39.1478	167.0231	259.0883
2018	1	G05	S1	3	A	21.0201	5.4218	36.189	68715	76155	497	25.578	30.1905	105.3108	166.9103
2018	1	G05	S1	4	D	15.8387	10.2073	150.39	76170	85500	623	0.217	30.1906	40.8717	105.173
2018	1	G05	S2	1	A	2.6944	0.9703	44.951	49425	57810	560	8.4735	39.1477	259.2446	320.2556
2018	1	G05	S2	2	D	7.6164	4.5252	26.875	57825	65190	492	28.051	39.1478	193.3331	259.0883
2018	1	G05	S2	3	A	16.3793	1.8228	4.6871	68880	76155	486	25.5829	30.1905	105.3108	165.6687
2018	1	G05	S2	4	D	7.8375	0.4536	140.67	76170	85485	616	0.2993	30.1906	40.9164	105.173
2018	1	G07	S1	1	A	5.8856	17.3102	38.82	30345	38280	530	17.6266	59.5929	211.5279	273.5294
2018	1	G07	S1	2	D	3.0584	13.5253	93.13	38295	55245	1131	9.8012	59.5931	0.0426	359.9522
2018	1	G07	S1	3	A	21.0201	0.1442	24.15	55260	59055	254	9.8012	10.4217	52.1887	80.3383
2018	1	G07	S1	4	D	21.0201	0.0031	163.83	59070	59730	45	10.3593	10.4218	80.4529	85.509

From the data above the SMC values were calculated using equation (1.3) which shows the relation between oscillating frequency, wavelength of GPS signal and the Vertical reflecting height of a signal. The SMC values were obtained as the difference between the vertical reflecting height and the height of antenna from the surface. Table 4-1 to 4-4 shows the calculated values of reflecting height and the SMC values for OLO3 and SNGC for both 2017 and 2018.

Table 4- 2 : Sample Computed values of Vertical Reflecting Height and Soil moisture content for OLO3 2017

Year	doy	Satellite RPN	SNR type	Frequency	Vertical Reflecting Height (m)	Height of Antena (m)	SMC Value (m)
2017	23	G02	S2	1.6625	0.2030	0	0.2030
2017	27	G02	S2	1.6461	0.2010	0	0.2010
2017	27	G25	S2	1.5315	0.1870	0	0.1870
2017	28	G02	S2	1.6052	0.1960	0	0.1960
2017	29	G02	S2	1.5970	0.1950	0	0.1950
2017	29	G25	S2	1.5233	0.1860	0	0.1860
2017	32	G10	S2	16.3793	1.9999	0	1.9999
2017	42	G18	S2	1.7362	0.2120	0	0.2120
2017	43	G18	S2	1.6953	0.2070	0	0.2070
2017	45	G18	S2	1.8918	0.2310	0	0.2310
2017	46	G18	S2	1.8918	0.2310	0	0.2310
2017	48	G18	S2	2.0147	0.2460	0	0.2460
2017	49	G18	S2	2.0966	0.2560	0	0.2560
2017	50	G18	S2	2.1539	0.2630	0	0.2630
2017	71	G32	S2	1.9082	0.2330	0	0.2330
2017	72	G32	S2	1.9573	0.2390	0	0.2390
2017	73	G20	S2	16.3793	1.9999	0	1.9999
2017	84	G20	S2	12.3582	1.5089	0	1.5089

Table 4- 3: Sample Computed values of Vertical Reflecting Height and Soil moisture content for OLO3 2018

Year	doy	Satellite RPN	SNR type	Frequency	Vertical Reflecting Height (m)	Antena Height (m)	SMC Value (m)
2018	1	G01	S1	1.5029	0.1430	0	0.1430
2018	2	G01	S1	1.4924	0.1420	0	0.1420
2018	3	G01	S1	1.4924	0.1420	0	0.1420
2018	4	G01	S1	1.4924	0.1420	0	0.1420
2018	7	G01	S1	1.5029	0.1430	0	0.1430
2018	8	G01	S1	1.4924	0.1420	0	0.1420
2018	10	G02	S2	1.7116	0.2090	0	0.2090
2018	12	G02	S2	1.6134	0.1970	0	0.1970
2018	13	G02	S2	1.6216	0.1980	0	0.1980
2018	14	G02	S2	1.6134	0.1970	0	0.1970
2018	15	G25	S2	16.3793	1.9999	0	1.9999
2018	16	G01	S1	1.5135	0.1440	0	0.1440
2018	20	G32	S2	1.9819	0.2420	0	0.2420
2018	22	G25	S2	16.3793	1.9999	0	1.9999
2018	27	G23	S2	16.2565	1.9849	0	1.9849
2018	37	G10	S2	16.3793	1.9999	0	1.9999
2018	40	G10	S2	16.3793	1.9999	0	1.9999

