การแปรเปลี่ยนของอิเล็กตรอนรวมในประเทศไทยระหว่างเดือนมกราคม พ.ศ.2552 ถึงเดือนธันวาคม พ.ศ.2555

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VARIATIONS OF TOTAL ELECTRON CONTENT IN THAILAND DURING JANUARY 2009 - DECEMBER 2012

Miss Porntip Jaimun

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Earth Sciences

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Thesis Title	VARIATIONS OF TOTAL ELECTRON CONTENT IN THAILAND DURING JANUARY 2009 - DECEMBER 2012
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พรทิพย์ ใจมั่น : การแปรเปลี่ยนของอิเล็กตรอนรวมในประเทศไทยระหว่างเดือนมกราคม พ.ศ.2552 ถึงเดือนธันวาคม พ.ศ.2555. (VARIATIONS OF TOTAL ELECTRON CONTENT IN THAILAND DURING JANUARY 2009 - DECEMBER 2012) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ. ดร.สมบัติ อยู่เมือง, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม: ศ. ดร.เฉลิมชนม์ สถิระพจน์, 108 หน้า.

ชั้นบรรยากาศไอโอโนสเฟียร์เป็นชั้นบรรยากาศระดับบนของโลกที่มีความหนาแน่นของอิเล็กตรอนสูงหรือเรียกว่า ปริมาณอิเล็กตรอนรวม (Total Electron Content (TEC)) ซึ่งมีการเปลี่ยนแปลงตลอดเวลา โดยเฉพาะอย่างยิ่งบริเวณละติจูดต่ำมักเกิดการเปลี่ยนแปลงอย่างฉับพลันทั้งขนาดเล็กและขนาดใหญ่ภายในชั้นบรรยากาศไอโอโนสเฟียร์สูง การเปลี่ยนแปลงของ TEC นี้จะส่งผลกระทบโดยตรงต่อคุณภาพความแม่นยำของระบบการสื่อสารโทรคมนาคมในบริเวณนี้เป็นอย่างมาก วัตถุประสงค์หลักของงานวิจัยนี้เพื่อศึกษาการแปรเปลี่ยนของปริมาณอิเล็กตรอนรวมรายวัน รายเดือน รายปีและฤดูกาลทั่วประเทศไทย โดยใช้ข้อมูลจีพีเอส ระหว่างปี พ.ศ. 2552 – พ.ศ. 2555 ค่า TEC ที่ได้รับจะถูกคำนวณหาค่าดัชนีอัตราการเปลี่ยนแปลงของปริมาณอิเล็กตรอนรวม (ROTI) รูปแบบรายวัน เพื่อแสดงให้เห็นความผิดปกติของชั้นบรรยากาศไอโอโนสเฟียร์ ค่าเฉลี่ยการแปรผัน ROTI แบบรายวัน แสดงให้เห็นแนวโน้มการเกิดผิดปกติของชั้นบรรยากาศไอโอโนสเฟียร์จะแปรผันสองครั้งต่อปีและมีค่าเพิ่มขึ้นทุกปี อัตราการเกิดความผิดปกติของชั้นบรรยากาศไอโอโนสฟียร์ขนาดใหญ่ที่พบในช่วงเวลากลางคืนนั้น ผลลัพธ์ที่ได้ยืนยันได้ว่าความผิดปกติของชั้นบรรยากาศจะขึ้นอยู่กับเดือนและฤดูกาล โดยความผิดปกติของชั้นบรรยากาศไอโอโนสเฟียร์มีอัตราการเกิดสูงสุดในฤดูกาลอิคิวน๊อกซ์ (มีนาคม, เมษายน, กันยายน และตุลาคม) นอกจากนี้ลักษณะการแปรผันแบบรายปีนั้นยังยืนยันการลักษณะกระจายความผิดปกติของชั้นบรรยากาศไอโอโนสเฟียร์เชิงพื้นที่ในช่วงเวลากลางคืนทั่วประเทศไทยได้ การแปรผันนี้จะมีความรุนแรงมากในพื้นที่ทางภาคตะวันออกเฉียงเหนือและภาคกลาง

ผลการศึกษาการแปรผันของชั้นบรรยากาศไอโอโนสเฟียร์ที่ได้รับจากข้อมูลจีพีเอสบริเวณภาคกลางของประเทศไทย ในการสร้าง VTEC แบบท้องถิ่นหรือชื่อ Thai Ionosphere Map (TIM) โดยใช้ Single layer model ของ Bernese software และข้อมูล Global Ionosphere Map (GIM) ซึ่งดาวน์โหลดมาเพื่อเปรียบเทียบผลของ TIM ในเดือนเมษายน พ.ศ. 2553 ที่ใช้เป็นตัวแทนของข้อมูล เนื่องจากเดือนนี้มีการแปรผันสูง ผลลัพธ์ของการเปรียบเทียบค่าระหว่าง TIM และ GIM แสดงให้เห็นว่าค่าสัมประสิทธิ์สหสัมพันธ์เชิงเส้นของทั้งสองโมเดลมีความสัมพันธ์กันสูงมาก (r=0.87)

ภาควิชา	ธรณีวิทยา	ลายมือชื่อนิสิต	....
สาขาวิชา	โลกศาสตร์	ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก	....
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PORNTIP JAIMUN: VARIATIONS OF TOTAL ELECTRON CONTENT IN THAILAND DURING JANUARY 2009 - DECEMBER 2012. ADVISOR: ASST. PROF. SOMBAT YUMUANG, Ph.D., CO-ADVISOR: PROF. CHALERMCHON SATIRAPOD, Ph.D., 108 pp.

Ionosphere is the upper atmosphere of Earth’s. There are high electron densities or so-called Total Electron Content (TEC), which changes all the time. Especially, low latitudes region often sudden changes both small and large within the ionosphere. Variation of TEC will directly affect to quality the accuracy of the telecommunications system in this region. The main purpose of this research is to study daily, monthly, annual and season variations of the TEC over Thailand by using GPS data between January 2009 and December 2012. The TEC values obtained were calculated in a form of the daily rate of change of total electron content index (ROTI) to demonstrate the ionosphere irregularities. The average daily variations of ROTI show a semiannual trend and an increasing annual of the ionosphere irregularities activity. The occurrence rate of the ionosphere irregularities were found on a large scale during night time. The results also confirmed that the ionosphere irregularities depend on month and season. The ionosphere irregularities reached high occurrence rates during the equinox season (March, April, September and October). In addition, the characteristic of annual variation confirms the spatial distribution of the ionosphere irregularities during nighttime over Thailand. The variations are also severe in the northeastern and central regions.

The ionosphere variation results were obtained from the use of GPS data in a central part of Thailand to generate a local VTEC so-called Thai Ionosphere Map (TIM) using a Single Layer Model by Bernese software. The Global Ionosphere Map (GIM) was downloaded and compared with the TIM. The results from April 2010 are selected as an example because this month is the period of high ionosphere variability. A comparison of results between the TIM and GIM shows that a coefficient of correlation value is relatively high (r = 0.87).

Department:	Geology	Student's Signature	....
Field of Study:	Earth Sciences	Advisor's Signature	....
Academic Year:	2013	Co-Advisor's Signature	....

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LIST OF ABBREVIATIONS

CODE	: Center for Orbit Determination in Europe
DOL	: Department of Lands
DOY	: Day of Year
DPT	: Department of Public Works and Town & Country Planning
GIM	: Global Ionosphere Map
GPS	: Global Positioning System
IGS	: International GNSS Service
IONEX	: IONosphere Map Exchange
NASA	: National Aeronautics and Space Administration
RINEX	: Receiver INdependent Exchange
ROTI	: Rate of change of TEC index
SOPAC	: The Scripps Orbit and Permanent Array Center
TEC	: Total Electron Content

CHAPTER I
INTRODUCTION

1.1 Background

The atmosphere of the Earth is a layer of gases surrounding the planet which prevents impacts on solar radiation by absorption, scattering and reflection. For example, temperature between day and night to maintain the appropriate condition for live on Earth. The changing of atmosphere near the Earth's surface directly impact on the daily activities of human [1], so the global scientists are tracked and reported this change regularly of weather on radio and television. By observing frequency and quantity of weather phenomenon, human are able to learn and predict what does climate change to be in each year, and should be prepared to provide proper sustenance such as bringing an umbrella before leaving home on rainy day, or Rain should not be in the open because it was occur the lightning event., etc. Not just near surface atmosphere, the upper atmosphere is often suddenly change as well, caused by an effect of Earth's magnetic field and the solar emission, which impact directly on the telecommunications and many electromagnetic receivers on Earth.

The Earth's atmosphere can be divided into four main layers based on the changing of temperature with altitude. Firstly, The Troposphere is the lowest level of the atmosphere above the ground approximately 10 to 12 kilometers. Air temperature in this layer reduced as an altitude increased until the temperature constant. It contains gases, water vapor and aerosols. Most of the phenomena effect Human lift occurs in the troposphere. The Stratosphere is above the troposphere and the temperature increases with altitude due to ozone gas (O_3). In this region will be absorbs ultra-violet radiation from the sun to prevent the damage of plants and human skin. This region is located at a height about 45 – 50 kilometers. The

Mesosphere is above the stratosphere and temperature decreases with altitude again. This region is located at an altitude of 80 kilometers. Finally, The Thermosphere is located above an altitude at 85 kilometers. In this region, the air masses are not the gas state, but presence of ions. Heat from shortwave radiation of the sun cause the atoms ionized [2], so this region also called The Ionosphere. The temperature in this region rise rapidly as shown in Figure 1.1.

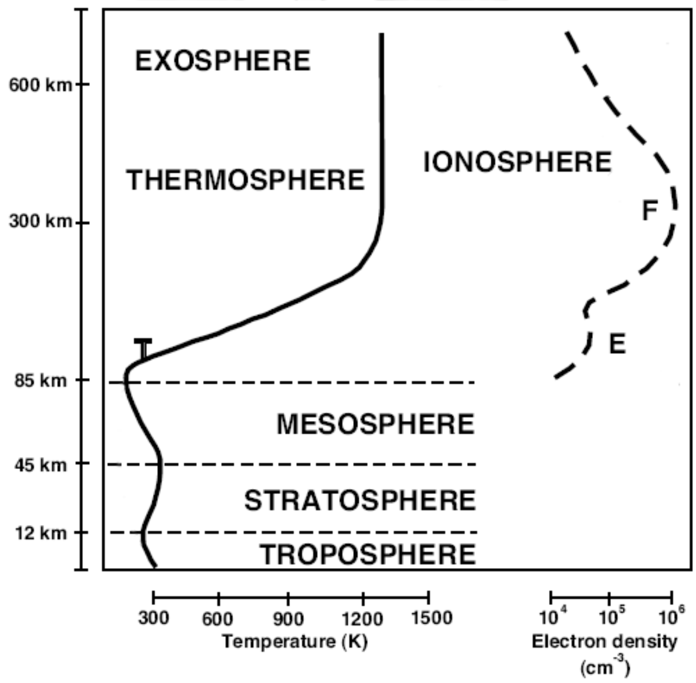

Figure 1.1 A profile of the Earth's atmosphere with the temperature and density of electrons [2].

Accordingly Figure 1.1, the Earth's atmosphere also can be divided by the changing of gas properties with altitude at 85 to 600 kilometers, it is so-called Ionosphere. The Ionosphere have many ions with electrical properties which can reflect radio waves, so people can be send radio signals to the remote locations around the world as shown in Figure 1.2. This region has a great role and direct impact for the radio wave communications.

Current telecommunication systems play a crucial role to worldwide communication for both economic and social. Many agencies take advantage of such systems directly such as Satellite system, Global Positioning System (GPS), etc. Thus ionosphere is an essential part for tracking it to characterize the variation that always occurs like weather or climate in each region and to planning the proper usage of radio receivers. The general characteristics of the ionosphere such as the morphology, general features, temporal and spatial variation are described in Chapter 2.

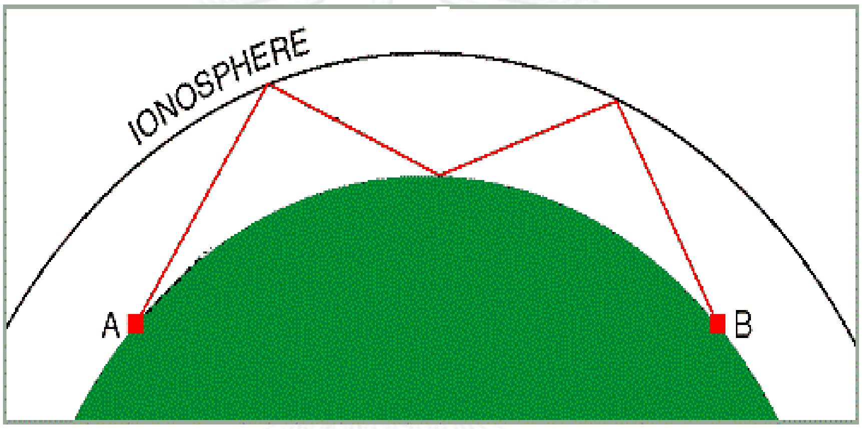

Figure 1.2 The reflection of radio waves from position A to position B in the ionosphere. Figure adapted from http://www.viewzone.com/

Variations of ionosphere that occur frequently have to be monitored continuously. This research use GPS data to observe the characteristics of ionosphere by measuring Total Electron Content (TEC), which the TEC is the electron number densities along the line of sight from satellite (S) to receiver (R) represent

$$TEC = \int_{R}^{S} N ds \tag{1.1}$$

where N is electron density along the signal path *s*.

ds is the path from satellite to receiver.

TEC is the Total number of free electrons in a column with section area 1 m^2, in TEC unit (TECU), where 1 TECU = 10^6 electrons per square meter. Which TEC measurements can be obtained from navigational systems such as GPS, ionosondes or geostationary satellites [2]. In chapter 2 is described the theory for finding the TEC from GPS data.

Ionosphere is a plasma that usually vary and unstable because of many factors from both outside and inside the earth. The outside the earth factor is solar cycle, solar wind. The inside the earth factor is daily and seasonal variation, etc. The ionosphere often occur the irregularities or disturbance in nighttime which cause scintillation on GPS signals. In previous studies, the ionosphere irregularities studied using TEC by GPS data was used to describe the electron density in the ionosphere [3-8]. By calculating Rate of Change of the TEC (ROT), defined the Rate of Change of the TEC Index (ROTI) derived the standard deviation of ROT over a period of 5 minutes [9]. ROT and ROTI indices are used to estimate the TEC fluctuations and indicate large scale-size ionosphere irregularities of the electron density.

This study aims to explain the ionosphere variation using Bernese 5.0 software and compare the result with Global ionosphere Map (GIM). In addition, it aims to explain the ROT of a large scale-size irregularity of electron density, daily, seasonal and annual variations which effects scintillation on GPS signal. The GPS data used in this study are provided by Department of Lands, Department of Public Works and Town & Country Planning and International GNSS service [10]. The data from the Department of Lands can be applied to study the TEC over Bangkok and its vicinity while those from Department of Public Works and Town & Country Planning can be used to study the TEC over the country. The last GPS station of the IGS was installed in Bangkok.

1.2 Research objectives

1. To study daily, monthly, annual and seasonal variations of the TEC over Thailand during January 2009 to December 2012.
2. To compare the TEC data receiving from ground-based GPS receivers and Global Ionosphere Map (GIM) between January 2009 to December 2012.

1.3 Study area and Scope

1. The TEC data were derived from 23 GPS stations located in Thailand during 28-day period of April 2010.
2. The TEC data from ground-based GPS receivers are compared with those from GIM.

1.4 Expected outputs

1. Temporal and spatial variations of the TEC over Thailand during January 2009 and December 2012 could be observed.
2. The ROTI and output TEC data are applied to observe space weather in the day and night times in Thailand.

CHAPTER II
THEORY AND LITERLATURE REVIEW

2.1 The basic idea

Total Electron Content is free electrons within ionosphere and it's become most important parameter for tracking and observing the ionosphere because the ionosphere will fluctuate over time. Variability and irregularities of the ionosphere may occur during the period of a few hours, months or years, depending on several factors. Such as latitude factor, especially the equatorial has high variability when compared to other areas around the world [11] or based on a high solar activity, which the solar are one factor cause variances and irregularities higher than normal. In 2009, there are the initial phase of the solar cycle #24, which begins with the intensity increasing and highest in 2012, according to the prediction of the National Aeronautics and Space Administration. The increase of the solar activity in conjunction with areas is high variability. It cause variation in the atmosphere has occurred more frequent and more severe. Particularly in Thailand, which area is regarded situated in the equatorial region may be affected by the variability of the Ionosphere. The communication system or GPS Satellite surveying, if the base station is located very far apart, variability in the ionosphere will cause increases the position error. Current, studies and monitoring characteristics of the ionosphere will be used to calculate the GPS satellite waves [3, 7]. To determine the TEC is based on using models. TEC is also an indication quite day or disturbance day of the ionosphere was calculated as the rate of change of TEC index (ROTI). When calculating the ROTI in several years are able to demonstrate period the irregularity of the ionosphere and areas with a high incidence as well. Thus, the monitoring characteristic variation of the ionosphere shows spatial and time variation. It is very useful for planning the installation of GPS base stations that may occur in the future. In present, there are many agencies that use GPS systems and may require the installation of GPS base station increases to cover the space responsibilities, include and to increased efficiency in the use of GPS as well.

2.2 The basic principle of the Ionosphere

2.2.1 Structure of the Ionosphere

Ionosphere is one of the Earth's atmospheres which composed of plasma, that generated by photoionization of neutral gases: O, N_2 and O_2. The ultraviolet (UV) radiation from the Sun plays an important role to ionize neutral gas atoms and molecules, can be seen Figure 2.1, when an electron inside the atom receives a photon energy from UV radiation, incoming energy will cause electrons loose from atoms. These electrons are called free electrons. The atom losing one electron becomes a positive ion. This process produces many free electrons and positive ions in the ionosphere. However, the morphology of the ionosphere in each area is not the same. It depends on geographic latitude and longitude, geomagnetic latitude and longitude, daytime and nighttime, season, and solar activity. This section will describe the Ionosphere foundation by including the morphology based on the stratification of the ionosphere and factors affecting the variability of the Ionosphere [12].

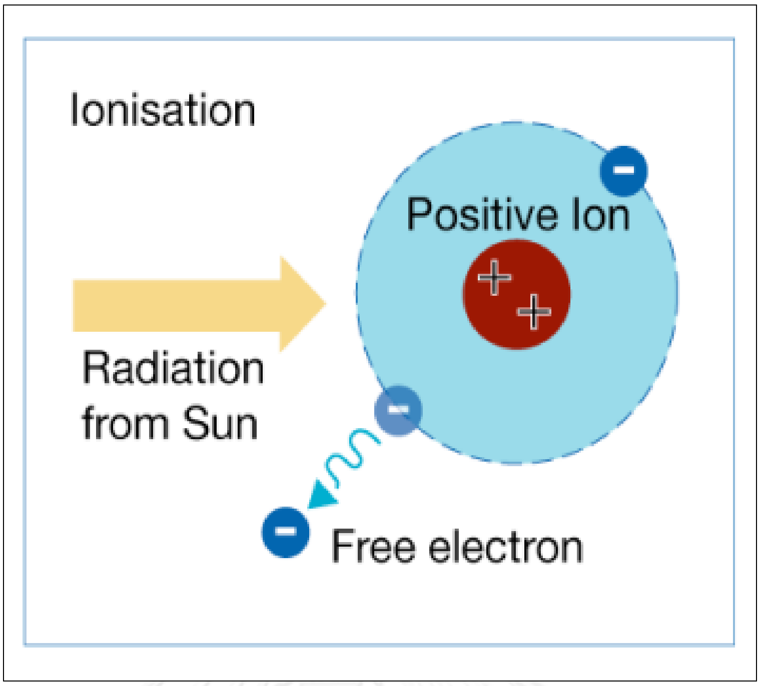

Figure 2.1 Photoionization process inside an atom [12].

The Upper Earth's Atmosphere or Ionosphere as the free electrons a result from ionization processes. It covers an altitude of 50 to 1,000 kilometers. The ionosphere can be divided into 3 regions according to the density of the plasma, that is D, E and F regions, which is described in detail, each regions is as follows [2].

2.2.1.1 The D - region is the lowest layer of the ionosphere at an altitude about 60 km to 90 km. This D region consists of N_2 and O_2, and N_2^+ and O_2^+ are generated by cosmic ray and x-ray radiation at height above 70 kilometers. Electrons and positive ions have high recombination rate cause the D region can appear in the daytime only [1].

2.2.1.2 The E - region is located above D-region about 90 to 130 kilometers. The major gases in this layer are N_2 and O_2 being ionized to O^{2+} and NO^+ by x-ray radiation. This layer appears in the daytime similar to the D layer. Sometimes, it can appear on the night time. In addition, this region can reflect low frequency radio waves being used in telecommunication systems.

2.2.1.3 The F - region is the highest region of the earth's ionosphere above 130 kilometers from the ground. The major gases in this layer are atomic Oxygen (O) and ionized by EUV radiation, the result has generated O^+ a lot. During the daytime, the F region has exhibits two sub-layers (F1 and F2). The F1 can appear only in the daytime due to electron density low [1]. In contrast to the F2 layer has electrons density is very high, making it can appear always. Therefore, the F2 is used in communications today.

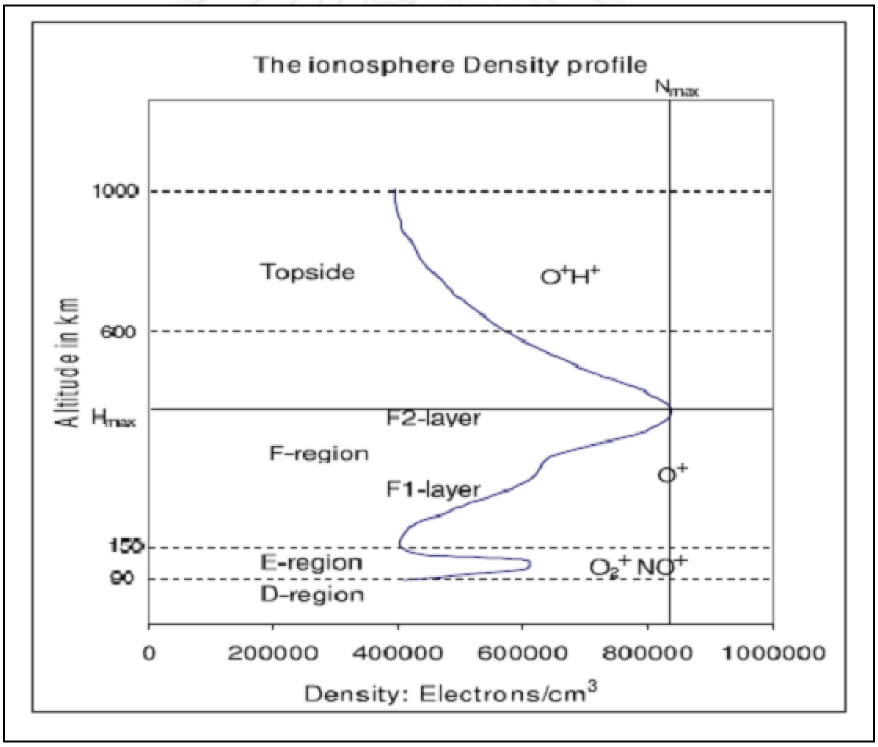

Figure 2.2 Ionosphere profiles in the vertical direction [2].

Generally found that the electron density is very high during the daytime than at night. During the daytime when the sun is perpendicular to the ground, that time is the radiation flux very high and result energy high in the atmosphere, Thus causes in high ionization. The ionization is resulted in the number of free electrons increases based on the incoming energy from the sun. Similarly, during the night has less energy, it cause the recombination of atoms. The electron density will be reduced. These processed is resulting in variability daily of the ionosphere.

2.2.2 Variations of the ionosphere

The electron density varies is an affect variation in the atmosphere. The factors causing this variation are due to many factors both within and outside the earth. The each variation has a unique both the characteristics and the mechanism

2.2.2.1 Factors of variation of Ionosphere by the Earth

Factor of geographic: Variation of Ionosphere is based on geographical location. The geographic area can be divided into 3 regions; Polar region, Mid-latitude region and the equatorial region see Figure 2.3. The polar region known as aurora zone is located above 60 degrees north and south. This area is areas the geomagnetic field lines perpendicular to the earth's atmosphere and allow the Ionosphere connect to magnetosphere. During the solar activities have high energy particles such as electrons and photons from the sun are stored in the magnetosphere. The particle move along the magnetic field lines on polar region to the ionosphere. This process is the cause of the variation in the electron density in polar ionosphere. Mid-latitude region, this area is located between 20 - 60 degrees. The ionosphere area will be influenced by the solar EUV radiation and the neutral wind, but the electron density gradient is not as steep as at low latitude and polar. The equatorial region, there are very high density of the electron in the ionosphere at latitudes 20 degrees and low of the electron density at the magnetic equator. These characteristics are called fountain effect. Plasma upward drift caused by the electrons eastward and became the electric field perpendicular to the magnetic field lines from pole in the south - north direction. This process is causing the electrons inside the magnetosphere rise up to low latitude exhibiting as high electron density and a strongly horizontal electron density gradient. Uplift of the plasma is called the (E x B) drift, see Figure 2.4.

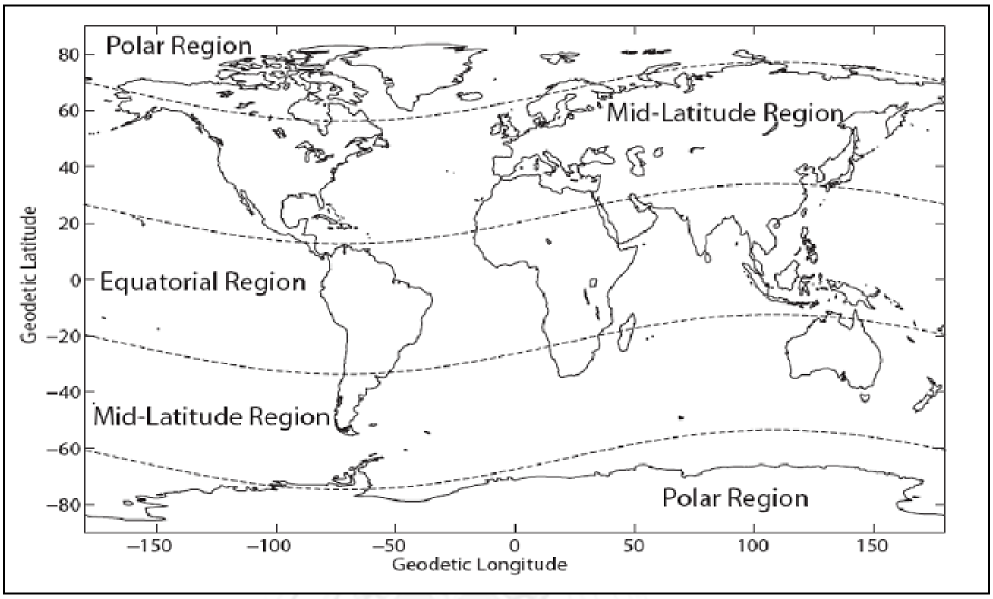

Figure 2.3 Ionosphere regions depend on geomagnetic dip angle. From high to low latitudes can divide into 3 regions: Polar region, Mid-latitude region and the equatorial region [13].

