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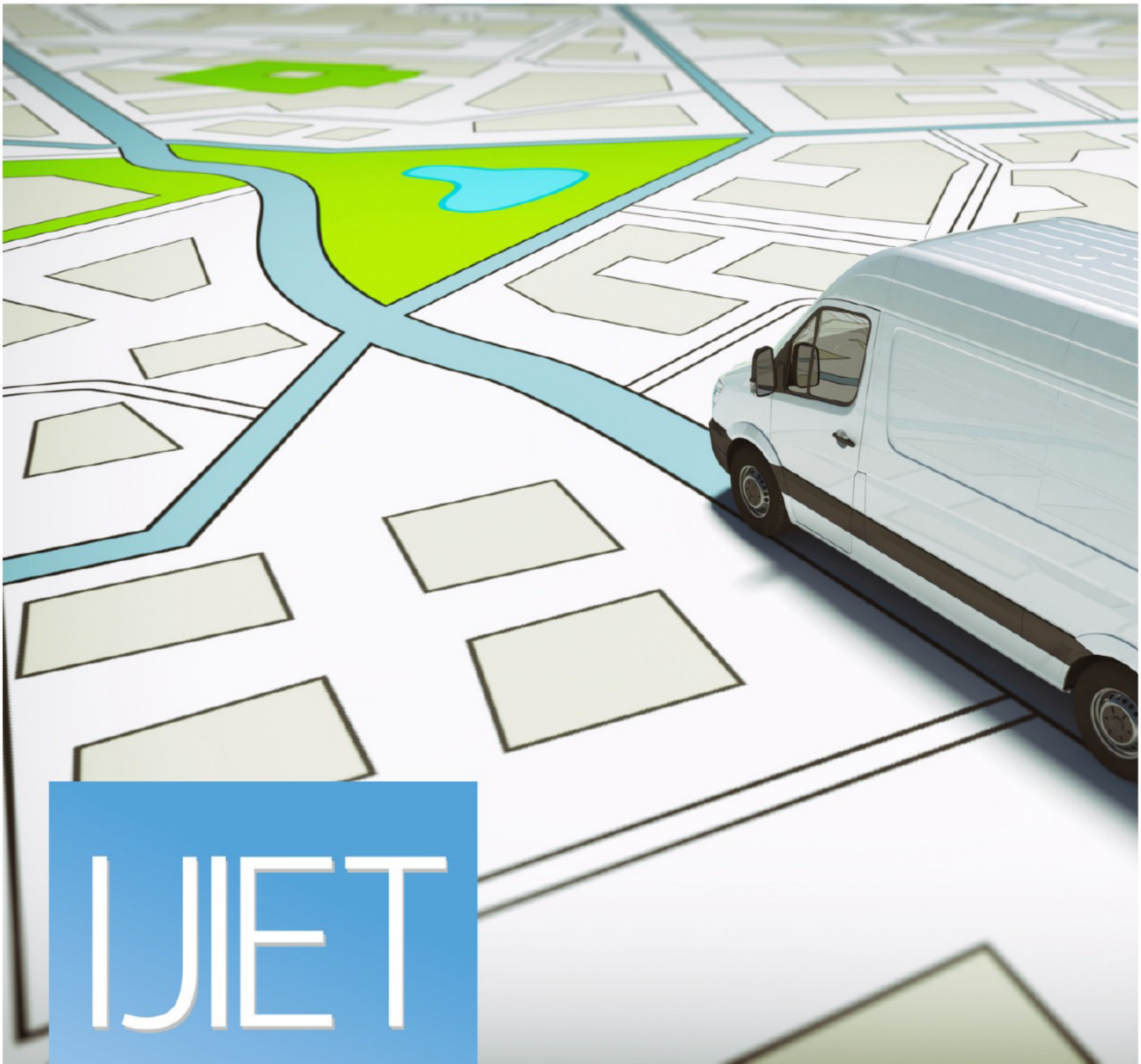

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Editorial Statement

I would like to welcome and present you with the research contents and articles in the fields of industrial education including education and technology. In this IJIET issues, it consists of a review article on “Multi frequency global navigation satellite system (GNSS)”, a book review on “GNSS Data processing”, and a research article on “Study and analysis on total electron content in seismo-ionospheric coupling for earthquake monitoring in Thailand”, respectively. For this IJIET issue, all interesting contents are authored by a professional and intelligent group of writers who are volunteers to share their outcomes of research and professional discussions.