Table 4- 4: Sample Computed values of Vertical Reflecting Height for SNGC 2017

Year	doy	Satellite RPN	SNR type	Frequency (Hz)	Vertical Reflecting Height (m)
2017	2	G03	S2	16.3793	1.9999
2017	2	G19	S2	16.3793	1.9999
2017	2	G23	S2	16.3793	1.9999
2017	3	G23	S2	16.3793	1.9999
2017	3	G32	S2	16.3793	1.9999
2017	4	G28	S1	20.9571	1.9941
2017	4	G14	S2	16.3793	1.9999
2017	4	G32	S2	16.3793	1.9999
2017	4	G19	S1	21.0201	2.0001
2017	5	G23	S2	16.3793	1.9999
2017	5	G32	S2	16.3793	1.9999
2017	7	G18	S1	20.9466	1.9931
2017	7	G28	S1	20.9571	1.9941
2017	7	G19	S2	16.3793	1.9999
2017	7	G23	S2	16.3793	1.9999
2017	8	G18	S1	20.9676	1.9951
2017	8	G23	S2	16.3793	1.9999

Table 4- 5: Sample Computed values of Vertical Reflecting Height for SNGC 2018

Year	doy	Satellite RPN	SNR type	Frequency(Hz)	Vertical Reflecting Height(m)
2018	1	G14	S2	16.3793	1.9999
2018	1	G18	S1	15.3657	1.4620
2018	1	G28	S2	16.1091	1.9669
2018	3	G25	S2	16.3793	1.9999
2018	3	G28	S2	16.0927	1.9649
2018	3	G30	S2	16.3793	1.9999
2018	4	G20	S2	16.3793	1.9999
2018	4	G22	S2	16.3793	1.9999
2018	4	G30	S2	16.3793	1.9999
2018	5	G22	S2	16.3793	1.9999
2018	5	G30	S2	16.3793	1.9999
2018	6	G30	S2	16.3793	1.9999
2018	7	G21	S2	16.3793	1.9999
2018	7	G30	S2	16.3793	1.9999
2018	7	G32	S2	16.3793	1.9999
2018	9	G21	S2	16.3793	1.9999
2018	9	G22	S2	16.3793	1.9999
2018	9	G30	S2	16.3793	1.9999
2018	10	G32	S2	16.3793	1.9999
2018	12	G18	S1	17.184	1.6351

From the above tables the OLO3 station SMC values has been ranging in which the higher values maybe caused by the reflecting signals coming from other features which causes the reflecting surface to become higher. For SNGC station the antenna height is 0.00m but the reflecting signals height are higher than the antenna height hence the computation of the SMC values was not possible as it does not show reality of the method.

4.2.2 Soil Moisture Content Time series

Soil moisture variation of the OLO3 and SNGC station was determined using the methodology explained in chapter 3. Figure 4-20 to 4-23 are the plots on the variation of soil moisture content using the GNSS-IR method of OLO3 and SNGC for both 2017 and 2018 which was plotted using the Oscillating frequency against epoch.

