

2019-09-23

SPATIO TEMPORAL VARIATIONS OF IONOSPHERIC TOTAL ELECTRON CONTENT (TEC) USING ETHIOPIAN GROUND BASED GPS RECEIVER. .

Getachew, Mulu

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**SPATIO TEMPORAL VARIATIONS OF IONOSPHERIC TOTAL ELECTRON
CONTENT (TEC) USING ETHIOPIAN GROUND BASED GPS RECEIVER. .**



A THESIS IS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF
BAHIR DAR UNIVERSITY
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE IN PHYSICS

By

Getachew Mulu

BAHIR DAR UNIVERSITY

BAHIR DAR, ETHIOPIA

Advisor: Tsegaye Kassa (PhD)

July 11, 2019

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CERTIFICATION

The undersigned hereby certify that they have read and recommend to the College of Science, Graduate Studies for acceptance a thesis entitled: ‘**Spatio temporal variation of ionospheric total electron content (TEC) using Ethiopian ground based GPS receiver**’ by **Getachew Mulu** in partial fulfillment of the requirements for the degree of **Master of Science in Physics** at Bahir Dar University.

APPROVED BY

July 11, 2019

Advisor: Dr. Tesgaye Kassa.

External examiner: Dr.....

Internal examiner: Dr.....

Chair Person: Dr.....

BAHIR DAR UNIVERSITY

July 11, 2019

Title: **SPATIO TEMPORAL VARIATIONS OF IONOSPHERIC TOTAL ELECTRON CONTENT (TEC) USING ETHIOPIAN GROUND BASED GPS RECEIVER.**

Department: **Physics**

Degree: **M.Sc.** Convocation: **July** Year: **2019**

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DEDICATION

*I would like to dedicate this work to My mam w/ro
Alemtu Assaye.*

Acknowledgement

Above all, I would like to thank the Almighty God, who has provided me with the opportunity to complete this research. Then I would like to thank deeply my advisor and instructor Dr. Tesgay Kassa for his constructive comments, encouragement, guidance and advices throughout the duration of my thesis work. I am also greatly to thank Dr. Ambelu Tebabal for his supporting, encouragement and advice. I want also to thank Mr. Amanual, Mr. Tewachew Agumas, Dasash and Tena Muluken for their valuable advice, giving direction and wonderful assistance. I would like to express my deep gratitude to Mr. Belayneh Andualem and Mr. Haymanote Andualem for their long lasting support, encouragement and advice starting from my undergraduate education life. I am also expressing my heartfelt gratitude to all my beloved friends and classmates for their constant encouragement and cooperation.

I would like to thank Bahir Dar University College of science for offering me the opportunity to study Msc degree. However, I have no words to acknowledge my best brother Mr. Addisu Andualm. This thesis as well as Msc program could have never been completed without his encouragement and valuable help. Finally and most importantly, I would like to express my deepest gratitude to my mother bellow the Almighty God, she has been a source of strength and motivation from the beginning up to end and to all people that have supported me and spent their precious time to bring this work to a success.

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Abstract

This thesis is aimed to study diurnal, monthly, seasonal and spatial variation of ionospheric TEC obtained from GPS satellite in the years of 2014 and 2015. TEC data measured by dual-frequency signals of the Global Position System (GPS) in two Ethiopian low latitude stations, such as Bahir Dar (BDAR) with geographic latitude (11.6° N) and Longitude (37.35° E) and Arba Minch (ARMI) with geographic latitude (6.06° N) and Longitude(37.57° E) during the years 2014 and 2015. The processed and archived data taken from GPS receiver has been imported in to a MATLAB code which gave us the results of the value of TEC. The results show that the diurnal variation TEC minimum between 23:00 UT to 02:00 UT or 17:00 h ELT to 20:00 h ELT; maximum at about 12:00 to 14:00 UT or 06:00 h ELT to 08:00 h ELT. As regards to monthly variations of ionospheric TEC, results of GPS satellite shows that highest mean TEC value is recorded on March and July recorded the least peak TEC value. The seasonal variation of TEC maximizes during the equinox months followed by winter months especially July. The latitudinal variation of ionospheric TEC at Bahir Dar is higher than Arba Minch. In addition to this we have also seen correlations between geomagnetic activity and TEC.

Key words: Ionospheric Total Electron Content(TEC), Low Latitude or Equatorial Stations, Diurnal, Monthly, Seasonal, Variation.

CHAPTER 1

Introduction

1.1 Background of the study

The ionosphere is defined as the layer of the Earth's upper atmosphere that is ionized when energetic electromagnetic and particle radiation from the Sun and space ionize air molecules creating plasma in the upper atmosphere. It lies 50-1000 km (46-621 miles) above the Earth surface (Loomis et al., 2018). The ionized electrons behave as free particles. The Sun's upper atmosphere, the corona, is very hot and produces a constant stream of plasma and UV and X-rays that flow out from the Sun and affect, or ionize, the Earth's ionosphere. The ionosphere is a highly variable and complex physical system where ions and electrons are present in quantities sufficient to affect the propagation of radio waves (Matsushita and Campbell, 1967). Free electrons populating this region of the atmosphere affect the propagation of the radio signals, changing their speed and direction of travel. Hence, the accumulation of electrons affects the electromagnetic waves that pass through the ionosphere by inducing an additional transmission time delay (Klobuchar et al., 1996). This delay is directly proportional to the number of free electrons in a cylinder of unit cross-section along the signal path extending from the satellite to the receiver on the ground and inversely proportional to the square of the frequency of the trans ionospheric radio wave (Hofmann-Wellenhof et al., 1992; Misra and Enge, 2006). Due to the unique geometry of the geomagnetic field, these phenomena are most pronounced in low-latitude and equatorial regions such as Ethiopia especially Bahir Dar and Arba Minch. In such regions, the plasma density in the ionosphere shows significant variations with time of day, latitude, longitude, hourly, diurnally, monthly, season and geomagnetic activity, which can result in a variation of different parameters such as total electron content (TEC). The daytime equatorial and low-latitude ionosphere is characterized by an F region electron density trough at the geomagnetic equator and two crests within $\pm 20^\circ$ magnetic latitude. The F region density, in particular, represents the greatest contribution to the maximum TEC in the ionosphere, which can significantly affect radio wave propagation. These layers can cause strong perturbations in radio-wave propagation and cause problems for communication and navigation systems (Kivelson, 1995). A variety of periodic and periodic variations could be observed in the ionosphere, which makes a serious impact on short

wave communication, satellite communication and precise navigation with the Global Navigation Satellite System (GNSS), such as GPS (Liu et al., 1015). TEC, which has both temporal and spatial variations, is one of the most important ionospheric parameters (Brunini et al., 2005). TEC is an important ionospheric characteristic for planning and operation of satellite navigation and communication system since it is directly related to ionospheric electron density, which is the major source of signal degradation (Hanbaba and Zolesi, 2000). Since the ionosphere varies from time to time and place to place, in other words the ionosphere exhibits both spatial and temporal variations hence it is important to study it at many places as possible and for as long as possible.

1.2 Motivation of the study

Ionosphere is a dispersion of free electrons released when gas molecules are ionized by the Sun's ultraviolet radiation. It is highly important for long distance communication by reflecting the radio waves back to Earth, both radio and TV transmissions use radio waves. The ionosphere is a continually changing area and it is obviously affected by radiation from the Sun. This changes including the time of day, the geographical area of the world, and the state of the Sun. As a result radio communications using the ionosphere varies from one day to the next and even one hour to the next. Because of its complexity still space weather is fairly new field in science today and has very interesting effects on humans, environment and technology in general. Since the dynamic changes taking place in the ionosphere affect our communication systems, understanding the physics of this region is important to know the changes and design a method to improve our day to day ways of communication. Many researchers have been studied the ionospheric variation of TEC by using GPS receiver network in Ethiopia sector. For example, Kifle (2012) has analyzed the response of ionospheric TEC variation by using GPS receiver. He studied the temporal, seasonal and spatial variations of ionospheric TEC in Ethiopian region, GPS data from January to December 2008 for all days at Bale Robe, Nazrit, Addis Abeba, Arba Minch and Bahir Dar stations. He has said that TEC gradually increased with decreasing latitude increasing in longitudinal direction and the value of TEC didn't indicate us variation due to storm time. But, this is not work in equatorial region or low latitude regions and storm time is a significant effect on the variation of TEC. Kassa and Damtie (2012) have also investigated the response of Bahir Dar, Ethiopia ionosphere to geomagnetic storm of 11 October 2008 by considering the change in the daily peak of the total electron content. But, they have used the limited data and small numbers of stations involved in such studies were not including on the role played by the level of ionospheric ionization over the Ethiopian region. Because it dose not any evidence Ethiopian ionospheric TEC is uniform or not. However, it does not study spatio temporal variation of iono-

spheric TEC very well, in East Africa, especially in Ethiopia. Because of this gap we motivate to study the spatio temporal variation of ionospheric total electron content by using GPS data in two low latitude Ethiopian stations at Bahir Dar and Arba Minch for the year of 2014 and 2015.

1.3 Objective

This thesis is aimed at characterizing the spatio-temporal variations of ionospheric TEC by using GPS network over Ethiopia. Specifically, we intend to achieve the following objectives:

1. To characterize the spatial variations of ionospheric TEC.
2. To characterize the temporal variations of ionospheric TEC.
3. To perform correlation analysis between solar/geomagnetic index and ionospheric TEC.

1.4 Significance of the study

The ionosphere plays a great role in broadcasting, ship and air-craft communication and navigation by reflecting the radio signals back to the receiver. Understanding the variation of TEC is the most important for the operation of different applications including satellite navigation and communication system. Therefore, the study and understanding of the characteristics of Ethiopian low latitude and equatorial ionosphere is crucial for modeling and forecasting the ionosphere and space weather conditions and it is also used as a source of other researchers. In addition to this it is important for addressing the spatio-temporal variations of ionospheric TEC by using GPS networking.

1.5 Organization of the thesis

The thesis comprises of five chapters. Chapter 1 covers a brief introduction of the thesis. Chapter 2 presents the basics of about Sun, Earth's atmosphere and ionosphere. In chapter three briefly described the source of data and methodology. In chapter four, results and discussions of the thesis was presented. Finally, conclusion is presented in the last chapter.

CHAPTER 2

Letrutur Review

2.1 Basics about Sun

Sun is an extremely a huge bright ball of plasma hot ionized gas. But unlike the Earth and the Moon, is not solid. It is one of an estimated 100 billion stars in the Milky Way galaxy (Montmerle et al., 2006). Most atoms in the Sun exist as plasma, or a fourth state of matter made up of superheated gas with an electrical charge. It consists mostly 75 percent hydrogen, 24 percent helium and 1 percent other heavy elements by mass and also it consists 91.2 percent of hydrogen and 8.7 percent helium the other 0.1 percent heavy elements. Because the Sun is not solid, it does not have a defined outer boundary. It does, however, have a definite internal structure. There are several identifiable layers of the Sun (Morozov, 2012).

2.1.1 Internal structure of the sun

The interior cross-section of the Sun divided into three main region:- the core, radiation zone, and the convection zone. As it shown on the figure bellow.

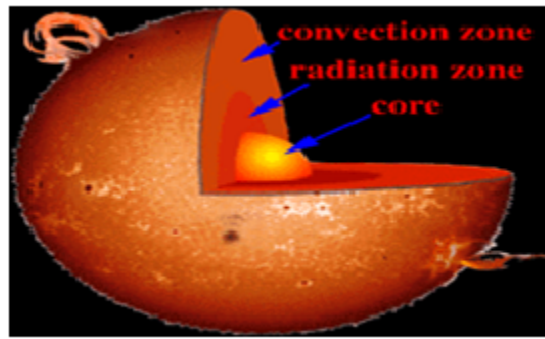


Figure 2.1: Schematic view of the inner structure of the Sun (<https://www.windows2universe.org>).

2.1.1.1 Core

The core is the innermost or central layer of the Sun. It is plasma, but moves similarly to a gas. Its temperature is around 27 million degrees Celsius. In the core, nuclear reactions combine hydrogen atoms to form helium, releasing vast amounts of energy in the process. The energy released then begins to move outward, towards the outer layers of the Sun (Sparrow et al. , 2015).

2.1.1.2 Radiative zone

The radiative zone is just outside the core, which has a temperature of about 7 million degrees Celsius. The energy released in the core travels extremely slowly through the radiative zone. Particles of light called photons can only travel a few millimeters before they hit another particle in the Sun, are absorbed and then released again. It can take a photon as long as 50 million years to travel all the way through the radiative zone (Cameron, 1957).

2.1.1.3 Convection zone

The convection zone surrounds the radiative zone. In the convection zone, hot material from near the Sun's center rises, cools at the surface, and then plunges (fall or move suddenly) back downward to receive more heat from the radiative zone. This movement helps to create solar flares and sunspots, which we'll learn more about in a bit (a small piece or quantity). These first three layers make up what we would actually call the Sun (García et al., 2007).

2.1.2 The Solar Atmosphere

Above the convective zone of the solar interior is the solar atmosphere. Solar atmosphere have not a definet outer boundary structure. Because the Sun is a gaseous object, its 'surface' is a matter of definition. It is entirely natural, however, to associate the surface with the limb of the visible solar disk. This boundary is very sharply defined, implying that the light must come from a very thin emission layer (Sparrow et al. , 2015). This is denoted the photosphere and we consider its level of maximum radiative emission as the surface of the Sun. The density of the solar atmosphere decrease away from the Sun. But the solar temperature decease to some height and then increase.

Temperature and density serve as a convenient guideline for subdividing the atmosphere into different layers: The solar atmosphere because of temperature and density profile mostly divided into three regions same times divided in to may be four regions based on temperature and density profile (García et al., 2007).

- Photosphere
- Chromosphere
- Transition region
- Corona

The innermost region reaching out to about 600 km above the top of the convection zone is the photosphere. Between 600 and 2,000 km is the chromosphere, and outside this the corona.