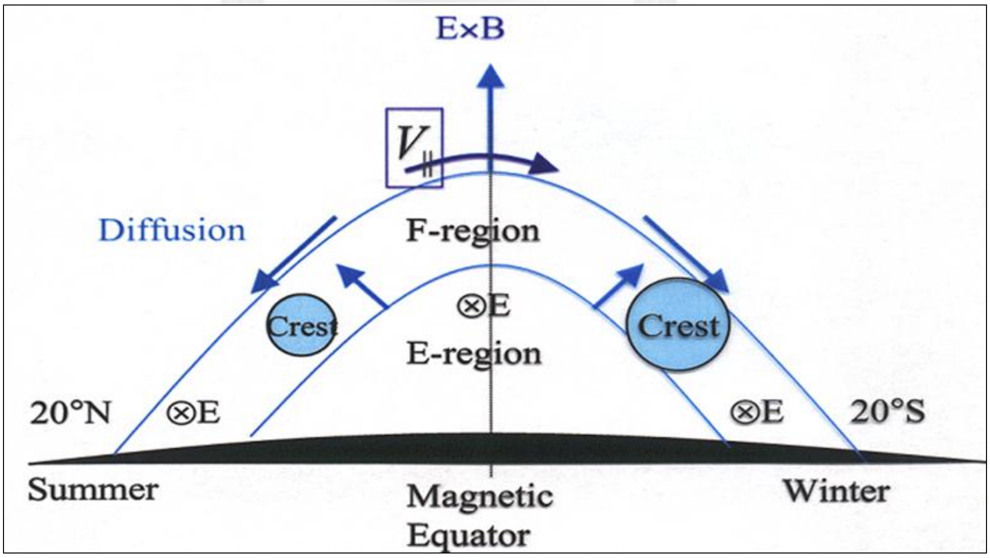

Figure 2.4 Fountain effects and asymmetry of the equatorial anomaly [14].

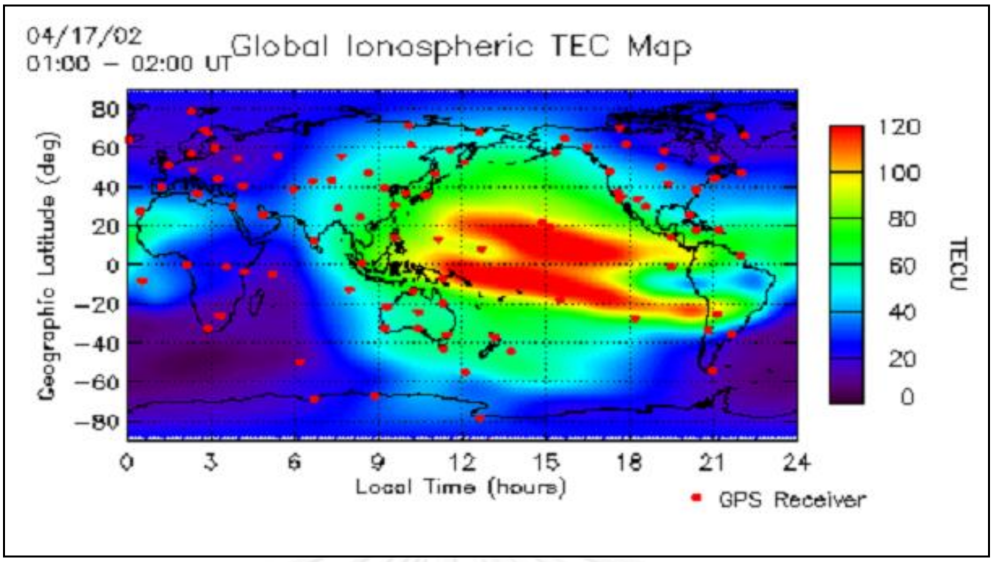

Figure 2.5 Show global ionospheric TEC map daily, source http://iono.jpl.nasa.gov.

The daily variation is a result of the rotation of the earth within one day. At the local time, the electron density is very high in the afternoon and will be less during the night, see Figure 2.5.

Seasonal variations: as a result of the earth's rotation around the sun. Electron densities will be seasonal variation. For instance, the electron density is higher in the summer than the winter due to a period that the earth perpendicular to the sunlight, an ionizations being greater. Sometimes, it is found that the electron density in the winter more than the summer. This phenomenon is referred to seasonal anomaly which caused by the season change of the relative concentrations of atoms and molecules in the ionosphere. The phenomenon often found in mid-latitudes more than the equatorial and at high latitudes.

Earth's magnetic field: Earth's magnetic field will be directly affected by external charged particles that a result the earth's magnetic field is disturbed. Generally be divided into three regions according to the geomagnetic reference frame: the equator, mid-latitudes and high latitudes. The area is often a large variation of the electron density occurs at the equator and pole region.

2.2.2.2 Factors by the Sun

Solar cycle: A phenomenon the sun UV radiation release associated with sunspot number on the surface, the Sun is a cycle every 11 years. In period, high sunspot activity would a result the electron density increase in the atmosphere. Meanwhile, when compared with the low sunspot number density of electrons is reduced [7], shown in Figure 2.6. In currently is the range of solar cycle #24.

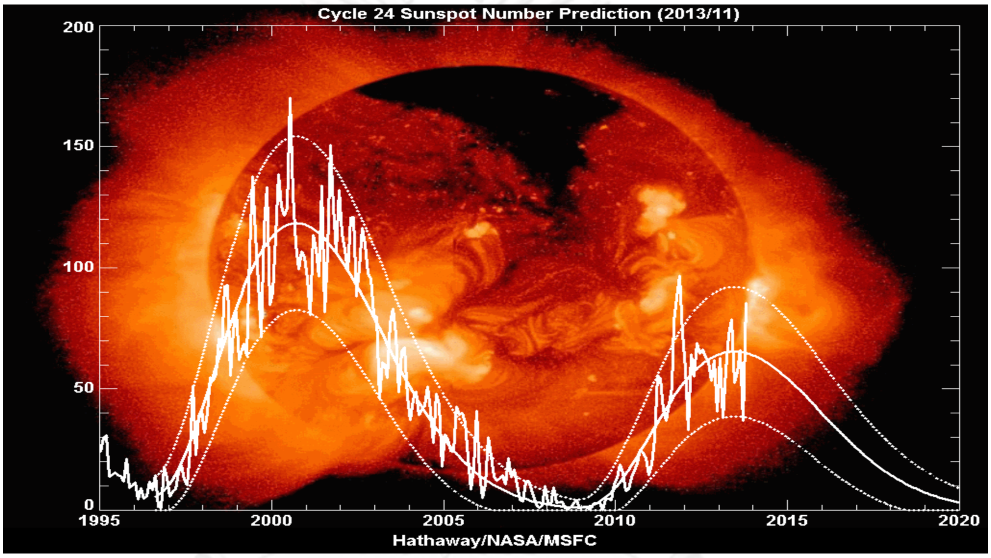

Figure 2.6 Show solar cycle #24, source http://en.wikipedia.org.

Solar wind: as the ejection of particles energy emitted from the sun into Earth's atmosphere and caused magnetic field disturbances. The solar wind can often cause a variation of the electron density.

Ionosphere storm: Sometimes the surface of the Sun will emit solar flares and Coronal Mass Ejections (CME) causes the ejection of energy particles into the atmosphere of the hugely increased. This phenomenon will cause disturbance in atmospheric and the electron density are changing rapidly. Generally it occurs in the arctic region. When a particle moves along earth's magnetic field lines and lower ionosphere is disturbed by the aurora.

2.2.2.3 Another factor

Ionosphere scintillation: small-scale disturbance with period 1-15 seconds, depending on the scale-size anomaly on the ionosphere. It's causing a rapid variation in line-of-sight electron density. This Ionosphere scintillation causes tune phase and amplitude scintillation on the GPS signal such as cycle slips and loss-of-lock [15]. The characteristic of ionosphere scintillation in worldwide is severe and frequent around the equatorial regions, particularly after sunset, while scintillation at high latitude region often occur but less severe magnitude than equatorial regions. Scintillation activity varies with geographic location and the Earth's magnetic field. The region approximately 15° North and South of the magnetic equator (Red bands) is referred to the equatorial anomaly [16], shown in Figure 2.7. The magnetic equator (Yellow band between the two red bands) has less intense of scintillation.

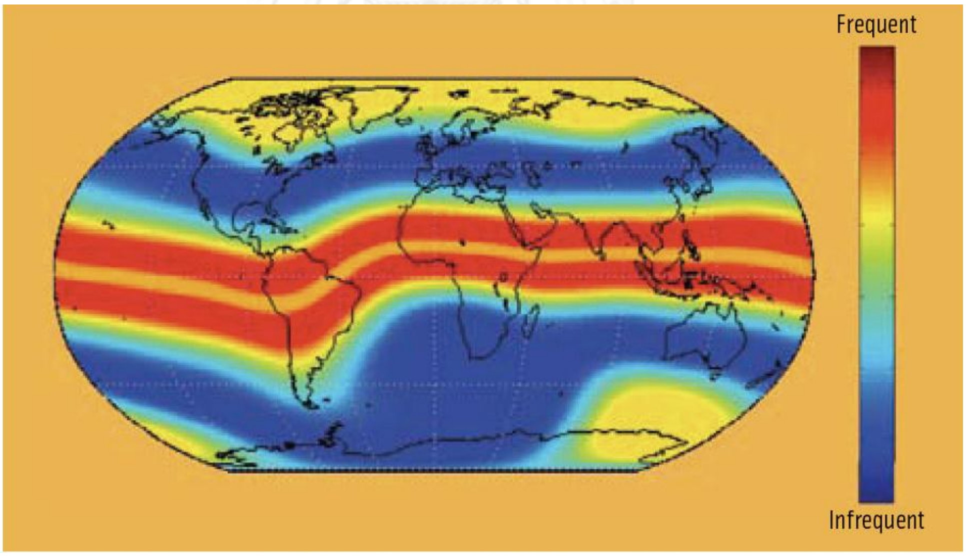

Figure 2.7 The characteristics occurrence of scintillation activity around the world [16].

Traveling Ionospheric Disturbances (TIDs): is wave of the electron density and propagation in the horizontal direction. This phenomenon is cause the passage of gravity wave in the lower atmosphere and causes variation of the ionosphere. In general, large-scale TIDs will occur over a period of 30 minutes to 3 hours and wavelength of more than 1,000 kilometers. Medium-scale TIDs takes 10 minutes to 1 hour and wavelength hundreds of kilometers. Small-scale TIDs will occur period minute and a wavelength of tens of kilometers [17].

Tides: tides wave in the atmosphere is caused by the gravity force of the moon and the sun, which affect the centrifugal force of the earth and the gravitational force of the sun / moon. Hemisphere near the gravity force of the sun / moon, the atmospheric pressure of the earth varies and causing ionospheric disruptions. Disturbances in the atmosphere takes place approximately 14.77 days, which corresponds with half a synodical month [18].

2.2.3 The Influence of the Ionospheres on wave

Propagation of electromagnetic waves or radio waves found a reflective medium will influence greatly the waves and particles in the medium. This medium can cause propagation amplitude and phase of waves, and changing a direction and velocity which medium are discussed is ionosphere. Propagation of electromagnetic waves depends on condition of the ionosphere directly, because it is the main reason that causes the delay of the signal. Propagation of electromagnetic waves in the atmosphere to the Fermate's principles, by saying "that the path taken between two points by an electromagnetic wave is the path that can be traversed in the least time” [12] as shown in Equation 2.1.

$$\Delta t = \int_{signalpath} dt = \min \tag{2.1}$$

Of the above will lead to the refraction principles that describe the relationship between the angle of incidence and angle of refraction of electromagnetic waves moving through the atmosphere (see Figure 2.8). It is said that the ratio of the sine of the incidence angles depends on the medium and it is constant.

$$\frac{\sin\alpha_1}{\sin\alpha_2} = \frac{\upsilon_1}{\upsilon_2} = \frac{n_1}{n_2} \text{ or } n_1 \sin\alpha_1 = const. \tag{2.2}$$

where n_1 and n_2 are the refractive indexes of each medium.

υ_1 and υ_2 are the respective incidence and refractive angles.

This demonstrates that the signal velocity depends directly on the refractive index *n*.

$$\upsilon = \frac{c_0}{n} \tag{2.3}$$

where $c_0 = 3\text{x}10^8$ m/s is the speed of light in vacuum.

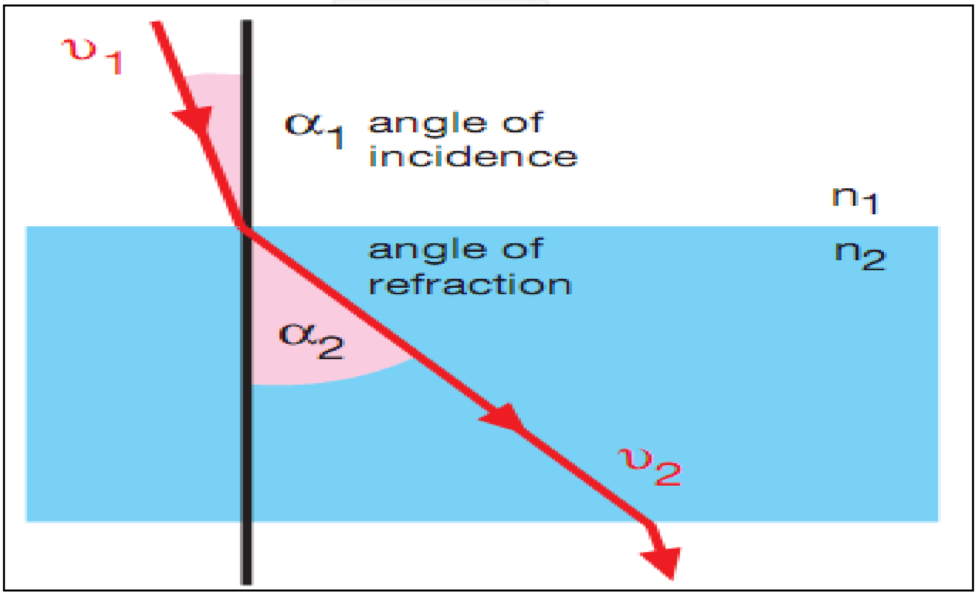

Figure 2.8 The Law of refraction [12].

Early 20th century, Appleton and Hartree have developed a refractive index *n*, also known as Appleton and Hartree formula. The equation is several the assumptions such as a uniform charge distribution, electron collisions independent of electron energy and an electrically natural medium. In detail the derivation of the equation can be viewed [8]. The refractive index depends on the number of free electrons along the path of the signal and the frequency of the radio waves. Which can be expressed by a simple equation Appleton and Hartree [19] are as follows.

$$n_z^{ion} = 40.3\frac{TEC}{f^2} \tag{2.4}$$

where n_z^{ion} is the path delay though the ionosphere of zenithal propagation

TEC is the Total Electron Content 1 TECU = 10^{16} el/m^2

f is the frequency of signal.

From the equation 2.4 shows the path delay of signal moving through the atmosphere which dependent on frequency of signal. The high frequency is small path delay [12]. This relationship can be used to estimate the TEC along the path of the signal moves through the ionosphere to receiver. TEC values can be used to describe to characteristic of the ionosphere activity, which used by the modeling to find the TEC.

2.3 Basic concepts of Global Positioning Systems (GPS)

GPS is a system that is capable of providing precise location and direction to users on the ground. GPS was developed by United States Department of Defense (DOD) for military and government agencies to purpose. Subsequently, GPS system was developed to provide more complete and has been used in the private sector, other agencies. Until, current GPS system used widely around the world and involves multiple disciplines such as geography, environmental, science and engineering, including GPS surveying techniques the terrain used to create contour lines and building roads. Also it used to define boundaries of forest reserve and track conditions of ionosphere.

General characteristics of systems, GPS will be divided into three segments, including user segment, control segment and space segment: User segment is GPS receiver on the ground, which will have a different solution such as a GPS receiver, is a single frequency, dual frequency, capable of radio-link contact with other receivers etc. Control segment currently consists of 12 monitoring stations scattered throughout the world along the equator. These control stations to communicate with the satellite, to satellite maintenance, to calculate the position of the satellites, predict the ephemeris of satellites and to periodically update each satellite navigation message. Space segment consists of 24 satellites (currently has 31 satellites) to transmits satellite signals and navigation message. The 24 satellites are a six orbits, each orbit consist four satellites. Each orbit inclined at an angle to the equator plane at 55 degrees, each orbital plane consist four satellites above the ground about 20,200 kilometers. Therefore, every location and anytime on the surface appear to have four satellites in the sky all the time, as Figure 2.9 the satellites are orbiting around the earth takes 12 hours. Principle of GPS is based on measuring the time of electromagnetic waves that are emitted by satellites and receives at GPS receiver. When compare between the times of release the signal with time at reception of receivers, result as the travel time and distance from satellite to receiver. Therefore, it is important to accurately synchronize the satellite clocks. Each satellite has an atomic clock that requires a highly stable, which makes synchronize the GPS time. The high stability of clock is very important during the measurement of time, generally used quartz clock which is cheap and effective. However, the travel time and the distance between the satellites to receiver is also the clock error of the receiver. The time of synchronization error between satellites with the time of receiver, this is called pseudodistance.

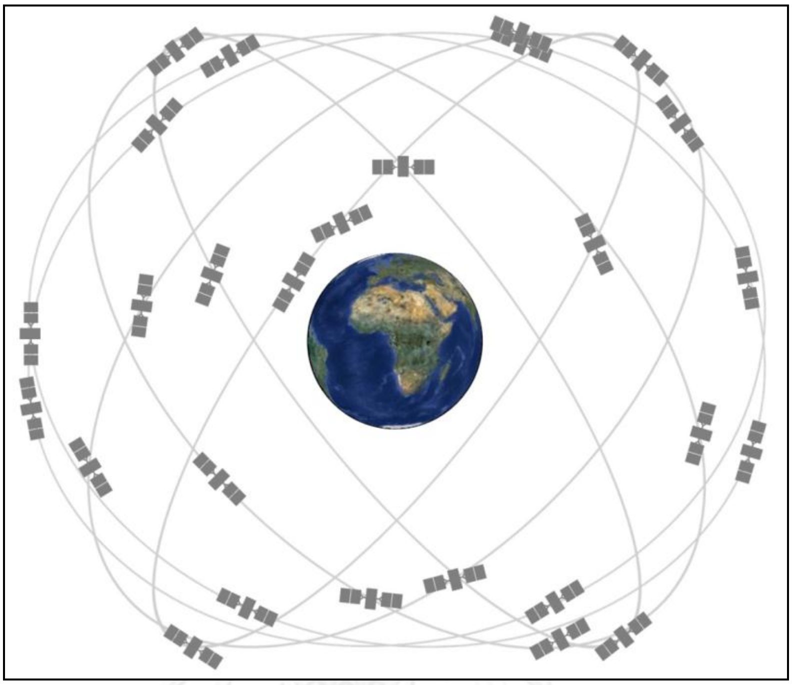

Figure 2.9 A six orbital planes of GPS satellites, source http://www.gps.gov/.

Broadcasting of satellite GPS as two signals on the carrier frequency in L-band: L1 (1,575.42 MHz) and L2 (1,227.60 MHz) carrier waves. Both carrier waves from satellite are modulated in form of radio signals, called pseudo-random noise (PRN) codes: coarse/acquisition (C/A) code onto L1 carrier. The dual frequencies receiver can be measured difference of ionospheric delay between L1 and L2. Basically, these two frequencies are assumed travel along the path through the atmosphere, the delay of the signal from the equation (2.5) can calculate the distance of the two frequencies from the following equation.

$$\Delta n = n_{g,1} - n_{g,2} = \frac{40.3}{c}.TEC\left(\frac{1}{f_1^2} - \frac{1}{f_2^2}\right) = P_1 - P_2 \qquad (2.5)$$

where P_1 is the group path length obtained from high frequency (f_1=1575.42MHz)

P_2 is the group path lengths obtained from low frequency (f_2 =1227.6 MHz)

Similarly could find the TEC value from equation (2.5) below

$$TEC = \frac{1}{40.3}\left(\frac{f_1 f_2}{f_1 - f_2}\right)(P_2 - P_1) \qquad (2.6)$$

where P_1 and P_2 are the pseudoranges measured in L1 and L2.

2.3.1 Single Layer Modeling Approximation Mapping Function

In calculation of the absolute of TEC is value along the path from the satellite into the receivers, general called Slant Total Electron Content (STEC) The STEC will be converted to the Vertical Total Electron Content (VTEC) which normally used Single Layer Modeling (SLM) [20-22] see Figure 2.10. This Single Layer Modeling assume that the total number of free electrons density within a spherical shell of infinitesimal thickness around the earth and at a fixed height. In general, assume a height of approximate 350 to 450 kilometers. The Ionosphere model will be considered the zenith of the receiver (ξ') and the zenith at the surface ionosphere (ξ) above the Earth's surface as *(h)*. The both zenith is the waves traveling from the satellite to the receiver which can be write the following equation.

$$TEC = \frac{1}{\cos\xi} VTEC \qquad (2.7)$$

where ξ is satellite zenith angle at the intersection point between the line of sight and the spherical single layer ionosphere

$VTEC$ is the TEC in the vertical direction

$\frac{1}{\cos\xi}$ is the mapping function which is a function of elevation angle ξ, see equation (2.8)

The vertical projection of the ionospheric piercing point (IPP) on the ground is referred to the sub-ionospheric point (SIP) as in Figure 2.9. Geometrically, relation between the satellite zenith angles at the receiver location (ξ') and the ionospheric pierce point (ξ) is (2.8)

$$\sin\xi = \frac{R_e}{R_e + h_i}\sin\xi' \tag{2.8}$$

where h_i is the height of the ionospheric single layer from the earth's surface.

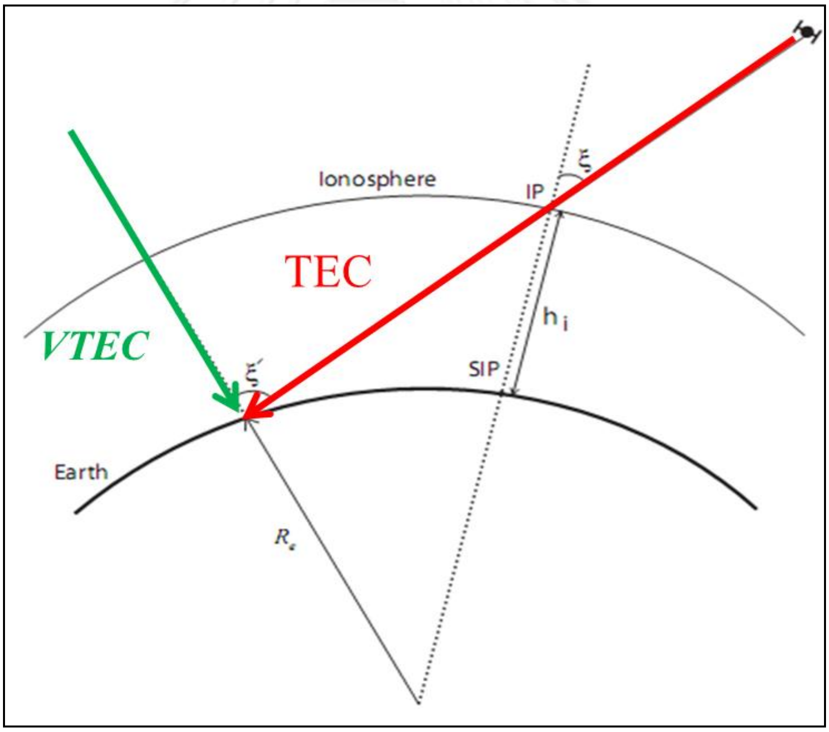

Figure 2.10 Geometry of the ionospheric single layer approximation [8]

Considering the angle ξ' of waves, each wave is different, depending on size of the angle ξ' because if the angle ξ' is large-scale, that means the path of the wave that travels through the ionosphere to the receiver have the distance rather than the path of wave that is less of an angle ξ'. So the wave of satellites is near the horizon with tolerances of Ionosphere more than the satellite is far from the horizon.

2.3.2 GPS for Ionosphere purpose

GPS systems are used to track the characteristic of variation of Ionosphere by estimating the TEC. Particularly in the period after sunset often occur disturbances in the atmospheric may briefly occur a few minutes to several hours, known as ionosphere irregularity. It is a condition of the electron density variation within the ionosphere. Ionosphere irregularity is typically small to medium which usually occurs often such as small anomalies are associated with the occurrence scintillation etc. A variation of the TEC in evening, it is an indicator that the ionosphere there was irregular. It is increased by season and solar activity. Ionosphere irregularities, it is more severe in the equatorial region. The kind of malfunction of the ionosphere of equatorial can be classified as shown in Table 2.1.

Ionosphere irregularities can be calculating by rate of change of Total Electron Content Index (ROTI) as standard deviation of ROT over a period of 5 minutes [9]. ROTI indices are used to estimate the TEC fluctuations and indicate large scale-size ionospheric irregularities of the electron density, follow equation (2.9) and (2.10)

$$ROT = \frac{TEC_k^i - TEC_{k-1}^i}{t_k - t_{k-1}} \quad (2.9)$$

$$ROTI = \sigma_{ROT} \quad (2.10)$$

where TEC is Total Electron Content

i is the visible satellite

k is the epoch time

σ_{ROT} is the standard deviation of ROT over a 5-min period

Table 2.1 Irregularities and anomalies prevalent at Equatorial locations [23]

Type of variation	Ionosphere region	Distribution	Time most prevalent	Duration
Electrojet irregularities	E region	East-wast	All times (stronger in daytime)	<30 minutes to hours
Appleton anomaly	Above the F region	Enhancement at 10 - 20° north-south (depletion at equator)	Late afternoon and early evening	>4 hours
Rayleigh-Taylor instabilities	F region	Along magnetic field line (north - south)	After sunset and early evening	>2.5 hours
Magnetic-storm effects	E region and F region	Global	All time	Seconde to hours

2.4 Overview

Wu, Fry [24], studied the variations of total electron content during the solar cycle #22, September 1996 to August 1997. The analysis of dual frequency signals from GPS 9 stations around Taiwan. They found that the TEC variation occurs semiannual by the peak in the equinox months and peak the TEC at 14:00 LT. Subsequently, Wu, Liou [25], conducted a study using the study period lasting up to

10 years, from 1994 to 2003 using the same analysis on study previously. They found that the average of TEC value occur variation of semiannual. In comparison, there each year is a similar variation. There each year is a very high the TEC during the equinox months and a very low in the summer months. Kumar and Singh [20], studied the variation of the TEC, daily, seasonal and yearly using dual frequency signals of GPS during the solar minimum period from May 2007 to April 2008 at Varanasi in India. They found that the maximum daily TEC is very high during the equinox months and shows the variation of the TEC semiannual and characteristic of seasonal and annual variations in similar studies [24, 25]. In addition, their study showed the electron density the nighttime increases during 23:00 - 01:00 LT, and then gradually decreased. Studies the variation of Ionosphere at Chumphon in Thailand [26]. Used GPS data during 2004 - 2006 found the TEC is decreased. Three years has a very high TEC values during the equinox and the winter more than the summer, and the maximum value in daily occur during the afternoon and a very large range in the equinox.

Gwal, Dubey [4] studied the variability of the ionosphere during the nighttime at the equatorial region using a single frequency receiver from GPS during 2001 - 2002. They that found occurrence the rate of scintillation there is very high during night time. Especially during the equinox months was very high and usually occurs before midnight. Gwal et al. [27] studied the variability of ionosphere during night time in Chiang Rai, Thailand by calculating the statistical of the scintillation in percentage unit. The results have been found the rate of scintillation is variation from month to month by the highest rates occurrence in April and September, minimum in May and June, which is consistent with previous studies. Research showed that the areas in Chiang Rai, often occurrence variability of the ionosphere during the night regularly. Which the scintillation will cause fading of the signal, cycle slip, Lock-of-Loss etc. These studies demonstrate that low latitude region occur often variation of ionosphere both day and night in severity depend on season and year. The studies of SBAS Ionosphere Working Group [16] explained that the cause of the scintillation during nighttime caused by ionosphere irregularity. The scale size of the ionosphere irregularities that affect to GPS signal, it will be different away. For example, the ionosphere irregularities a small size is related to the scintillation. Ionosphere irregularities cause the scintillation on the radio, found that the ROTI can show fluctuations in the atmosphere before midnight clearly and a good results, according to a studies Oladipo and Schüler [21]. In addition, they have divided the irregularities levels to affect to phase fluctuation are 3 levels; 1. ROTI < 0.4 mean no phase fluctuation activity 2. $0.4 <$ ROTI < 0.8 to mean there is phase fluctuation activity 3. ROTI > 0.8 mean a high or sever phase fluctuation activity. However, previous studies [28] have reported that the ROTI ≥ 0.5 is to a value that indicates a large scale-size of ionosphere irregularities of kilometers. Zou [29] studied the ionosphere irregularities in few of kilometers and 400 meter can provide result a similar between scintillation (S4) index and ROTI. Tanna et al. [6] studied the ionosphere irregularities near the equator region using ROTI ≥ 0.5 showed ionosphere irregularities is consistent with occurrence scintillation. This confirms that the equator is often occurrence by abnormalities in the atmosphere.