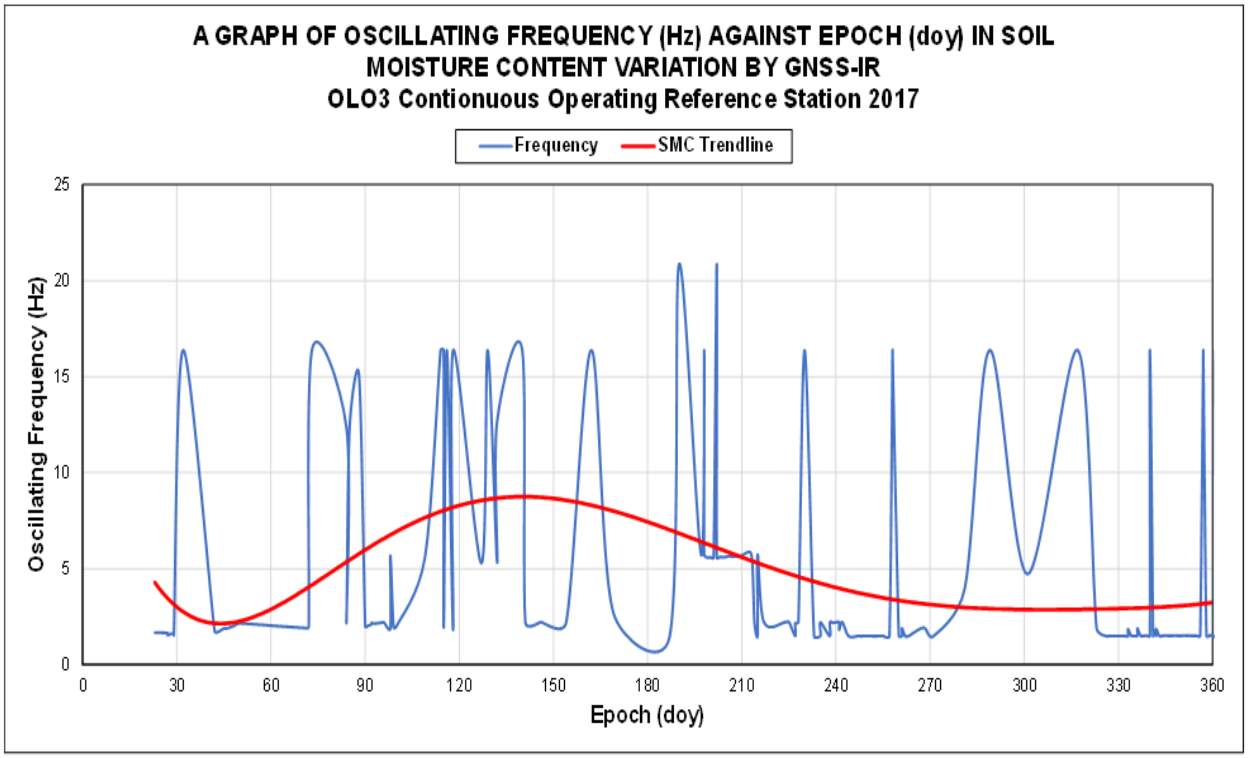

Figure 4- 19: Soil Moisture Content Variation of 2017 OLO3 station

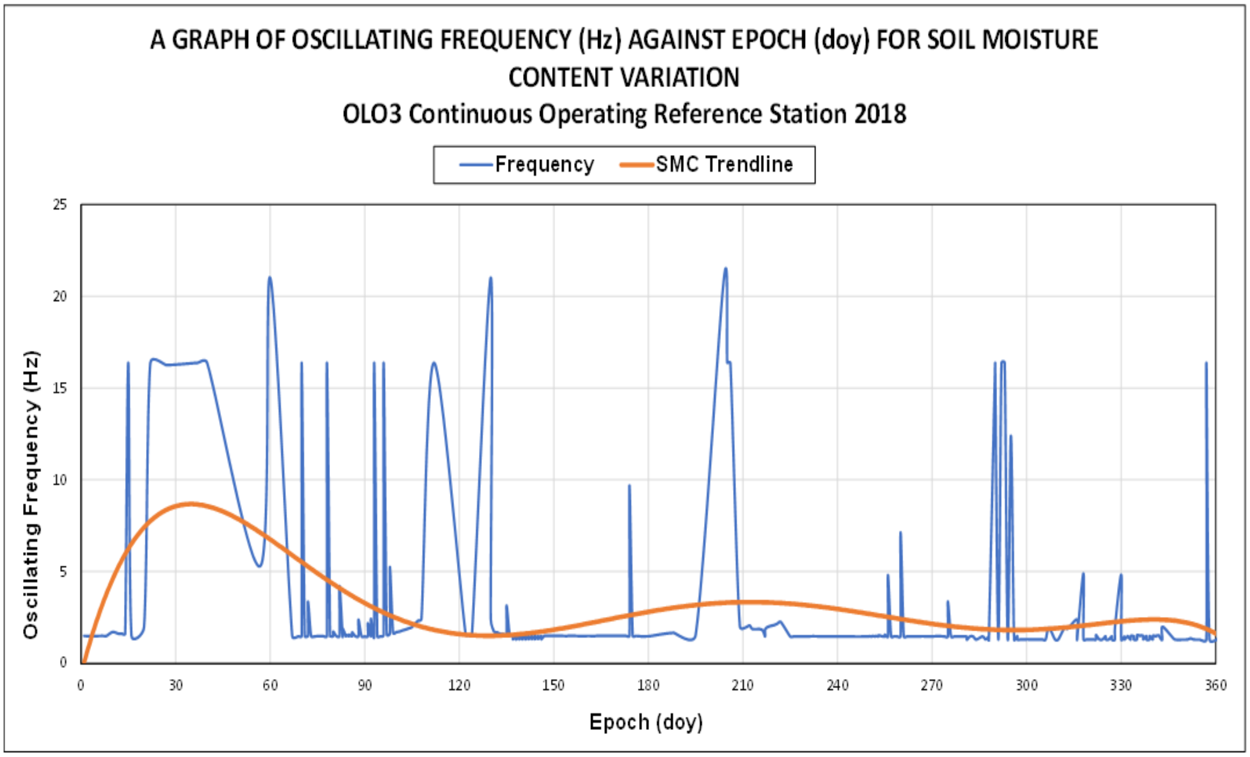

Figure 4- 20: Soil Moisture Content Variation of 2018 OLO3 station

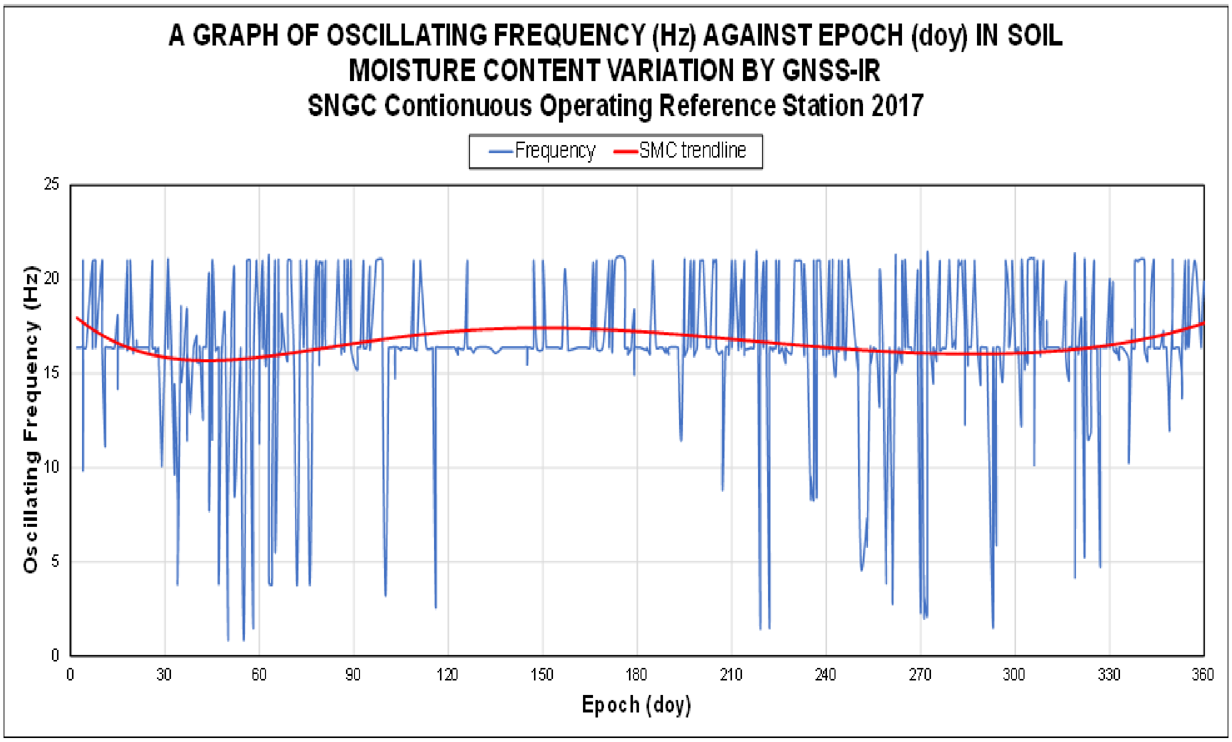

Figure 4- 21: Soil Moisture Content Variation of 2017 SNGC station

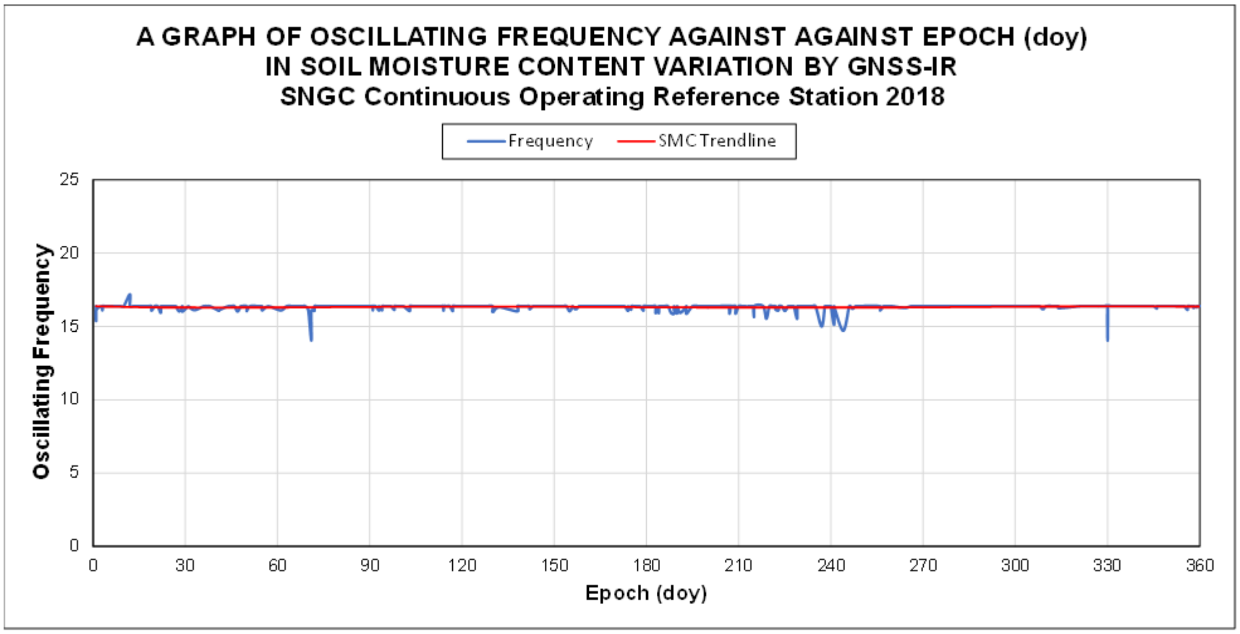

Figure 4- 22: Soil Moisture Content Variation of 2018 SNGC station

From the plots above according to the GNSS-IR method the soil moisture content around the OLO3 station 2017 varies over time. The soil wetness from February to August was high compared to other months. Also, for 2018 the soil wetness from January to April was high compared to other days of the year. It can be seen that as the days go on the wetness around the OLO3 station continues to decrease, although there was an increase in wetness from May to September but still it was not as high as it was in 2017. For both 2017 and 2018 in November and December the soil wetness has always been in the same range in which it has the lowest amount of wetness compared to other days of the year. For SNGC the variation of soil wetness has also been decreasing over time. For 2017 from March to July there was a high amount of soil wetness compared to other days except January which also has shown to have a high range of soil wetness. From August it can be seen that the soil wetness has been decreasing up to December. The soil wetness in 2018 can be seen to remain constant over the days and hence this shows the amount of rainfall is decreasing for a little amount that cannot be seen directly.