On behalf of the editorial board, I would like to sincerely delight to thank you very much for your kind support and interest. If you would like to make us the comments and give us the suggestions regarding on this issue, I would be appreciated and sincerely accepted that to make things better.

With best regards,

P. Ken

Assistant Professor Dr. Prasert Kenpankho, D.Eng.
Editor in Chief
International Journal of Industrial Education and Technology (IJIET)

Contents	Page

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Review Article

MULTI FREQUENCY GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS)

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ABSTRACT

Multi frequency Global Navigation Satellite System (GNSS) is an important tool for using and investigating earthquakes, ionosphere, and communications. It is very significant understanding and applying on the multi frequency GNSS for supporting and solving in positioning and locating around and everywhere on the earth. GNSS is used as a support for seismo-ionospheric coupling for earthquake monitoring. GNSS finds the Total Electron Content (TEC) in the ionosphere. In communications, GNSS solves the delay time which is depended on the signal path from space to the earth. So, it is very significant understanding and applying on the multi frequency GNSS.

Keywords: GNSS; Multi frequency GNSS; GNSS frequency

I. INTRODUCTION

GNSS satellite is a key role in positioning and locating around and on the earth. At the present, rarely in research, GNSS is a main technique to classify geodetic methodology. Three types of research using GNSS are presented in earthquakes, ionosphere, and communications. For earthquake monitoring, GNSS is used as a support for seismo-ionospheric coupling. For ionosphere, GNSS is used for finding the Total Electron Content (TEC) in ionosphere. In communications, GNSS is used for solving the delay time which is depended on the signal path from space to the earth.

An et al. (2020, p. 7) researched on the multi-constellation GNSS precise point positioning with multi-frequency raw observations and dual-frequency observations of ionospheric-free linear combination. Huang et al. (2020, pp. 21-24) studied on efficient FPGA implementation of a dual-frequency GNSS receiver with robust inter-frequency aiding. Kim et al. (2021, pp. 10-20) reported the area-efficient universal code generator for multi-GNSS receivers. Krypiak-Gregorczyk (2019, pp. 931-951) found that the ionosphere response to three extreme events occurring near spring equinox in 2012, 2013, and 2015, observed by regional GNSS-TEC model. The fact is found out about carrier phase bias estimation of geometry-free linear combination of GNSS signals for ionospheric TEC modelling (Krypiak-Gregorczyk & Wielgosz, 2018, p. 45). Li et al. (2019, pp. 399-417) investigated the geometry-based cycle slip and data gap repair for multi-GNSS and multi-frequency observations. Lyu and Gao (2020, pp. 20-24) worked in an SVM based weight scheme for improving kinematic GNSS positioning accuracy with low-cost GNSS receiver in urban environments.

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In addition, Odolinski and Teunissen (2020, p. 91) analyzed on the best integer equivariant estimation: performance analysis using real data collected by low-cost, single-and dual-frequency, multi-GNSS receivers for short- to long-baseline RTK positioning. Moreover, Sreeja (2016, p. 24) found the impact and mitigation of space weather effects on GNSS receiver performance.

Above research about GNSS information is advantages in using multi frequency for earthquake, ionosphere, and communications. The main advantages associated with the use of GNSS systems in the study of anthropogenic and natural phenomena monitoring are widely used with a network of permanent reference stations. In addition, differential solutions which are required the use of a permanent stations are often used in above studies.

Multi frequency GNSS is an important tool for using and investigating earthquakes, ionosphere, and communications. It is very significant understanding and applying on the multi frequency GNSS for supporting and solving in positioning and locating around and everywhere on the earth.

II. GNSS REVIEW

GNSS is Global Navigation Satellites System which is the satellite network for positioning the location around and on the earth. GNSS has continuedly transmitted the signal to the GNSS receiver which can be received the data 24 hours a day. At the present, there are six GNSS systems, GPS (USA), GLONASS (Russia), Galileo (Europe), BeiDou (China), Quasi-Zenith Satellite System: QZSS (Japan), and Regional Navigation Satellite System: IRNSS (India) as shown in Table 1.

Table 1: GNSS information.