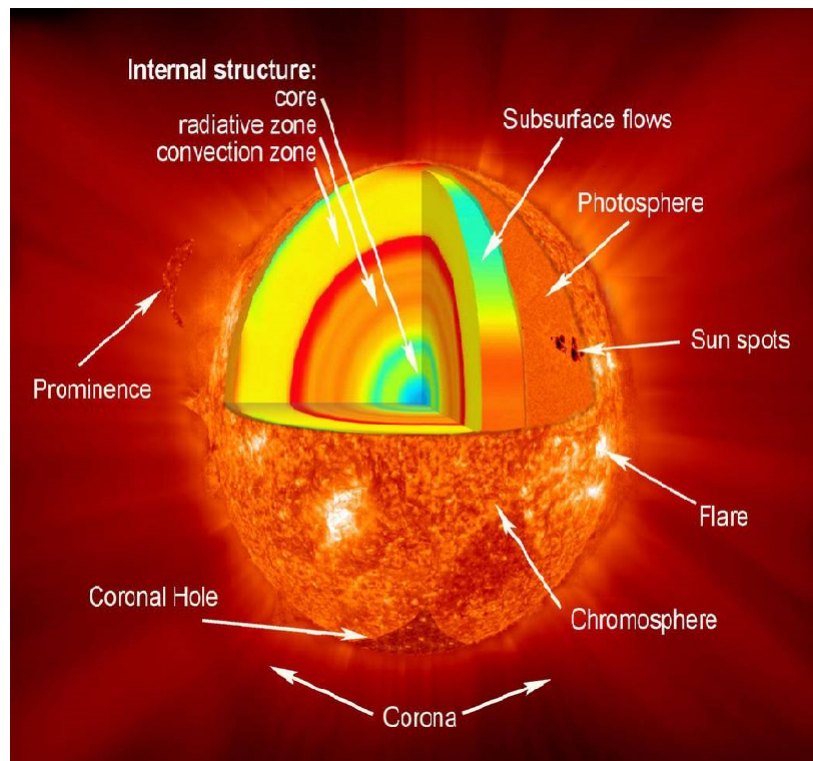


Figure 2.2: The Sun and its atmosphere consist of several zones or layers (<https://www.nasa.gov.com>).

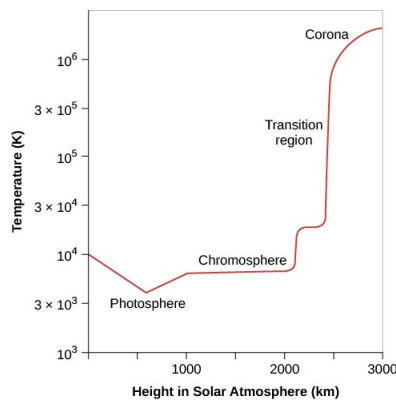


Figure 2.3: Temperatures in the Solar Atmosphere: (<https://courses.lumenlearning.com>).

2.1.2.1 The Photosphere

The photosphere is the lowest layers of the atmosphere that we can observe directly. It reaches from the surface visible at the center of the solar disk to about 250 miles (400 km) above that. The temperature in the photosphere varies between about 6500 K at the bottom and 4000 K at the top (11,000 and 6700 degrees F, 6200 and 3700 degrees C). It is the optical 'surface' of the sun, but it isn't actually a solid surface, it is a shallow shell of gas about 400km deep (Osterbrock , 1961). All visible light is emitted from the photosphere akin (similar character) to a black body (i.e. peak of the black body spectrum is in the visible waveband). Most of the photosphere is covered by granulation. It represents the top of convection currents operating just below the photosphere, transporting heat from below to the surface. This convection produces columns of rising gas (granules) to the upper levels, which then cools off and plunges back down into the interior. This is done at a rate of a few kilometers per second, so not very rapid, but noticeable. The brighter, central regions show hotter gas rising upwards and the darker, narrower parts correspond to cooler gas sinking back down into the interior of the Sun. It consists granules, super granules Sun spots and facula. In this layer energy is transported by radiative and convection (Priest, 2012).

2.1.2.2 The Chromosphere

The chromosphere is a layer in the Sun above the photosphere and is the middle layer of the solar atmosphere. It is a layer of gas a few thousand kilometers (2000-3000km) thick and is transparent to visible light, so cannot be seen against the brightness of the photosphere. However, it can be observed during a total solar eclipse. The temperature increases with height and ranges from 4400K to 25000K at the top, so in this layer (and higher layers) it actually gets hotter if you go further away from the Sun, unlike in the lower layers, where it gets hotter if you go closer to the center of the Sun. Spicules are seen when observing the chromosphere through a H-alpha filter. They are jet eruptions of gas that shoot upwards, ejecting material off of the surface and outwards into the Corona at speeds of about 20 -30 km/s. They are usually found on boundaries between supergranules and form as a result of magnetic field disturbances in the solar atmosphere. They appear dark against the photosphere as they are cooler and have relatively short lifetimes (of order of a few minutes). Perhaps the most impressive of activity seen on the chromosphere (and indeed the Sun itself) are solar prominences. They are dense clouds of incandescent(emitting light as a result of being heated) ionized solar gas suspended above the Sun's surface by its magnetic field (Böhm et al., 2012).

2.1.2.3 Transition Region

The transition region is a very narrow layer between the chromosphere and the corona where the temperature rises abruptly from about 8000 to about 500,000 K (14,000 to 900,000 degrees F, 7700 to 500,000 degrees C) (Feldman, 1983).

2.1.2.4 The Corona

The corona is the outermost layer of the solar atmosphere, seen as a white glow around the limb(wing) of the Sun. It extends from the top of the chromosphere out to a distance of several million kilometer's, where it becomes the Solar Wind. The corona is not as bright as the photosphere, hence, it cannot be seen with the naked eye except during a total solar eclipse, or with the use of a coronagraph. The corona does not have an upper limit. Although it has a very high temperature (between 1 million and 5million Kelvin), and is much hotter than the visible surface of the Sun, or photosphere. It is not actually 'hot' as that it contains very little thermal energy. This is because there are very few atoms per cubic meter. Although the high temperatures cause these atoms to move at very high speeds, because there are so few, there are few collisions. The corona shines very brightly in the x-ray part of the spectrum, despite being blocked out by the photosphere in the visible. This is because of the very high temperatures. The solar wind is a stream of high-speed photons and electrons constantly escaping the Sun at velocities as high as 400km/s. It occurs because the temperature of the corona is so high that the Sun's gravity can't counter it. From early observations of the corona, you could see bright emission lines at wavelengths, which didn't correspond to any known elements at the time. The reason for this is the temperatures are so high that the gases are superheated, stripping the minor elements such as Hydrogen and Helium of their electrons. Therefore, only the heavier elements, such as Calcium and Iron, retain some of their electrons, producing these spectral lines. This is known as the Emission Line Corona. This fact is used in corona graphs, where a disk covers the solar disk and a filter is used to detect the Calcium and Iron spectral lines. Coronal Holes are associated with the 'open' magnetic field lines found at the solar poles. These are places of weak magnetic field where the field lines don't connect regions on the solar surface. Solar winds are known to originate from coronal holes. They appear as dark regions, where the corona is very dark (Lyons et al. , 2014).

2.2 The Earth's Atmosphere and the Ionosphere

2.2.1 The Earth's atmosphere

The atmosphere of the Earth is a mixture of nitrogen 78 percent , oxygen (21percent), and other gases (1 percent) that surrounds Earth. High above the planet, the atmosphere becomes thinner until it gradually reaches space. The atmosphere is an important part of what makes Earth livable. It blocks some of the Sun's dangerous rays from reaching Earth. It traps heat, making Earth a comfortable temperature and the oxygen within our atmosphere is essential for life (Liou, 2002). Earth is the only planet in the solar system with an atmosphere that can sustain life. The blanket of gases not only contains the air that we breathe but also protects us from the blasts of heat and radiation emanating from the Sun. It warms the planet by day and cools it at night (Stevenson, 1999).

2.2.2 Structure of Earth's atmosphere

The atmospheric layer of the Earth is about 300 miles (480 kilometers) thick, but most of it is within 10 miles (16 km) the surface (Sharp, 2017). Air pressure decreases with altitude. At sea level, air pressure is about 14.7 pounds per square inch (1 kilogram per square centimeter). At 10,000 feet (3 km), the air pressure is 10 pounds per square inch (0.7 kg per square cm) (Godish and Fu , 1997). It is divided into may be four layers, based on temperature. Thus are troposphere, stratosphere, mesosphere and thermosphere.

2.2.2.1 Troposphere

The troposphere is the layer of the atmosphere closest to the earth. As we have seen from figure 2.4 the height of troposphere extends up to 12km. This atmospheric layer is in which man along with other organism's lives (Seinfeld and Pandis, 2016). The troposphere, the basal part of the atmosphere, is the most important zone for organisms and is composed mainly of Nitrogen and Oxygen. It also contains Argon and Carbon-dioxide and traces of Helium, Neon, Krypton, Nitrogen -di- Oxide, Hydrogen, Carbon-dioxide, Ozone, Ammonia, Sulfur dioxide etc. The troposphere contains more than 80 percent of the earth's atmosphere. Nearly all the earth's weather conditions including most clouds, rain, and snow occur in this layer. Meteorologists forecast the weather by studying the troposphere. The troposphere is usually warmest near the earth's surface because sunlight that passes through the air heats the ground and seas. The ground and seas, in turn, warm the air directly above. Sometimes, especially at night and during winter, the air near

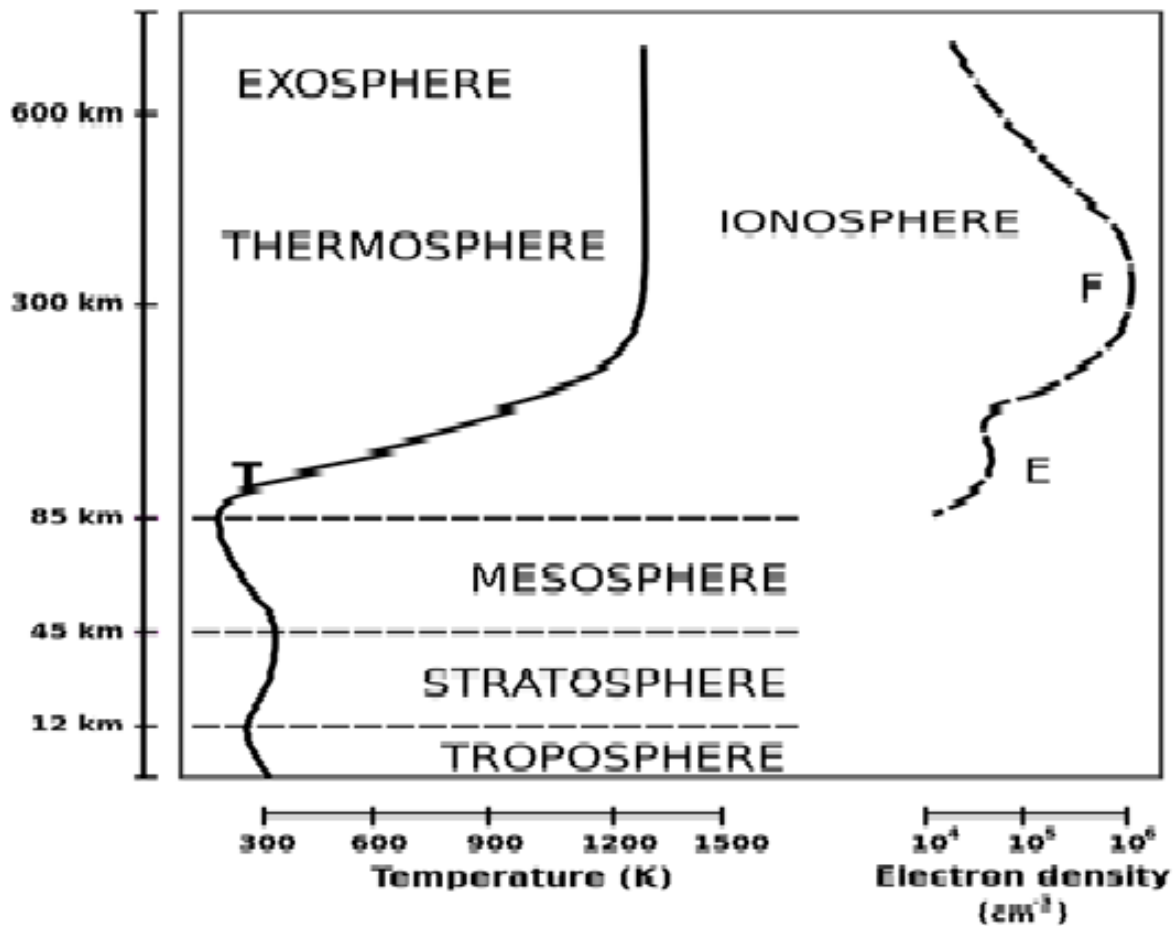


Figure 2.4: The vertical thermal structure of the Earth's atmosphere and density structure of its ionosphere (<https://www.researchgate.net/figure/>).

earth's surface becomes cooler than the air above. The temperature of the troposphere decreases about 6.5°C for every kilometer of increase in altitude. The temperature stops decreasing at the tropopause, which is the upper boundary of the troposphere. At the tropopause, the air becomes too thin to support life and the air is so cold that the clouds consist of ice crystals. The coldest part of the troposphere is at the tropopause over the equator (Liou, 2002).

2.2.2.2 Stratosphere

The stratosphere extends from the tropopause to about 45 kilometers above the earth's surface. It contains relatively large amounts of ozone formed by absorption of ultraviolet radiation (Seinfeld and Pandis, 2016). The principal chemical species in the stratosphere are Nitrogen, Oxygen, Ozone and some water vapour and these are active chemically because of their interaction with

ultraviolet solar radiation. Temperature increases with height occurs due to absorption of ultraviolet UV radiation from the Sun by this ozone. Ozone layers peak at 20-30 km protecting Earth from harmful UV radiation. Temperatures in the stratosphere are highest over the summer pole and lower over the winter pole. By absorbing dangerous UV radiation, the ozone in the stratosphere protects us from skin cancer and other health damage. However, chemicals (called CFCs or freons and halons) which were once used in refrigerators spray cans and fire extinguishers have reduced the amount of ozone in the stratosphere, particularly at polar latitudes leading to so called Antarctic ozone hole (Dunkerton, 1978).

2.2.2.3 Mesosphere

Mesosphere extends from the stratopause to about 80 kilometers above the earth. The height varies from about 48 Kilometers (30 miles) to 80 Kilometers (50 miles) above Earth's surface (Cicerone, 1987). Scientists believe the mesosphere has variable air motion like that of the troposphere (Dunkerton, 1978). The principal chemical species in the mesosphere are N_2 , O_2 , O_2^+ and NO^+ . The temperature of the mesosphere decreases with altitude. The mesosphere has the coldest atmospheric temperatures. It's also the highest clouds, which appear in summer just after sunset, as silvery strands called night shining clouds. The lowest temperatures in earth's atmosphere occur at the top of the mesosphere, called the mesopause. This is due to decreasing of solar heating. At the mesopause over the poles, air temperature drops as low as -109°C during summer. Extremely strong winds blow in this layer. These winds blow from west to east during winter and from east to west during the summer. It contains positive and negative ions in a small amount (Flasaret al., 2005).