4.3 Soil moisture Data Validation

In order to validate the results obtained from the analysis of GNSS data, Merra-2 soil wetness data was used to assess the validity of the method in determination of soil moisture content variation which is highly influenced by rainfall over the specified station. The validation was done by both OLO3 and SNGC stations in 2017 and 2018. The below figures 4-24 to 4-27 are graphs of soil moisture content variation by Merra-2 soil wetness data.

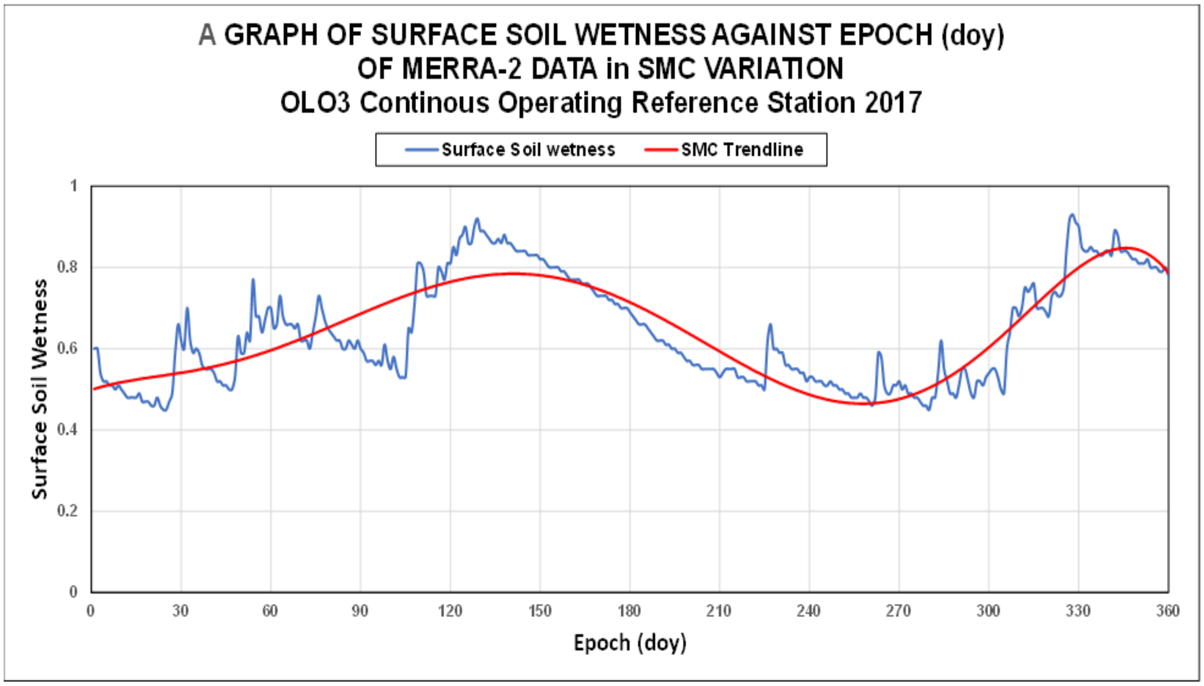

Figure 4- 23: Merra-2 Soil wetness data of OLO3 station 2017

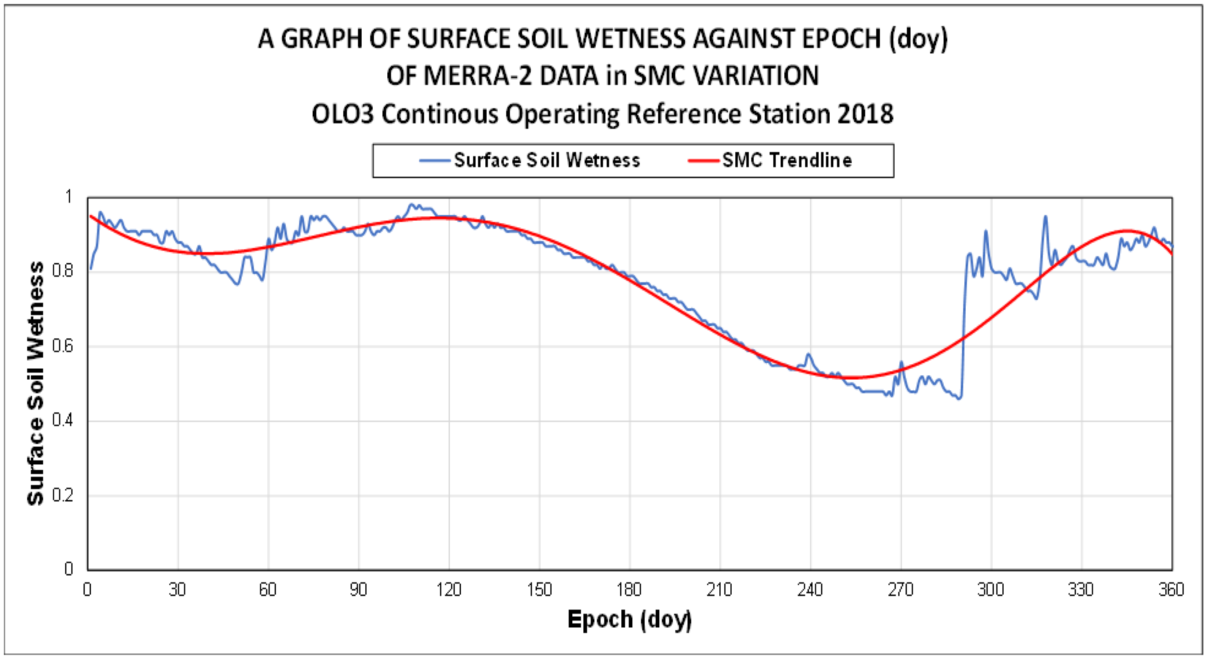

Figure 4- 24: Merra-2 soil wetness data of OLO3 station 2018

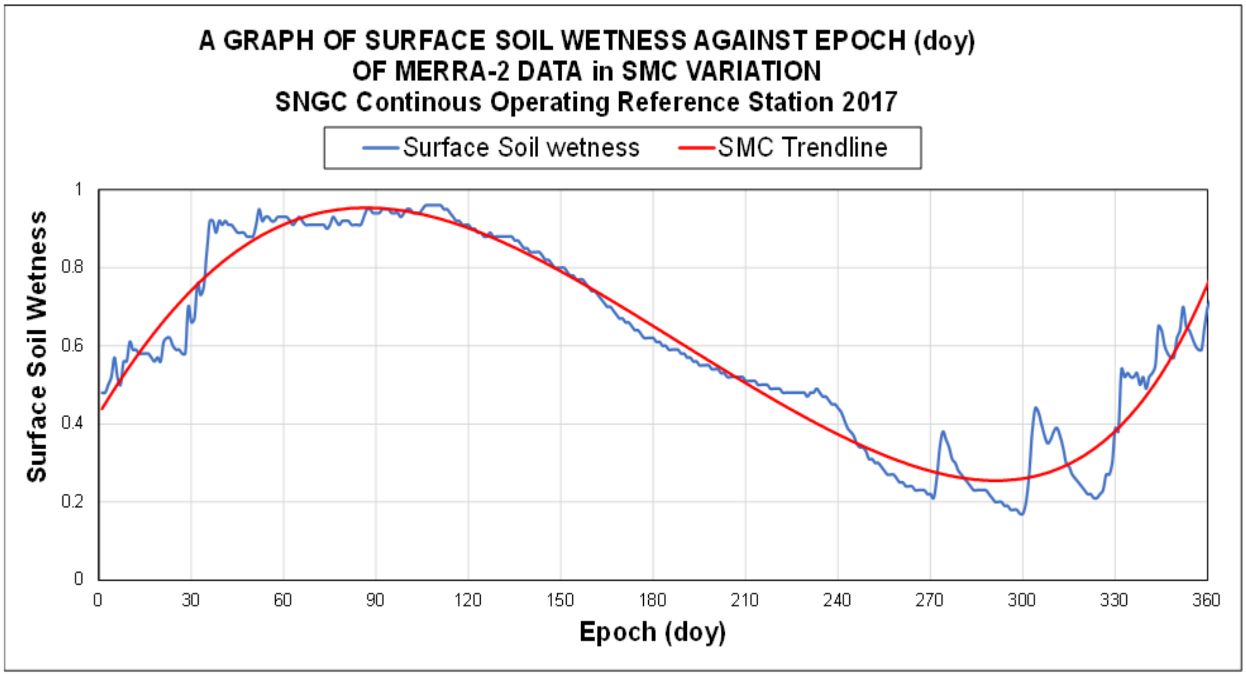

Figure 4- 25: Merra-2 soil wetness data of SNGC station 2017

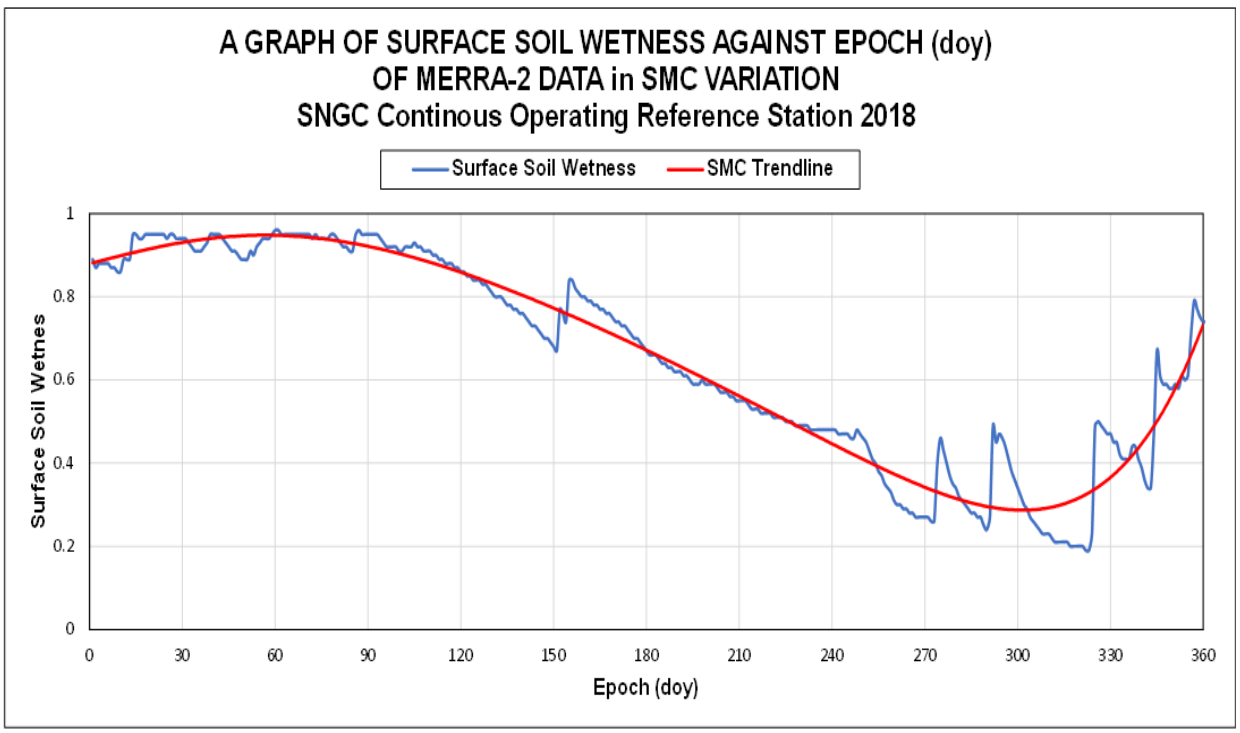

Figure 4- 26: Merra-2 soil wetness data of SNGC station 2018

For OLO3 2017 the variation SMC retrieved from GNSS-IR and MERRA-2 from Nasa correlated in which the amount of SMC from March to July for both methods were the same. Also, for Merra-2 data the trending of soil moisture from September to October had decreased which correlates as the variation of SMC retrieved from GNSS-IR. For OLO3 2018 the variation of SMC retrieved from GNSS-IR and Merra-2 also correlated in which the soil wetness was decreasing from January to October. For SNGC 2017 the SMC variation also correlated with the data from Merra-2 in which the amount of water within the soil was high in January and from the GNSS-IR March to July was also high which then correlated with the Merra-2 data. In 2018 the data between the Merra-2 and GNSS-IR did not correlate as the trendline of soil wetness was Linear compared to Merra-2 data.