System	Country	Frequency	Number of Satellites	Orbit height (km.)	Covered Area
GPS	USA	- L1/1575.42 MHz - L2/1227.60 MHz - L5/1176.45 MHz	24 reserved 8	20,200	World
GLONASS	Russia	- G1/ 1602 MHz - G1a/ 1600.995 MHz - G2/ 1246 MHz - G2a/ 1248.06 MHz - G3 / 1202.025 MHZ	24 reserved 3	19,100	World
GAlileo	Europe	- E1 / 1575.42 MHz - E5a / 1176.45 MHz E5b / 1207.140 MHz - E5(E5a+E5b) / 1191.795 MHz - E6 / 1278.75 MHz	24 reserved 6	23,222	World
QZSS	Japan	- L1 / 1575.42 MHz - L2 / 1227.60 MHz - L5 / 1176.45 MHz - L6 / 1278.75 MHz -	4	32,000 - 40,000	Japan and Eastern Asia

Table 1: GNSS information (Cont.).

System	Country	Frequency	Number of Satellites	Orbit height (km.)	Covered Area
BeiDou	China	- B1 / 1561.098 MHz - B1C / 1575.42 (BDS-3 Signals) - B1A / 1575.42 MHz (BDS-3 Signals) - B2a / 1176.45 MHz (BDS-3 Signals) - B2 / 1207.140 MHz (BDS-2 Signals) - B2b / 1207.140 MHz (BDS-3 Signals) - B2(B2a+B2b)/1191.795 MHz (BDS-3 Signals) - B3/1268.52 MHz (BDS-2/3 Signals) - B3A / 1268.52 MHz (BDS-3 Signals)	41	7 GEO 35,786 7 IGSO reserved 3 35,786 21 MEO reserved 6 21,528	World
IRNSS	India	- L5 / 1176.45 MHz - S / 2492.028 MHz	6 reserved 1	36,000	India and neighbouring in 1,500 km.

III. MULTI FREQUENCY GNSS

GNSS composes of the Global Positioning System (GPS) of the United States, the Global Navigation Satellite System (GLONASS) of Russia, the Galileo system of the European Union, the BeiDou Navigation Satellite System (BDS) of China, Quasi-Zenith Satellite System (QZSS) designed by Japan, and India Regional navigation Satellite System (IRNSS) operated by India. GNSS has the advantages of earthquakes, ionosphere, and communications. GNSS provides highly precise positioning, navigation, and timing services for users all over the world. GPS uses L5 (1176.45 MHz) apart from L1 (1575.42 MHz) and L2 (1227.60 MHz). Besides, some GLONASS satellites can transmit the signal G1 (1602 MHz) and G2 (1246 MHz). The Galileo system run by the European Space Agency (ESA) provides services through frequency signals centered at E1 (1575.42 MHz) and E6 (1278.75 MHz). The BDS uses B1 (1561.098 MHz) and B2 (1207.14 MHz) signals. The QZSS designed by Japan transmits frequency signals centered at L1 (1575.42 MHz) and L2 (1227.60 MHz). Moreover, IRNSS operated by India transmits two frequency signals centered at L5 (1176.45 MHz) and S (2492.028 MHz) as shown in Table 2 and Table 3.

Table 2: GNSS Carriers.

GNSS	Carrier
GPS	L1CA, L1P, L1C, L2C, L2P, L5
GLONASS	G1CA, G1P, G2CA, G2P, G3 CDMA
Galileo	E1, E1b, E5a, E5b, E6, E5-AltBoc
BeiDou	B1I, B1C, B2a, B2b, B2I, B3I
QZSS	L1CA, L1C, L1S, L2C, L5, L6
IRNSS	L5, S

Table 3: GNSS frequency and frequency length.

GNSS	Frequency		Frequency length	
	f_1	f_2	λ_1	λ_2
GPS	1,575.42	1,227.60	0.1902	0.2442
GLONASS	1,602.00	1,248.60	0.1871	0.2401
Galileo	1,575.42	1,278.75	0.1902	0.24344
BeiDou	1,561.098	1,207.140	0.1920	0.2483
QZSS	1,575.42	1,227.60	0.1902	0.2442
IRNSS	2,492.028	1,176.45	0.1203	0.25482

IV. GNSS RECEIVER

In order to receive signals from GNSS satellites, GNSS receivers are needed for this purpose. There are many GNSS receivers in the markets that can be used. However, the full function of GNSS receiver has to use as a multi frequency GNSS receiver. In Table 4, GNSS receivers are shown in different supports and manufacturers.