2.2.2.4 Thermosphere

Thermosphere is extending upwards from about 100 km above the surface in which atoms tend to be ionized by incoming solar radiation. It extends up to 480 km above the earth surface and is characterized by steady temperature increase with height from mesopause. The increasing temperature in the thermosphere is due to a partial absorption of the UV-ray by the oxygen molecules (O_2). The air in the thermosphere is extremely thin and more than 99.99 per cent of the atmosphere lies below it. The chemical composition of the thermosphere differs from that of the lower layers. The principal Chemical species in the ionosphere are O^+ , O_2^+ and NO^+ . In the lower regions of the thermosphere, many of the oxygen molecules in the air are broken into oxygen atoms. The outer layer of the thermosphere consists chiefly of hydrogen and helium. Thermosphere is completely exposed to the Sun's radiation, which heats the thin air there to extremely high temperatures. Ordinarily, the temperature climbs rapidly from the mesopause to about 600

degree Celsius at 200 kilometers above the earth and then levels off, but during solar storms, more radiation and particles strike the thermosphere. It then becomes much hotter. Reaching a temperature as high as 2000 °C at the top of the thermosphere, called the thermopause. The lower part of the thermosphere and the upper part of the mesosphere form the ionosphere. When radiation from the Sun and from other sources in outer space strikes the air in the thermosphere, it ionizes (charges electrically) some of the atoms and molecules of the air. These charged atoms and molecules are called ions. The ionosphere plays an important part in long-distance radio communication. It reflects back to earth radio waves that would otherwise travel into space and it contains positive ions and electrons (Liou, 2002).

2.3 Ionosphere

The ionosphere is one of the layers of the atmosphere and it is partially an ionized gas in the region of upper Earth's space environment, between the upper atmosphere and the magnetosphere. The main source of charged particles of ionosphere is photo ionization of neutral molecules through extreme ultraviolet (EUV) and X-rays from the Sun. The incident solar radiations of energetic photons interact with neutral atoms and molecules in the upper atmosphere, yielding the outer electrons of such neutral species enough energy to escape the nucleus of the parent atom. Thus an electron becomes free and a positively charged ion is formed, this process is called photo ionization and when the reverse process occurs in the absence of radiation the phenomenon is known as recombination. It is highly varies with altitude, latitude, longitude, universal time, season, and also affected by solar activity and geomagnetic activity (Fuller Rowell et al., 1987).

2.3.1 Formation of Ionosphere

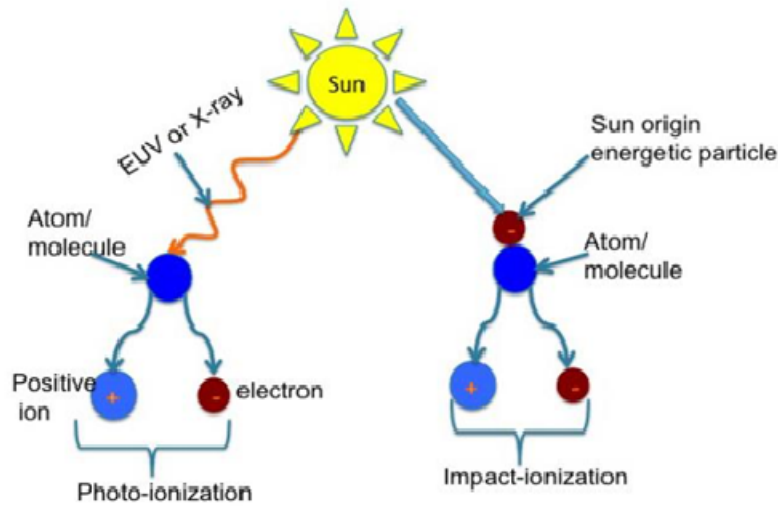


Figure 2.5: Formation of the Earth's ionosphere(Source: Nigussie,2013).

The main source of energy that forms the ionosphere is the electromagnetic (EM) radiation from the Sun and in the form of solar extreme - ultraviolet (EUV) radiation and X ray radiation. Collisions of particles of EUV beam, called photons, with the atoms and molecules of gas in the atmosphere, can create enough energy for the occurrence of photo ionization, forming positively charged ions (cations) and negatively charged free electrons (Komjathy, 1997). Another source of ionization is the cosmic radiation, which consists of highly charged particles from space, with the level of energy so high that can penetrate to the Earth's surface (Rishbeth, 1998).

2.3.2 Vertical Profile of Ionosphere

The vertical structural profile of the ionosphere is varies continuously. It changes from day to night, with the seasons of the year and with altitude. Based on altitude the ionosphere subdivided into three different regions. The different layers or regions in the ionosphere have different characteristics and affect radio communications in different ways. These regions are known as the D region, E region, F1 region and F2 region's formed by their chemical components and their ability to absorb different wavelengths of radiation emitted from the Sun, which causes the heterogeneous spread of ions and electrons in the upper atmosphere. The general characteristic of the ionospheric layers are (Komjathy, 1997): .

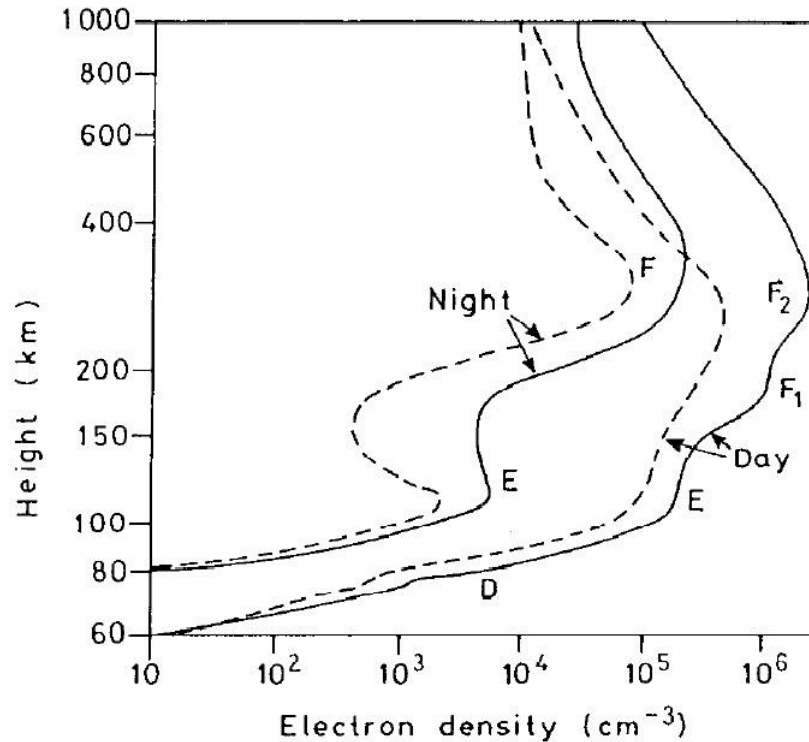


Figure 2.6: Typical ionospheric electron density profiles(<https://www.google.com>).

2.3.2.1 D-Region

The D layer is the innermost layer. It is present at altitudes between about 60 km (37 mi) to 90 km (56 mi) above the surface of the Earth and the radiation within it is only present during the day to an extent that affects radio waves noticeably. It is sustained by the radiation from the Sun and levels of ionization fall rapidly at dusk when the source of radiation is removed. Ionization here is due to Lyman series-alpha hydrogen radiation at a wavelength of 121.6 nm ionizing nitric oxide (NO). In addition, high solar activity can generate hard X-rays (wavelength $< 1nm$) that ionize N_2 and O_2 . Recombination rates are high in the D layer, so there are many more neutral air molecules than ions. That means very weakly ionized and dominated by neutral gas dynamics (not a plasma) (Nickolaenko and Hayakawa, 2002).

2.3.2.2 E-Region

The E layer is the middle layer, 90 km (56 mi) to 150 km (93 mi) above the surface of the Earth. Ionization is due to soft X-ray (1-10 nm) and by long wavelength UV (90nm) solar radiation ionization of molecular oxygen (O_2). At high latitudes impact ionization also plays important role. Electron density greatly reduced at night. The vertical structure of the E layer is primarily determined by the competing effects of ionization and recombination. At night the E layer

weakens because the primary source of ionization is no longer present. After sunset an increase in the height of the E layer maximum increases the range to which radio waves can travel by reflection from the layer. This region is also known as the Kennelly-Heaviside layer or simply the Heaviside layer. Its existence was predicted in 1902 independently and almost simultaneously by the American electrical engineer Arthur Edwin Kennelly (1861-1939) and the British physicist Oliver Heaviside (1850-1925). However, it was not until 1924 that its existence was detected by Edward V. Appleton and Miles Barnett (Rishbeth, 1998; Nickolaenko and Hayakawa, 2002; Danilov and Lastovika, 2001).

2.3.2.3 F-Region

The F-region is located directly above the E region (formerly the Kennelly-Heaviside layer) and below the protonosphere. The F region contains ionized gases at a height of around 150-480 km above sea level, placing it in the Earth's thermosphere, a hot region in the upper atmosphere, and also in the heterosphere, where chemical composition varies with height. Generally speaking, the F region has the highest concentration of free electrons and ions any where in the atmosphere. Its ionic composition varies with the sunspot cycle. The most important region in the ionosphere for long distance HF radio communications is the F region. During the daytime when radiation is being received from the Sun, it often splits into two: the lower one being the F1 region and the higher one, the F2 region (Danilov and Lastovika, 2001).

F1 Region

The F1 layer is the lower sector of the F layer and exists from about 150 to 220 km above the surface of the Earth and only during daylight hours. F1 region, it can account for up to 10 of the ionospheric delay en-counted by GPS. It has a highly predictable density of molecular species, and its electron density merges into the bottom-side of the F2 region. It is composed of a mixture of molecular ions O_2^+ and NO^+ , and atomic ions O^+ . Above the F1 region, atomic oxygen becomes the dominant constituent because lighter particles tend to occupy higher altitudes above the turbopause (at 100 km). The F1 layer has approximately $5 \times 10^5 e/cm^3$ (free electrons per cubic centimeter) at noontime and minimum sunspot activity, and increases to roughly $2 \times 10^6 e/cm^3$ during maximum sunspot activity. The density falls off to below $10^4 e/cm^3$ at night (Danilov and Lastovika, 2001).

F2 Region

The F2 region is located approximately 220- 480 km above the Earth's surface. It is the most dense and also has the highest variability, causing most of the observed effects on GPS receivers. The height of the peak of the electron density of the F2 region generally varies from 250 to 400

km. The principle constituent of the atmosphere at this height is atomic oxygen. The F2 layer is formed by the ionization of this chemical species via EUV radiation. This layer provides with the maximum profile density within the ionosphere due to the combination of the absorption of EUV light and the increase of the neutral atmospheric density as altitude decreases. This region is highly variable and unpredictable. The F2 region provides most of the delay experienced by GPS frequencies. Typical values at mid-latitude region range from 2.8×10^{11} to $5.2 \times 10^{11} \text{ electrons/m}^3$ (Danilov and Lastovika, 2001; Lipеровsky et al., 2000).

2.3.3 Ionization

Ionization is the process by which electrically an atom or a molecule acquires a negative or positive charge by gaining or losing electrons to form ions, often in conjunction with other chemical changes. Ionization is one of the principal ways that radiation, such as solar EUV, X-rays and charged particles transfers its energy to matter. The solar emission directed towards the Earth's atmosphere plays the main role in the ionization process. The Sun's UV emission ionizes the gaseous O , O_2 and N_2 molecules and produces free electrons and ionized particles. Solar radiation is responsible for the ionization process results in maximum free electron content of the ionosphere at local 14 time, just after local noon.

The ionospheric electron density increases dramatically on the day side due to the increase of the UV, X-ray and γ -ray photons (Pulinets and Ouzounov, 2011). The Chapman layer function is efficient for describing the vertical structure of the electron density. It is physics-motivated and primarily relies on the recombination process of free electrons with positive ions to atoms or neutral molecules. Combining a F2-Chapman layer with a plasma sphere profile yields the fundamental observation model.

The Chapman function derives a general formula for the rate of ion production as a function of height (h), the reduced height for the neutral gas (z) and solar zenith angle (χ).

To find classical Chapman formula for ion production rate (q), there are assumptions

- The atmosphere is isothermal.
- Obeys hydrostatic equation.
- Scale height (H) is independent of altitude.
- Atmosphere is composed of a single neutral species and
- Absorption cross section (σ) is constant. To derive the ionization production function in the atmosphere, take the intensity of solar proton radiation at wavelength λ be, $\frac{I}{\lambda \chi Z}$ in units of photon $m^2 s^{-1}$ at an altitude (Stankov et al., 2003). Then the total number of photons absorbed per unit time in a slab with an area A and thickness S is.

$I \sigma n A dS$. Hence the total number of photons absorbed per unit volume per unit time is

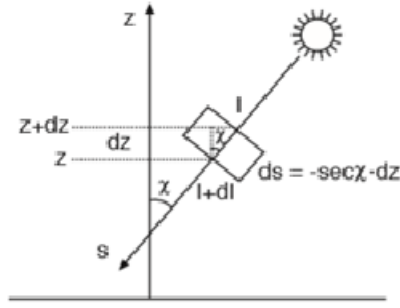


Figure 2.7: Decrease of radiation intensity I in a slab of thickness ds (Stankov et al., 2003).

$$\frac{I \lambda A ds}{dv} = I \lambda n$$

Then, the ion production function ($q(\chi, Z)$) is derived as:

$$q(\chi, Z) = \frac{-\eta dI}{ds}. \quad (2.1)$$

But, from the figure we have, $dS = \frac{dZ}{\cos \chi} = -\sec \chi dZ$

$$\frac{dI}{I} = -\sigma n dS = \sigma n \sec \chi dZ \quad (2.2)$$

where, $\sec \chi = \frac{1}{\cos \chi}$

$$I(z) = I_{\infty} \exp(-\tau), \quad (2.3)$$

And from density profile we have

$$\begin{aligned} n &= n_0 \exp\left[\frac{Z - Z_{m,0}}{H}\right], \\ n &= n_0 \exp[-h], \end{aligned}$$

where, $h = \frac{Z-Z_{m,o}}{H}$,

$$\tau = \sigma \sec \chi H_n(Z) \quad (2.4)$$

The optical depth τ , is given by

$$\tau = \sigma \sec \chi H n_{m,o} \exp[-h] \quad (2.5)$$

Then

$$q(\chi, h) = \eta n(h) \sigma I \infty \exp\left[\frac{-\tau}{h}\right] \quad (2.6)$$

$$q(\chi, h) = \eta n_{m,o} h \sigma I \infty \exp[-h - \sec \chi \sigma H n_{m,o} \exp(-h)] \quad (2.7)$$

Where, $\sigma H n_{m,o} = 1$

Then

$$q(\chi, h) = \frac{\eta I \infty \exp[-h - \sec \chi \exp(-h)]}{H_e} \quad (2.8)$$

$$q(\chi, h) = q_{m,o} \exp[1 - h - \sec \chi \exp(-h)] \quad (2.9)$$

Where, $q_{m,o} = \frac{\sigma I \infty}{H_e}$

$$q(\chi, h) = q_{m,o} \cos \chi \exp[1 - h' - \exp(h')] \quad (2.10)$$

Where, $h' = h - \ln \sec \chi$

$$q_m = q_{m,o} \cos \chi \quad (2.11)$$

shows that the maximum production is encountered at $\chi = 0$, i.e when the Sun is shining overhead, also the maximum is encountered at lowest latitude, at $h(z \gg z_{m,o})$. This implies;

$$q_m = q_{m,o} \exp\left(\frac{-z}{H}\right) \quad (2.12)$$

This means above the maximum ionization profile decays with height. The Chapman production function is important because it expresses fundamentals of ionospheric formation and of the absorption of radiation in any exponential atmosphere.