Another popular technique is to study the variability of the ionosphere is to create a model to determine the free electrons in the atmosphere from GPS network using Bernese 5.0 software. Ya'acob et al. [30] studied the predictive of TEC on the ionosphere in Malaysia using two GPS stations on November 8, 2005. The TEC maps create using Bernese 5.0 software, which displays maps out every two hours starting at 00:00 to 24:00 UT. Variation of the TEC track found that the TEC starts increased 7 TECU at 00:00 UT and gradually increased until the total electron up to 28 TECU at

06:00 UT (14:00 LT or local time). Then the TEC begins to decline steadily at 20:00 UT, during the before the sun rises, there will be very few TEC. However, the result was compared with the TEC of the ionosphere world (Global Ionosphere Map) the section is from about 150 GPS stations around the world. Which, in comparison with the TEC will cover the area and the format of the data will start at 00:00 UT to 24:00 UT as well. The studies found that the TEC values of the ionosphere map around the world will have more than the TEC from Bernese software process approximately 0 to 5 TECU. Alcay et al. [31] studied the ionosphere mapping, quiet day and storm day on geomagnetic field in 2003 using GPS data from a 2 GPS station, the installed at mid-latitude and high latitude. The ionosphere map is processed by Bernese 5.0 software and compared with the data of GIM. They found the TEC from the two regions corresponding to the TEC of GIM, especially, quiet day on the geomagnetic field. However, the research uses data GPS networks in central part of the country to find the TEC using Bernese Software processing as well. The comparison of the ionosphere map which created by ionosphere model and which observed by the Global Ionosphere Map may provide an information to improve ionosphere model performance over Thailand in future such as improvement in the GPS surveying in reducing the error due to ionosphere.

CHAPTER III

DATA FOR RESEARCH

3.1 GPS Data

In this research, the GPS data from a 23 GPS stations in Thailand during January 2009 to December 2012 was used as shown in Figure 3.1. There are three sources of data. Firstly, 11 GPS receivers from Department of Lands (DOL) are installed in 10 provinces: Nonthaburi, Nakhon Nayok, Nakhon Prathom, Phra Nakhon Si Ayutthaya, Rayong, Samut Sakhon, Saraburi, Samut Phakran and Chon buri. A remark, there are two GPS receivers are installed in Chon buri province. Secondly, 11 GPS receivers from Department of Public Works and Town & Country Planning (DPT) are installed in 11 provinces: Bangkok, Chanthaburi, Chiang Mai, Nakhon Sawan, Nakhon Ratchasima, Prachuap Khilikhan, Songkhla, Sri Saket, Surat Thani, Udon Thani and Uttaradit. Last data resource, a GPS receiver from International GNSS Service [10] is installed at Department of Survey Engineering, Faculty of Engineering, Chulalongkorn University. All GPS receivers are dual frequency types that receive data for 24 hour per day. Table 3.1 shows the information of each receiver at 23 stations in Thailand. GPS data collected from 23 stations during 2009 to 2012 of the three agencies. Most of the data is not continuous by numbers of days to collected data can listed in Table 3.2.

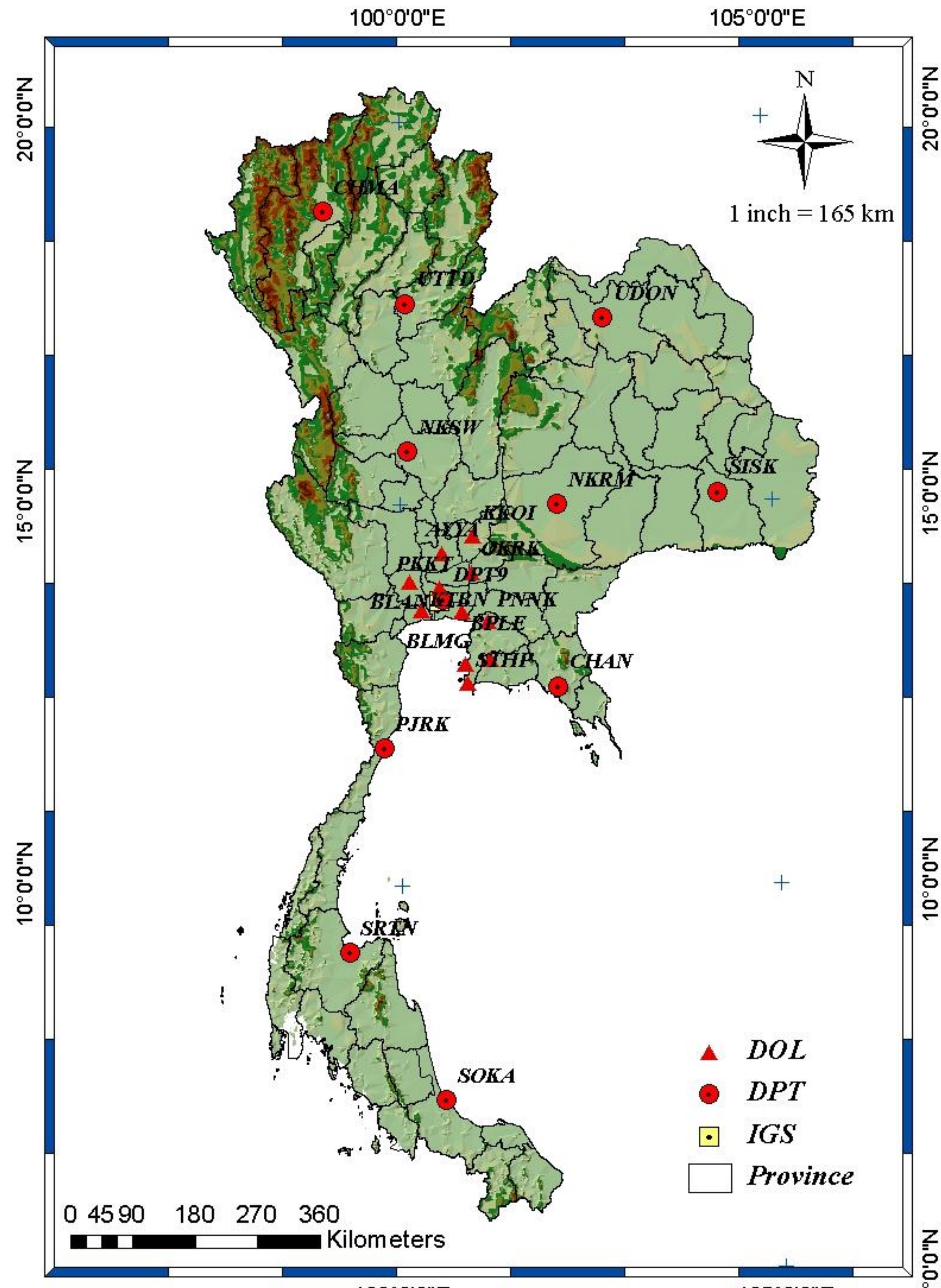

Figure 3.1 Map shows all GPS receivers at 23 stations in Thailand.

Table 3.1 Information of receivers at 23 stations in Thailand

	Name	Code	Organizations	Reciver. Type	Antenna. Type
1	Phra Nakhon Si Ayutthaya	AYYA	DOL	TRIMBLE NETR5	TRM55971.00 TZGD
2	Nakhon Prathom	BLAN	DOL	TRIMBLE NETR6	TRM55971.00 TZGD
3	Nonthaburi	BLMG	DOL	TRIMBLE NETR7	TRM55971.00 TZGD
4	Samut Phakran	BPLE	DOL	TRIMBLE NETR8	TRM55971.00 TZGD
5	Saraburi	KKOI	DOL	TRIMBLE NETR9	TRM55971.00 TZGD
6	Samut Sakhon	KTBN	DOL	TRIMBLE NETR10	TRM55971.00 TZGD
7	Nakhon Nayok	OKRK	DOL	TRIMBLE NETR11	TRM55971.00 TZGD
8	Nonthaburi	PKKT	DOL	TRIMBLE NETR12	TRM55971.00 TZGD
9	Rayong	PLDG	DOL	TRIMBLE NETR13	TRM55971.00 TZGD
10	Chonburi	PNNK	DOL	TRIMBLE NETR14	TRM55971.00 TZGD
11	Chonburi	STHP	DOL	TRIMBLE NETR15	TRM55971.00 TZGD
12	Chulalongkorn University	CUSV	IGS	TRIMBLE NETRS	TRM41249.00
13	Chanthaburi	CHAN	DPT	LEICA GRX1200PRO	LEIAT504
14	Chiang Mai	CHMG	DPT	LEICA GRX1200PRO	LEIAT505
15	DPT Rama 9	DPT9	DPT	LEICA GRX1200PRO	LEIAT506
16	Nakhon Ratchasima	NKRM	DPT	LEICA GRX1200PRO	LEIAT507
17	Nakhon Sawan	NKSW	DPT	LEICA GRX1200PRO	LEIAT508
18	Prachuap Khilikhan	PJRK	DPT	LEICA GRX1200PRO	LEIAT509
19	Sri Saket	SISK	DPT	LEICA GRX1200PRO	LEIAT510
20	Songkhla	SOKA	DPT	LEICA GRX1200PRO	LEIAT511
21	Surat Thani	SRTN	DPT	LEICA GRX1200PRO	LEIAT512
22	Udon Thani	UDON	DPT	LEICA GRX1200PRO	LEIAT513
23	Uttaradit	UTTD	DPT	LEICA GRX1200PRO	LEIAT514

*DOL (Department of Land)

*DPT (Department of Public Works and Town and Country Planning)

*IGS (International GNSS Service)

Figure 3.2 Show GPS base CUSV station at Faculty of Engineering, Chulalongkorn University.

Table 3.2 GPS data collected of each station during 2009 - 2011.

Stations	No. of Day			
	2009	2010	2011	2012
CHMA	251	342	295	266
UTTD	308	337	338	275
UDON	256	351	355	278
SISK	224	332	357	238
NKRM	214	345	360	280
NKSW	340	333	334	279
KKOI	No data	318	325	224
AYYA	No data	332	259	194
OKRK	254	297	272	273
BLAN	226	320	302	302
PKKT	300	338	336	249
CUSV	365	360	333	351
DPT9	313	346	340	369
BPLE	246	219	248	241
KTBN	262	334	268	312
PNNK	245	266	No data	205
BLMG	271	324	262	288
PLDG	123	233	133	192
STHP	238	168	220	289
CHAN	334	361	353	284
PJRK	310	341	333	279
SRTN	337	342	353	284
SOKA	334	316	348	270

3.2 Global Ionosphere Map Data

Global Ionosphere Maps (GIMs) are global TEC maps based on RINEX files which created by Analysis Centers of the International GPS Service for Geodynamics [10]. GIM are routinely estimated as product by analyzing the geometry-free linear combination, which in IONEX format. TEC of GIM is estimate based on the so-called single layer model (SLM) [32]. This TEC is a value along the zenith direction called

Vertical TEC (VTEC), and the points are arranged in a globally distributed grid of size -180° to 180° longitudes with spatial resolution of 5°, -87.5° to 87.5° latitudes with spatial resolution of 2.5° every two hours, respectively. Starting at 00:00 – 24:00 UT, 12 TEC maps are created every day at the same time. TEC maps are computed with a resolution of 2 hours at 2.5° latitudes and 5° longitudes. Figure3.3. shows GIMs on 3 April 2010. However, the GIM data is stored many formats such as Predicted, Rapid and Final on depend the use. The Predicted format can be downloaded 1 - 2 days in advance. The Rapid format can be downloaded after 1 - 2 hours. Finally, the final format used in research can be downloaded after the third day, can see detail Figure 3.3.

```
     1                                                        START OF TEC MAP
2010     4     3     0     0     0                            EPOCH OF CURRENT MAP
  87.5-180.0 180.0   5.0 450.0                                LAT/LON1/LON2/DLON/H
 68   68   67   67   66   66   65   65   64   63   63   62   61   61   60   59
 59   58   57   56   56   55   54   53   53   52   52   51   51   51   51   51
 51   51   51   51   52   52   53   54   55   55   56   57   58   59   60   61
 62   63   64   65   65   66   67   67   68   68   69   69   69   70   70   70
 70   70   70   70   69   69   69   68   68
  85.0-180.0 180.0   5.0 450.0                                LAT/LON1/LON2/DLON/H
 75   74   73   73   72   72   71   70   70   69   68   67   67   66   65   63
 62   61   60   58   57   55   54   52   51   49   48   47   46   45   44   44
 44   44   44   45   46   47   48   49   51   53   55   57   58   60   62   64
 66   68   69   71   72   73   75   75   76   77   77   78   78   78   78   78
 78   78   77   77   77   76   76   75   75
  82.5-180.0 180.0   5.0 450.0                                LAT/LON1/LON2/DLON/H
 79   79   78   78   77   77   77   76   76   76   75   75   75   74   73   72
 71   69   68   66   64   61   59   56   54   52   49   47   45   43   42   41
 41   41   41   42   43   45   46   48   51   53   55   58   60   63   65   67
 70   72   74   76   77   79   80   81   82   82   83   83   83   83   83   83
 82   82   82   81   81   81   80   80   79
  80.0-180.0 180.0   5.0 450.0                                LAT/LON1/LON2/DLON/H
 82   82   82   82   82   82   82   82   82   83   83   84   84   84   83   83
 82   80   79   77   74   72   69   65   62   59   55   52   49   47   45   43
 42   42   42   43   45   46   48   50   53   55   57   60   62   64   67   69
 71   73   75   77   78   80   81   82   82   83   83   83   83   83   83   83
 83   83   83   83   83   83   83   82   82
  77.5-180.0 180.0   5.0 450.0                                LAT/LON1/LON2/DLON/H
```

Figure 3.3 Example of GIMs was Final format on 3 April 2010.

3.3 Data processing strategy for high accuracy positioning applications

In general, the processing has requirements for high accuracy can be use 3 software is BERNESE, GIPSY and GAMIT. This study will use the Bernese Software because there a license of software at Department of Survey Engineering, Faculty of Engineering, Chulalongkorn University. For the processing to estimate the TEC using Bernese 5.0 software and create the ionosphere modeling in the central part region, Thailand. Necessary information have to require for processing as section following.

3.3.1 Precise Orbit Data

To reduce the errors of the satellite orbit on a processing step, high resolution orbit data is required instead of using regular broadcast orbit data. The International GNSS Service [10], governed by the cooperation of over 200 organizations in 80 countries with more than 300 stations and included in Thailand, which GPS station installed at Department of Survey Engineering, Faculty of Engineering, Chulalongkorn University, can see permanent reference GPS stations Figure 3.4. There are records and correct the GPS data for calculating the high resolution satellite orbits. Which Precise Orbit Data have many formats such as Final, Rapid and Ultra Rapid. This data can be downloaded from the website of the Center for Orbit Determination in Europe (CODE) at ftp://ftp.unibe.ch/aiub/CODE/ or the website of IGS. The example of orbit data on 1 July 2012 is shown in Figure 3.5. This research uses the satellite orbit data in Final format which is the highest resolution data.

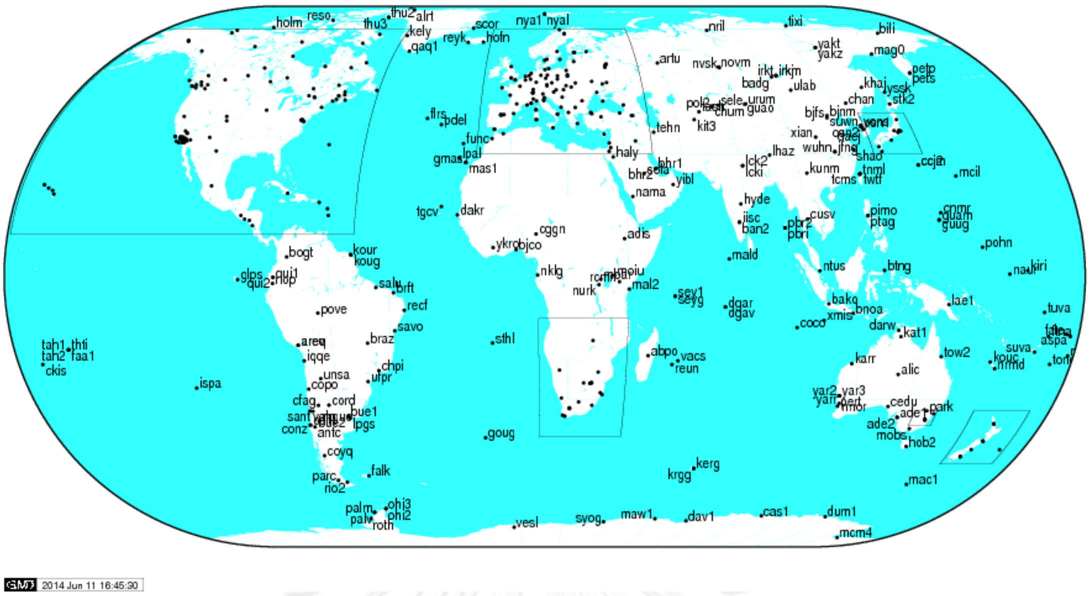

Figure 3.4 Location permanent reference stations of IGS network stations around the world. Source http://igs.org.

```
/* Center for Orbit Determination in Europe (CODE)
/* Final GNSS orbits and GPS clocks for year-day 12183
/* Note: Middle day of a 3-day arc GPS/GLONASS solution
/* PCV:IGS08      OL/AL:FES2004  NONE     YN ORB:CoN CLK:CoN
*  2012  7  1  0  0  0.00000000
PG01  15362.512717  -1451.437359  21613.291303    263.662045
PG02 -13671.598350 -21064.983224  -9255.131677    395.371188
PG03  21782.731693  10832.910295 -11450.247500     69.357481
PG04  -6071.682906 -25591.656469   1871.336137    230.226062
PG05 -12636.091634  -9055.970029 -21560.261953   -330.397279
PG06  18267.973203  13612.015553 -13788.209597     12.546828
PG07   9428.359083 -15316.548315 -19428.352746     95.856292
PG08   1586.506694 -24461.242337  -9369.838437      1.623773
PG09 -15490.613516  -3751.443455  20678.397825    168.697733
PG10   3462.381237 -20461.547933 -16600.241915    -43.189968
PG11  19391.016021   4315.237752  17373.174511   -277.081244
PG12 -20995.202676   7265.743236  14395.340879     77.445523
```

Figure 3.5 Show an example for a precise orbit file in an .EPH format on 1 July 2012.

3.3.2 Data correction

Many datasets are needed for data correction process they are Differential code biases (.DCB) information, the Troposphere data (.TRO), Satellite clock information (.CLK). These can be downloaded at http://www.aiub.unibe.ch/download/CODE/ see Figure 3.6. The Earth orientation parameters data (.ERP) can be downloaded at ftp://ftp.unibe.ch/aiub/BSWUSER50/ORB/. The satellite information file (e.g SATELLIT.I05), The information receiver (RECEIVER.), The nutation and subdaily pole model files are describing the rotation of the Earth and the subdaily tidal variation of pole, several gravity field and The Information antenna phase file can be downloaded ftp://ftp.unibe.ch/aiub/BSWUSER50/GEN/.

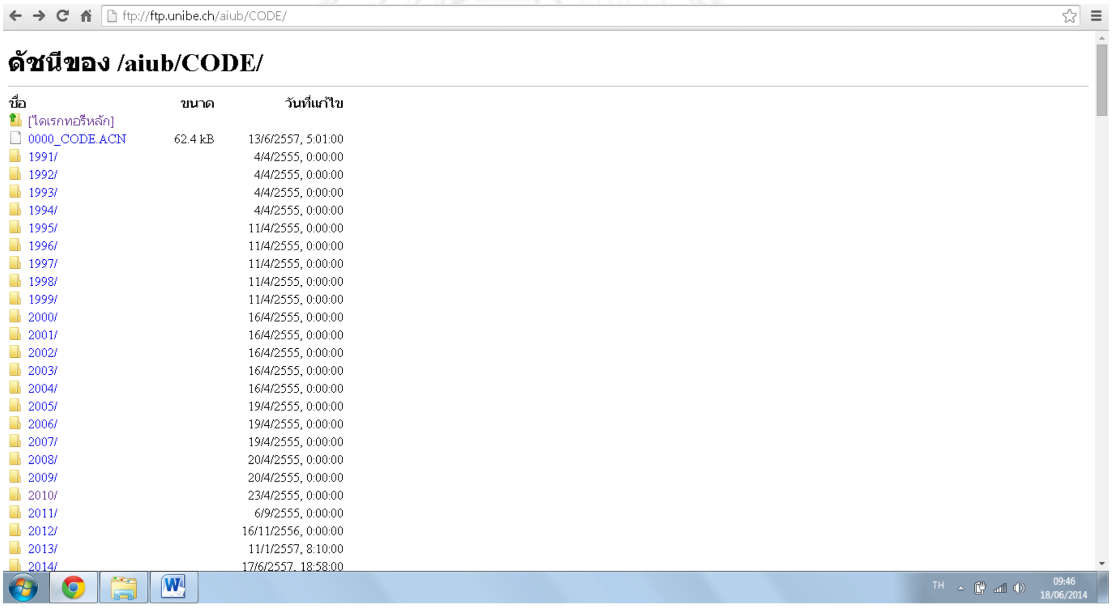

Figure 3.6 Shown website of center for Orbit Determination in Europe (CODE) to download information.

CHAPTER IV

METHODOLOGY

The methodology studies the variability of TEC in Thailand, during January 2009 to December 2012, using GPS data over Thailand. The study methods can be divided into two parts according purposes. The first part is an analysis daily, monthly, seasonal and annual variation of TEC in Thailand. In the second part is estimate TEC value from ionosphere modeling using Bernese 5.0 software to compare TEC from Global Ionosphere Map. The both processes can be described in this chapter.

4.1 Methodology the daily, monthly, seasonal and annual variations of the electrons as in Thailand during January 2009 to December 2012

This study will characterize the variability of Ionosphere irregularities by calculating the rate of change of Total Electron Content index (ROTI) daily. Using GPS data collected from GPS stations around the country. In the research process will use processing from multiple software could explain the process and the result, see Figure 4.1.

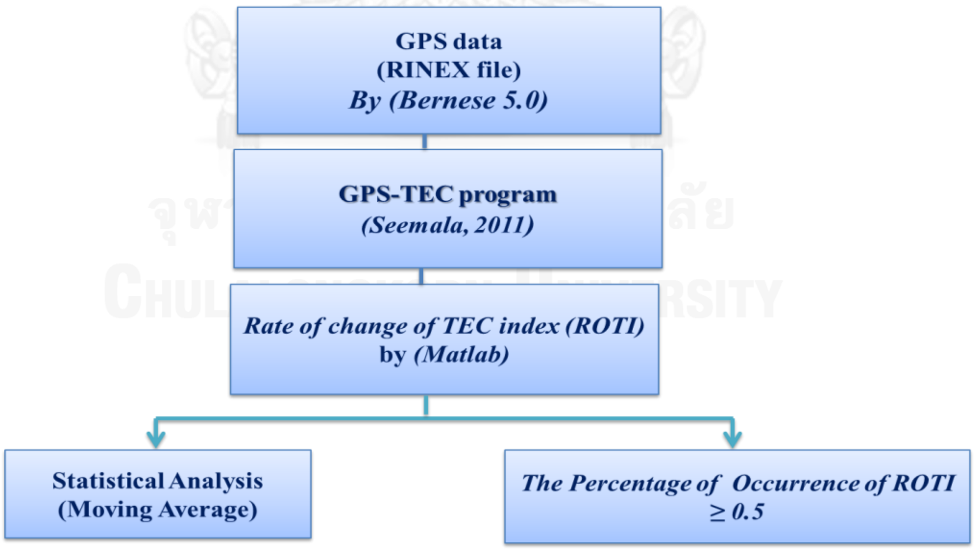

Figure 4.1 Show flowchart diagram calculated ROTI value.

4.1.1 GPS data preparation

This research used GPS data in RINEX format (Receiver - INdependent EXchange format). The RINEX version 3.00 consists of three ASCII file types: 1) Observation data file 2) Navigation message file and 3) Meteorological data file. This study used Observation data file. Which a file also contains data from one station and one session only. The file consists of a header section, containing all auxiliary information on the station [33] can see detail in Figure 4.2. By The file naming is as follows:

CCCCdddf.yyO

where CCCC is a four character station code such as CHMA is Chiang Mai station.

ddd is the day of year.

f is a file sequence number collected during the same day such as A-X are a file 24 hours.

yy is the year.

O is the label for observation files.

All stations collected GPS data every hour as hourly files, and all the hourly files must be assembled to daily files. However, GPS data stored in Thailand, according to local time (LT). It is necessary to convert files from local time to Universal Time (LT = UT + 7) for processing in GPS-TEC program and compared to the GIM data. MyRename program used to change all file names in the same format. Then the CCRINEXO function of Bernese software used to assemble hourly RINEX files as daily files see Figure 4.2. For the arrangement files from Local time into Universal time and merge them into daily file, this is done a total of 22 stations and totaling 24,543 days. Except the data of CUSV station, it can be used the data by download at http://sopac.ucsd.edu/dataArchive/ see Figure 4.3 show website the GPS data of script orbit permanent array center (SOPAC) data archive.

```
     2          OBSERVATION DATA    G (GPS)             RINEX VERSION / TYPE
CCRINEXO V2.4.1 LH  YING            02-NOV-13 12:04     PGM / RUN BY / DATE
CUT for daily                                           COMMENT
SPIDER V2,1,0,2270                      2009 01 0  01:1    COMMENT
BIT 2 OF LLI FLAGS DATA COLLECTED UNDER A/S CONDITION      COMMENT
SNR IS MAPPED TO RINEX SNR FLAG VALUE [2-9]             COMMENT
L1&L2:  = 25DBHZ -> 1; 26-27DBHZ -> 2; 28-31DBHZ -> 3     COMMENT
      32-35DBHZ -> 4; 36-38DBHZ -> 5; 39-41DBHZ -> 6      COMMENT
      42-44DBHZ -> 7; 45-48DBHZ -> 8; >=49DBHZ -> 9       COMMENT
CHIANG MAI                                                MARKER NAME
CHMA                                                      MARKER NUMBER
JAKKARIN            JAKKARIN                              OBSERVER / AGENCY
462962              LEICA GRX1200PRO    4.03/2.122        REC # / TYPE / VERS
103352              LEIAT504        NONE                  ANT # / TYPE
  -941627.0325  5965073.5632  2046364.2815                APPROX POSITION XYZ
        0.0000        0.0000        0.0000                ANTENNA: DELTA H/E/N
     1     1                                              WAVELENGTH FACT L1/2
     4    C1    L1    P2    L2                            # / TYPES OF OBSERV
    30                                                    INTERVAL
  2009     1     2     0     0    0.000000                TIME OF FIRST OBS
                                                          END OF HEADER
 09  1  2  0  0  0.0000000  1 10 07 08 11 13 17 19 23 25 27 28
  20268314.261   106510714.393 9  20268313.149   82995386.92849
  22235360.884   116847605.849 8  22235360.012   91050092.28746
  20535939.564   107917087.693 9  20535938.178   84091228.52448
  22428167.851   117860810.425 8  22428166.501   91839592.75346
  23636509.471   124210683.839 7  23636508.411   96787562.66046
  22468175.487   118071055.503 8  22468172.766   92003411.43847
```

Figure 4.2 RINEX files as daily files of CHAM station on 2nd January 2009

Figure 4.3 Show website the GPS data of the Scripps Orbit and Permanent Array Center (SOPAC) data archive.

4.1.2 Estimate the TEC using GPS-TEC Program

To estimate the TEC from GPS Observation file daily use GPS-TEC program 2.2 Versions, which the program was developed by [34]. The program used to study the variation of TEC several studies [35], see Figure 4.4 shows GPS-TEC program. In the processing of the program need to connect internet always, due to the program need to import data such as a RINEX navigation file, the differential code bias (DCB) files automatically to calculate elevation and azimuth angles of the satellites which are required for vertical TEC calculation. The results are ASCII files (.CMN file) see Figure 4.5 shows detail on 1 January 2012 of CUSV station. The first row of data is station name and country name, second row is latitude and longitude information, the third row is miscellaneous data described in Table 4.1.