4.4 Discussion and prediction

From the findings the soil moisture over the case study areas have been decreasing over time. The trendline of the soil moisture varies over two years in which it was expected to remain the same or the trendline to increase. The changing trendline of the soil wetness shows that the climate is dynamic and changes due to various activities. OLO3 station is located on the flanks of Mount Ol Doinyo Lengai and its soil moisture trendline shows it has been decreasing over the years with minimum soil moisture content, hence from the analysis it indicates drought situation around the area. The SNGC site the amount of soil wetness is still decreasing but not as fast as that of OLO3 station. The situation around the SNGC site can be overcomed by taking various measures that will help assess the dynamic of the climatic condition.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.0 Overview

This chapter describes a conclusion that is drawn from the result obtained in the previous chapter. Furthermore, here the author provides a suggestive idea to enhance a better result derived from the study methodology and results.

5.1 Conclusion

The Global Position System has shown it is not only used for navigation purposes but also it can be used to determine environmental parameters around the station. GNSS-IR was used in this study to determine the soil moisture content variation around OLO3 and SNGC Continuous Operating Reference Station located at Arusha and Songea respectively. The method was able to produce a data set that was used to plot the variation of soil moisture content over the specified area which showed that the soil moisture content is decreasing over time. The GNSS-IR method was validated using Merra-2 data to see the correlation of the two methods. Merra-2 data correlated with output produced by GNSS-IR for both OLO3 and SNGC.

5.2 Recommendation

The GNSS-IR method is useful in determining the environmental parameters around a quality geodetic station. In Tanzania there are various Continuous Operating Reference Stations that have been installed for various purposes, these stations can be used to determine other parameters such as land deformation and sea level surface change for GNSS installed near water bodies. There is a need for monitoring of these environmental parameters as it is important since the results obtained will be used to determine changes in the environment and hence predict any hazardous issues that can be encountered later. Also, the Tanzania Meteorological Agency can use the method as an addition in ways that can help in monitoring climatic dynamics in Tanzania which will help in prediction of drought in various areas. Its recommended that other researcher to consider signals reflecting from other source and the structure of the soil as it may affect the accuracy of the use GNSS-IR and use different data apart from MERRA-2 to validate the results.