2.3.4 Variabilites of Ionosphere

The ionosphere is variable in space and time. Some of the changes are chemical in origin and can be readily understood on the basis of the general considerations outlined above. There is a systematic variation, for example, according to the time of day. In early morning the Sun is relatively low in the sky, so that radiation must penetrate a large column of air before reaching a given level of the atmosphere. As a result, ionization rates are lower, and the location of ionized layers shifts to higher altitudes. As the Sun rises, the D, E, and F1 layers shift in altitude. The layers are lowest and densities of electrons are highest at noon. At night, on the other hand, ionization in the D, E, and F1 regions tends to disappear as electrons and ions recombine to form neutral gases (Pikovsky et al., 2003).

2.3.4.1 Diurnal Variation

Diurnal variations are caused by Extreme Ultraviolet flux, geomagnetic activity, equatorial electro jet and local atmospheric conditions in the thermosphere. The ionosphere exhibits a diurnal variation where ionization is normally higher during the day and lower at night. As the Earth rotates with respect to the Sun, the intensity of the solar radiation increases and the ionization also increases to a maximum at around noon. During afternoon ionosphere begins to increase its thickness due to electron loss and with darkness the ionosphere becomes higher and thinner (Richards et al., 1994).

2.3.4.2 Seasonal Variation

The ionosphere exhibits strong seasonal and solar cycle variations because the main source of ionization and energy for the ionosphere is photo ionization. Therefore, whenever either the solar zenith angle or the solar radiations flux change, the ionosphere dynamics may reflect these

changes. As the Earth revolves around the Sun, a seasonal cycle is generated, determined by which hemisphere the Sun is overhead. It is summer on the hemisphere where the Sun is overhead and winter on the other hemisphere. The Sun is overhead at the equator around the time of equinoxes. Seasonal variation of ionospheric total electron content (TEC) depends on the solar zenith angle, thermospheric composition and the ratio of O/N_2 , while its solar cycle variation is related to a change in solar EUV and X-ray radiation fluxes. This seasonal cycle causes a corresponding seasonal and spatial variation in the global ionospheric structure. The D, E and F1 region electron densities are greater in summer than in winter. However, the variation in F2 region electron densities are more complicated. In both hemispheres, electron densities generally peak around the equinoxes (Gebreselasse and Abraha, 2017).

2.3.4.3 Latitudinal variation

Latitudinal variation of ionospheric total electron content (TEC) depends on the time of the day. At altitude about ± 20 degrees either side of the geomagnetic equator, high TEC values are produced by so called fountain effect. It is caused by $\mathbf{E} \times \mathbf{B}$ drifting electrons interacting with the Earth's magnetic field to produce large scale movement of ionization. The equatorial anomaly is formed as a consequence of $\mathbf{E} \times \mathbf{B}$ upward plasma drifts associated with an eastward E-field and northward horizontal B-field. The lifted plasma then diffuses down ward along the geomagnetic field lines due to gravitational force and pressure gradient and this result in ionization enhancements on both sides of the magnetic equator ($\pm 15^\circ$ in the latitude) (Olwendo et al., 2012).

2.3.5 Ionospheric Disturbance

Ionospheric disturbances can result from solar disturbances or geomagnetic field disturbances. The ionospheric disturbances are associated directly or indirectly with the events on the Sun. The geomagnetic disturbances are also caused by events initiated from the Sun, However, these events rather affect the outermost geomagnetic field line (also called the magnetopause) and compress the geomagnetic field causing the geomagnetic disturbances. And the layers of the ionosphere vary, therefore, often very irregularly, in the auroral zone. Specially important is the ion production that takes place in the E-and D-layer. Here, the increase in electron density can give rise to great disturbances in radio-wave propagation conditions (reflection, absorption, and scatter). Disturbances in the polar ionosphere can cause a total breakdown in shortwave communication ("radio blackouts"), and the electric currents that are induced in the ionosphere can influence power supply, corrosion in oil pipe lines, etc (Ratcliffe, 1972).

2.3.5.1 Geomagnetic Storm

A geomagnetic storm (commonly referred to as a solar storm) is a temporary disturbance of the Earth's magnetosphere caused by a solar wind shock wave or cloud of magnetic field that interacts with the Earth's magnetic field. The increase in the solar wind pressure initially compresses the magnetosphere. The solar wind's magnetic field interacts with the Earth's magnetic field and transfers an increased energy into the magnetosphere. Both interactions cause an increase in plasma movement through the magnetosphere (driven by increased electric fields inside the magnetosphere) and an increase in electric current in the magnetosphere and ionosphere. It produces large and rapid changes in magnetospheric convection currents. As a result the field is perturbed, the perturbation field affects the distribution of ionospheric plasma (Fejer and Scherliess, 1997). An ionospheric storm is disturbances of the ionosphere that can be easily absorbed by means of an ordinary ionospheric radio recorder. During ionospheric storms, the GPS-TEC fluctuates. Such fluctuations can lead to errors on GPS position estimates or total loss of lock to GPS satellites. In most ionospheric studies data from quiet and disturbed magnetic periods are considered separately. The two most commonly used geomagnetic indices are Dst index (Disturbance storm time) and Kp indices (Weighted average of K indices from a network of geomagnetic observatories i.e planetary k indices). Dst index is a measure of geomagnetic activity used to assess the severity of magnetic storms. It is horizontal component of geomagnetic field at the magnetic equator and is usually measured in nanotesla (nT). It is inversely proportional to and indicative of the ring current intensity. During geomagnetic activity or storm, the Dst is found to shoot up for a brief period before falling to drastically low negative values. The Dst values drop more and more negative as intensity of the magnetic storm increases. For example, storm types have been defined based on the magnitude of Dst index: minor storm ($-30\text{nT} > Dst > -50\text{nT}$), moderate storm ($-50\text{nT} > Dst > -100\text{nT}$), intense storm ($Dst < -100\text{nT}$) and great storm ($Dst < -250\text{nT}$). Kp index (Planetary K index) is a three hour basis measuring the variation in geomagnetic intensity due to solar activity. It is measured on a scale of 1 to 9 (Rostoker, 1972).

CHAPTER 3

Data and methodology

3.1 Data sources

In order to characterize the spatio-temporal variations of ionospheric TEC specifically diurnal, monthly, seasonal, spatial and geomagnetic storm, the vertical TEC data sets are obtained from two low latitude Ethiopian stations namely, Bahir Dar (geographical latitude: 11.5742° N, Geographical longitude: 37.3614° E), and Arba Minch (Geographical latitude: 6.0206° N, Geographical longitude: 37.5641° E) in 2014 and 2015. Besides of the GPS data, we have used geomagnetic activity indicators such as disturbed time index (**Dst**). The data used in this is taken from a dual frequency GPS receiver installed.

The method proposed by (Ciraolo et al., 2007) was used to calibrate the required GPS-TEC data obtained from the *UNAVCO website* (see <http://facility.unavco.org/data/dai2/app/dai2.html>) and the data of geomagnetic activity inductors, such as Dst index are obtained from *Owminweb data explores website* (see <https://omniweb.gsfc.nasa.gov/form/omni-min.html>). After the data has received from the source it has been calibrated by using the calibrated software called RENEX - TEC. Then the MATLAB code has been developed by importing the calibrated data. The elevation cut-off $> 20^{\circ}$ was used to reduce the error emanating from multi path effects. In this thesis to proposed temporal variations of ionospheric TEC, we have only used Bahir Dar station data in 2014 and 2015 and from this to show diurnal variation of ionospheric TEC we have used all months from January to December by selected two days, 10 and 11 from all months in 2014 data. To show the monthly variations of ionospheric vTEC, we have used 2015 data. But we have not got completed data, because of this reason we only used for four months (March, February, November and December) in 2015 year. The study presented the spatial temporal, diurnal, monthly and seasonal variation of ionospheric TEC in Ethiopian low latitude regions Bahir Dar and Arba Minch by taking the GPS data in each station.

3.2 GPS (Global Positioning System)

GPS is one of the most popular global satellite positioning systems due to global availability of signal as well as performance. The GPS data provide an efficient way to estimate TEC values with a greater spatial and temporal coverage (Ciraolo et al., 2007). GPS nowadays allows to measure position in real time with an accuracy of few centimeters. It has a great importance in scientific applications and the GPS satellites that are orbiting the Earth, at altitudes of about 20, 200km transmit signals that propagate through the ionosphere that exists at about 60-1500km above the Earth surface (Grewal et al., 2007). The signals are minimally affected by the ionospheric absorption and Earth's magnetic field both in the short-term as well as in the long-term changes in the ionospheric structure.

3.3 Ionospheric Total Electron Content (TEC)

TEC is a measure of the total number of electrons in a cylinder with a cross section of 1 m^2 centered on the line of sight from the transmitter on a satellite to receiver. TEC is an essential component to study the temporal and spatial characteristic of ionospheric variations and dynamics, since this parameter provides overall description of the ionosphere. It is measured along the line of sight of the satellite signal is called the slant TEC. It also serves as a good indicator for geographical distribution of the ionization of the Earth's ionosphere. The TEC data is a continuous and can be used to study long term behavior and the variation of the ionosphere on a wide range of time scales. TEC is one of the most important quantitative parameters of the Earth's ionosphere and plasma sphere. Total Electron Content (TEC) is defined as the total number of electrons integrated along the path from the receiver to each GPS. It is an indicator of ionospheric variability that is derived by the modified GPS signal through free electrons (Olwendo et al., 2012).

3.4 Data analysis

All modern TEC measuring techniques rely on the observation of signal phase differences or on pulse travel time measurements, based on geostationary and orbiting satellite signals (Grewal et al., 2007). A standard way of measuring TEC is to use a ground-based receiver capable of processing signals from satellites in geostationary orbits and polar orbiting satellites. GPS is signals that propagate through the ionosphere at the two L- band GPS frequencies (Rao et al., 2006). The RINEX (Receiver Independent Exchange) observation files were processed by the

GPS-TEC analysis application software, developed by Gopi Seemala of the Institute for Scientific Research, Boston College, USA. The ionosphere is a dispersive medium, hence the GPS frequencies L1 (1575.42 MHz) and L2 (1227.6 MHz) provide an important ionospheric parameter which is TEC (Jakovvski et al. , 1997) . TEC is the number of electrons in the column of 1 m^2 cross section that extends from a GPS satellite to a GPS receiver. GPS receiver measurement is used to calculate the electron density along a ray path between the satellite to the receiver on the ground by utilizing dual frequency and usually expressed in the total electron content units(TECU) as;

$$TEC = \int N_s ds \quad (3.1)$$

Where, N_s is total number of accumulated electrons in each square meter area through the differential distance(ds) along the path from the satellite to the receiver on the ground. The ionospheric time delays(t_1 and t_2) at the L1(of F1) and L2 (of F2) carrier frequencies are given by

$$t_1 = 40.3(\frac{TEC}{cf_1^2}); \text{ and, } t_2 = 40.3(\frac{TEC}{cf_2^2}) \quad (3.2)$$

Where, c is speed of light in free space. A dual frequency (f_1 and f_2) receiver measures the difference in time delay between the two frequencies, $\Delta t = t_2 - t_1$ is given by

$$\Delta t = (\frac{40.3}{c}) \times TEC \times (\frac{1}{f_2^2} - \frac{1}{f_1^2}) \quad (3.3)$$

3.4.1 Determination of TEC

One of the most fundamental GPS observable is C/A code pseudo range which is generally used for standard positioning. The code pseudo range is measured from propagation time of the signal from i^{th} satellite to the receiver and is represented by (Ratcliffe , 1972):

$$R^i = \rho^i + c(\delta t_r + \delta^i t_s) + \delta_{ion} + \delta^i tro + \varepsilon \quad (3.4)$$

Where, ρ^i is the geometric distance between satellite and receiver

- c is the velocity of light or speed of time
- $\delta^i t_s$ is transmitting time errors
- δt_r is receiving time errors
- δ_{ion} is the ionospheric effects along the propagation path of the signal
- $\delta^i tro$ is the tropospheric effects along the propagation path of the signal.
- ε denotes the other effect, such as multi path effect and receiver noise.

The ionospheric delay δ_{ion} is directly proportional to the total electron content (TEC) from the

i^{th} satellite to the receiver. This TEC is called slant TEC and represented by I_{slant}^i as shown in the following formula,

$$\delta_{ion}^i = \left(\frac{e^2}{2\Pi^2 m \varepsilon_0 c f^2} \right) I_{slant}^i \equiv \frac{I_{slant}^i}{\Lambda} \quad (3.5)$$

Where, e , m , ε_0 and f are charge and mass of the electron, permittivity of free space and the signal frequency, respectively. For convenience, the coefficient of I_{slant}^i in the right term in equation (3.5) is defined as $\frac{1}{\Lambda}$. When δ_{ion}^i is represented as meter and I_{slant}^i as TECU (1 TECU = 10^{16} electrons/ m^2), $\frac{1}{\Lambda}$ is approximately equal to $\frac{40.3}{f^2}$, where $f=1575.42$ MHz. Since only the ionospheric effect depends on the signal frequency among the measurement errors in equation (3.4), I_{slant}^i is generally calculated from distance measurements by dual frequency signals as follows;

$$I_{slant}^i = \frac{\Lambda f_2^2}{f_1^2 - f_2^2} (R_2^i - R_1^i) \quad (3.6)$$

Where, the subscripts 1 and 2 corresponds to L1 and L2 signals. In practical this value is compensated by differential code bias of the satellite and the receiver. Under the condition that the receiver location is accurately known, the terms δ_{ion}^i and δ_{tr}^i are undetermined in equation (3.1). while, δ_{tr}^i is common for all the satellite δ_{ion}^i depends on the satellite locations. This is an essential feature to distinguish each effect. From equation (3.1) and (3.2) the slant TEC I_{slant}^i is represented by

$$I_{slant}^i = \Lambda(R^i - \rho^i + c\delta_{ts}^i - \delta_{tro}^i) - \Lambda c\delta_{tr} + \varepsilon \quad (3.7)$$

The right side of the equation (3.7) can be separated in to two parts and defined, $k = \Lambda(R^i - \rho^i + c\delta_{ts}^i - \delta_{tro}^i)$ as a known part and $\alpha = \Lambda c\delta_{tr}$ as an unknown part. Since the ionospheric TEC distribution is usually shown by vertical TEC map, the slant TEC is converted to vertical TEC by a slant factor. This conversion is important in the TEC map reconstruction from single frequency GPS data because the effects of slant TEC and the receiver clock error on propagation delays should be distinguished depending on the slant effects. In practical, the ionosphere can be assumed to be a thin layer and the ray path crosses the ionosphere at one point called the ionospheric pierce point (IPP) as shown in Fig. The conversion method from slant TEC I_{slant}^i to vertical TEC $I_{vertical}^i$ can be used as follows;

$$I_{slant}^i = I_{vertical}^i \left(\frac{1}{\cos \chi^i} \right) \quad (3.8)$$

Where, the angle χ between zenith direction and satellite direction from the IPP can be calculated as follows;

$$\chi^i = \sin^{-1} \left(\frac{R_E \cos \theta_{eL}^i}{R_E + h} \right) \quad (3.9)$$

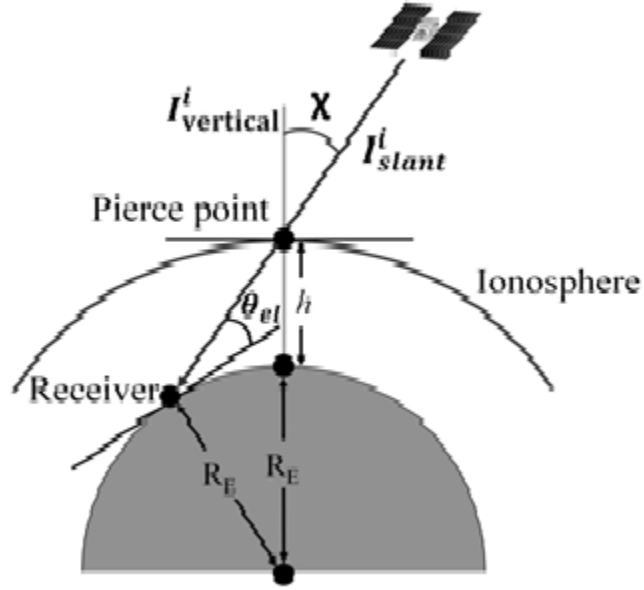


Figure 3.1: Conversion model from slant TEC to vertical TEC in a thin layer assumption for the ionosphere(<https://www.google.com>).