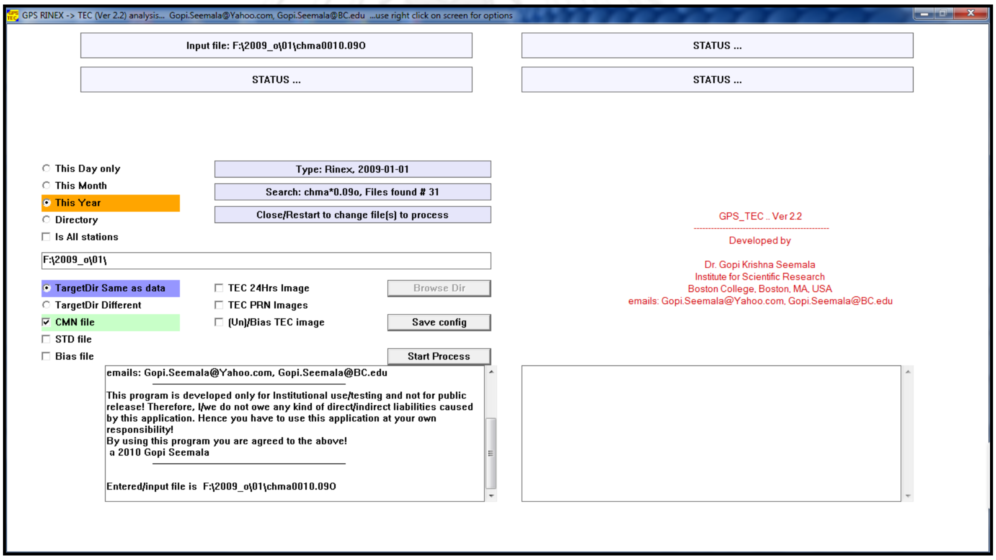

Figure 4.4 Show GPS -TEC program

```
kusv,    Thailand
13.73591         100.53391        76.05997
Jdatet           Time     PRN     Az      Ele     Lat     Lon     Stec    Vtec    S4
2454832.611111   2.66667  2       221.23  7.86    4.42    92.47   31.77   17.29   -99.00
2454832.611458   2.67500  2       221.32  8.03    4.52    92.53   31.84   17.35   -99.00
2454832.611806   2.68333  2       221.41  8.20    4.61    92.58   31.87   17.39   -99.00
2454832.612153   2.69167  2       221.51  8.37    4.70    92.63   31.92   17.45   -99.00
2454832.612500   2.70000  2       221.60  8.54    4.79    92.68   31.98   17.50   -99.00
2454832.612847   2.70833  2       221.70  8.71    4.88    92.73   32.03   17.55   -99.00
2454832.613194   2.71667  2       221.80  8.88    4.97    92.79   32.08   17.61   0.41
2454832.613542   2.72500  2       221.89  9.05    5.06    92.83   32.22   17.70   -99.00
2454832.613889   2.73333  2       221.99  9.22    5.14    92.88   32.39   17.80   -99.00
2454832.614236   2.74167  2       222.09  9.39    5.23    92.93   32.39   17.83   -99.00
2454832.614583   2.75000  2       222.19  9.56    5.31    92.98   32.47   17.90   -99.00
2454832.614931   2.75833  2       222.29  9.74    5.40    93.03   32.56   17.97   -99.00
2454832.615278   2.76667  2       222.39  9.91    5.48    93.07   32.71   18.07   -99.00
2454832.615625   2.77500  2       222.49  10.08   5.56    93.12   32.74   18.12   -99.00
2454832.615972   2.78333  2       222.60  10.24   5.64    93.17   32.77   18.17   -99.00
2454832.616319   2.79167  2       222.70  10.41   5.72    93.21   32.88   18.26   -99.00
2454832.616667   2.80000  2       222.81  10.58   5.80    93.25   32.90   18.31   0.12
2454832.617014   2.80833  2       222.91  10.75   5.88    93.30   32.95   18.37   -99.00
2454832.617361   2.81667  2       223.02  10.92   5.96    93.34   32.97   18.42   -99.00
2454832.617708   2.82500  2       223.12  11.09   6.04    93.38   32.96   18.46   -99.00
2454832.618056   2.83333  2       223.23  11.26   6.11    93.43   33.01   18.52   -99.00
2454832.618403   2.84167  2       223.34  11.43   6.19    93.47   32.93   18.54   -99.00
2454832.618750   2.85000  2       223.45  11.60   6.26    93.51   33.00   18.62   -99.00
2454832.619097   2.85833  2       223.56  11.77   6.33    93.55   32.94   18.64   -99.00
2454832.619444   2.86667  2       223.67  11.94   6.41    93.59   32.88   18.66   -99.00
2454832.619792   2.87500  2       223.78  12.10   6.48    93.63   32.88   18.71   -99.00
2454832.620139   2.88333  2       223.89  12.27   6.55    93.67   32.87   18.75   0.12
2454832.620486   2.89167  2       224.01  12.44   6.62    93.71   32.82   18.78   -99.00
2454832.620833   2.90000  2       224.12  12.61   6.69    93.75   32.79   18.82   -99.00
```

Figure 4.5 Show the TEC processed by GPS-TEC program

Table 4.1 Short description of data columns [34].

Name	Description
Jdatet	Julian date with fraction of day as time (next column [time in UT] may be preferred to Julian date as it is easier to interpret)
Time	time in UT (it is in decimals, means hrs + minutes/60 + Secs/3600, to convert back take integer as hours and multiply the fraction part with 60 & 3600 to get minutes & seconds respectively)
Az	Azimuth of the satellite in degrees.
Ele	Elevation of the satellite in degrees.
Lat, Lon	Sub-ionosphere pierces point latitude & longitude at 350 Km altitude.
Stec, Vtec	Slant and vertical TEC values respectively.
S4	S4 index where available

4.1.3 Analysis Rate of Change of Total Electron Content Index (ROTI)

TEC data received from GPS-TEC program will calculate the ROTI using Matlab software, based on the standard deviation of ROT over a period of 5 minutes. To indicate the variation of the electron density that the ionosphere irregularities of each day. The details of the equation described in Section 2.3.2. In this procedure consists of code files important for the data conversion. The Code files needed to convert the data consists of:

- **doy2date.m** codes file, to convert day of the year to date. This file can download from http://www.mathworks.com/
- **days2hms.m** codes file, to convert days to hours, minutes and seconds. This file can download from http://home.online.no/
- **jd2date.m** codes file, to convert a Julian date to a Gregorian date. This file can download from http://www.mathworks.com/
- **ROTI.m** codes file, to calculate the ROTI which was developed by [36] to show atmospheric conditions of the ionosphere on disturbance day or quiet day.

After processing, the rate of change of TEC index value is shown in Figure 4.6 duration time of disturbance in ionosphere on 4 April 2012, 19:00-01:00 UT and in Figure 4.7 shown quiet day on 13 April 2012. In this calculation must calculate the ROTI every day, according to the data collected total 25,952 day from 23 station cover Thailand.

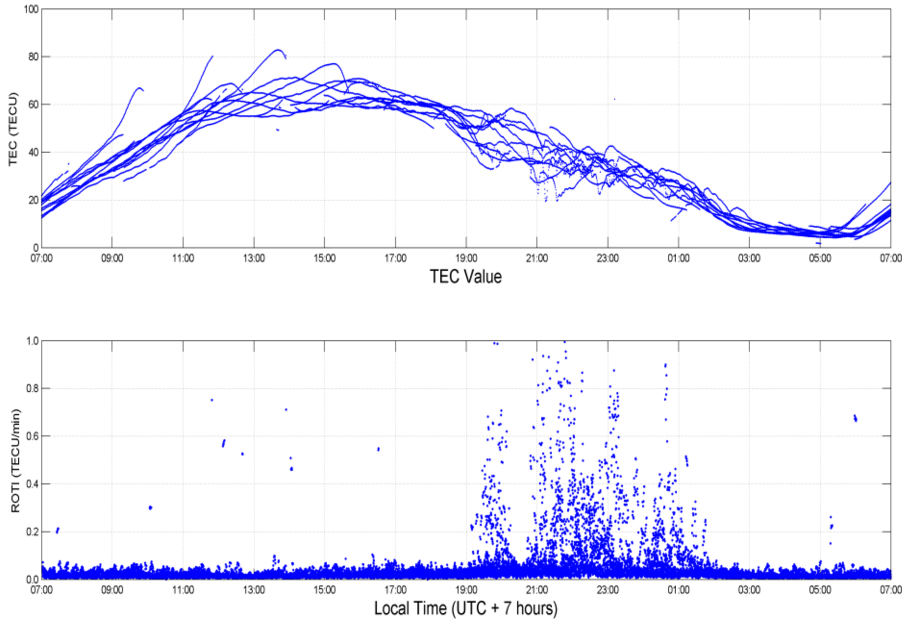

Figure 4.6 Shows ionosphere irregularities day on 04 April 2012

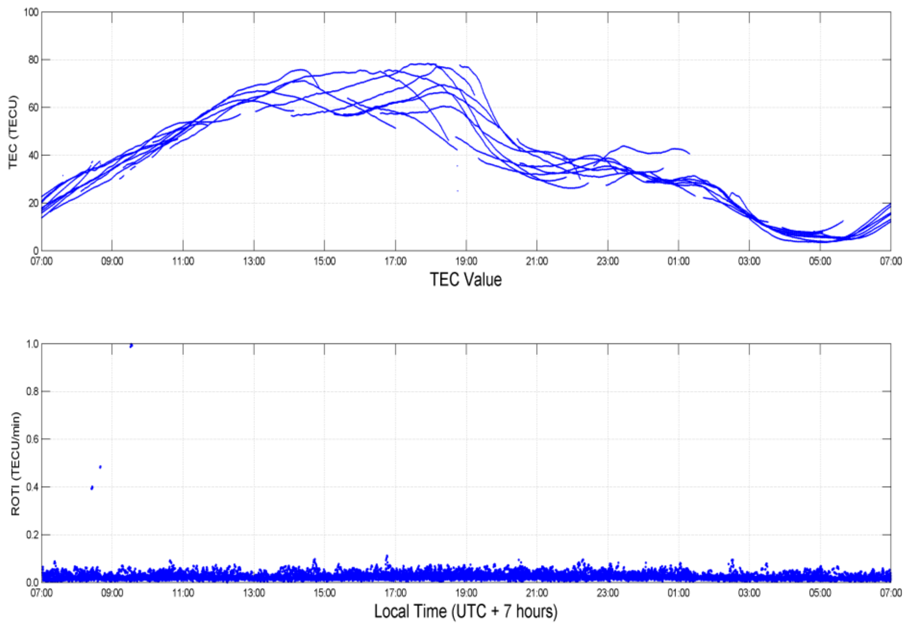

Figure 4.7 Shows ionosphere quiet day on 13 April 2012

The results of the data has a lot of this is calculated statistically by using moving average or sometimes called Multiply-and-Accumulate (MAC). Moving Average is a filter that simple, applications quickly and provides better results. The obtained results are filtered using raw data, through the simple and uncomplicated. This filtering method can also be modified to the results most obvious. Especially if want to forecast result the future. This filter works using the received data (input data - x_i) of not less than one. To calculate results (output - y_i), show the relationship of the equation (4.1)

$$y_i = \sum_{j=0}^{n} C_i x_{i-j} \tag{4.1}$$

where n is the number of data

C_i is a constant called Coefficient, which determines the behavior of this filter.

In addition, this research will analyze scale-size of ionosphere irregularities on F - region using the ROTI value from 23 stations in Thailand during January 2009 to December 2012. The enhancement of ROTI ≥ 0.5 is causing ionosphere irregularities of a few kilometers and 400 meters, determined by [28]. Several the research used analyze by calculating the rate of occurrence of ROTI ≥ 0.5 in each month and presented the result in percentage unit [4-6]. The results of statistical analysis and ROTI will be shown in next chapter.

4.2 Methodology the TEC estimate from ionospheric model using Bernese 5.0 software

The process of calculating TEC value using GPS data is rather complex. This section describes the various steps which contain the following: the preparation of orbit data, global ionospheric map, Earth orientation parameter / pole information and other necessary data. All of these data have to convert to Bernese format.

For started used the Bernese 5.0 software for GPS processing. It will need to create a campaign to serve for data store when processing of each stage. Inside a campaign will consisted nine folders for storing data of the processing. These folders can store be IGS products file or general Bernese files such as antenna phase center file, IERS pole files, troposphere and orbit, see Figure 4.8. In any create a campaign and detail of folder to that explain to them and detail can see Appendix B.

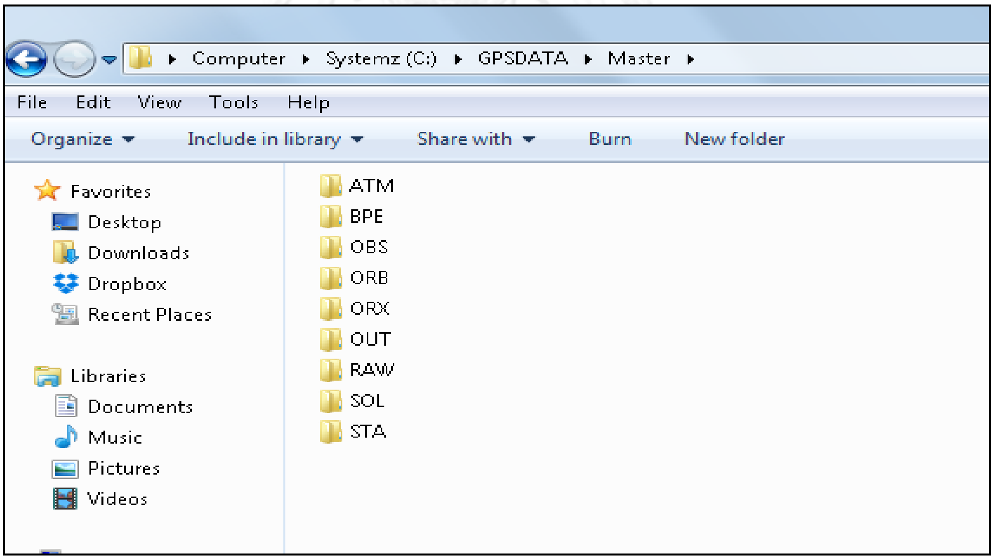

Figure 4.8 Show folders in a campaign

4.2.1 Data Preparation

4.2.1.1 Precise Orbit data

This study used Final Orbital data, a daily format, which can be downloaded from ftp://ftp.unibe.ch/aiub/CODE/. The data is formatted in the extension EPH format and need to convert to the extension PRE format by using MyRename program. Then, the data is stored in the folder C:\GPSDATA\XXXX\ORB which XXXX is a campaign name in the Bernese 5.0 software.

4.2.1.2 Earth Orientation Parameter / Pole Data

This data is a yearly format in the extension ERP format (C04_2012.ERP; 2012 means year) which can be downloaded from ftp://ftp.unibe.ch/aiub/BSWUSER50/ORB/ . Then, the data is stored in the folder C:\GPSDATA\XXXX\ORB which XXXX is a campaign name in the Bernese 5.0 software.

4.2.1.3 Satellite Clock Information Data

This data is a daily format in the extension CLK format (CODE16002.CLK; 1600 means GPS Week and 2 means the number of days of the week.) which can be downloaded from ftp://ftp.unibe.ch/aiub/CODE/. Then, the data is stored in the folder C:\GPSDATA\XXXX\ORB which XXXX is a campaign name in the Bernese 5.0 software.

4.2.1.4 The differential code biases Data

This data is a month format in the extension DCB format (P1P21009.DCB; 10 means year and 09 mean months) which can be downloaded from ftp://ftp.unibe.ch/aiub/CODE/. Then, the data is stored in the folder C:\GPSDATA\XXXX\ORB which XXXX is a campaign name in Bernese software.

4.2.1.5 General Files

Bernese 5.0 is complex processing software usefully for many researches. The general files are important for processing such as Earth orientation parameter / pole Information data, phase center variation data, ocean loading data which will be stored in the GEN directory under Bernese 5.0. Table 3.3 shows the list of general files for Bernese 5.0.

Table 4.2 Show the list of general files for Bernese 5.0

File name	Content	Modification	Download
CONST.	All constants used in the Bernese GPS software	No	Aiub*
DATUM.	Definition of geodetic datum	Introducing new reference ellipsoid	Aiub*
RECEIVER.	Receiver information	Introducing new receiver type	Aiub*
PHAS_COD.I01 PHAS_COD.I05	Phase centre Eccentricities and variations	Elevation-dependent	Aiub*
SATELLITE.I01 SATELLITE.I05	Satellite information file	New launched satellite	Aiub*
SAT_yyyy.CRX	Satellite Problems	Satellite manoeuvres, bad data	Aiub*
GPSUTC.	Leap seconds	When a new lead second is announced by the IERS	Aiub*
IAU2000.NUT	Nutation model coefficients	No	Aiub*
IERS2000.SUB	Subdaily pole model	No	Aiub*
POLPFF.	Pole offset coefficients	Introducing new values from IERS annual report	Aiub*
JGM3.	Earth potential coefficients	No	Aiub*
DE200.EPH	Planetary and Lunar ephemerides.	No	JPL**
_____ .BLQ	Ocean tides model coefficients	New Stations	OSO***

Aiub* (ftp://ftp.unibe.ch/aiub/BSWUSER50/GEN/)
JPL** (http://www.jpl.nasa.gov)
OSO*** (http://holt.oso.chalmers.se/loading/)

4.2.1.6 Troposphere and Ionosphere Data

Both troposphere and ionosphere data are a daily format, but different extension. Troposphere and ionosphere are formatted in the extension TRO format and .ION format, respectively. These data can be downloaded from ftp://ftp.unibe.ch/aiub/CODE/. Then, the data are stored in the folder C:\GPSDATA\XXXX\ATM which XXXX is a campaign name in the Bernese 5.0 software.

4.2.2 The Process of Converting Data to the Bernese 5.0 Format

For all processing is shown in Figure 4.9. This process aims to convert data from many formats to a Bernese format that used in the next process.

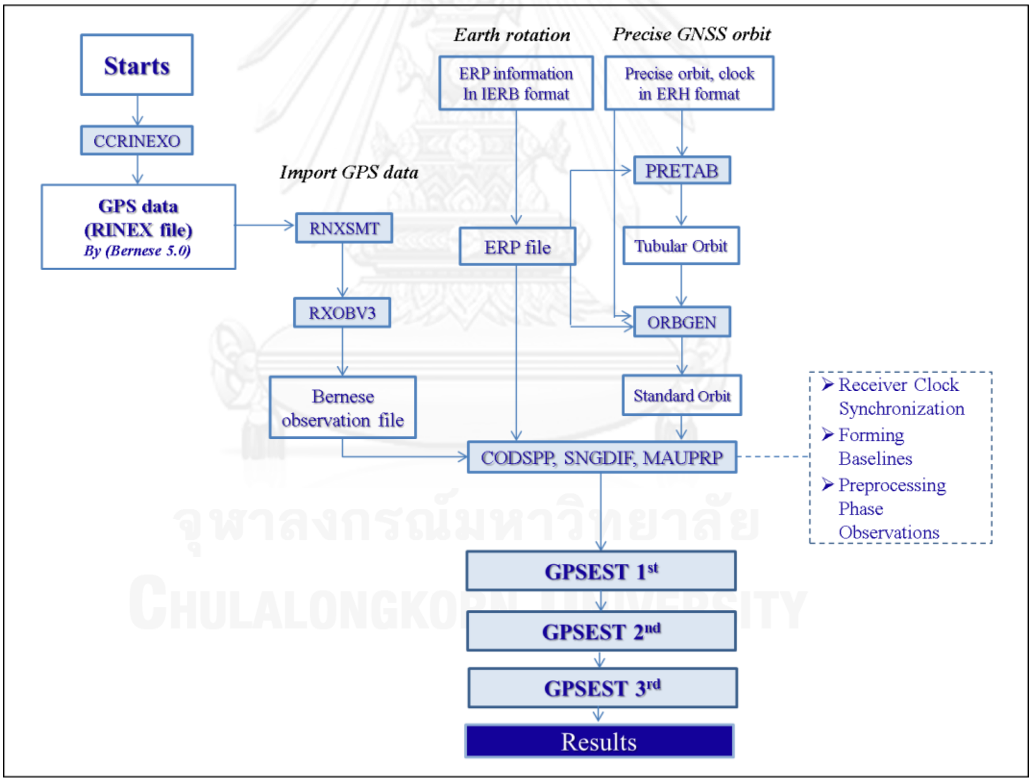

Figure 4.9 Flowchart diagram of Bernese method, figure adapted from Bernese software version 5.0 manual [33].

- **RNXSMT**: The original RINEX observation files are being made a smoothed RINEX observation files through this module. To eliminate the error of initial information from RINEX files to smooth the data [33]. The results are the extension SMT file stored in the folder C:\GPSDATA\XXXX\RAW which XXXX is a campaign name in the Bernese 5.0 software, can see in Appendix B.

- **RXOBV3**: This is an import RINEX files or smooth data from RNXSMT (. SMT files) to be convert to Bernese binary format. To eliminate data with a low signal-to-noise ratio, Cycle slip [33]. The results are Code/SLR (Satellite Laser Ranging) range header, Code/SLR range observations, Phase header and Phase observations or the extension CZH, .CZO, .PZH and .PZO, respectively. These are store in the folder C:\GPSDATA\XXXX\RAW which XXXX is a campaign name in Bernese software, can see in Appendix B.

- **PRETAB**: This is generating the intermediate tabular orbit files by transformation Earth orientation parameter form a pole file together with precise orbit data file, the nutation and subdaily earth rotation information to generate a standard orbit next [33]. The results are the extension TAB and the extension CLK format in the folder C:\GPSDATA\XXXX\ORB which XXXX is a campaign name in Bernese software can see in Appendix B.

- **ORBGEN**: To create a satellite orbit is based on tabular orbit files (.TAB) from modules previously together with a pole file, also evaluated together with the modern gravity models and planet ephemeris for the gravitational attraction of Sun, Moon and major planet, the nutation and subdaily earth rotation information, tidal ocean loading data [33]. The results are the extension STD format in the folder C:\GPSDATA\XXXX\ORB which XXXX is a campaign name in Bernese software, can see in Appendix B.

4.2.3 Data preparation

These processing programs do check and prepare the data such as to eliminate the error cycle slip, Muti-Path propagation wave and other for the main estimation program. The programs are included:

- **CODSPP:** this method is computes the corrections for synchronizing the receiver clocks with respect to GPS time by used only code observations file (.CZH). The program may be used to screen code data or smooth code. Code observations files is calculated for each observation of an epoch in conjunction with the satellite orbits, satellite clocks, pole file, code bias input file and the a priori position of the station [33].

- **SNGDIF:** To create Baselines from zero – difference observation files (.PZH). While the program generating baseline files, it eliminate eccentric observations and keeps the phase ambiguities from the zero-difference observation files. This research has the STAR strategy the baselines are built by connecting one reference station with all remaining stations.

- **MAUPP:** Using to detect and resolve cycle slips for the phase observations can be identified more reliably.

- **GPSEST:** to improved preliminary to find to Root Mean Square (RMS) value. In this process is used to process the data using an equation Ionosphere free linear combination L3 Float solution. This will reduce the ionospheric refraction effects.

4.2.4 Ambiguity Resolution

Ambiguity resolution is an integer of wavelet transmitted from a satellite to receivers, when the receivers lock on GPS signal. In the process of solving the equations of satellite GPS surveying, it needs to find the ambiguity number as a float number, and then find the integer (ambiguity resolution) again. This process uses GPSEST module under Bernese software. GPSEST uses L1 + L2 waves to find ambiguity resolution as an integer, which this research uses a method of QIF (Quasi Ionosphere-Free), due to have very long the baseline and use of deterministic ionosphere models.