Table 4: GNSS receiver.

GNSS receiver	GNSS support
 SATLAB GNSS SLX1-NG	- GPS (L1C/A, L1C, L2C, L2P, L5) - GLONASS (L1C/A, L2C/A, L2P, L3, L5) - Galileo (E1, E5 AltBOC, E5A, E5B, E6) - BeiDou (B1, B2, B3) - IRNSS (L5) แบบ QZSS (L1C/A, L1C, L2C, L5, L6) - SBAS (L1, L5) - L-Band (up to 5 channels)
 ComNav GNSS M300 Pro	- GPS (L1, L2, L2C, L5) - GLONASS (L1, L2, L3) - Galileo (E1, E5 AltBOC, E5a, E5b) - BeiDou (B1, B2, B3)

Table 4: GNSS receiver (cont.).

GNSS receiver	GNSS support
 Novatel GNSS PwrPak7D™	- GPS (L1 C/A, L1C, L2C, L2P, L5) - GLONASS (L1 C/A, L2 C/A, L2P, L3, L5) - Galileo (E1, E5 AltBOC, E5a, E5b) - BeiDou (B1I, B1C, B2I, B2a, B2b) - QZSS (L1 C/A, L1C, L1S, L2C, L5) - IRNSS (L5)
 VERIPOS GNSS receiver LD900	- GPS (L1 C/A, L1C, L2C, L2P, L5) - GLONASS (L1, L2, L3) - Galileo (E1, E5 AltBOC, E5a, E5b) - BeiDou (B1I, B1C, B2I, B2a, B2b) - QZSS (L1 C/A, L1C, L1S, L2C, L5)
 Bynav Technology GNSS receiver X1-6 RTK	- GPS (L1 C/A, L2C, L2P) - GLONASS (G1,G2) - Galileo (E1, E5b) - BDS (B1I,B2I) - BDS-3 (B1C, B2a) - QZSS (L1 C/A, L2C) IRNSS (L5)
 CHCNAV AVAZADA GNSS P5E	- GPS (L1 C/A, L2C, L2E, L5) - GLONASS (G1,G2) - Galileo (E1, E5A, E5B, E5AltBOC, E6[(2)]) - BDS (B1, B2, B3[(2)]) - BDS-3 (B1C, B2a) - QZSS (L1 C/A, L2C)

V. CONCLUSION

The study on multi frequency GNSS is very important understanding for supporting and solving in positioning and locating around and everywhere on the earth. GNSS is used as a support for seismo-ionospheric coupling for earthquake monitoring, finding TEC for the ionosphere study, and solving problems in communications. In the future, the number of multi frequency GNSS will increase, the number of GNSS users will add more, too. So, it is not too late to get the knowledge on the multi frequency GNSS.

AKNOWLEDGEMENT

The authors would like to thank Assistant Professor Dr.Prasert Kenpankho, Department of Engineering Education, King Mongkut's Institute of Technology Ladkrabang, Thailand, for giving and consulting on the multi frequency GNSS.