Where, R_E is Earth radius, h is the altitude of IPP which is assumed to be 350 km and θ_{eL}^i is elevation angle of the satellite at the receiver location. From Eq. (3.6), (3.7) and (3.8), vertical TEC can be represented by,

$$I_{vertical}^i = (k - \alpha) \cos \chi \equiv (k - \alpha) F \quad (3.10)$$

Where, $\cos \chi$ is defined as a slant factor F . This factor is used as a thin layer slant model for conversion of slant TEC to vertical TEC.

CHAPTER 4

Results and Discussions

4.1 Introduction

In this thesis we have characterized spatio temporal variation of ionospheric total electron content for the year of 2014 and 2015 by using GPS satellite observation. Mainly we have analyzed spatial, diurnally, monthly, seasonal and geomagnetic storm time variations of ionospheric total electron content by using the data obtained from two low latitude Ethiopian stations that is Bahir Dar (Geographical latitude 11.6^0 degree N, longitude 37.36^0 degree E) and Arba Minch (Geographical latitude 6.06^0 degree N, longitude 37.56^0 degree E) GPS satellite observation. The basic finding's of our investigation's are presented as follows.

4.2 Temporal variation of ionospheric TEC

4.2.1 Diurnal variation of TEC

To study the temporal variation of the proposed GPS stations, we have the diurnal variation of ionospheric vTEC is shown in the figure 4.1 to 4.6. By using the data from Bahir Dar station in 2014 and by selecting two days 10 and 11 from January to December all months. As we have seen the the figure below.

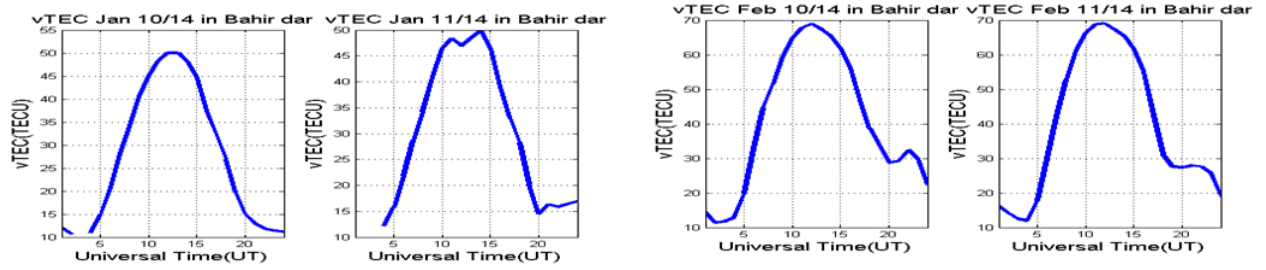


Figure 4.1: Diurnal variation of ionospheric TEC at Bahir Dar stations January 10 and 11 in the right panel and in the left panel February, 10 and 11 in 2014.

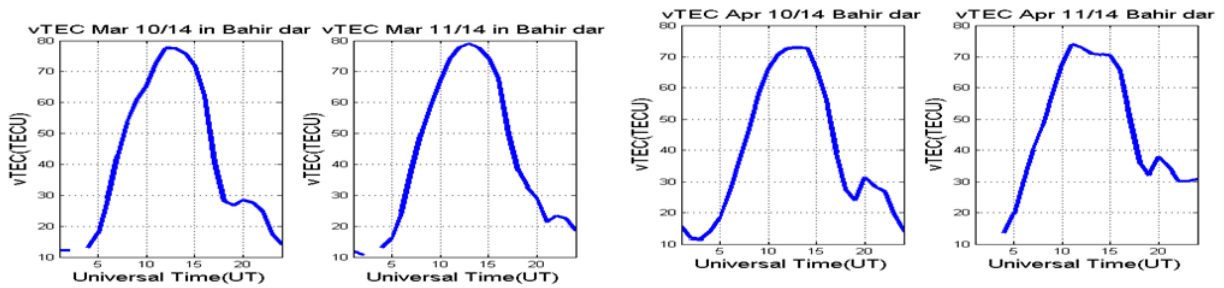


Figure 4.2: Diurnal variation of ionospheric TEC at Bahir Dar stations March, 10 and 11 in the right panel and April, 10 and 11 the left panel in 2014.

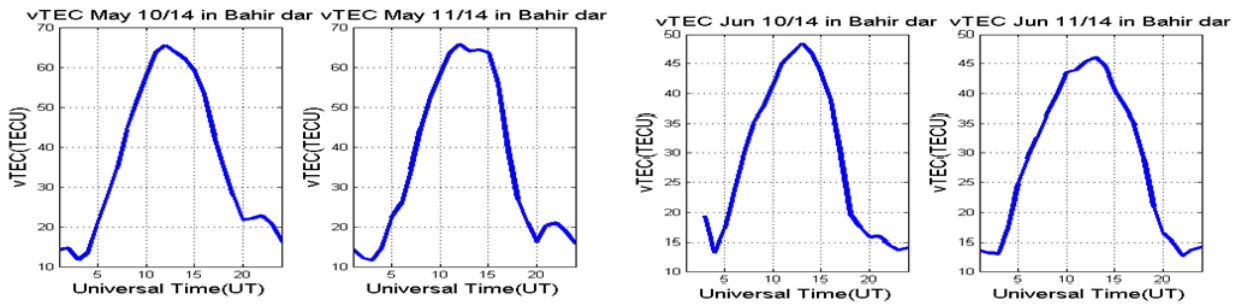


Figure 4.3: Diurnal variation of ionospheric TEC at Bahir Dar stations May, 10 and 11 in the right panel and June, 10 and 11 the left panel in 2014.

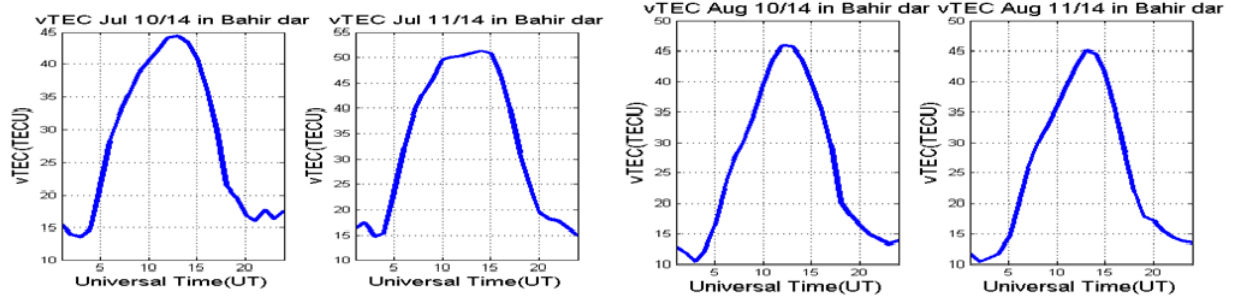


Figure 4.4: Diurnal variation of ionospheric TEC at Bahir Dar stations on July, 10 and 11 in the right panel and August, 10 and 11 the left panel in 2014.

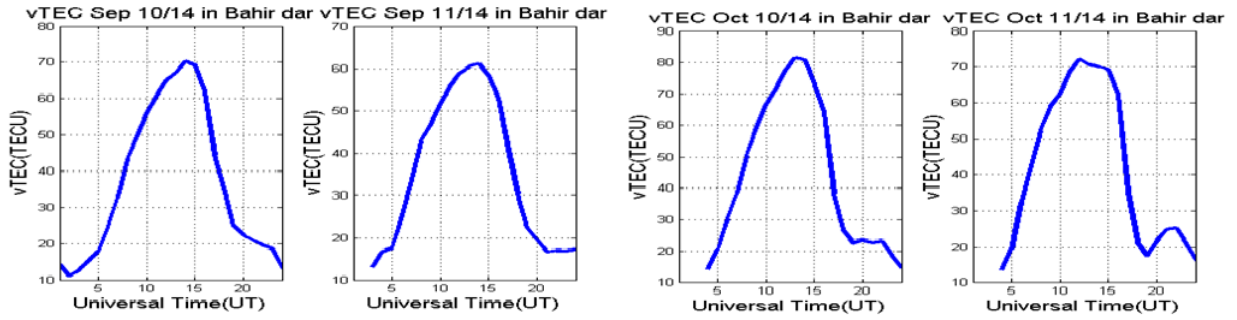


Figure 4.5: Diurnal variation of ionospheric TEC at Bahir Dar stations on September, 10 and 11 in the right panel and October, 10 and 11 the left panel in 2014.

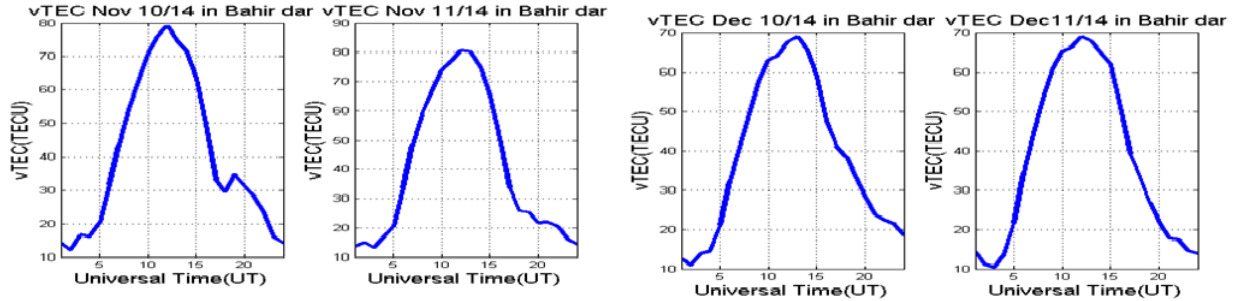


Figure 4.6: Diurnal variation of ionospheric TEC at Bahir Dar stations on November, 10 and 11 in the right panel and December, 10 and 11 the left panel in 2014.

The result for the diurnal variations of ionospheric vTEC are shown in the figure 4.1 to 4.6, by taking 2014 Bahir Dar GPS data. The hour to hour vTEC values attained their peak mostly between 12:00 and 14:00 UT decreased in the nighttime hours, reaching a minimum after mid-night around (23:00 UT and 03:00 UT). In addition, the peak hour to hour values are maximum in the equinoctial months and reach's a minimum during in a solstices months. For instance results

obtained from Bahir Dar stations on the same day in 2014 from the selected two days 10 and 11 shown that the highest and the lowest peak daily vTEC values of about 81.6 and 44.45 TECU were recorded in October and July respectively. The diurnal vTEC value for every hour in Bahir Dar stations vary. The variations can be divided into three different sections, namely: the Sun raise, midday and the Sun set. The diurnal variation of vTEC at Bahir Dar exhibits many characteristics typical to low latitude ionosphere such as a vTEC minimum at midnight and gradual increase with the time of day attaining a maximum in the afternoon and a gradual decrease after Sun set. The day to day variability of vTEC is contributed by the various parameters like EUV flux, zenith angel, geomagnetic activity, Electro jet strength, local atmospheric conditions in the thermosphere and the product of east ward and west ward directed electric filed which produces an up ward and dawn ward motion of ionospheric plasma during the day and night respectively (Leick et al., 2015). (Rama Rao et al, 2006a) reported maximum day to day variability in TEC at the EIA crest regions, increasing peak value of TEC with increase in integrated equatorial electron jet (IEEJ) strength, maximum monthly average diurnal variations during equinox months followed by winter months and lowest during summer months. Diurnal variation of ionospheric TEC is exhibits where ionospheric TEC is normally higher during the day and lower at night. As the Earth's rotates with respect to the sun, the intensity of the solar radiation increases and ionospheric TEC also increases to a maximum at around noon. At night the ionospheric TEC is lower or tends to disappear as electrons and ions are recombine to form neutral gas (Ratcliffe , 1972).

4.2.2 Monthly variation of TEC

Monthly variations of ionospheric total electron content (vTEC) have been studied by plotting contour graph the monthly mean of vTEC of the year 2015 at Bahir Dar station. We have not got the completed data because of this we have only used some data as shown in Figures bellow.