4.2.5 The Final Solution for the Total Electrons Content in the Ionosphere.

The ambiguity resolution will be utilized for the final solution by GPSEST module using geometry free linear combination (L_4). This process has input file the differential code biases, standard orbit, Earth orientation parameter, Troposphere estimate, Ionosphere Model. In addition, Spherical Harmonics Expansion model is used to calculate VTEC value at 15 degrees of Solar - Geomagnetic Reference Frame and the Price Wise Linear Function for the representation of time. The result is IONEX file (extensions are INX) are stored in the campaign ATM directory. This information is the VTEC data the spatial resolution of the grid at every hour starting at 0-1, 1-2, 2-3, UT. The grid point is TEC value on 0.1 degrees longitude and 0.1 degrees latitude, covering 100° – 102° Longitude, 13° – 15° Latitude.

```
  55    55    55    55    55
   17                                                                END OF TEC MAP
   18                                                                START OF TEC MAP
 2010      4      2     17      0      0                             EPOCH OF CURRENT MAP
   13.0 100.0 102.0   0.1 450.0                                      LAT/LON1/LON2/DLON/H
  39    39    39    39    39    39    39    40    40    40    40    40    41    41    41    41
  41    41    42    42    42
   13.1 100.0 102.0   0.1 450.0                                      LAT/LON1/LON2/DLON/H
  39    39    39    39    40    40    40    40    40    40    41    41    41    41    41    42
  42    42    42    42    42
   13.2 100.0 102.0   0.1 450.0                                      LAT/LON1/LON2/DLON/H
  39    40    40    40    40    40    40    41    41    41    41    41    41    42    42    42
  42    42    43    43    43
   13.3 100.0 102.0   0.1 450.0                                      LAT/LON1/LON2/DLON/H
  40    40    40    40    41    41    41    41    41    41    42    42    42    42    42    42
  43    43    43    43    43
   13.4 100.0 102.0   0.1 450.0                                      LAT/LON1/LON2/DLON/H
  40    41    41    41    41    41    41    42    42    42    42    42    42    43    43    43
  43    43    43    44    44
   13.5 100.0 102.0   0.1 450.0                                      LAT/LON1/LON2/DLON/H
  41    41    41    41    42    42    42    42    42    42    43    43    43    43    43    43
  44    44    44    44    44
   13.6 100.0 102.0   0.1 450.0                                      LAT/LON1/LON2/DLON/H
  41    42    42    42    42    42    42    43    43    43    43    43    43    44    44    44
  44    44    44    45    45
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Figure 4.10 Example of IONEX files on 3 April 2010 at 17:00 UT

CHAPTER V
RESULTS AND DISCUSSIONS

In this study, we obtained results in daily, monthly, seasonal and annual variability of TEC in Thailand between January 2009 and December 2012 as shown in the section 4.1. The ionosphere irregularities trends over Thailand are represented in the changing rate of TEC index (ROTI). The result of the statistical analysis can be divided into two types, that is, the moving average of 30-day data (Figure 5.1), and the enhancement percentage of ROTI in each month, season and year (Figure 5.2, 5.3 and 5.4, respectively). In addition, the result of occurrence analysis for each station spanning from year 2009 to 2012 are presented in Appendix A. In section 4.2, we describe the ionosphere model processed by the Bernese 5.0 software using data from the GPS network over central part of Thailand. The comparison of the TEC between TIM and GIM will be presented in Figure 5.10.

5.1 Daily, monthly, annual and seasonal variations of the TEC over Thailand between January 2009 and December 2012

5.1.1 Statistical results of the ROTI in Thailand between January 2009 and December 2012

In relation to Figure 5.1, it can be concluded that the rate of change of the TEC varies from day to day. The daily variations of ROTI for all stations are almost equal or less than 0.4, only a few stations is greater than 0.4. The changing rate of TEC gradually changed and rarely appeared the fluctuations in the ionosphere. However, there are some data which their values less than the average values in 2009 and 2010, when compared with 2011 and 2012. In addition, the daily data for a 4-yr period showed that the variation of TEC depends on season. It can be clearly seen that the rate of change TEC is increased every semiannual and they tend to increase year by year as shown in Figure 5.1. The legends of graph lines are sorted by provinces of the north region to the south region by segmenting the graph line on color tones: the North region (Red line group), the Northeast region (Green line group), the Central region (Blue and Purple line groups), the Southeast Region (Pink and Brown line groups) and the South (Yellow lines group). It is found that the data obtained from the station which shows significant fluctuation, that is UDON station in Udon Thani province (Green line), Accordingly, Udon Thani is located in Northeast area, and it is could be concluded that there are often fluctuations and irregularities within ionosphere in 2009 to 2010 as can be seen from the average of 30 days over this station, even it was during low solar activity.

The threshold was applied to average of ROTI to divide the irregularity level into 3 phase fluctuation levels based on Oladipo and Schüler [21]. Firstly, ROTI < 0.4 indicated no phase fluctuation activity. Secondly, $0.4 <$ ROTI < 0.8 represented phase fluctuation activity. Thirdly, ROTI > 0.8 suggest high or severe phase fluctuation activity. We found that the results showed the average of ROTI almost less than 0.4 in 2009 and 2010. It reveals that there are no phase fluctuation activities during that time. On the other hand, the average of ROTI in 2011 to 2012 is greater than 0.4. This is indicated that the phase fluctuation was active. Particularly, there are the average of ROTI ≤ 0.8 at UDON station was presented.

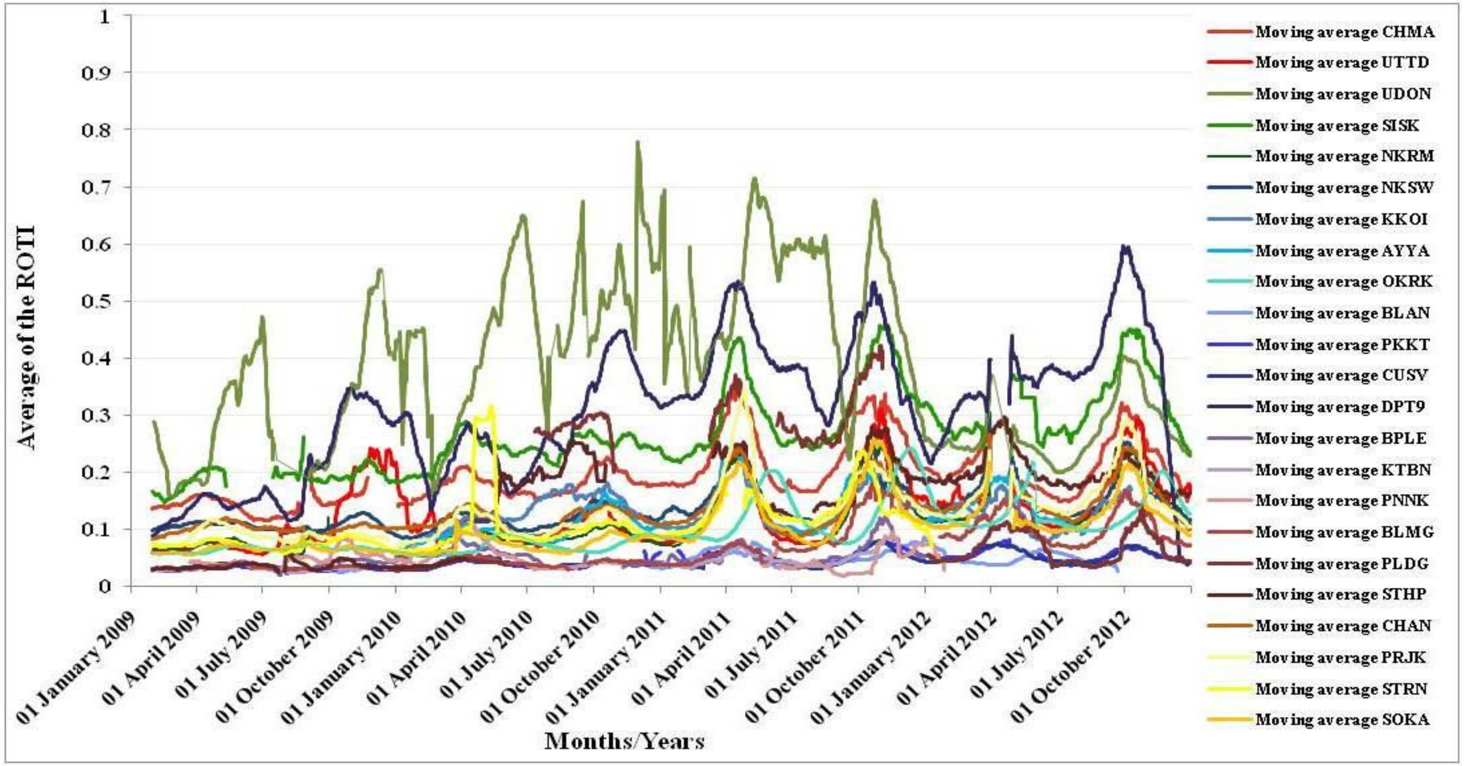

Figure 5.1 the 30-day moving averages of ROTI, the graph line has the sort as provinces from North region to South region

5.1.2 Annual and seasonal variations of occurrence of enhancement ROTI ≥ 0.5

The ROTI can be extended characteristic scale-size of ionosphere irregularities during the night time by calculating the rate of increasing of the ROTI ≥ 0.5 in percentage units. This value indicated the irregularities in the ionosphere layer a large scale particularly on the night time that causes the phase fluctuation and associated with the scintillation on the radio directly. The results in Figure 5.2 confirmed the rates of occurrence of the irregularities ionosphere as a large scale during night time in Thailand. The irregularities of the large scale varied on monthly basis and an enhancement of ROTI has increased in March and October. In addition, the trend of the irregularities has increased an activity during 2010 to 2012 as can in Figure 5.2. The figure shows in monthly comparison of each station by segmenting the graph line on color tones: North region (Red line group), Northeast region (Green line group), Central region (Blue and Purple line groups), Southeast Region (Pink and Brown line groups) and South (Yellow lines group), similar to Figure 5.1.

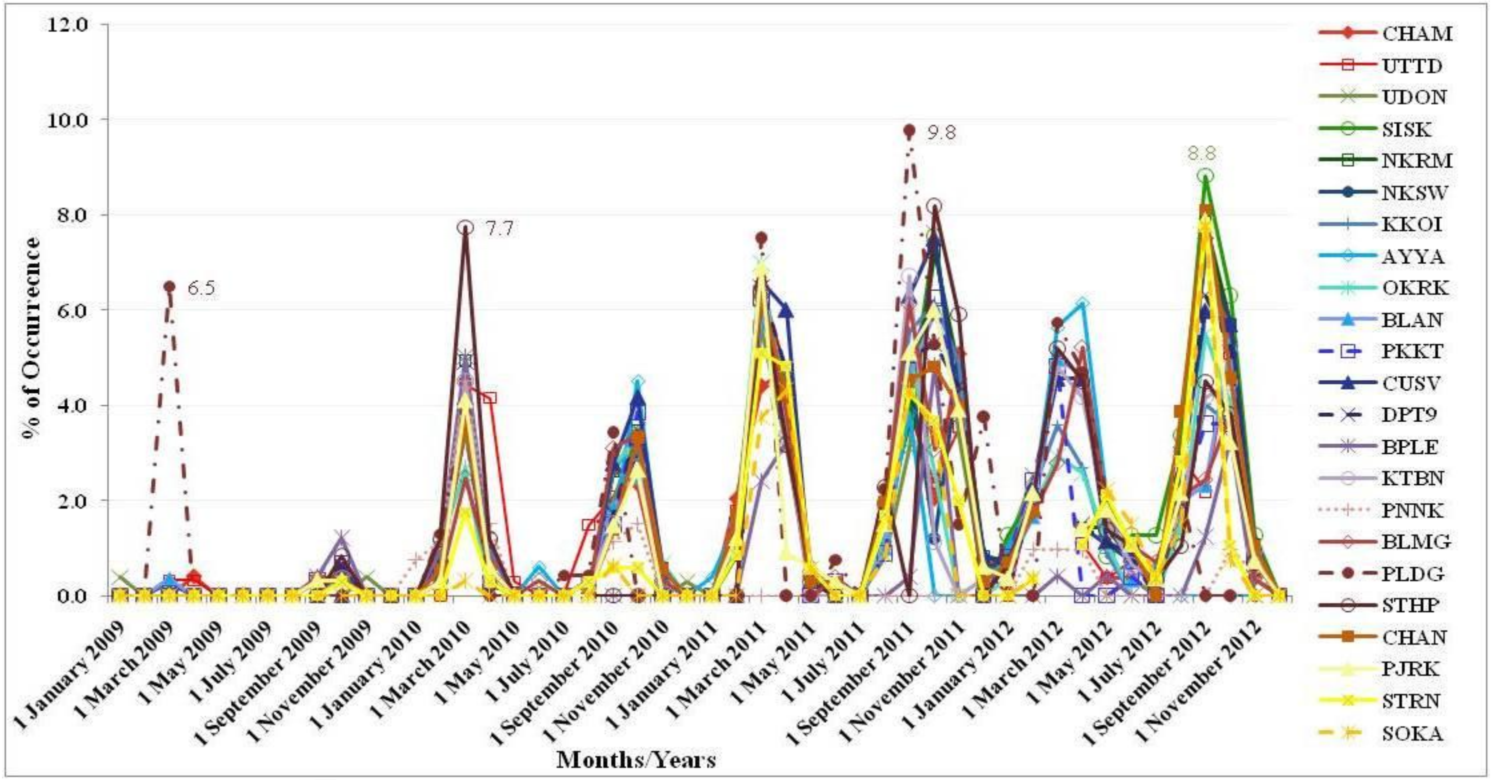

Figure 5.2 Rate of enhancement of the ROTI (ROTI ≥ 0.5) has monthly variation during 4 years.

To demonstrate the enhancement characteristic of the ROTI, the value greater than 0.5 depend on the season, the season variation will be divided into three seasons: Winter (January, February, November and December), Summer (May, June, July and August) and Equinox (March, April, September and October), as shown in Figure 5.3 - 5.6. The results confirm that the irregularities ionospheres in Thailand, during past four years were most increased during the equinox seasons, especially in 2011. The ionosphere irregularities reached a maximum at a rate of occurrence about 27% (green). While the summer and the winter seasons will be quite different in each year. From 2009 to 2011, it was found that the data approximated from 17-19 GPS stations have the rate of ionosphere irregularities in winter is higher than in summer, and a maximum value approximately 7.8% (blue). The results also showed a seasonal variation depending on the year. The rate of the ionosphere irregularities in summer is higher than the rate in winter during 2012.

The result confirmed that there is often a large scale ionosphere irregularities occurrence at the night time over Thailand, during equinox months: March, April, September and October. The high value of ROTI during the equinox months was probable induced by an energy from the sun. This is due to that fact that the sun light is perpendicular to the ground over Thailand and cause the optimum condition for the irregularity occurrence in the atmosphere. Moreover, a comparison of the large scale irregularities between summer and winter found that there is an influence on the irregularities of ionosphere over Thailand during both seasons as well.

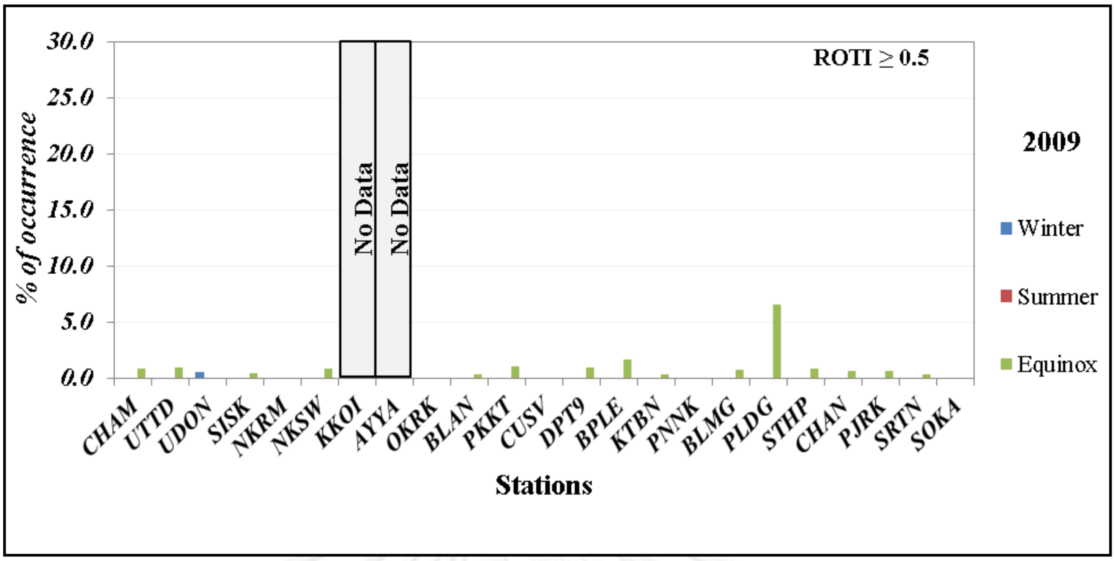

Figure 5.3 Rate of ROTI enhancement (ROTI ≥ 0.5) seasonal variation in 2009

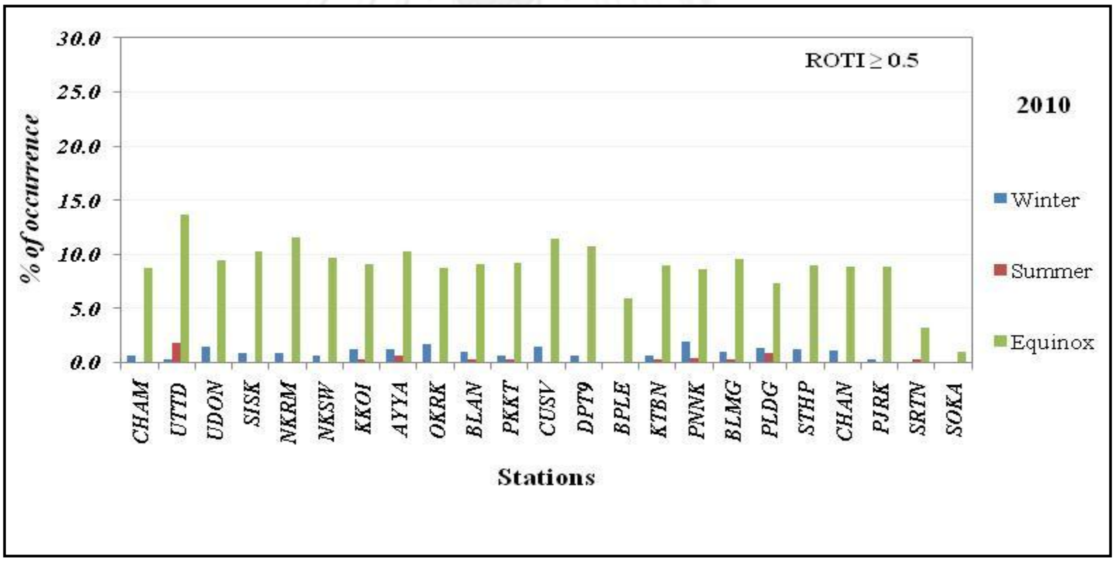

Figure 5.4 Rate of ROTI enhancement (ROTI ≥ 0.5) seasonal variation in 2010.

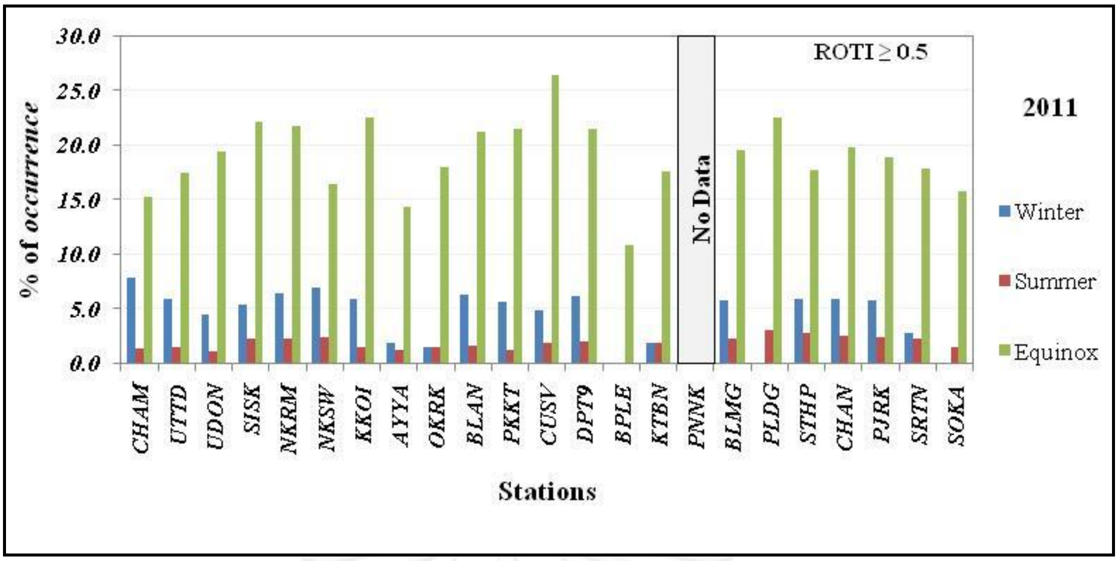

Figure 5.5 Rate of ROTI enhancement (ROTI ≥ 0.5) seasonal variation in 2011.

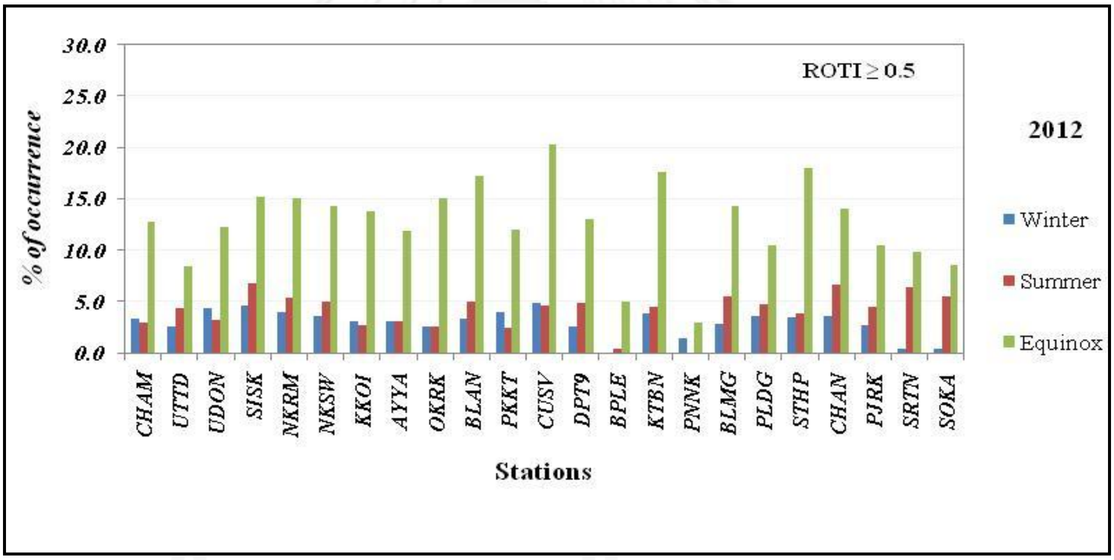

Figure 5.6 Rate of ROTI enhancement (ROTI ≥ 0.5) seasonal variation in 2012

The increase of the ROTI varies on the season while the intensity has changed tends to change each year. Results of all stations as shown in Figure 5.7, confirmed that the rate of occurrence reached a maximum value in 2011. Most of stations have the rate of occurrence over 25%. Our result was not agreed well with the predictions from NASA. The characteristic of annual variation can be used to demonstrate the increased rate of ROTI with a spatial distribution over Thailand during 2009 to 2012 as shown in Figures 5.8 to 5.11, respectively. In 2009, the spatial characteristic of each region has not significantly changed and the value is relative small. The map of year 2009 year is plotted in green color which the rate of occurrence is about 2-8%. The results also showed that all areas of Thailand in year 2009 were not affected by the ionosphere irregularities. In 2010, the spatial characteristic of the ROTI tends to show a significant change. It can be seen from the maps of the year 2010 that the color becomes yellow and the rate of occurrence is approximately 10-16%. The results confirmed that the upper part of Thailand has shown a higher rate of the ionosphere irregularities. Results showed that Prachuap Khiri Khan Province is an area that has an obvious activity of the atmosphere. It may be concluded that this area is prone to face the strong ionosphere irregularities. While the data during the past three years of the three stations from the southern provinces (Prachuap Khiri Khan (PJRK), Surat Thani (STRN) and Songkhla (SOKA)) demonstrate that the change of Surat Thani (STRN) and Songkhla (SOKA) is relatively small in comparison to the nationwide data. Similarly, the Prachuap Khiri Khan (PJRK) Province is considered as an observed point of changes as starting of the irregularities ionosphere an increase with latitude as well. In 2012, the occurrence rate was decreased from 2011, and the spatial variation can be clearly seen in the East and is relatively high such as Si Saket and Nakhon Ratchasima provinces. It was also found that the value for the southern past has decreased. While the central and southeastern regions tend to be shown a higher variation. However, a visibility of spatial can be implied that the severity of the ionosphere irregularities at a large scale was dependent on latitude positions.

The above mentioned result confirmed that variation of the TEC by calculating the ROTI in Thailand has a semiannual pattern and reached a maximum value in 2011. The study period was during solar cycle #24 which often faces the strong activity from the sun, such as sunspot number or solar flares that affect directly to the ionosphere condition. The results showed that the ROTI has a decreasing trend because solar activity was the calm down in 2012, which contradicts earlier predictions. The result confirmed that the variability of the ionosphere in Thailand has been influenced directly by the sun and the severity depends on latitude. However, the rate of ionosphere irregularities shows a large scale change especially during the equinox months. This phenomenon is usually appearing in the Northern hemisphere due to the balance of energy between the North and South hemisphere. It causes convection air (the meridional convection) from the summer season of the southern hemisphere into the winter season into the Northern hemisphere and also the high variability in the atmosphere the winter more than summer, [37]. The annual occurrence of ionosphere irregularities in Thailand is not very high because of this solar cycle #24 is regarded as relatively calm solar cycle as compared to the solar cycle #23 is quite different. The solar cycle #24 is regarded as the smallest cycle in 100 years [38].