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Book Review

BOOK REVIEW: GNSS DATA PROCESSING
AUTHOR: J. SANZ SUBIRANA, J.M. JUAN ZORNOZA AND M. HERNÁNDEZ-PAJARES

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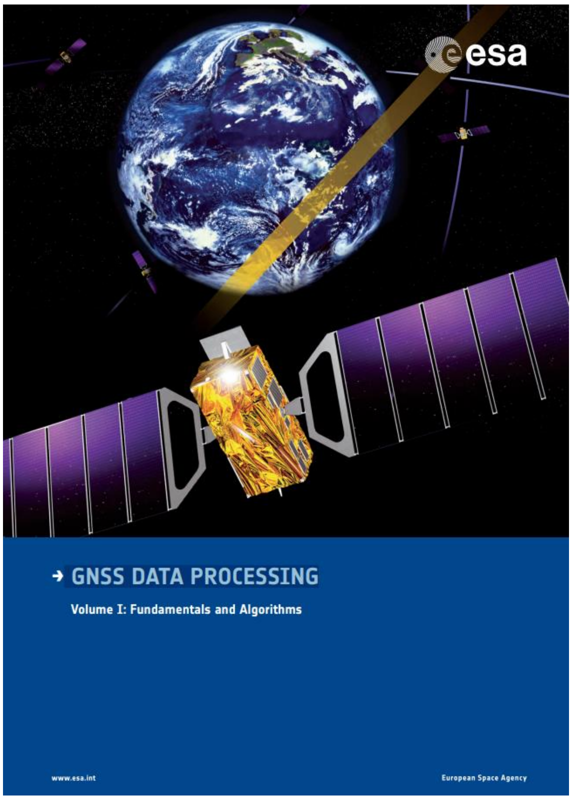
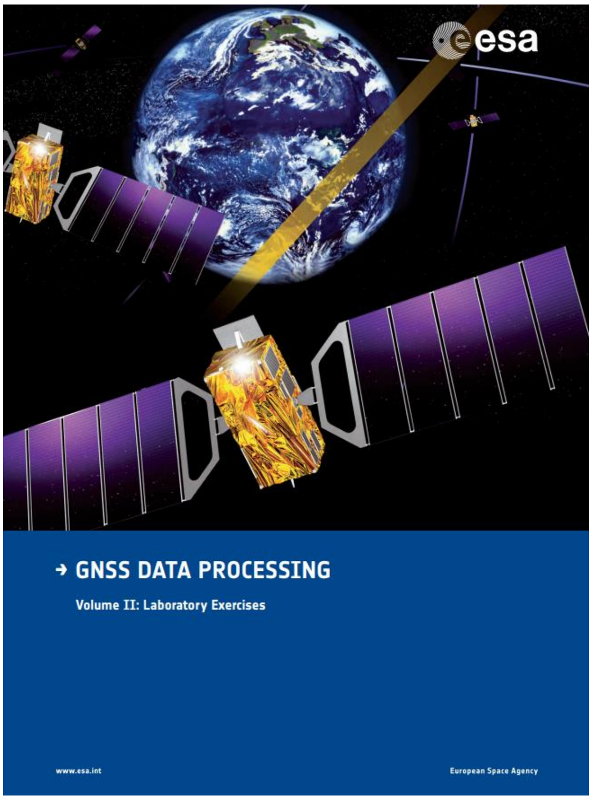
ABSTRACT

The book of GNSS DATA PROCESSING by J. Sanz Subirana, J.M. Juan Zornoza, and M. Hernández-Pajares, I finished reading this book and used it for understanding and referencing to my learning. I am fascinated and I like it. Its content is very useful for students, teachers, and people who interest in these matters. This book consists of the fundamentals, GNSS application by using self-learning materials, experimental software for addressing the GNSS-related problems emerging from different students capable of fast capacity, and experience development on real problem solving. Hopefully, you will love this book.

Keywords: GNSS





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The satellite communications industry has become an important part of today's communications infrastructure. There is constantly evolving and will bring more connectivity to the ways in which we communicate. Satellites have played a fundamental role in this connectivity where the many types of satellites provide data acquisition, research, telecommunications, safety and weather forecasts, navigation, business insights, environmental monitoring, and defense. In the last five years, the space industry has had a rapid increase in satellite launches. In many ways today's satellites are digital processors in the sky and they perform their communications capabilities.

Global Navigation Satellite System: GNSS is a satellite navigation system. Currently, GNSS systems have been brought into use in various fields for example navigation system, positioning, intelligence transportation systems, surveying, mapping, meteorology, forestry applications, precise agriculture and farming, earthquake and tsunami monitoring, emergency message service, structural health monitoring, or engineering design, etc. This technology is becoming very popular in many fields and research. Currently, many satellite navigation systems have been developed, such as GPS (USA), GLONASS (Russia), Galileo (Europe), BeiDou (China), QZSS (Japan), SBAS, etc.

As a researcher, I am studying in the field of GNSS signals application for earthquake surveying. I have studied from many different Information sources. I found a very interesting and informative book related to our research in the book of GNSS DATA PROCESSING. The details are as below.