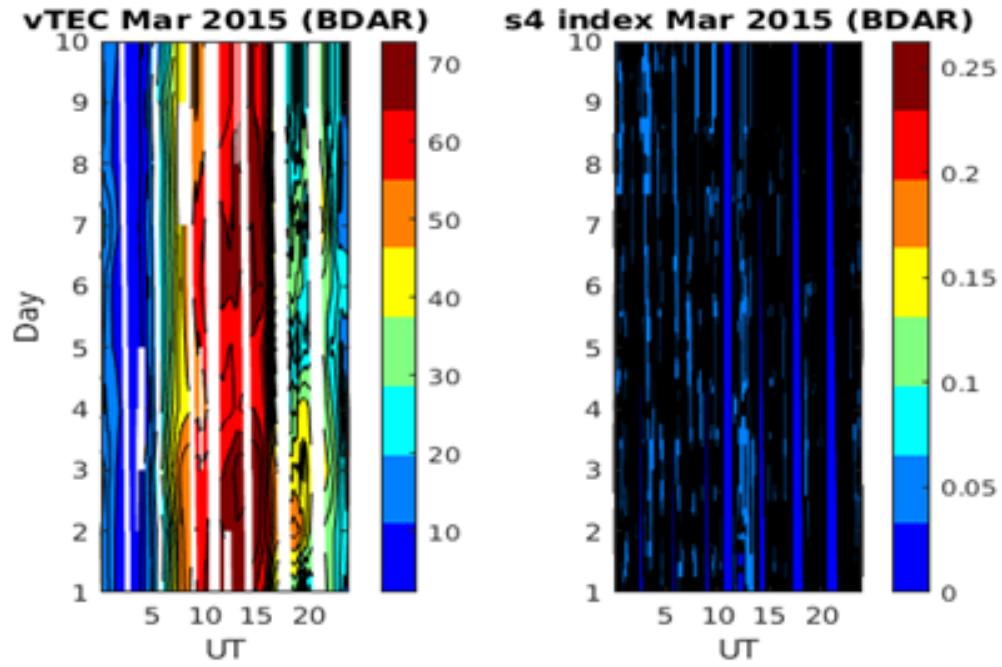


Figure 4.7: Contour plot variation of ionospheric vTEC and scintillation index(s4 index)in March month at Bahir Dar station GPS data in 2015.

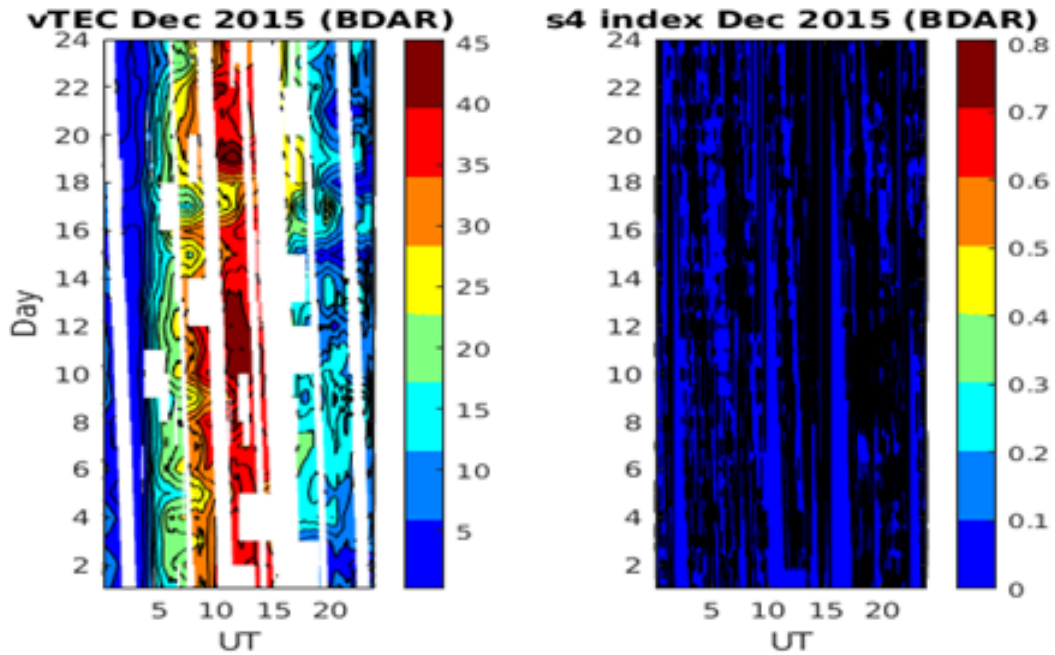


Figure 4.8: Contour plot variation of ionospheric vTEC and scintillation index(s4 index)in December month at Bahir Dar station GPS data in 2015.

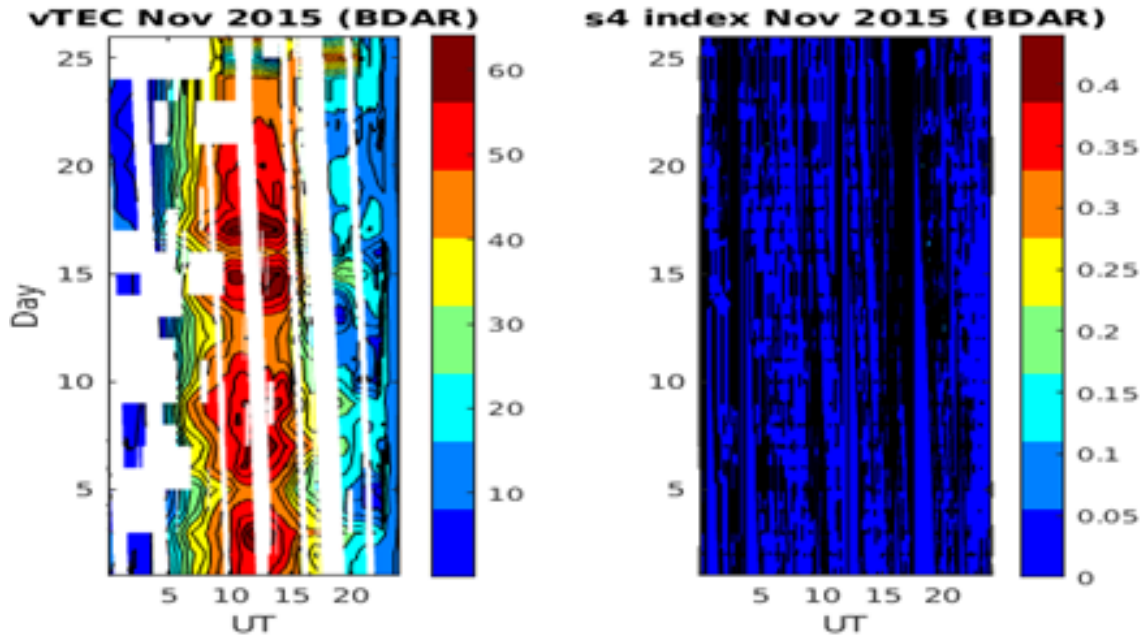


Figure 4.9: Contour plot variation of ionospheric vTEC and scintillation index(s4 index)in November month at Bahir Dar station GPS data in 2015.

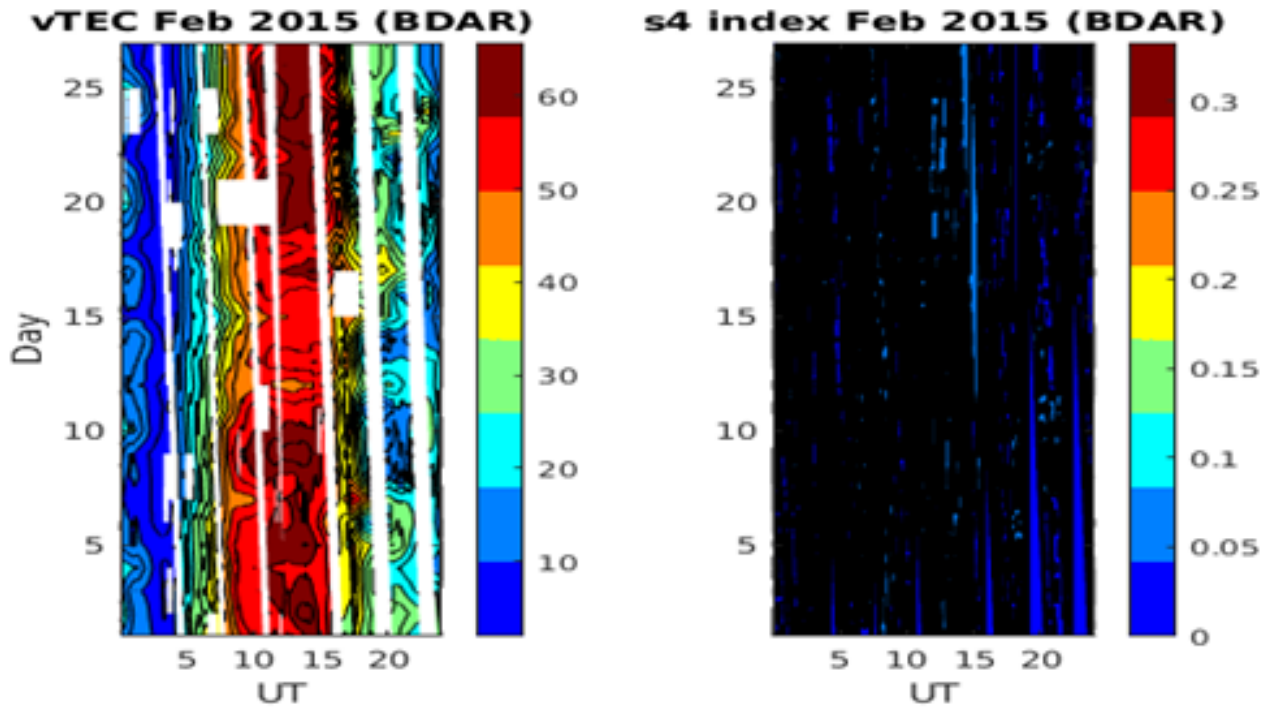


Figure 4.10: Contour plot variation of ionospheric vTEC and scintillation index(s4 index)in February month at Bahir Dar station GPS data in 2015.

The results for monthly variation of ionospheric vTEC and scintillation index are shown in Figures, 4.7 to 4.10 at Bahir Dar station in 2015.

Figure 4.7 shows that ionospheric vTEC variation and scintillation index in March month and variation of vTEC has been vary month to month and when we have observe from figure 4.7 the maximum value of vTEC is 70 TECU and s4 index is 0.25 and the minimum value of vTEC is 10TECU. Figure 4.8 shows that variation of ionospheric vTEC and scintillation index in December. In this month the maximum values of vTEC of 45 TECU and s4 index is 0.8 and the minimum values of ionospheric vTEC is 5 TECU. Figure 4.9 shows that ionospheric variations of vTEC and scintillation index in November. In November the maximum value of ionospheric vTEC is 60TECU and s4 index is 0.4 and the minimum values of ionospheric vTEC is 10 TECU and figure 4.10 shows that February month ionospheric vTEC variation and scintillation index. In February TEC value is 60 TECU and s4 index is 0.3 and minimum ionospheric vTEC value is 10 TECU. From the observed four figures monthly, higher values of vTEC is during March month compared with the other months. But s4 index is lower in March and higher values in December. On the other hand vTEC is minimum in December. From the plots we have seen that ionospheric vTEC has higher values during daytime compared with nighttime values, in all months and the daily peak values from this contour graph of the vTEC occurred around 10:00 to 14:00 UT. During the daytime, the equator is hotter than the North and South poles. This causes meridional wind flows towards the poles from the equator. As reported by (Balan et al. , 2000), this flow of meridional wind changes the neutral composition and O/N_2 decreases at equatorial stations. This decrease in O/N_2 ratio which is maximum during the equinox months will result in higher electron density; hence, equinox vTEC will be highest as found by our result. Monthly variations are caused by Extreme Ultraviolet flux, geomagnetic activity, equatorial electro jet and local atmospheric conditions in the thermosphere (Rama Rao et al., 1980). As we have seen from the above plot's vTEC is maximum in March and January due to the incoming direct solar radiation from the sun that causes atoms and molecules to ionize. In addition to this especially in March month vTEC is maximum due to the sun is overhead ($\chi = 0$) when, the sun is overhead due to Chapman profile formula vTEC is maximum and due to geomagnetic storms that have been indicated by the storm indicators such as **Dst** index in 2015.

4.2.3 Seasonal variation of TEC

The seasonal variation of vTEC for Bahir Dar station (Geographical latitude 11.6° degree N, Geographical longitude 37.36° degree E) since 2014 is stated by contour plot figure below. The study of TEC variation at Bahir Dar has been grouped in to four seasons, namely , March Equinox (ME) (February, March, April), June Solstice (JS) (May, June, July), September Equinox (SE) (August, September, October) and December Solstice (DS) (November, December, January), for the year of 2014 in Bahir Dar stations.

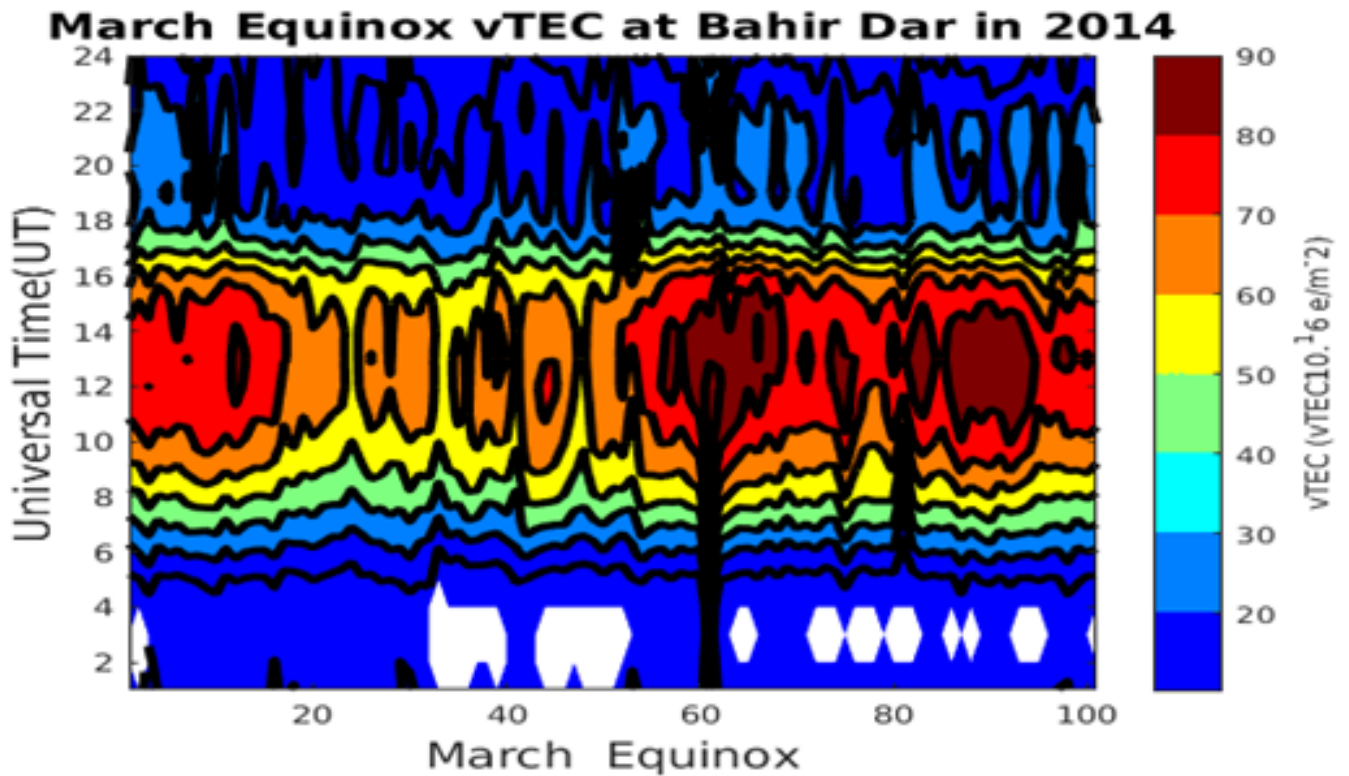


Figure 4.11: Seasonal variation of ionospheric vertical TEC in March Equinox at Bahir Dar GPS data in 2014 year.