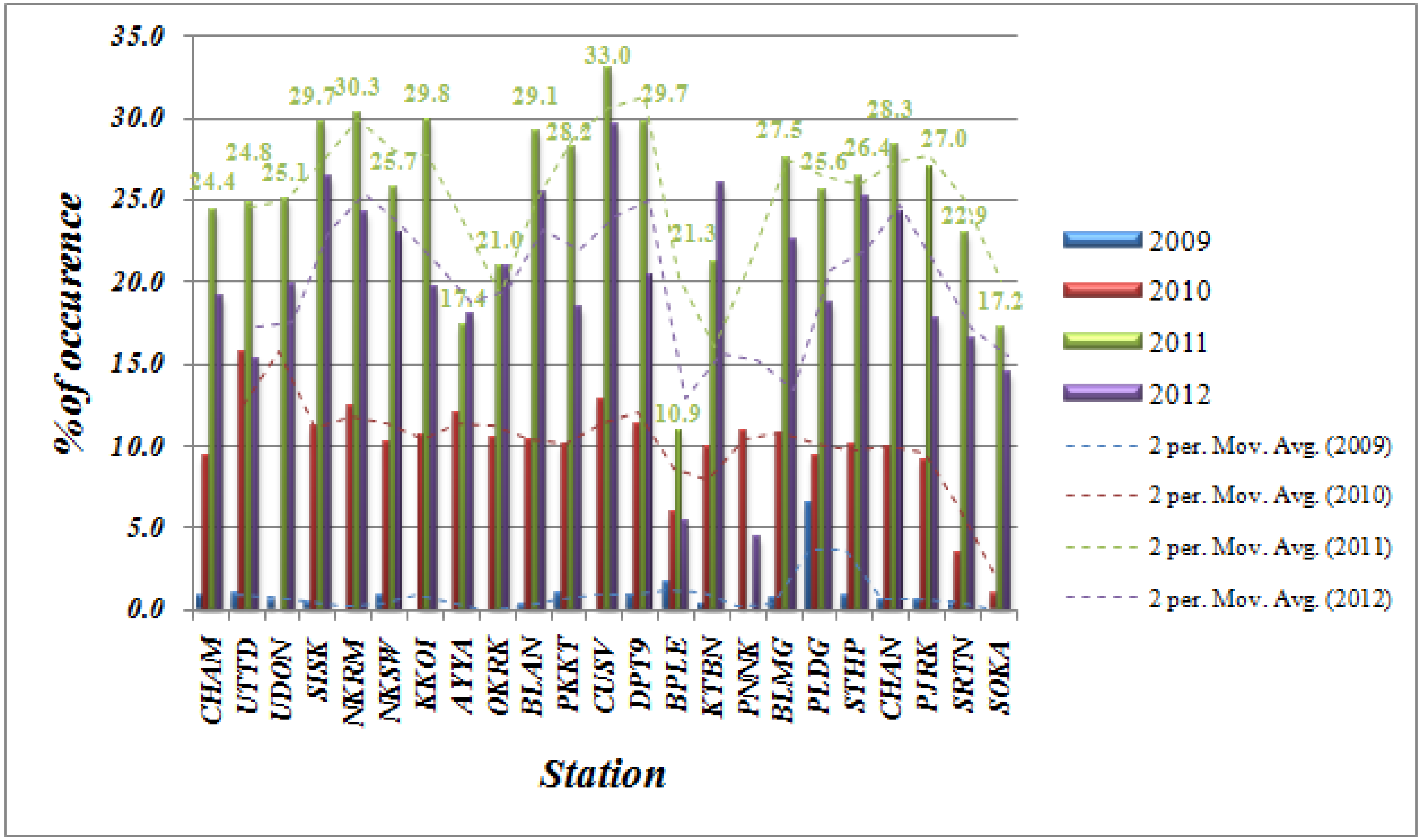

Figure 5.7 Show compare the rate of enhancement of the ROTI (ROTI ≥ 0.5) in 2009 to 2012.

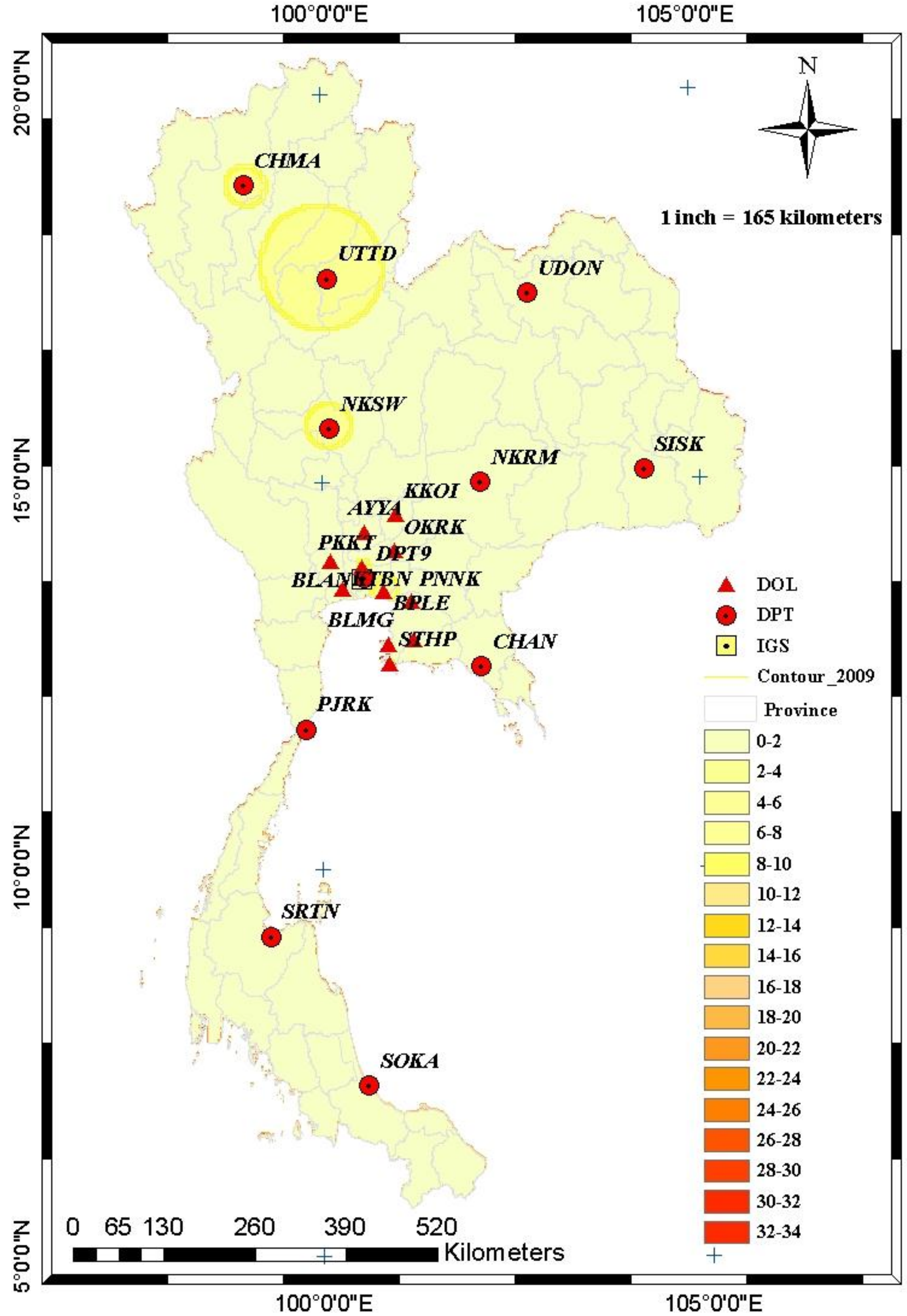

Figure 5.8 Show the enhancement of ROTI ≥ 0.5 maps at latitude of stations in 2009

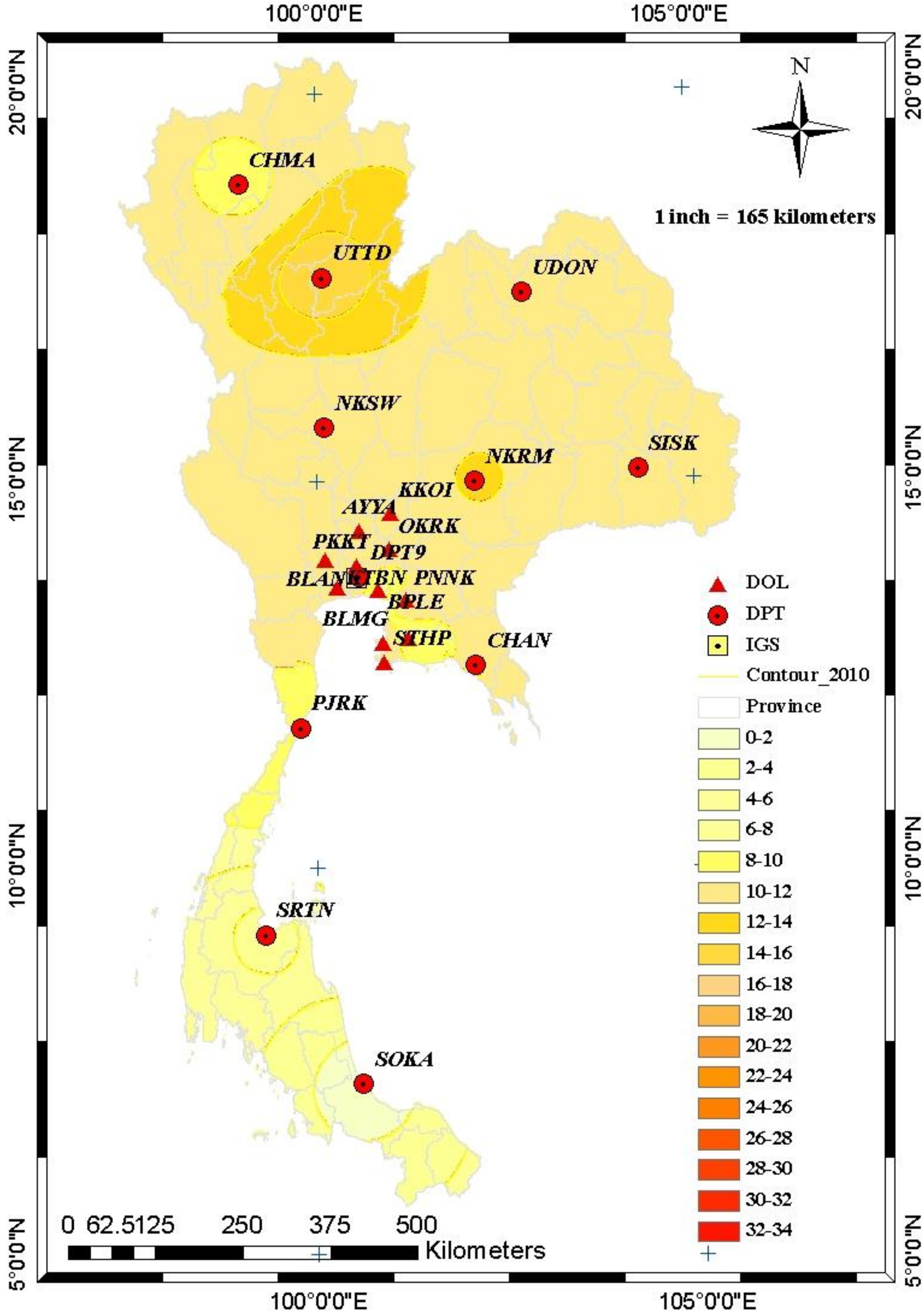

Figure 5.9 Show the enhancement of ROTI ≥ 0.5 maps at latitude of stations in 2010

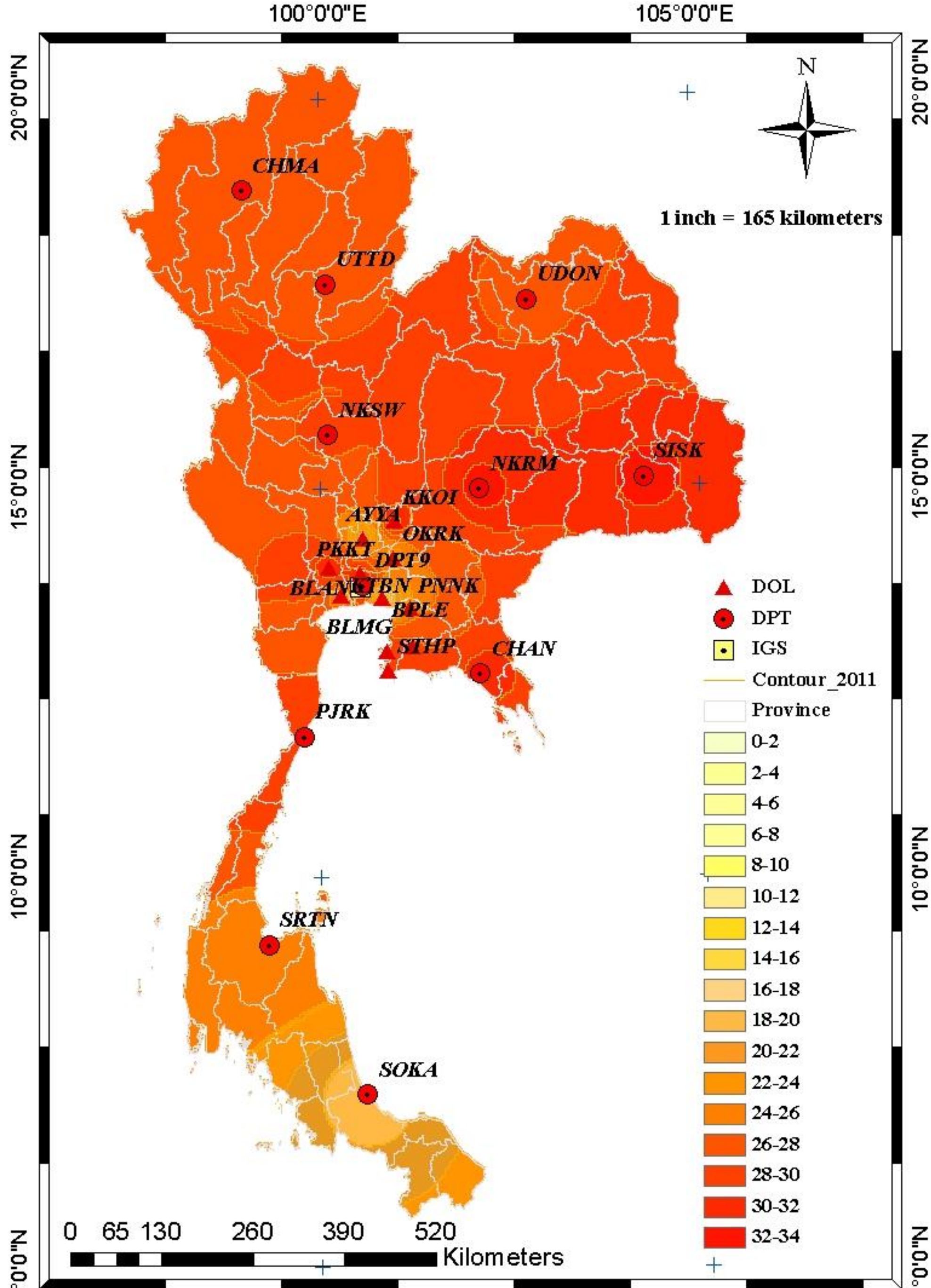

Figure 5.10 Show the enhancement of ROTI ≥ 0.5 maps at latitude of stations in 2011

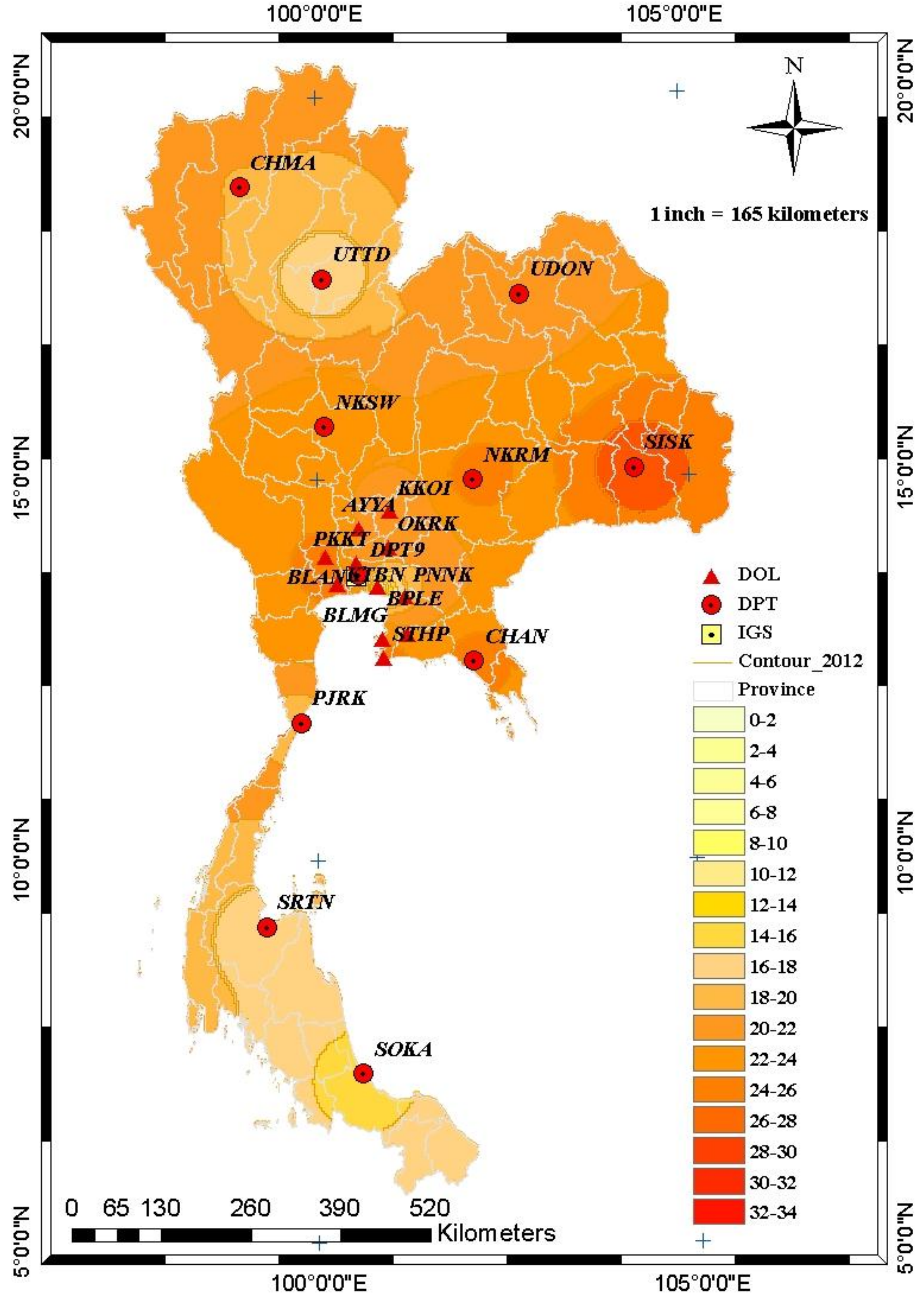

Figure 5.11 Show the enhancement of ROTI ≥ 0.5 maps at latitude of stations in 2012

The results of maps show that the upper part of Thailand has a high rate of the ionosphere irregularities compared to other regions. A large scale of the ionosphere irregularities has a major influence by the Earth's magnetic field that referred to the equatorial anomaly. This phenomenon occurs at approximately 15 degrees North and South of the magnetic equator. The ionosphere irregularities of these regions are very severe and frequent that can cause scintillation on satellite signal. The result of combination of electric fields and magnetic fields at the North and South of the anomaly regions causes the electrons density to be lifted vertically and diffuse to northward and southward. This process reduces the ionization at the magnetic equator although the sun is shining perpendicular to the magnetic equator, and increases ionization in the anomaly regions [16]. The increasing of the ionization over the equator causes higher ionosphere irregularity in the upper part than in the lower part of Thailand.

The result of the above analysis shows that during the April month is the time of high ionosphere variability and has more occurrences of ionosphere irregularities in Thailand. A further analysis is to calculate the TEC using Single layer Model by Bernese 5.0 software. The use of GPS data in the April 2010 is selected as an example.

5.2 The calculation of VTEC from land stations compared to VTEC from GIM

In this study, an estimation of the TEC using Bernese 5.0 software was carried out using networks of permanent GPS receivers of central part in Thailand, as shown Figure 5.12. Several GPS data sets were employed to create the ionosphere model and to monitor an ionospheric activity. The estimation of TEC using Bernese 5.0 is carried out on a local network basis and the data in April 2010 was selected for this study because the ionospheric variations have increased apparently in this month. The global network provides a set of continuous data in a global ionospheric model or global ionospheric maps (GIM). The local ionospheric model is as named Thai Ionospheric Map (TIM). TEC models from global (GIM) or locally (TIM) networks approach the ionosphere as a single layer. The Single layer model (SLM) assumed that ionosphere is a thin spherical shell located at a specified altitudes, so called slant TEC (STEC) is converted to the Vertical TEC (VTEC) the ionosphere piercing point (IPP) [39]. TEC values are presented by grid interpolation for the global and locally model. The output data of the locally model were TEC data in IONEX format by a temporal resolution of 1 h and a spatial resolution of 0.1° in latitude and 0.1° in longitude, covering 13° – 15° Latitude, 100° – 102° Longitude. While the database to generate daily IONEX files for GIM are represented by a temporal resolution of 2 h and a spatial resolution of 2.5° in latitude and 5° in longitude [32, 39], which comparison data used at 12.5° - 15° Latitude, 100° - 105° Longitude.

GPS data were Bernese software processed for 28 day on month of April 2010. The VTEC value of TIM found daily data of TIM are missing for some hours and gave the impression of VTEC each day of the TIM model discontinuous. For an analysis of the results, the obtained VTEC from the TIM model were selected from the data sets that are completed and continuous. A total of 15 days (i.e. 1, 2, 3, 6, 7, 10, 16, 18, 19, 23, 25, 26, 27, 28 and 29) were found to be unstable in this study. These data will be used to establish an averaged VTEC value for a comparison of the results from the GIM, see Figure 5.13.

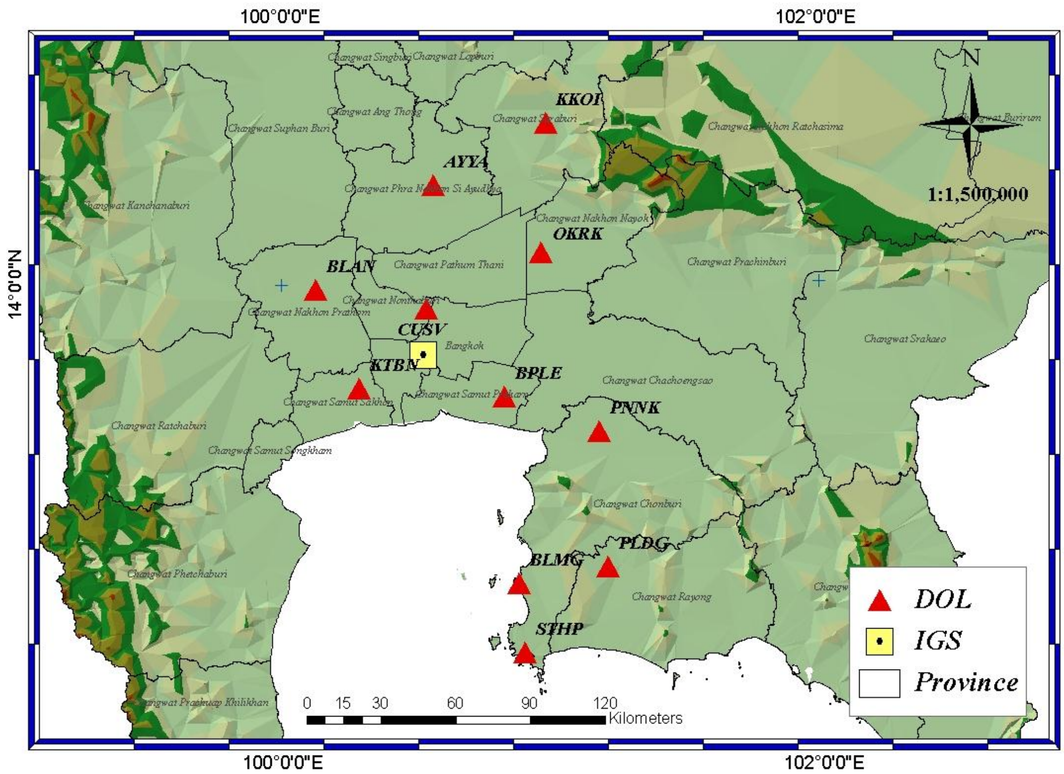

Figure 5.12 Locations of station in central part of Thailand for data processing by Bernese software.

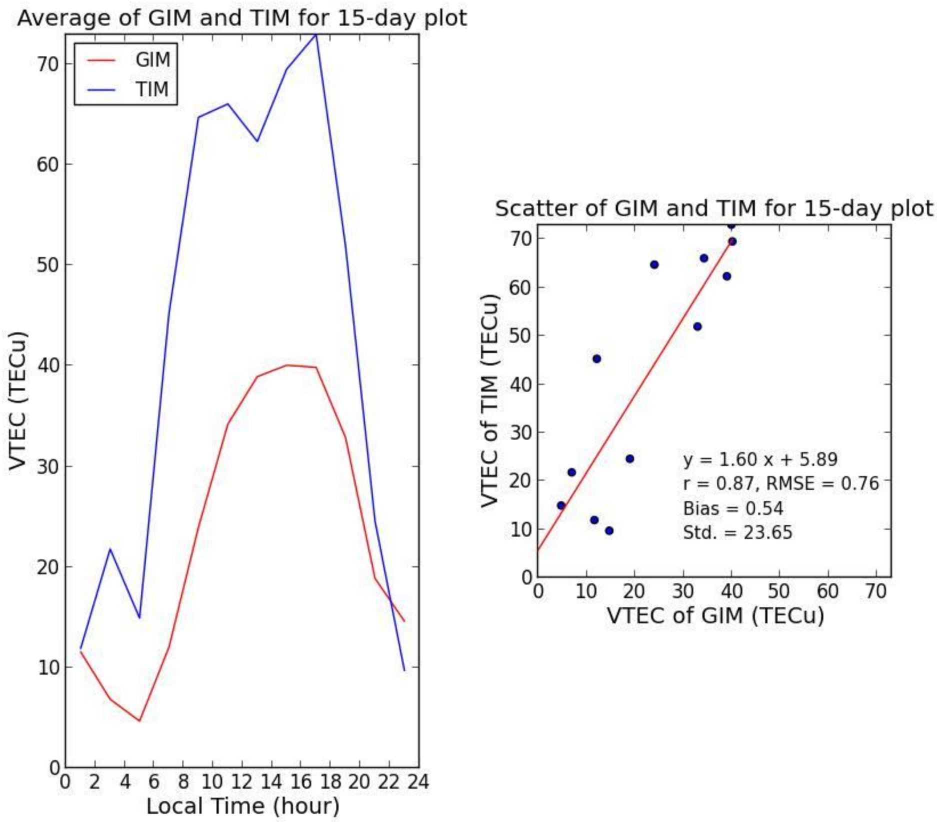

Figure 5.13 Comparison of TIM vertical TEC with GIM from the data 15 day on April (Left) and coefficient of correlation of the both (Right)

Figure 5.13 show graphically (left) compares VTEC over central part of Thailand for 15 day on April 2010 with the VTEC of GIM. The solid blue line represents VTEC from this study the VTEC of GIM is represented by the solid red line. GIM and TIM are TEC models provided at 2 hour interval at Local time (LT). The graph shows good agreement with the TEC of GIM and reveals higher temporal variability of the daily VTEC profile over central part of Thailand. The diurnal TEC for 15 day on April, with a wide peak VTEC centered over local noon, similar with VTEC of GIM. The diurnal VTEC wave is wide and appears a standstill for several hours then waves into nocturnal quietude. The VTEC wave shows a localized TEC depletion over midday local time with a small increase again during 04:00 LT. This TEC depression is also evident in TEC of GIM. The graph also shows considerable difference between the TIM and GIM for the predawn period. The evening VTEC reduction, between 08:00 LT and midnight is higher for a central part of Thailand than VTEC of GIM. Both data show the same general behavior for VTEC over central part of Thailand.

Figure 5.10 graphically (Right) shows the daily coefficient of correlation (r) of the VTEC between TIM and GIM for the data 15 day on April 2010. The coefficient of correlation (or Pearson Correlation Coefficient) (***r***) values were obtained from

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \tag{5.1}$$

where x_i and y_i are the value of the variable of GIM and TIM.

$\bar{x}$ and $\bar{y}$ are average values of the GIM and TIM.

The coefficient of correlation values between GIM and TIM are relationship rather high (***r*** = 0.87).

The VTEC of GIM was generated from GPS stations around the world, but there is no IGS station representative in Thailand. Therefore, the VTEC of GIM cover Thailand was generated from the GPS data located the near Thailand only such as China, Japan, Philippines and Indonesia. The VTEC data cover Thailand is the sampling data from GIM. This is different with TIM used data from the GPS stations located in Thailand, which rather the higher resolution. Figure 5.14 illustrates the global network of GPS stations around the world. However, the result the VTEC of TIM is qualitatively it may not be very good, which may need to be improved.

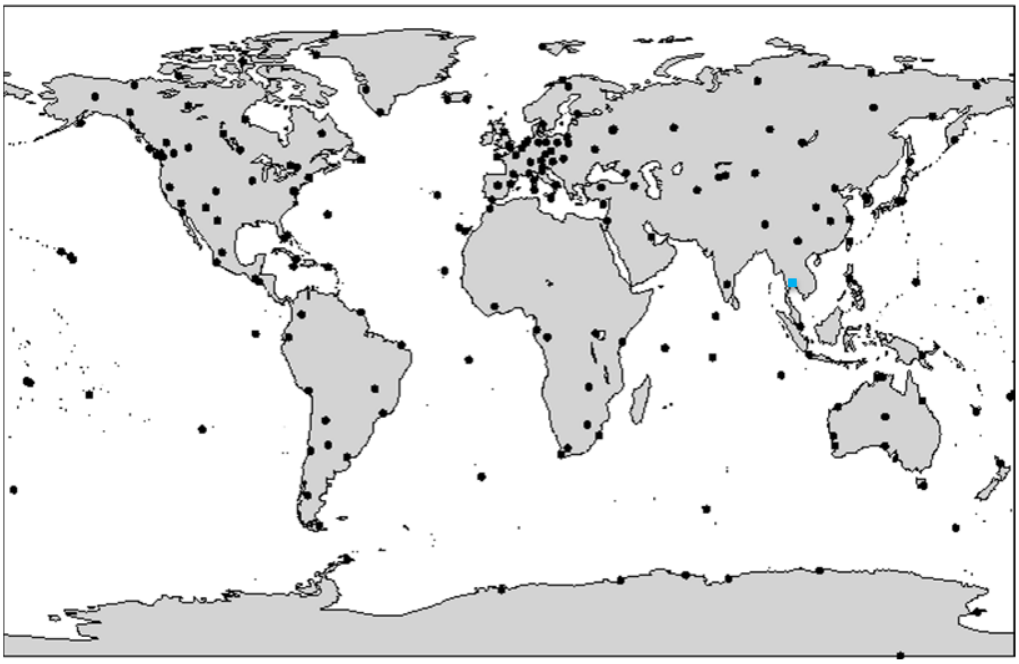

Figure 5.14 Locations of global station (Black dot) and the location of central part in Thailand (Blue box), figure adapted from http://aiuws.unibe.ch/.

The result of VTEC of TIM in this study can be adapted to certain applications for telecommunications. VTEC local model is two times of VTEC of GIM which suggests a high fluctuation of the ionosphere in this area. The variations are significant to enhance performance of the receiver system. A large scale of the ionosphere irregularities occurs frequently and intense during March, April, September, and October of each year, that should be given a special attention. Previous studies suggest that a large scale of the ionosphere irregularities are related to the occurrence scintillation and directly affect to the fade of signal. Increasing and intense of the ionosphere irregularities will affect many users in the upper of Thailand, especially in northeast that is often and more severe than other regions. Understanding about the ionosphere in Thailand will enhance the performance of the communication system and planning of installation of a GPS base station in the future. In addition, the ongoing study may help the development of tools or models for forecasting the occurrence period, similar to the current weather forecast.

CHAPTER VI

CONCLUSIONS AND RECOMEMDATIONS

6.1 Conclusions

This research aimed to study daily, monthly, annual and season variations of the TEC over Thailand between January 2009 and December 2012. A total of 23 GPS stations over Thailand were used to estimate the TEC value and calculate the ROTI value, The ROTI was used to show the ionosphere irregularities over Thailand. The results of the statistical analysis can be divided into two types; the moving average of data every 30-days and the enhancement percentage of ROTI in each month, season and year in percentage units. The results were explained in 1. – 3. In addition, this study also aimed to compare the VTEC data between receiving from ground-based GPS receivers and GIM. The VTEC from GPS ground stations was created the ionosphere model at the central part of Thailand, so-called TIM. Using Bernese 5.0 software approach, the ionosphere was treated as a Single-layer model. The results of this study can be summarized in.4.

1. The average daily variation of ROTI are almost equal or less than 0.4 during 2009 and 2010. That indicates low ionosphere irregularities. While the average of ROTI in 2011 to 2012 is greater than 0.4 and some stations are almost equal or less than 0.8, this indicates significant ionosphere irregularities activities. The result obtained in this study shows an increasing trend every semiannual of the ionosphere irregularities activities as well as every annual. In addition, the results showed that the Northeast region was faced often ionosphere fluctuations and irregularities.

2. The rates of occurrence of the ionosphere irregularities can be considered as a large scale impact during night time in Thailand. The result confirms variation on monthly and season basis. The ionosphere irregularities during four years were most enhancements during the equinox season (March, April, September and October) by

reaching a maximum occurrence rate at about 27%. The results showed a large scale ionosphere irregularity in the winter season while there the maximum rate of occurrence was approximately 7.8% in the summer season. In addition, a seasonal variation tends to depend on the year. In 2011, the seasonal variation reached a maximum value.

3. The characteristic of annual variation can be used to demonstrate the increasing rate of ROTI with a spatial distribution over Thailand between 2009 and 2012. The result confirmed that the upper part of Thailand has shown a higher rate of the ionosphere irregularities. The result obtained from the central and southeast regions confirmed that the severity of the ionospheric variability in Thailand depends on latitude. Moreover, the result showed that Prachuap Khiri Khan Province is an area that has an obvious activity of the atmosphere. It may be concluded that this area is prone to face the strong ionosphere irregularities.

4. The VTEC of TIM shows a localized TEC depletion over midday local time and a wide peak VTEC during afternoon. During the night time, TEC shown a small increasing trend again around 04:00 LT and then the trend is gradually decreased. A compared of VTEC result between TIM with GIM shows that the coefficient of correlation values are relative high (r = 0.87) both temporal and the general characteristics of VTEC.

6.2 Limitations, Barriers and Problems

1. The GPS data used in this study come from the several agencies. So, the data files were in different format. Tha data cleaning step has to be carried out process step.

2. Bernese processing are unstable for the ionospheric model with a long period because, that is often an error in each the modules and functions, especially

the final result. Also, the collection of data at the same period from each agency was difficult for processing in a long period. (In this study selected April month was represented data the high variability in the TEC for processing data).

3. The GIM can be downloaded for use after 3 days, which GIM may not be appropriate for the real time processing.

6.3 Recommendations