REFERENCE

Adhikari, U., Nejadhashem, P., Herman, M. R., & Messina, J. P. (2016). Multiscale Assesment of the impacts of Climate Change on Water Resources in Tanzania. *Journal of Hydrologic Engineering*.

AfricanMecca Safaris. (2023, May). *Best time to visit Arusha city during northern Tanzania travels*. Retrieved from AfricanMecca Safaris: http://www.africanmeccasafaris.com

Altuntas, C., & Tunalioglu, N. (2020). Estimation Performance Of Soil Moisture With Gps-Ir Method. *Sigma Journal of Engineering and Natural Sciences*, 2217-2230.

Chang, X., Jin, T., Yu, K., Li, Y., Li, J., & Zhang, Q. (2019). *Soil Moisture Estimation by GNSS Multipath Signal.* Wuhan, China: School of Geodesy and Geomatics,Wuhan University.

Civeira, G. (2019). *Introductory Chapter: Soil Moisture.* Retrieved from IntechOpen: www.intechopen.com

EartScope Consortium. (2023, May). *Data Archive Interface version 1 (Dav v1)*. Retrieved from UNAVCO: http://www.unavco.org

Ghilani, C. D., & Wolf, P. R. (2012). *Elementary Surveying an Introduction to Geomatics 13th Edition.* New Jersey: Library of Congress Cataloging-in-Publication Data.

Kavanagh, B. F. (2010). *Surveying with construction applications 7th ed.* New Jersey: Library of Congress Cataloging-in-Publication Data.

Kimaro, D. N., & Hieronimo, P. (2014). Land for Agriculture in Tanzania: Challenges and Opportunities. *Journal of Land and Society*, 91-102.

Larson, K. M., Braun, J. J., Small, E. E., Zavorotny, V. U., Gutmann, E. D., & Bilich, A. L. (2010). GPS Multipath and Its Relation to Near-Surface. *Applied Earth Observations And Remote Sensing, Vol. 3*, 91-99.

Li, Y., Yu, K., jin, T., Chang, X., Wang, Q., & Li, J. (2021). Development of a GNSS-IR instrument based on low-cost positioning chips and its performance evaluation for estimating the refector height. *GPS Solutions*.

Madhavi, G. N., Kumar, P. S., Chipade, R. A., Bhate, J., & Chandrasekhar-Sarma, T. V. (2022). Estimation a nd Validation Study of Soil M oisture Using GPS-IR Technique Over a Tropical Region. *Ieee Journal Of S Elected Topics In Applied Earth Observations And Remote Sensing, Vol. 15*, 42-49.

Minchin, M. (2016). *Introduction to Surveying 2nd Edition.* West Perth: Department of Training and Workforce Development.

Oevelen, P. J. (1998). Soil moisture variability: a comparison between detailed field measurements and remote sensing measurement techniques. *Hydrological Sciences Journal*, 511-520.

Osima, S. E. (2014). *Drought conditions and management strategies in Tanzania.* Dar es Salaam: Tanzania Meteorological Agency.

Rasheed, M. W., Tang, J., Sarwar, A., Shah, S., Saddique , N., Khan, M. U., . . . Sultan, M. (2022). Soil Moisture Measuring Techniques and Factors Affecting the Moisture Dynamics. *Sustainability*.

Roesler, C., & Larson, K. M. (2018). *Software tools for GNSS interferometric reflectometry (GNSS-IR).* Retrieved from GPS TOOL BOX: https://doi.org/10.1007/s10291-018-0744-8

Sharma, P. K., Kumar, D., Srivastava, H. S., & Patel, P. (2018). Assessment of Different Methods for Soil Moisture Estimation. *Journal of Remote Sensing & GIS Volume 9*, 57-73.

Stamps, D.S., Saria, Elifuraha, Hyeun Ji, Kang, *Jones, J. Robert, *Ntambila, Daud, Daniels, Mike and Mencin, Dave, 2016c, TZVOLCANO: *OLO3-OLO3_OLO_TZA2016* P.S., UNAVCO, GPS Data Set, doi:10.7283/T5Z31XFX

Tanzania Meteorological Agency. (2018). *National Framework For Climate Services 2018- 2025.* Dar Es Salaam: Ministry of Transport and Infrastructure.

UNDP. (2023). *Tanzania Climatic change adaptation*. Retrieved from United Nations Development Programe: https://www.adaptation-undp.org/explore/eastern-africa/united-republic-tanzania

Wang, L., & Qu, J. J. (2009). Satellite remote sensing applications for sur face soil moisture monitoring: A review. *Earth Sci*, 237–247.

Weather Spark. (2023, may). *Climate and average weather year round in Songea*. Retrieved from Weather Spark: http://weatherspark.com/y/98677