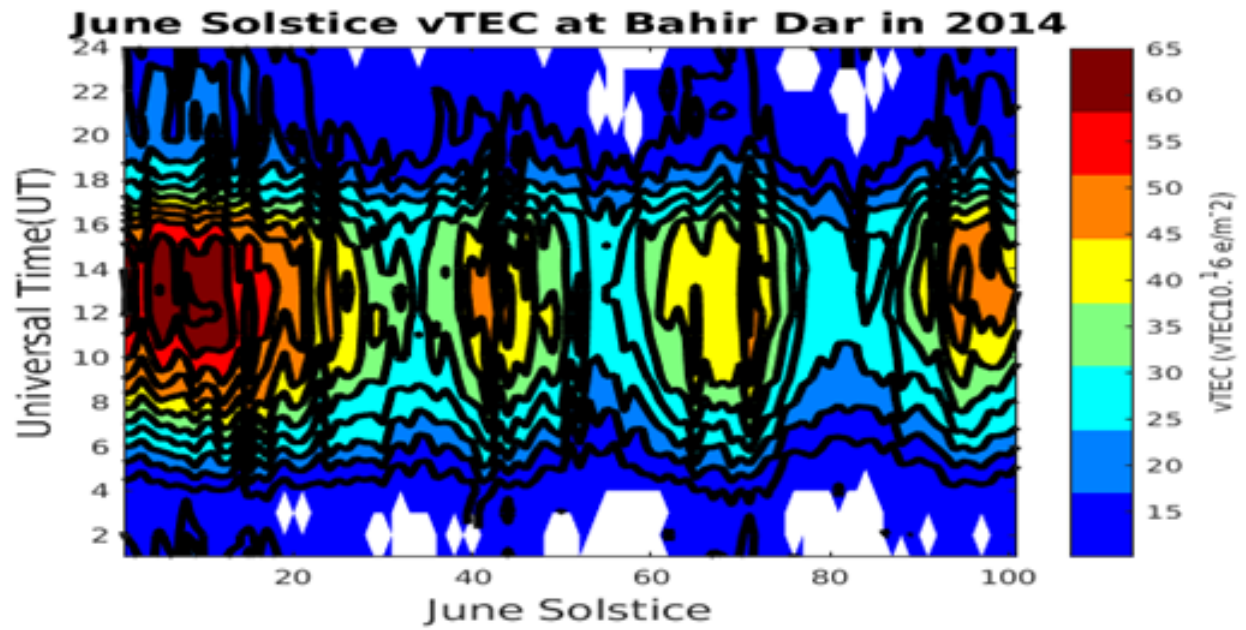


Figure 4.12: Seasonal variation of ionospheric vertical TEC in June Solstice at Bahir Dar GPS data in 2014 year.

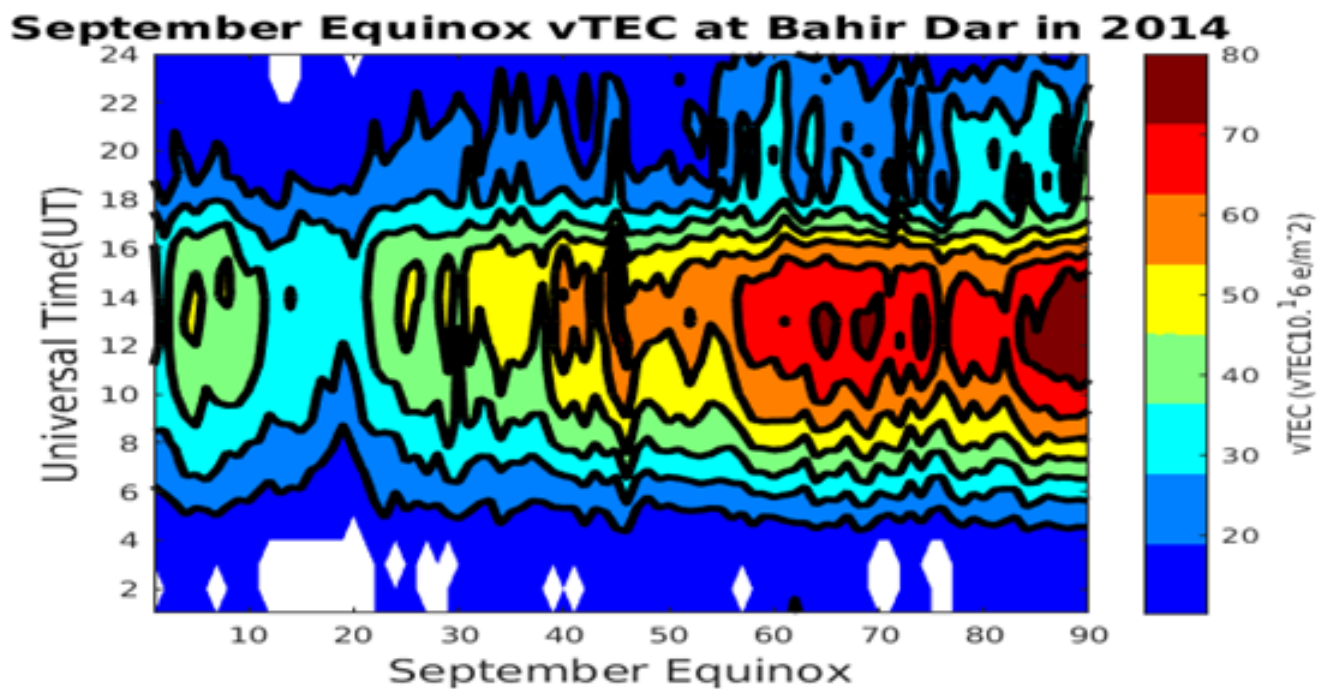


Figure 4.13: Seasonal variation of ionospheric vertical TEC in September Equinox at Bahir Dar GPS data in 2014 year.

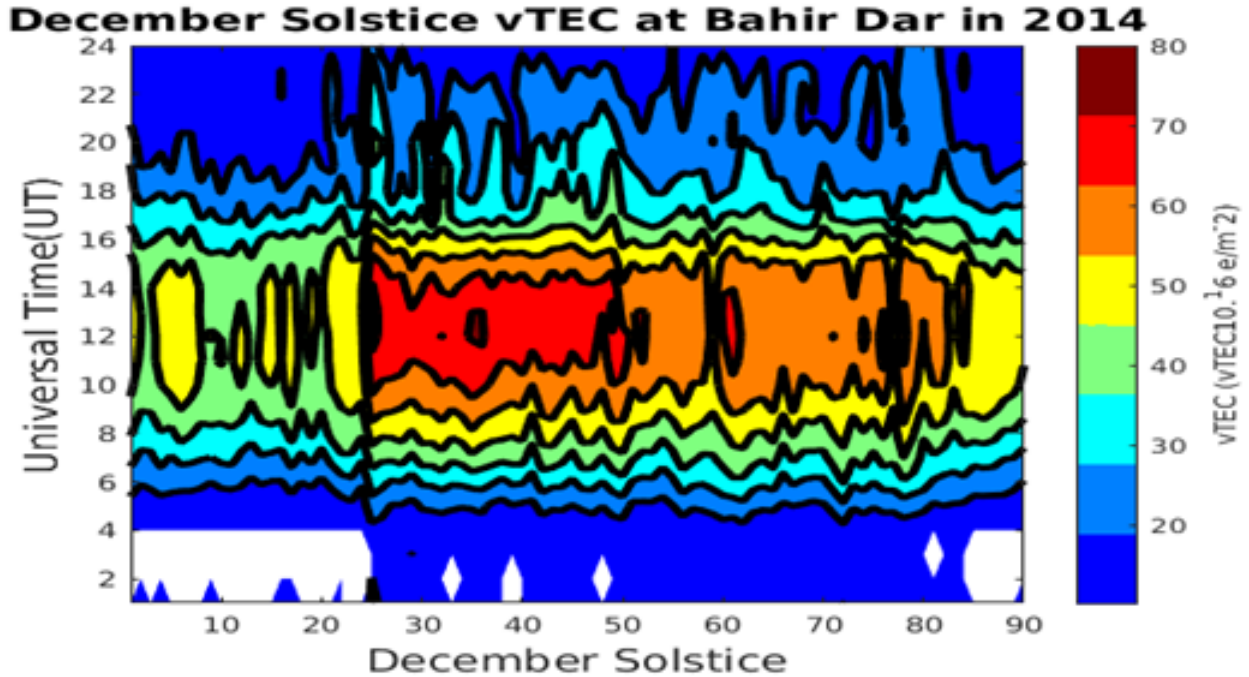


Figure 4.14: Seasonal variation of ionospheric vertical TEC in December Solstice at Bahir Dar GPS data in 2014 year.

The contour plot figures 4.11- 4.14 shows seasonal variation of ionospheric vTEC during different seasons recorded at Bahir Dar for the years of 2014. Figure 4.11 show that the seasonal variation of ionospheric vTEC during March equinox, the TEC value in March equinox is 90 TECU and figure 4.12 also show that the seasonal variation's of ionospheric vTEC during June solstice, the TEC value in this season is 65 TECU. From figure 4.13 we have seen that the seasonal variation of ionospheric vTEC during September equinox, the TEC values are 80 TECU. Figure 4.14 also shows that the seasonal variation of ionospheric vTEC during December solstice, in this season the values of TEC is 80 TECU. As we have seen from the above figure's, the vTEC values are high in equinoctial months especially in March equinox 90 TECU and September equinox 80 TECU, followed by December solstice 80 TECU and lowest in June solstice that is 65 TECU. In 2014 December solstice magnitude was highest, followed by the equinoxes, March and September respectively and lowest in June solstice. During the equinox the Sun is overhead at the equator, and in terms of solar control the ionization density is expected to be maximum in that region. This corresponds to result obtained by (Akala et al., 2013). Thermospheric neutral composition has a direct control on the seasonal variation of TEC. (Rabiu et al., 2007) attribute the seasonal variation to the electrodynamics effect of local winds since winds are subjected to day to day and seasonal variation. During the daytime, the equator is hotter than the pole therefore meridional wind flows towards the pole from the equator. This flow of meridional

wind changes the neutral composition and $\frac{O}{N_2}$ decreases at equatorial and low latitude stations. In equinox, this decrease will be maximum. At 350 km altitude (F2 layer) N_2 dissociation is the major process which removes ambient electrons. Hence, the decrease in $\frac{O}{N_2}$ ratio will result in higher electron density and therefore in equinox TEC will be highest (Balan et al. , 2000). The primary source of ionization and energy for the ionosphere is photo ionization. Therefore, the ionosphere shows strong seasonal and solar cycle variations on account of solar zenith angle or the solar radiations flux change, these changes may be reflected by the ionosphere dynamics. The ionospheric seasonal variation is connected to solar zenith angle change , while its solar cycle variation is related to a change in solar EUV and X-ray radiation fluxes (Schunk, 2009; Kelly, 1989).

4.3 Spatial variation of ionospheric TEC

Ionospheric total electron content is varying with in geographical longitude and latitude. In this thesis to characterize the spatial variation of ionospheric vTEC, we have taken data from two low latitude stations which are Bahir Dar (Geographical latitude 11.6^0 N, Geographical longitude 37.36^0 E) and Arba Minch (Geographical latitude 6.06^0 N, Geographical longitude 37.56^0 E). This is compared by taking data at the days on March 17 and 18 in 2014 and September 17 and 18 in 2014 and also by taking annual vTEC in 2014 for the selected two stations.

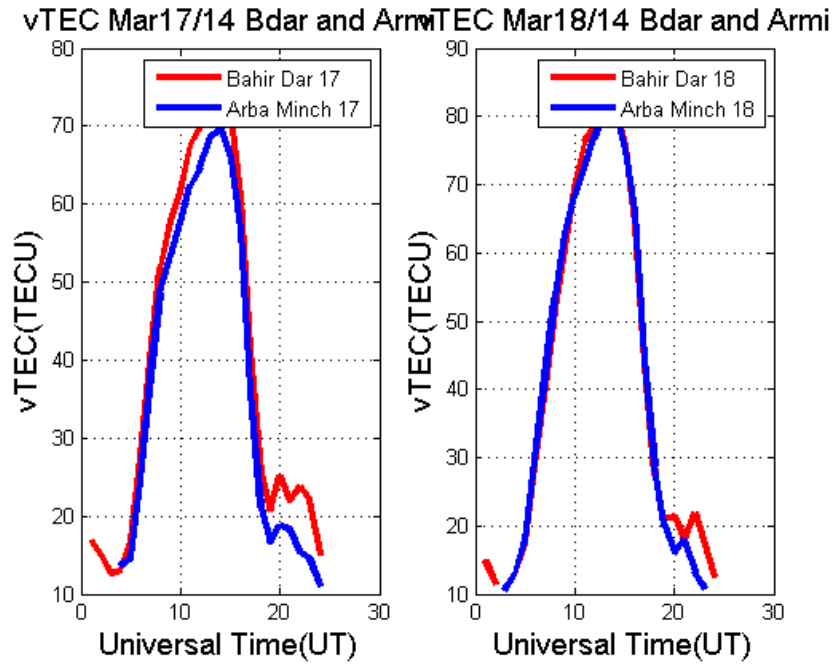


Figure 4.15: Spatial variation of ionospheric TEC in Bahir Dar and Arba Minch on March 17 and 18 in 2014.