1. If the GPS data are available for a period 12 years from the several agencies. They can be used to study the irregularities ionosphere relationship for a completed solar cycle, during solar minimum activity to the solar maximum activity to affect the scintillation on the satellite signal.

2. The ionosphere irregularities or a small scale ionosphere perturbation are mainly caused by scintillation on the radio wave or telecommunications. It is also one of the factors causing lead to loss of lock of the receiver and reduces the efficiency of a GPS surveying technique.

3. The process of a local ionosphere model require the use of equally distributed GPS stations with relatively short baseline length to reduce error in the data processing step and to ensure high accuracy in the ionosphere modeling.

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APPENDIX

APPENDIX A

Rates of the ionosphere irregularities (ROTI ≥ 0.5)

This section is the results rates of the ionosphere irregularities during the night time by calculating the rate of increasing of the ROTI ≥ 0.5 in percentage units. The seasonal will be divided into three seasons: winter season (January, February, November and December), summer season (May, June, July and August) and equinox season (March, April, September and October). The results of 23 stations will shows sorted by regions, as shown in Table A-1.

Table A-1 Show the results of 23 stations

	Changwat	Code	Organizations
Northern region			
1	Chiang Mai	CHAM	DPT
2	Uttaradit	UTTD	DPT
Northeast region			
3	Nakhon Ratchasima	NKRM	DPT
4	Sri Saket	SISK	DPT
5	Udon Thani	UDON	DPT
Central region			
6	Phra Nakhon Si Ayutthaya	AYYA	DOL
7	Nakhon Prathom	BLAN	DOL
8	Nonthaburi	BLMG	DOL
9	Samut Phakran	BPLE	DOL
10	Bangkok	CUSV	IGS
11	Bangkok	DPT9	DPT
12	Saraburi	KKOI	DOL
13	Samut Sakhon	KTBN	DOL
14	Nakhon Sawan	NKSW	DPT
15	Nakhon Nayok	OKRK	DOL
16	Nonthaburi	PKKT	DOL
Eastern region			
17	Chanthaburi	CHAN	DPT
18	Rayong	PLDG	DOL
19	Chonburi	PNNK	DOL
20	Chonburi	STHP	DOL
Southern region			
21	Prachuap Khilikhan	PJRK	DPT
22	Songkhla	SOKA	DPT
23	Surat Thani	SRTN	DPT

*DOL (Department of Land)

* DPT (Department of Public Works and Town and Country Planning)

*IGS (International GNSS Service)

Table A-3 Show the results of enhancement ROTI ≥ 0.5 at CHMA station, Chiang Mai, Thailand.

CHAM Scintillation event/season	**Year:2009** Total no. of day:**251** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2010** Total no. of day:**342** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2011** Total no. of day:**295** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2012** Total no. of day:**266** Number of event associated ROTI>= 0.5	**% of occurrence**
Winter	0	0.0	2	0.6	23	7.8	9	3.4
Summer	0	0.0	0	0.0	4	1.4	8	3.0
Equinox	2	0.8	30	8.8	45	15.3	34	12.8
Total	***2***	***0.8***	***32***	***9.4***	***72***	***24.4***	***51***	***19.2***

Table A-2 Show the results of enhancement ROTI ≥ 0.5 at UTTD station, Uttaradit, Thailand.

UTTD Scintillation event/season	**Year:2009** Total no. of day:**308** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2010** Total no. of day:**337** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2011** Total no. of day:**339** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2012** Total no. of day:**275** Number of event associated ROTI>= 0.5	**% of occurrence**
Winter	0	0.0	1	0.3	20	5.9	7	2.5
Summer	0	0.0	6	1.8	5	1.5	12	4.4
Equinox	3	1.0	46	13.6	59	17.4	23	8.4
Total	***3***	***1.0***	***53***	***15.7***	***84***	***24.8***	***42***	***15.3***

Table A-4 Show the results of enhancement ROTI ≥ 0.5 at NKRM station, Nakhon Ratchasima, Thailand.

NKRM Scintillation event/season	**Year:2009** Total no. of day:**214** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2010** Total no. of day:**345** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2011** Total no. of day:**360** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2012** Total no. of day: **280** Number of event associated ROTI>= 0.5	**% of occurrence**
Winter	0	0.0	3	0.9	23	6.4	11	3.9
Summer	0	0.0	0	0.0	8	2.2	15	5.4
Equinox	0	0.0	40	11.6	78	21.7	42	15.0
Total	***0***	***0.0***	***43***	***12.5***	***109***	***30.3***	***68***	***24.3***

Table A-5 Show the results of enhancement ROTI ≥ 0.5 at SISK station, Sri Saket, Thailand.

SISK Scintillation event/season	**Year:2009** Total no. of day:**224** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2010** Total no. of day:**332** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2011** Total no. of day:**357** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2012** Total no. of day: **238** Number of event associated ROTI>= 0.5	**% of occurrence**
Winter	0	0.0	3	0.9	19	5.3	11	4.6
Summer	0	0.0	0	0.0	8	2.2	16	6.7
Equinox	1	0.4	34	10.2	79	22.1	36	15.1
Total	***1***	***0.4***	***37***	***11.1***	***106***	***29.7***	***63***	***26.5***

Table A-6 Show the results of enhancement ROTI ≥ 0.5 at UDON station, Udon Thani, Thailand

UDON	**Year:2009** Total no. of day:**256**		**Year:2010** Total no. of day:**351**		**Year:2011** Total no. of day:**355**		**Year:2012** Total no. of day: **278**	
Scintillation event/season	Number of event associated ROTI>= 0.5	**% of occurrence**	Number of event associated ROTI>= 0.5	**% of occurrence**	Number of event associated ROTI>= 0.5	**% of occurrence**	Number of event associated ROTI>= 0.5	**% of occurrence**
Winter	2	0.5	5	1.4	16	4.5	12	4.3
Summer	0	0.0	0	0.0	4	1.1	9	3.2
Equinox	0	0.0	33	9.4	69	19.4	34	12.2
Total	***2***	***0.5***	***38***	***10.8***	***89***	***25.1***	***55***	***19.8***

Table A-7 Show the results of enhancement ROTI ≥ 0.5 at AYYA station, Phra Nakron Si Ayuthaya, Thailand.

AYYA	**Year:2009** Total no. of day:**332**		**Year:2010** Total no. of day:**332**		**Year:2011** Total no. of day:**259**		**Year:2012** Total no. of Day:**194**	
Scintillation event/season	Number of event associated ROTI>= 0.5	**% of occurrence**	Number of event associated ROTI>= 0.5	**% of occurrence**	Number of event associated ROTI>= 0.5	**% of occurrence**	Number of event associated ROTI>= 0.5	**% of occurrence**
Winter			4	1.2	5	1.9	6	3.1
Summer	No		2	0.6	3	1.2	6	3.1
Equinox	Data		34	10.2	37	14.3	23	11.9
Total			***40***	***12.0***	***45***	***17.4***	***35***	***18.0***

Table A-9 Show the results of enhancement ROTI ≥ 0.5 at BLAN station, Nakron Phathom, Thailand.

BLAN	**Year:2009** Total no. of day:**266**		**Year:2010** Total no. of day:**320**		**Year:2011** Total no. of day:**302**		**Year:2012** Total no. of day:**302**	
Scintillation event/season	Number of event associated ROTI>= 0.5	**% of occurrence**	Number of event associated ROTI>= 0.5	**% of occurrence**	Number of event associated ROTI>= 0.5	**% of occurrence**	Number of event associated ROTI>= 0.5	**% of occurrence**
Winter	0	0	3	0.9	19	6.3	10	3.3
Summer	0	0	1	0.3	5	1.7	15	5.0
Equinox	1	0.4	29	9.1	64	21.2	52	17.2
Total	***1***	***0.4***	***33***	***10.3***	***88***	***29.1***	***77***	***25.5***

Table A-8 Show the results of enhancement ROTI ≥ 0.5 at BLMG station, Nonthaburi, Thailand.

BLMG	**Year:2009** Total no. of day:**271**		**Year:2010** Total no. of day:**324**		**Year:2011** Total no. of day:**262**		**Year:2012** Total no. of day:**288**	
Scintillation event/season	Number of event associated ROTI>= 0.5	**% of occurrence**	Number of event associated ROTI>= 0.5	**% of occurrence**	Number of event associated ROTI>= 0.5	**% of occurrence**	Number of event associated ROTI>= 0.5	**% of occurrence**
Winter	0	0	3	0.9	15	5.7	8	2.8
Summer	0	0	1	0.3	6	2.3	16	5.6
Equinox	2	0.7	31	9.6	51	19.5	41	14.2
Total	***2***	***0.7***	***35***	***10.8***	***72***	***27.5***	***65***	***22.6***

Table A-10 Show the results of enhancement ROTI ≥ 0.5 at BPLE station, Samut Phakran, Thailand.

BPLE	**Year:2009**		**Year:2010**		**Year:2011**		**Year:2012**	
	Total no. of day: ***246***		Total no. of day: ***219***		Total no. of day: ***248***		Total no. of day: ***241***	
Scintillation event/season	Number of event associated ROTI>= 0.5	**% of occurrence**	Number of event associated ROTI>= 0.5	**% of occurrence**	Number of event associated ROTI>= 0.5	**% of occurrence**	Number of event associated ROTI>= 0.5	**% of occurrence**
Winter	0	0	0	0	0	0	0	0
Summer	0	0	0	0	0	0	1	0.4
Equinox	4	1.6	13	5.9	27	10.9	12	5.0
Total	***4***	***1.6***	***13***	***5.9***	***27***	***10.9***	***13***	***5.4***

Table A-11 Show the results of enhancement ROTI ≥ 0.5 at CUSV station, Bangkok, Thailand.

CUSV	**Year:2009**		**Year:2010**		**Year:2011**		**Year:2012**	
	Total no. of day:**365**		Total no. of day:**360**		Total no. of day:**333**		Total no. of day:**351**	
Scintillation event/season	Number of event associated ROTI>= 0.5	**% of occurrence**	Number of event associated ROTI>= 0.5	**% of occurrence**	Number of event associated ROTI>= 0.5	**% of occurrence**	Number of event associated ROTI>= 0.5	**% of occurrence**
Winter	0	0	5	1.4	16	4.8	17	4.8
Summer	0	0	0	0	6	1.8	16	4.6
Equinox	0	0	41	11.4	88	26.4	71	20.2
Total	***0***	***0***	***46***	***12.8***	***110***	***33.0***	***104***	***29.6***

Table A-13 Show the results of enhancement ROTI ≥ 0.5 at DPT9 station, Bangkok, Thailand.

DPT9 Scintillation event/season	**Year:2009** Total no. of day:**331** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2010** Total no. of day:**346** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2011** Total no. of day:**340** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2012** Total no. of day:**269** Number of event associated ROTI>= 0.5	**% of occurrence**
Winter	0	0.0	2	0.6	21	6.2	7	2.6
Summer	0	0.0	0	0.0	7	2.1	13	4.8
Equinox	3	0.9	37	10.7	73	21.5	35	13.0
Total	***3***	***0.9***	***39***	***11.3***	***101***	***29.7***	***55***	***20.4***

Table A-12 Show the results of enhancement ROTI ≥ 0.5 at KKOI station, Saraburi, Thailand.

KKOI Scintillation event/season	**Year:2009** Total no. of day:**246** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2010** Total no. of day:**318** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2011** Total no. of day:**325** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2012** Total no. of day:**224** Number of event associated ROTI>= 0.5	**% of occurrence**
Winter			4	1.3	19	5.8	7	3.1
Summer	No		1	0.3	5	1.5	6	2.7
Equinox	Data		29	9.1	73	22.5	31	13.8
Total			***34***	***10.7***	***97***	***29.8***	***44***	***19.6***

Table A-15 Show the results of enhancement ROTI ≥ 0.5 at KTBN station, Samut Sakhon, Thailand.

KTBN Scintillation event/season	**Year:2009** Total no. of day:**262** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2010** Total no. of day:**334** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2011** Total no. of day:**268** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2012** Total no. of day:**312** Number of event associated ROTI>= 0.5	**% of occurrence**
Winter	0	0	2	0.6	5	1.9	12	3.8
Summer	0	0	1	0.3	5	1.9	14	4.5
Equinox	1	0.4	30	9.0	47	17.5	55	17.6
Total	***1***	***0.4***	***33***	***9.9***	***57***	***21.3***	***81***	***26.0***

Table A-14 Show the results of enhancement ROTI ≥ 0.5 at NKSW station, Nakhon Sawan, Thailand.

NKSW Scintillation event/season	**Year:2009** Total no. of day:**340** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2010** Total no. of day:**333** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2011** Total no. of day:**334** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2012** Total no. of day:**279** Number of event associated ROTI>= 0.5	**% of occurrence**
Winter	0	0.0	2	0.6	23	6.9	10	3.6
Summer	0	0.0	0	0.0	8	2.4	14	5.0
Equinox	3	0.9	32	9.6	55	16.5	40	14.3
Total	***3***	***0.9***	***34***	***10.2***	***86***	***25.7***	***64***	***22.9***

Table A-17 Show the results of enhancement ROTI ≥ 0.5 at OKRK station, Nakhon Nayok, Thailand.

OKRK Scintillation event/season	**Year:2009** Total no. of day:**254** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2010** Total no. of day:**297** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2011** Total no. of day:**272** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2012** Total no. of day:**273** Number of event associated ROTI>= 0.5	**% of occurrence**
Winter	0	0	5	1.7	4	1.5	7	2.6
Summer	0	0	0	0	4	1.5	7	2.6
Equinox	0	0	26	8.8	49	18.0	41	15.0
Total	***0***	***0***	***31***	***10.4***	***57***	***21.0***	***57***	***20.9***

Table A-16 Show the results of enhancement ROTI ≥ 0.5 at PKKT station, Nonthaburi, Thailand.

PKKT Scintillation event/season	**Year:2009** Total no. of day:**300** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2010** Total no. of day:**338** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2011** Total no. of day:**336** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2012** Total no. of day:**249** Number of event associated ROTI>= 0.5	**% of occurrence**
Winter	0	0	2	0.6	19	5.7	10	4.0
Summer	0	0	1	0.3	4	1.2	6	2.4
Equinox	3	1	31	9.2	72	21.4	30	12.0
Total	***3***	***1***	***34***	***10.1***	***95***	***28.3***	***46***	***18.5***

Table A-19 Show the results of enhancement ROTI ≥ 0.5 at CHAN station, Chanthaburi, Thailand.

CHAN Scintillation event/season	**Year:2009** Total no. of day:**334** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2010** Total no. of day:**361** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2011** Total no. of day:**353** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2012** Total no. of day:**284** Number of event associated ROTI>= 0.5	**% of occurrence**
Winter	0	0.0	4	1.1	21	5.9	10	3.5
Summer	0	0.0	0	0.0	9	2.5	19	6.7
Equinox	2	0.6	32	8.9	70	19.8	40	14.1
Total	***2***	***0.6***	***36***	***10.0***	***100***	***28.3***	***69***	***24.3***

Table A-18 Show the results of enhancement ROTI ≥ 0.5 at PLDG station, Rayong, Thailand.

PLDG Scintillation event/season	**Year:2009** Total no. of day:**123** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2010** Total no. of day:**233** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2011** Total no. of day:**133** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2012** Total no. of day:**192** Number of event associated ROTI>= 0.5	**% of occurrence**
Winter	0	0	3	1.3	0	0	7	3.6
Summer	0	0	2	0.9	4	3.0	9	4.7
Equinox	8	6.5	17	7.3	30	22.6	20	10.4
Total	***8***	***6.5***	***22***	***9.4***	***34***	***25.6***	***36***	***18.8***

Table A-21 Show the results of enhancement ROTI ≥ 0.5 at PNNK station, Chonburi, Thailand.

PNNK Scintillation event/season	**Year:2009** Total no. of day:**245** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2010** Total no. of day:**266** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2011** Total no. of day:**336** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2012** Total no. of day:**205** Number of event associated ROTI>= 0.5	**% of occurrence**
Winter	0	0	5	1.9	No		3	1.5
Summer	0	0	1	0.4	Data		0	0
Equinox	0	0	23	8.6			6	2.9
Total	***0***	***0***	***29***	***10.9***			***9***	***4.4***

Table A-20 Show the results of enhancement ROTI ≥ 0.5 at STHP station, Chonburi, Thailand.

STHP Scintillation event/season	**Year:2009** Total no. of day:**238** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2010** Total no. of day:**168** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2011** Total no. of day:**220** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2012** Total no. of day:**289** Number of event associated ROTI>= 0.5	**% of occurrence**
Winter	0	0	2	1.2	13	5.9	10	3.5
Summer	0	0	0	0.0	6	2.7	11	3.8
Equinox	2	0.8	15	8.9	39	17.7	52	18.0
Total	***2***	***0.8***	***17***	***10.1***	***58***	***26.4***	***73***	***25.3***

Table A-23 Show the results of enhancement ROTI ≥ 0.5 at PJRK station, Prachuap Khilikhan, Thailand.

PJRK Scintillation event/season	**Year:2009** Total no. of day:**310** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2010** Total no. of day:**341** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2011** Total no. of day:**333** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2012** Total no. of day:**279** Number of event associated ROTI>= 0.5	**% of occurrence**
Winter	0	0.0	1	0.3	19	5.7	9	2.7
Summer	0	0.0	0	0.0	8	2.4	15	4.5
Equinox	2	0.6	30	8.8	63	18.9	35	10.5
Total	***2***	***0.6***	***31***	***9.1***	***90***	***27.0***	***59***	***17.7***

Table A-22 Show the results of enhancement ROTI ≥ 0.5 at SOKA station, Songkhan, Thailand.

SOKA Scintillation event/season	**Year:2009** Total no. of day:**334** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2010** Total no. of day:**316** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2011** Total no. of day:**348** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2012** Total no. of day:**270** Number of event associated ROTI>= 0.5	**% of occurrence**
Winter	0	0	0	0.0	0	0.0	1	0.4
Summer	0	0	0	0.0	5	1.4	15	5.6
Equinox	0	0	3	0.9	55	15.8	23	8.5
Total	***0***	***0***	***3***	***0.9***	***60***	***17.2***	***39***	***14.4***

Table A-24 Show the results of enhancement ROTI ≥ 0.5 at STRN station, Surat Thani, Thailand.

SRTN Scintillation event/season	**Year:2009** Total no. of day:**337** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2010** Total no. of day:**342** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2011** Total no. of day:**353** Number of event associated ROTI>= 0.5	**% of occurrence**	**Year:2012** Total no. of day:**284** Number of event associated ROTI>= 0.5	**% of occurrence**
Winter	0	0.0	0	0.0	10	2.8	1	0.4
Summer	0	0.0	1	0.3	8	2.3	18	6.3
Equinox	1	0.3	11	3.2	63	17.8	28	9.9
Total	***1***	***0.3***	***12***	***3.5***	***81***	***22.9***	***47***	***16.5***

APPENDIX B

Estimation using ionosphere model by Bernese 5.0 software

Bernese software is a tool for research in geodetic and calculates with high accuracy. This appendix lists the steps in the process to find the Total Electron Content using the Bernese software.

1. System User Variables

The installation program will need to create a System User Variables. The System User Variables determine the data storage path of the operating system. A reference to the System User Variables in Bernese program will begin with the symbol "$" followed by braces, such as $ {P} refers to the C: \ GPSDATA etc., shown in Table B-1.

2. Menu Variable

Menu variable was used to control process and the convenience for users. For example, import GPS Data from multiple stations in one day can be use $S+0 symbols within blank channels, show details in Table B-2.

Table B-1 Show detail of Folder and User Variable [40]

Folder	Description	User Variables
BERN50	The main storage program files	${C}
BERN50/ GPS	Data storage for the processing	${S}
BERN50/ GPS/GEN	Store information necessary for the processing such as Antenna Phase Variation, Receiver Information	
GPSDATA	GPS storage	${P}
GPSDATA/ ATM	Atmosphere data storage	
GPSDATA/ OBS	GPS storage in Bernese format.	
GPSDATA/ ORB	Orbit data storage	
GPSDATA/ ORX	RINEX data storage	
GPSDATA/ OUT	Process results storage	
GPSDATA/ RAW	RINEX data Storage, before conversion	
GPSDATA/ SOL	Solution etc., data storage	
GPSDATA/ STA	Storage base station coordinates data	
GPSUSER	Option data storage for the processing of the user, such as Scripts.	${U}
GPSUSER/ OPT	Option data storage in automatic	
GPSUSER/PAN	processing with Bernese Processing Engine	
	Option data storage of the processing	
GPSUSER/PCF	Process Control File (PCF) data storage	
GPSUSER/WORK	BPE processing data storage	

Table B-2 Menu Variable [40]

Without ranges*		With ranges**	Format	Description
$+n	$-n	$+-	DDD	Day of Year (DOY)
$S+n	$S-n	$S+-	DDDS	DOY, Session Charact.
$Y+n	$Y-n	$Y+-	YYYY	Year
$W+n	$W-n	$W+-	WWWW	GPS Week
$M+n	$M-n	$M+-	YYMM	Year, Month
$JD+n	$JD-n	$JD+-	DDDDD	Modified Julian Date
$WD+n	$WD-n	$WD+-	WWWWD	GPS Week and Day
$YD+n	$YD-n	$YD+-	YYDDD	Year and DOY
$YSS+n	$YSS-n	$YSS+-	YYDDDS	Year, DOY, Sess. Char
$YMD_STR+n	$YMD_STR-n	$YMD_STR+-	YYYY MM DD	Year, Month, Day

***n=0,1,...9**

***if n=10,...: $+(n), $S+(n), ..., $-(n), $S-(n), ...**

**** ranges control by VAR_MINUS VAR_PLUS in Menu Variables Panel**

3. Create and selected campaign

Create a Campaign in the Bernese are meaning creating a workspace for data storage of the processing. The steps are as follows.

- *Menu -> Campaign -> Edit of Campaign*
- *Clink "+ symbol" together with campaigns naming such as ${P}/Master* (see figure B-1)

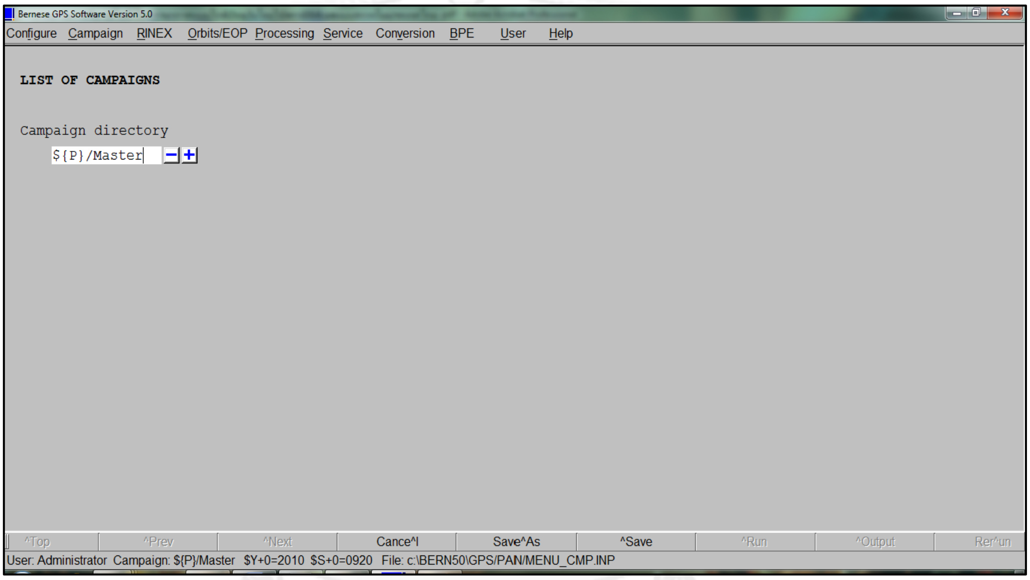

Figure B-1 Show create a new campaign

For select a campaign to be active.

- *Menu -> Campaign -> Select active campaign (see figure B-2)*

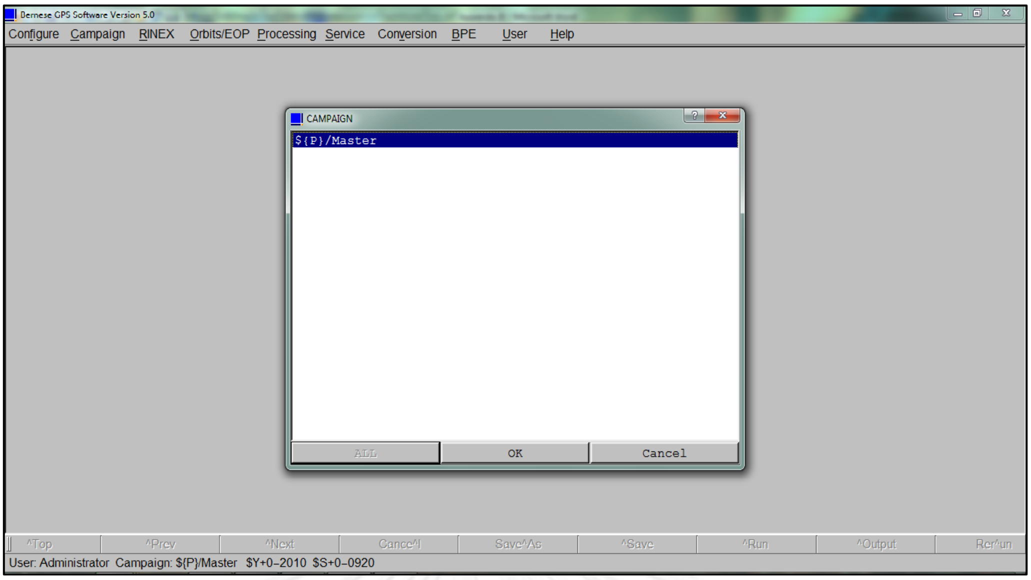

Figure B-2 Show selects a campaign

Create wok space or folders for storing data, including session file.

➢ *Menu -> Campaign -> Create new campaign -> Click Run at the bottom bar* (See figure B-3)

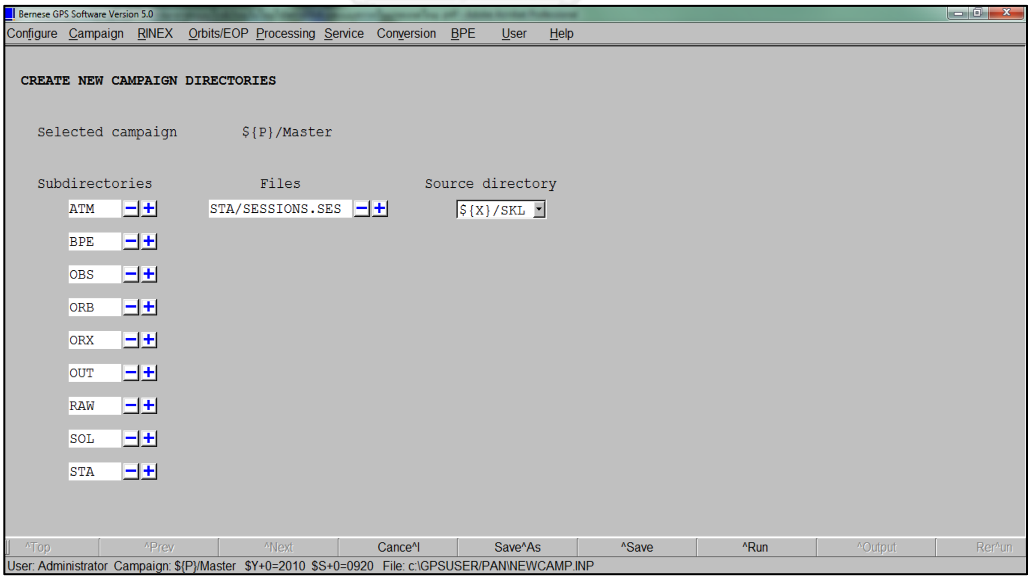

Figure B-3 Create new campaign

4. Determination the session table

The session is a period determination for the all data process, such as such as a data process on the date of 1 April 2010 to 5 April 2010 can be to edit in the table. In the case several days processing that recommend should not any changes, can see Figure B-4

➢ *Menu -> Campaign -> Edit session table.*

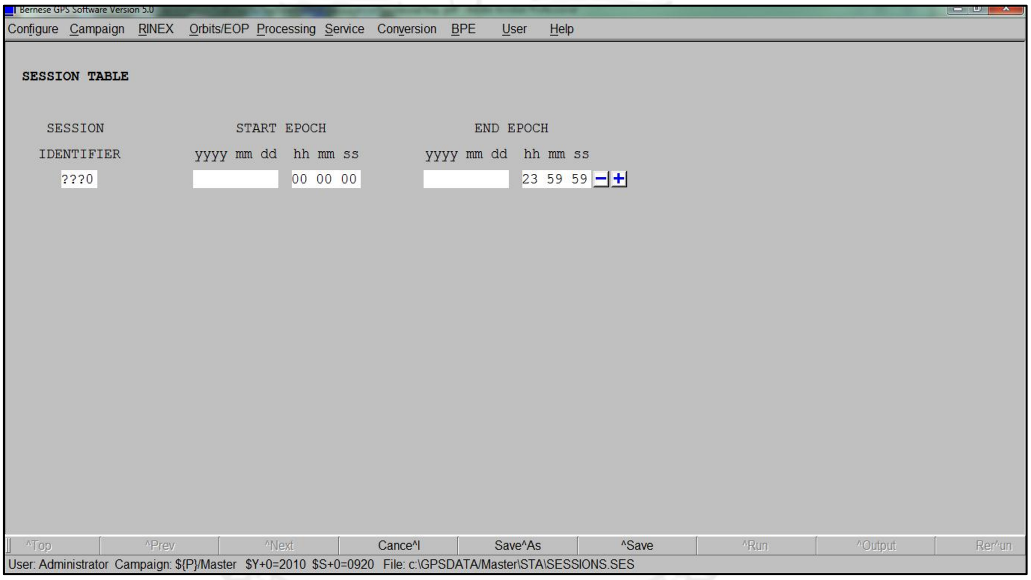

Figure B-4 Show edit session table

5. Determination current session

The current session is determination the days required to the data process. The program will extract the data on date specified for the processing and until complete. For example, DOY 92, 2010 was a day to processing. So, the number of the Year, Day of Year (YYYY DDD)can be change the number within blank channel, shown in Figure B-5

➢ *Menu -> Configure -> Set session/compute date*

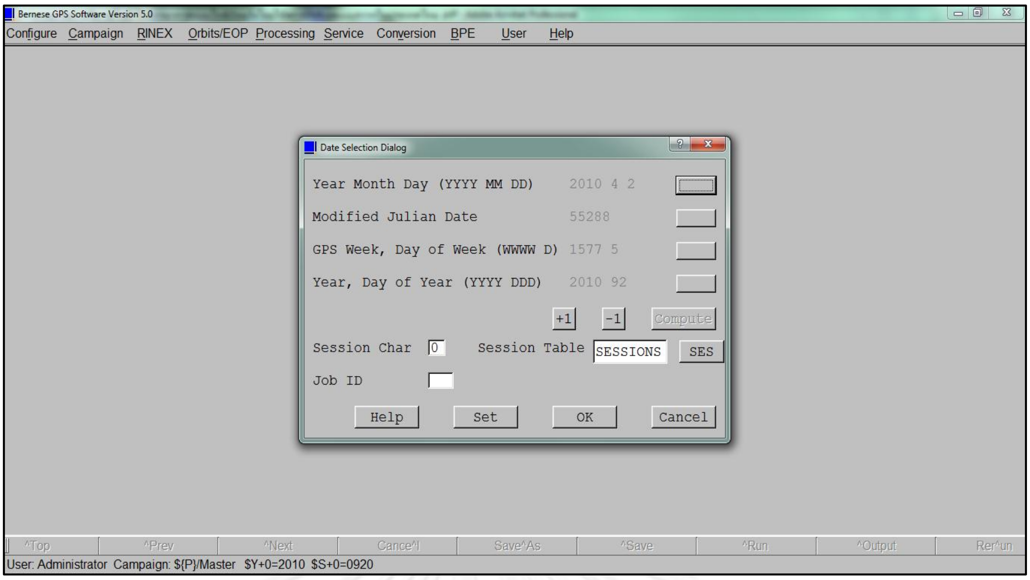

Figure B-5 Shows determination current session.

6. Data preparation for processing

Data preparation for processing including GPS Data, Precise Orbit data, Earth Orientation Parameter / Pole Data, Satellite Clock Information Data as described in Chapter 3.

6.1 Import RINEX data

GPS data are RINEX format the hourly files must be concatenation the hourly files to a daily files by using CCRINEXO program. The program can be cut and concatenates RINEX observation files program, see Figure B-6. (In case of multiple stations use the symbol " ???? $ S +0 ", to running all files).

- *Menu -> RINEX -> Cut/concatenate RINEX files -> Observation files*

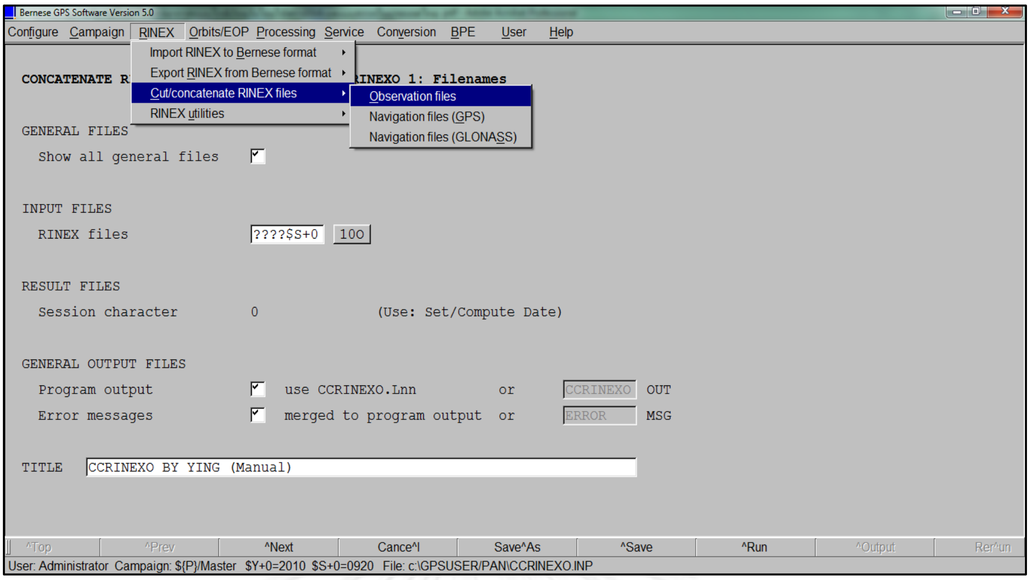

Figure B-6 Show Cut/concatenate RINEX files

The daily RINEX files must to smooth the data using the RNXSMT function before importing data see Figure B-7.

➢ *Menu -> RINEX utilities -> Clean/smooth observation files*

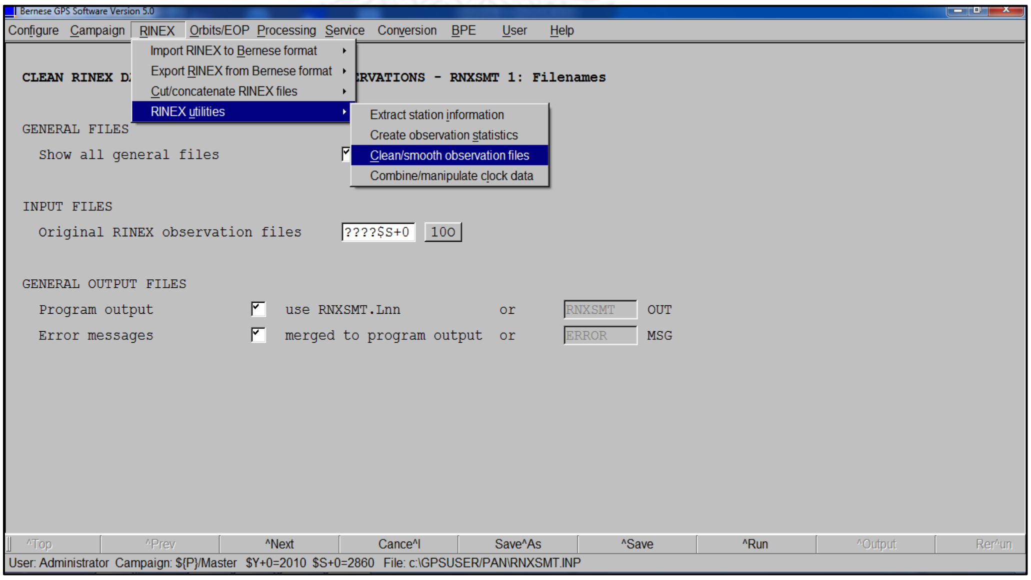

Figure B-7 Show smooth observation files data

6.2 Import RINEX to Bernese

RINEX observation files were through smooth data, the observation files will be converting into Bernese files using the RSOBV3 functions, see Figure B-8. This program is performs numerous checks on the RINEX header information and skip files with dubious header content.

- ➢ *Menu-> Import RINEX to Bernese format -> Observations*

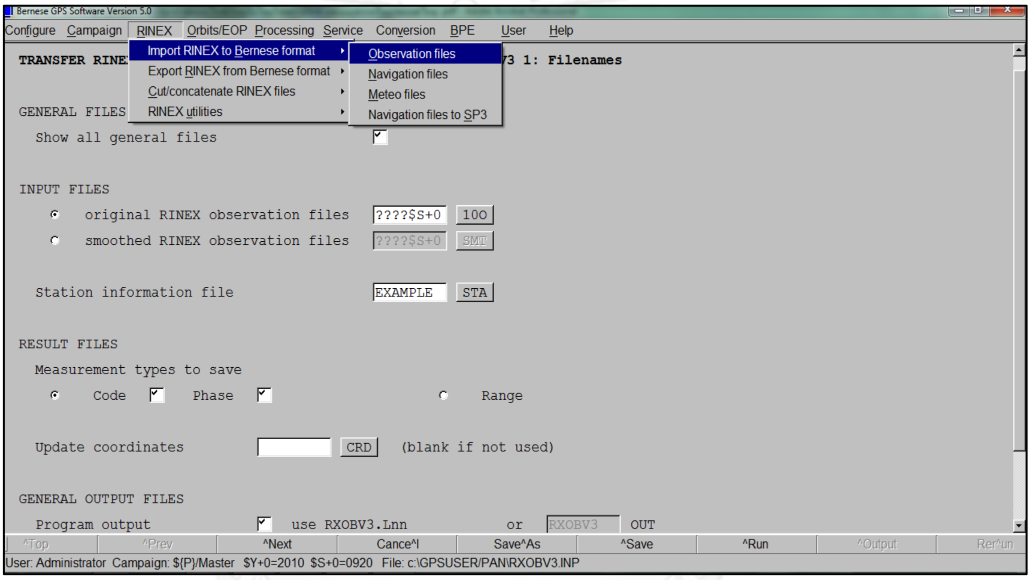

Figure B-8 Show import RINEX data to Bernese

6.3 Import precise orbit data

The precise orbit files were used directly to generate called tabular file with program PRETAB (the extension TAB) to generate a Bernese standard orbit file (the extension STD) in program ORBGEN (.EPH can change to the extension .PRE format used MyRename program) can see Figure B-9 and B-10, respectively.

- ➢ *Menu -> Orbit/EOP-> Create tabular orbits -> Result ".TAB"*

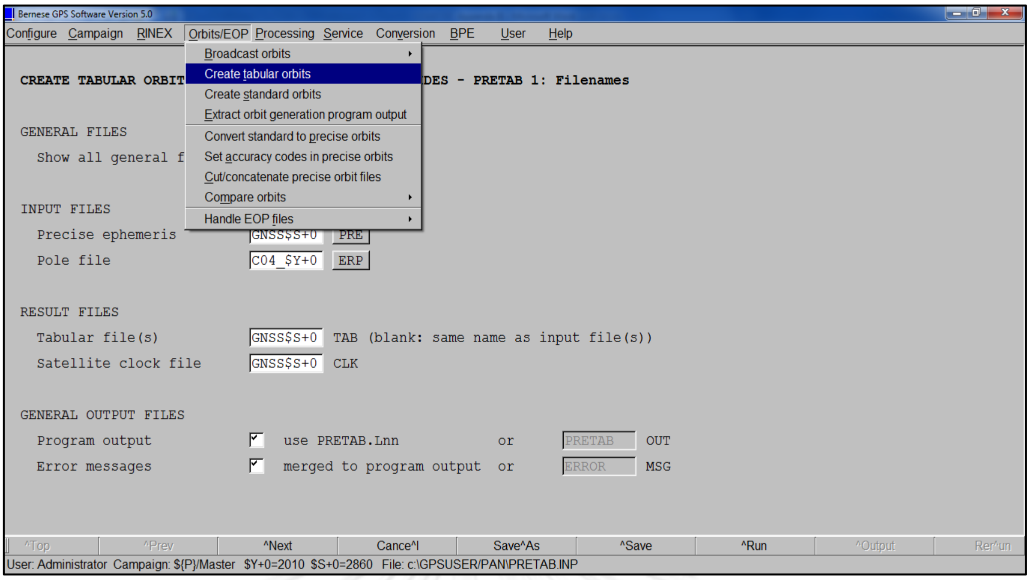

Figure B-9 Show creates tabular orbits

➢ *Menu -> Orbits/EOP -> Create standard orbits -> Result ".STD"*

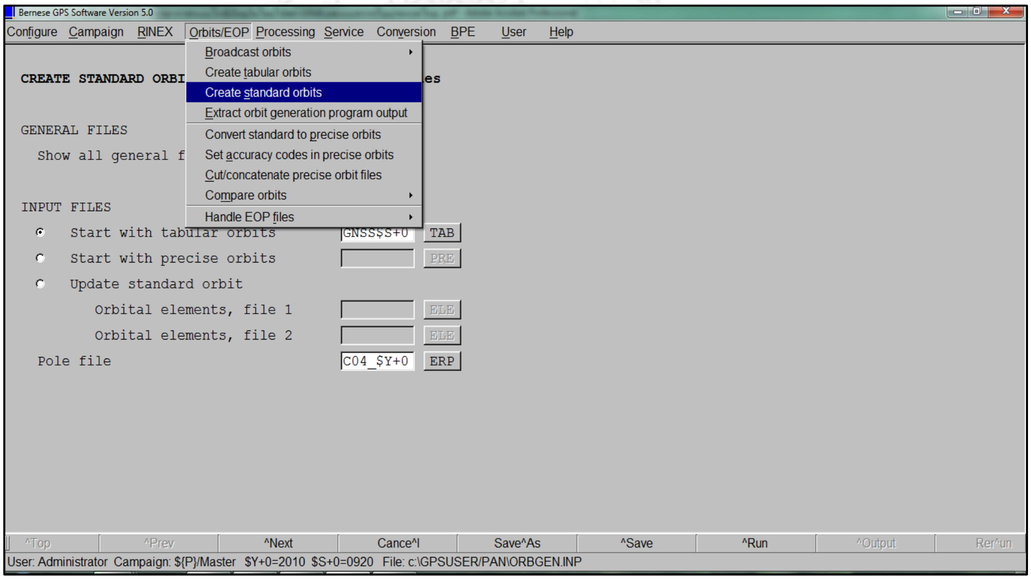

Figure B-10 Show creates standard orbits.

6.4 The code based clock synchronization

Code based clock synchronization is the receiver clocks corrections for synchronizing with the satellite clocks used the CODSPP program, can see in Figure B-11. The results are written into the Bernese files.

- *Menu -> Processing -> Code-based clock synchronization*

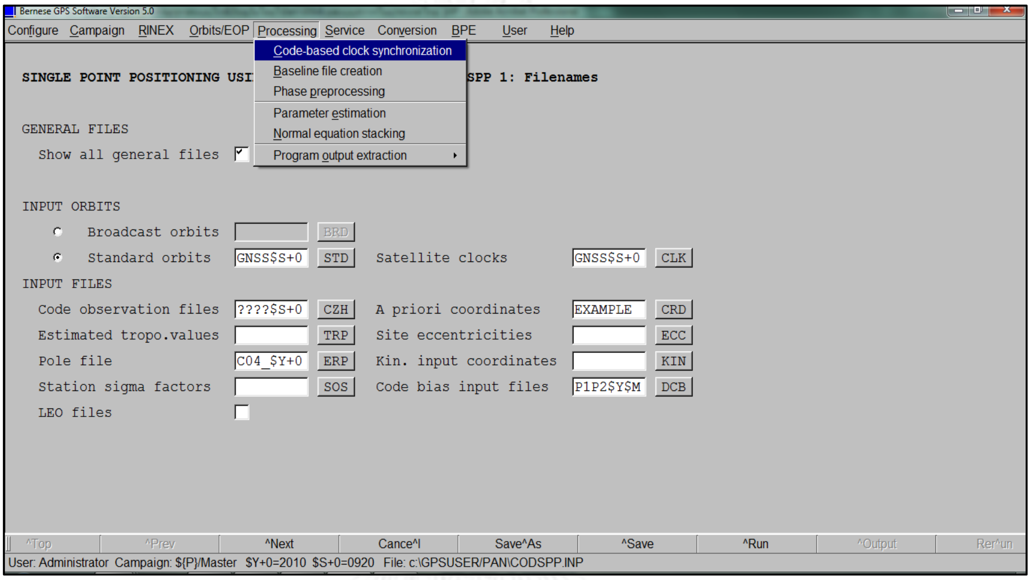

Figure B-11 Show create code based clock synchronization

6.5 Forming baselines

In this step are created baselines used the STAR strategy that are built by connecting one reference station. This research has chosen the STAR strategy the baselines by using SNGDIF function see Figure B-12.

- *Menu -> Processing -> Baseline file creation*

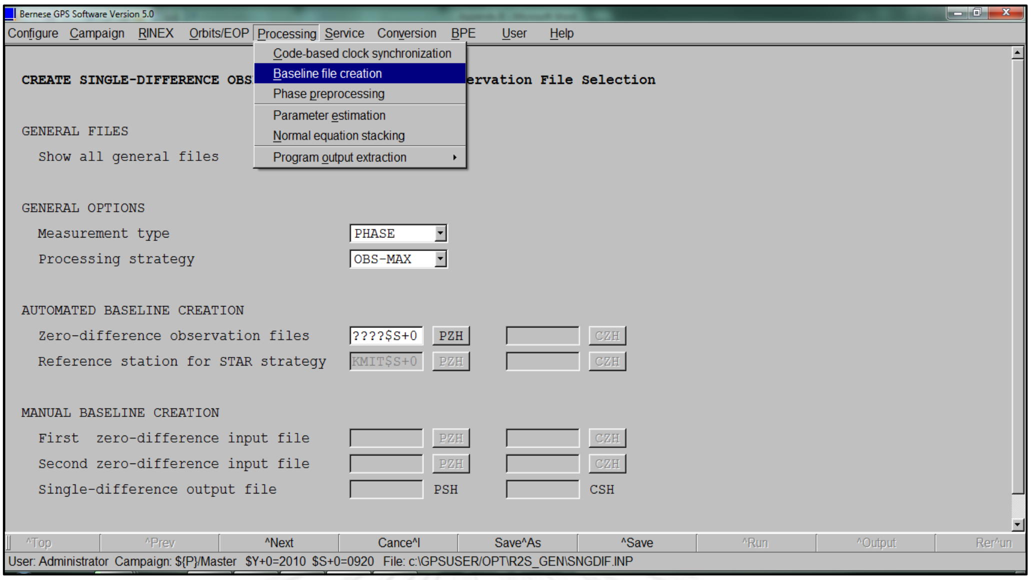

Figure B-12 Show creates the baseline file

6.6 Phase pre-processing

Phase preprocessing used to detect and resolve wide-lane cycle slips and clock jump by the MAUPP function see figure B-13

- *Menu -> Processing -> Phase processing*

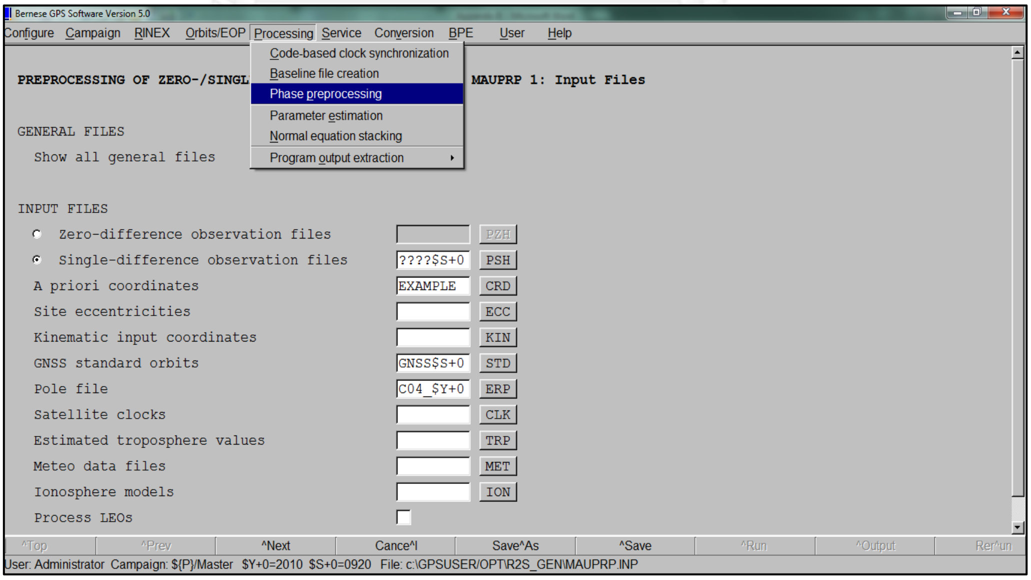

Figure B-13 Show create Phase preprocessing

7. Total Electron Content estimation

- *Menu -> Processing -> Parameter estimation (The 1st)* uses improved preliminary to find to Root Mean Square (RMS) value. That is unusual or not. In this process is used to process the data using an equation Ionosphere free linear combination L3 Float solution.

- *Menu -> Processing -> Parameter estimation (The 2nd)* uses L1 + L2 waves to find ambiguity resolution as an integer, which this research uses a method of QIF (Quasi Ionosphere-Free), in case of very long the baseline.

- *Menu -> Processing -> Parameter estimation (The 3rd)* using Geometry Free Linear Combination equation (L_4). The output result is .IONEX file (default extensions are ION and INX) which determination file name as can see in Figure B-15.

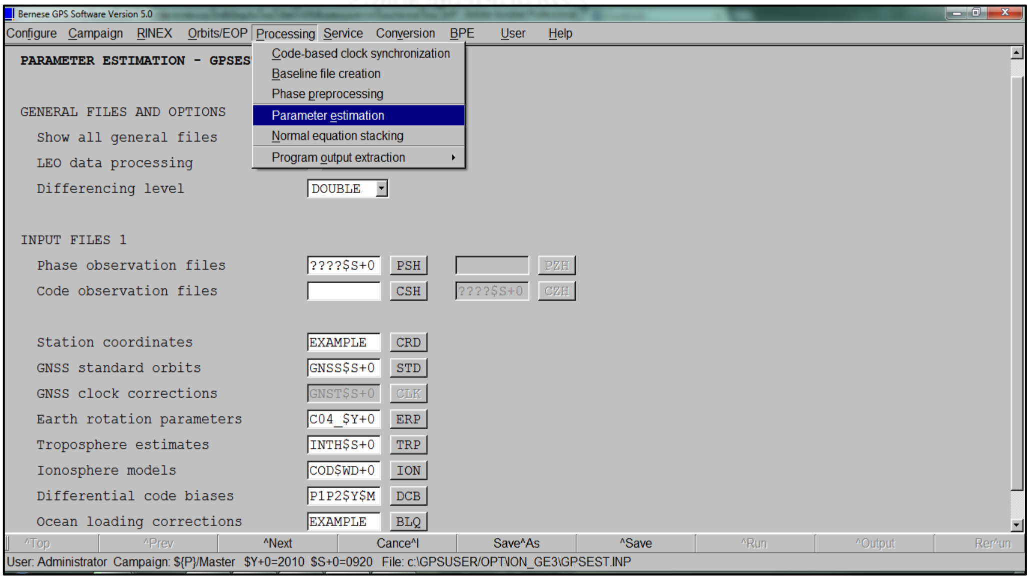

Figure B-14 Show Parameter estimate

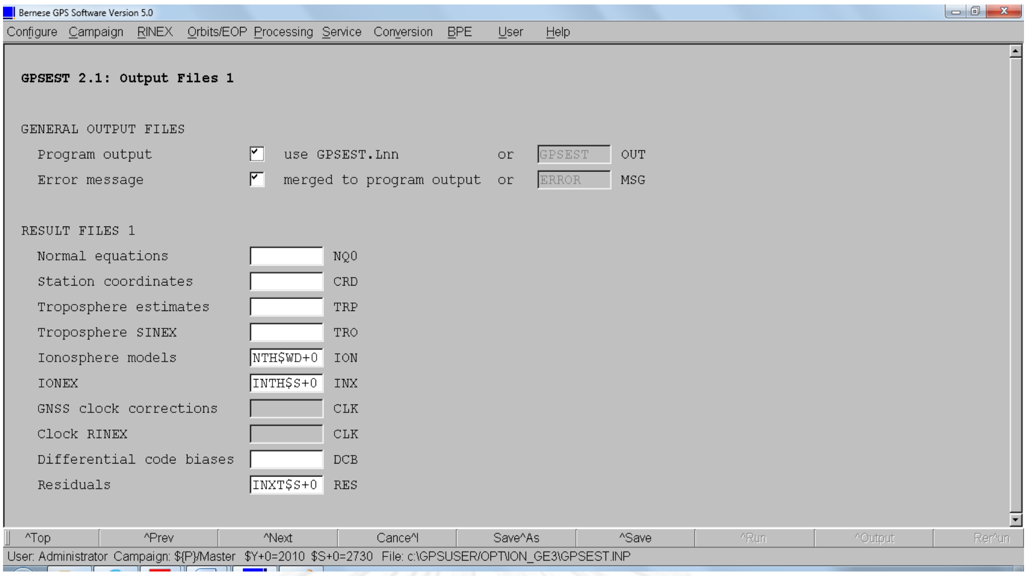

Figure B-15 Shown output files for GPSEST.

VITA

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