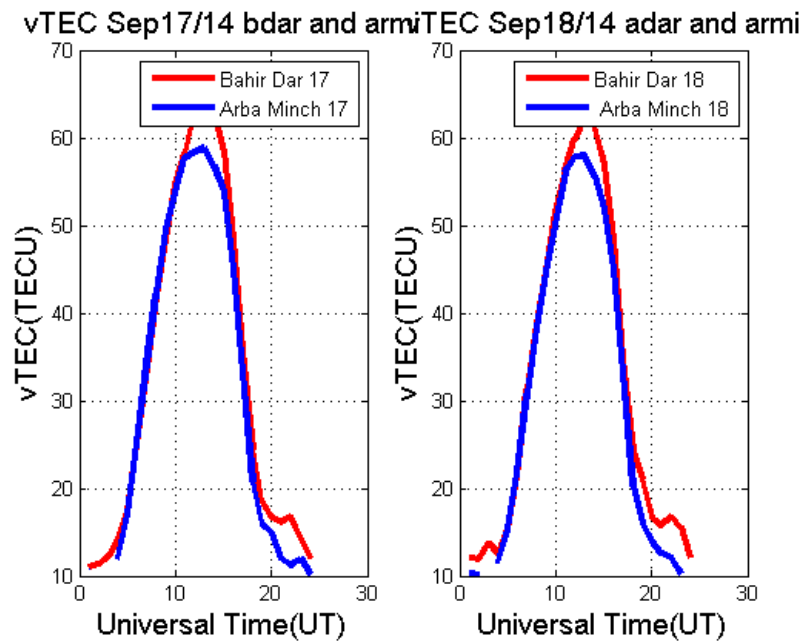


Figure 4.16: Spatial variation of ionospheric TEC in Bahir Dar and Arba Minch on September 17 and 18 in 2014.

From figure 4.15 to 4.17 we have seen that the latitudinal variations of ionospheric vTEC, in Bahir Dar and Arba Minch stations. Figure 4.15 shows that latitudinal variation of ionospheric

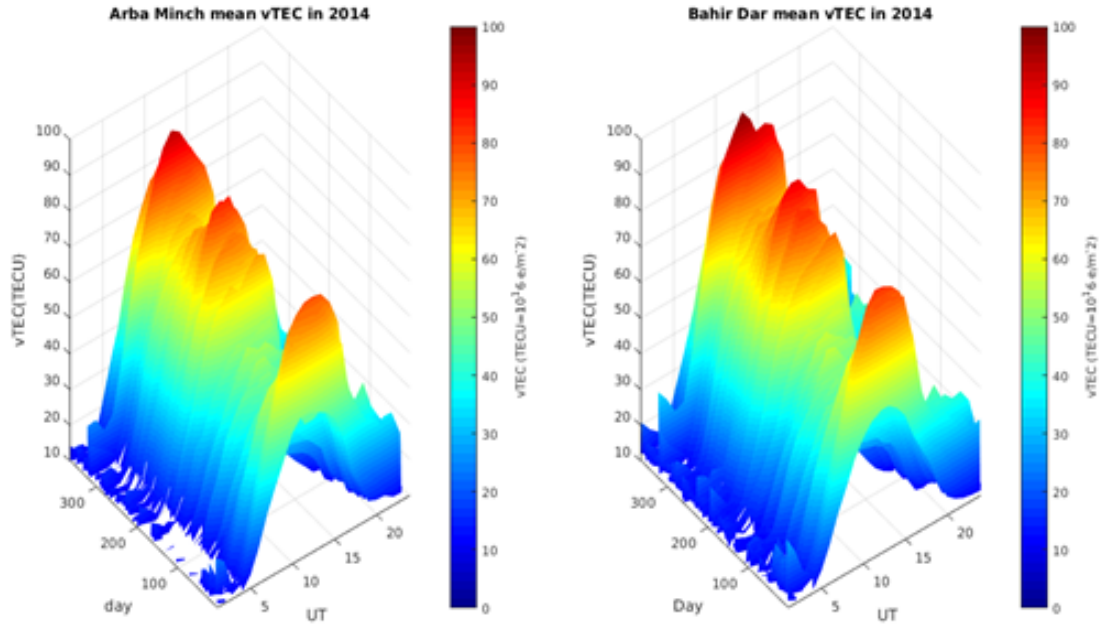


Figure 4.17: Shows spatial variation of mean ionospheric vTEC at Arba Minch and Bahir Dar in 2014.

vTEC in March 17 and 18 at Bahir Dar is higher than Arba Minch with latitude the daily peak values of vTEC is 76 TECU at 13:00 UT in March 17 and 82 TECU at 13:00 UT in March 18 at Bahir Dar station and the value of vTEC in Arba Minch station is 69 TECU at 14:00UT and 81 TECU at 13:00UT respectively in March 17 and 18. Figure 4.16 also shows that latitudinal variation of ionospheric vTEC in September 17 and 18 at Bahir Dar is slightly higher than Arba Minch. The daily peak values of vTEC is 65 TECU at 13:00 UT in September 17 and 62 TECU at 13:00UT in September 18 in Bahir Dar station and the value of vTEC in Arba Minch station is 59 at 13:00 UT and 58 TECU at 13:00 UT respectively in September 17 and 18. Figure 4.17 shows that latitudinal variation of ionospheric vTEC, But this contour graph does not show such a significant variation of vTEC as a daily variation because it is the variation of mean value. As we have seen the above figure both stations are found in low latitude or equatorial regions, because of equatorial ionospheric regions it has prone to a unique phenomenon called equatorial ionization anomaly (EIA). Latitudinal variation in the distribution of plasma due to fountain effect is known as equatorial ionization anomaly(EIA) which is one of the most important features of the equatorial and low latitude ionosphere. This feature is distinguished by higher plasma density on both sides of equator $\pm 15^\circ$, rather than the equatorial itself. Equatorial anomaly is formed within approximately $\pm 20^\circ$ of the magnetic equator it is occurrence of ionization trough in F2 layer and crest at $\pm 15^\circ$ in magnetic latitude (Olwendo et al., 2012). So these two stations Bahir

Dar and Arba Minch are in the ranges of equatorial ionization anomaly (EIA) ranges and Bahir Dar is higher latitude than Arba Minch that means Bahir Dar is near to equatorial anomaly crest than Arba Minch because of this Bahir Dar is highest vTEC value than Arba Minch. Therefore, we have obtained vTEC of Bahir Dar higher and vTEC of Arba Minch. (Pandey and Dashora , 2005) reported stations near the anomaly crest using GPS TEC measurements at Udaipur (26.4⁰ N 73.7⁰ E, Geographic, 15.6⁰ N Geomagnetic). The TEC response to the storm depends on the local time of the Storm Sudden Commencement (SSC). In the case of a day time SSC storm, a prompt penetration electric field directed eastward raises low latitude plasma upward due to the $\mathbf{E} \times \mathbf{B}$ drift where the recombination rate is slow. An increase in the electro dynamic drift will lift more plasma from the equatorial region which diffuses down along the field lines to higher latitudes and results in the increase of the TEC at stations under the anomaly crest region. (Rama Rao et al, 2006a; Rama Rao et al., 2006b) reported maximum day-to-day variability in TEC at the EIA crest regions, increasing peak value of TEC with increase in integrated equatorial electro jet (IEEJ) strength.

4.4 Geomagnetic disturbance variation of ionospheric TEC

The storm time TEC variation **Dst** index is shown in the figure 4.18: this graph shows the daily variation of ionospheric TEC in March 16, 17 and 18 in 2015. By using geomagnetic indicators, disturbance time scale (Dst) index we have been seen the daily variation of vTEC for the selected three storm days respectively in a subplot form.

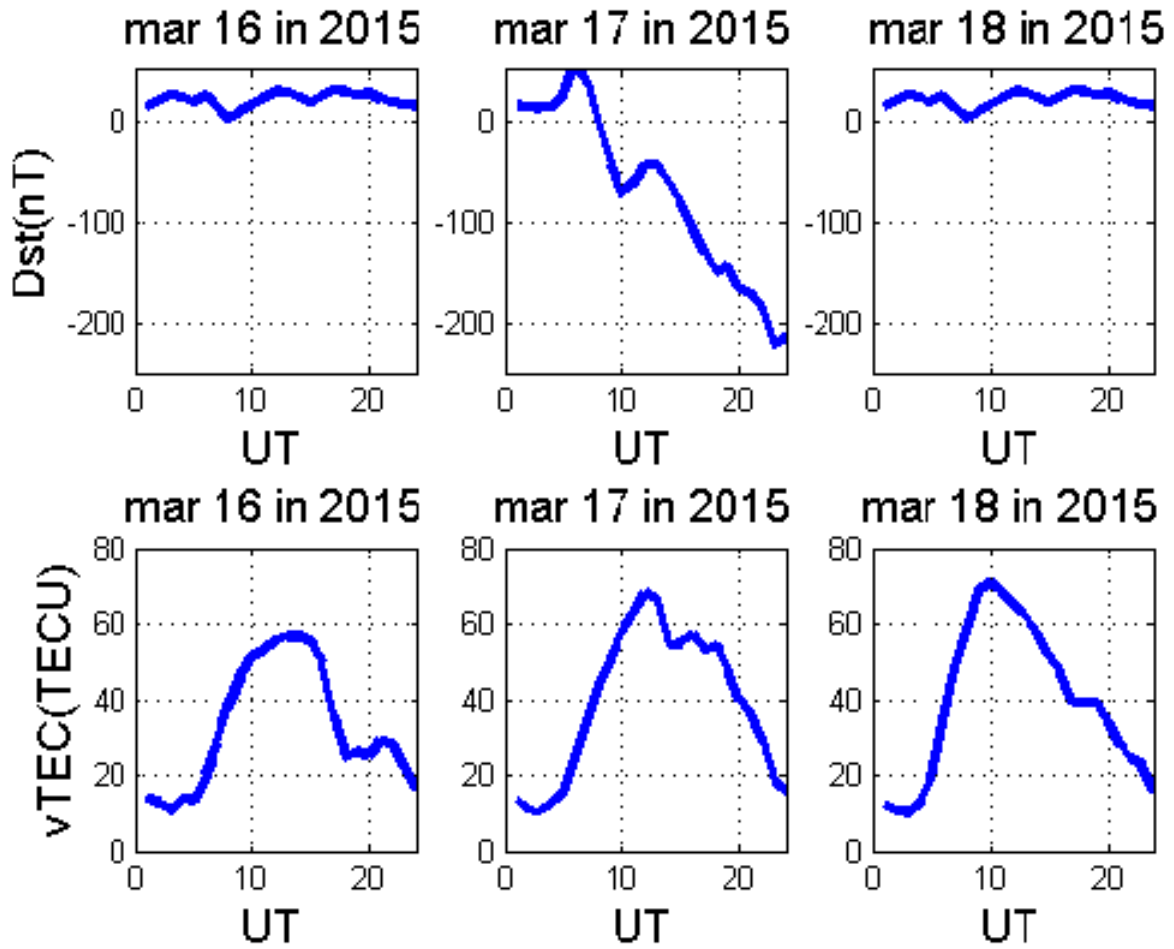


Figure 4.18: Storm time variation of TEC and Dst index in March 16, 17 and 18 in 2015 Bahir Dar station.

The effect of geomagnetic activity (storm) indicators Dst index on the variation of ionospheric vTEC during storm day 16-18 March in 2015. Figure 4.18 shows the variation of ionospheric vTEC with disturbance time scale (Dst). During the storm time from this figure we have been seen that, Dst index in March 16 has no more storm and the value of vTEC is also lowest slightly similar with the other quiet days. Dst index in March 17 has gone down minimum (-223nT) at 23:00 UT or 17:00 h ELT. In this day the value of vTEC shows an increment of 80 TECU at 12:00 UT or 06:00 h ELT and Dst index in March 18 has also storm, the value of Dst index is (-190nT) at 7:00 UT or 01:00 h ELT in this day the value of vTEC also high 80 TECU. Since in storm day Dst index has gone to decreases on the other hand the value of vTEC is increased. Therefore, as we have seen the above figure geomagnetic activity affects the pattern of ionospheric TEC. As the SSC occurred at sunlit hours, the daytime eastward electric field is probably enhanced due to prompt penetration of interplanetary electric field before the shielding occurs, which is

responsible for the TEC increase on the SSC day of 17 March 2015 and Dst decreased. The effect of a geomagnetic storm on the ionospheric total electron content has been studied by many researchers (Jakowaski et al., 1999; Sastri et al., 2002; Maruyama et al., 2004; Mannucci et al., 2005). (Pandey and Dashora , 2005) reported both positive and negative storm effects using GPS TEC measurements at Udaipur (26.4⁰ N 473.7⁰ E, Geographic, 15.6⁰ N Geomagnetic), a station near the anomaly crest. The TEC response to the storm depends on the local time of the Storm Sudden Commencement (SSC). In the case of a day time SSC storm, a prompt penetration electric field directed eastward raises low latitude plasma upward due to the $\mathbf{E} \times \mathbf{B}$ drift where the recombination rate is slow. An increase in the electro dynamic drift will lift more plasma from the equatorial region which diffuses down along the field lines to higher latitudes and results in the increase of the TEC at stations under the anomaly crest region.

CHAPTER 5

Conclusion and Recommendation

5.1 Conclusions

This study has presented spatio temporal variation of ionospheric TEC in Ethiopian two low latitude stations especially, at Bahir Dar and Arba Minch during 2014 and 2015. The daily average TEC values were seen to be highest during the months of March, April, September and October (equinoctial months), while lower TEC values occurred during the solstice months particularly in July month. The results showed that vTEC has higher values during daytime when compared with nighttime values. Since the Earth rotates with respect to the sun the intensity of the solar radiation increases and ionospheric TEC also increases to a maximum at around afternoon. At night the ionospheric TEC decreases or tends to disappear as electrons and ions recombine to form neutral gas and also the sun is overhead at afternoon because of this ionospheric TEC is maximum in all the equinoctial months and seasons and reach its maximum value during 12:00 UT - 14:00 UT or 6:00 h ELT - 8:00 h ELT and minimum 23:00 UT or 17:00h ELT. Generally, the results obtained revealed that daytime values of vTEC are greater in December Solstice while the lowest values are observed during July Solstice. We have also seen that latitudinal variation of ionospheric vTEC at Bahir Dar and Arba Minch, the ionospheric vTEC of Bahir Dar is higher than Arba Minch with in latitude. Because Bahir Dar has near to equatorial crests than Arba Minch. In addition to this we have also seen that Geomagnetic activity affects the pattern (variation) of ionospheric TEC.

5.2 Recommendation

Since ionosphere is a continually changing area and it is obviously affected by radiation from the Sun. This changes including the time of day, the geographical area of the world, and the state of the Sun. As a result radio communications using the ionosphere varies from one day to the next and even one hour to the next because of its complexity still space weather is fairly new filed in science today and has very interesting effects on humans, environment and technology in general. Since the dynamic changes taking place in the ionosphere affect our communication systems. I

greatly recommended understanding the physics of ionospheric region is important to know the changes and design a method to improve our day to day ways of communication. Our future work will concentrate on the investigation the spatial temporal variation of ionospheric TEC by taking different stations and characterize Ethiopian ionospheric TEC is uniform or not by using different model.

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Declaration

I, hereby declare that the thesis is my original work and has not been presented for a degree in any other university, and that all sources of materials have been duly acknowledged.

Candidate name: Getachew Mulu

Signature: _____

Date: _____

This thesis has been submitted for the examination with my approval as University advisor.

Advisor name: Tsegaye Kassa (PhD)

Signature: _____

Date: _____