Subirana et al. (2013) created this book of The GNSS DATA PROCESSING. This book has been updated and separated into two volumes which aimed at providing the basic information needed to begin studying or practicing on Global Navigation Satellite System (GNSS). This book contains materials for self-learning and software tools for practicing. The design and contents are focused on the concepts and techniques related to GNSS navigation and applications. Its purpose is to include all the elements necessary to understand how the system works and how to work with it.

Theory is the first volume that provides a summary of the fundamentals and algorithms of GNSS, including GPS, Glonass, Galileo, and Beidou. The laboratory experimental is the second volume with a wide range of selected practical examples going further into the theoretical concepts and their practical implementations. These exercises were developed with a special software package provided on CD-ROM with laboratory sheets for the practicing sessions. There are 15 practical sessions in a set of practical learning.

The GNSS course specified to all teachers, students, researchers and those who are interested wish to undertake a deeper study of satellite navigation, targeting the GNSS data processing, analysis issues, and the applications. The book of GNSS DATA PROCESSING, Fundamentals and Algorithms (Volume I) is divided into six chapters as follows:

Chapter 1 Introduction,

Chapter 2 GNSS Architecture,

Chapter 3 GNSS Time Reference, Coordinate Frames and Orbits,

Chapter 4 GNSS Measurements and Data Preprocessing,

Chapter 5 Measurement Modelling, and

Chapter 6 Solving Navigation Equations.

GNSS DATA PROCESSING: Laboratory Exercises (Volume II), this volume offers for the practicing part with the self-learning materials (GNSS-LABoratory: gLAB tool suite). These laboratories are the following advanced part of an experimental understanding of the Volume I: Fundamentals and Algorithms (theory). The contents of volume two consist of

Laboratory 1 The gLAB Tool Suite,
Laboratory 2 Laboratory Environment and Data Files,
Laboratory 3 Satellite Orbits and Clocks,
Laboratory 4 Measurement Analysis,
Laboratory 5 Measurement Modelling and Positioning,
Laboratory 6 Analysis of GPS SVN49 Anomaly, and
Laboratory 7 A GNSS Elemental Routines and gLAB Libraries.

After I finished learning from two books, I was inspired and supported my knowledge with theory and practice. I strongly believe that I can get benefits from the guideline and examples from GNSS DATA PROCESSING Volume I: Fundamentals and Algorithms and Volume II: Laboratory Exercises for applying them to solve the problems in the research. In addition, I believe that these are trust references in significant research resources.

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Research Articles

STUDY AND ANALYSIS ON TOTAL ELECTRON CONTENT IN SEISMO-IONOSPHERIC COUPLING FOR EARTHQUAKE MONITORING IN THAILAND

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ABSTRACT

This research shows the study and analysis on the relationship between earthquake events and the Total Electron Content (TEC) of the ionosphere over Thailand during 2007-2020. The method for this research is to use the International GNSS Service (IGS) network and the International Reference Ionosphere (IRI) model for finding TEC in the ionosphere and analyze the correlation on earthquake events and ionosphere characteristics. The result is correlated between IGS TEC and earthquake events at 0.089, which shows the positive evidence of correlation on earthquake magnitudes and ionosphere. The relationship between IRI TEC and earthquake events correlates at 0.056, which shows the positive correlation between earthquake events and ionosphere. A significant correlation among IGS TEC, IRI TEC, and earthquake events obviously showed direct evidence of correlation coefficient on ionosphere disturbance and earthquake magnitudes at 5.0 and upward magnitudes. As the results, it guides to making the future work and the researchers will study the significance of the development of earthquake warning systems.

Keywords: Earthquake; TEC; IGS TEC; IRI TEC; Correlation

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I. INTRODUCTION

According to earthquakes, there are natural phenomena caused by vibrations or shaking of the earth's surface, occurring at any time without humans being able to tell us. Wherever any places in the world, earthquakes can probably occur, causing damage to their entire property and various buildings, including the loss of life. Earthquakes may be related to changes Total Electrons Content (TEC) in ionosphere. The researchers investigated that earthquakes effect on the ionosphere which TEC changes. The behaviour of ionosphere TEC anomalies before large earthquakes have emerged as promising parameters for earthquake precursor detection and suggest the existence of a correlation between ionosphere disturbances in TEC and earthquake occurrences (Sharma et al., 2021, pp. 1-7). TEC is an important parameter in ionosphere which directly affects the propagation of radio waves through the ionosphere.

TEC computation can be extracted from Global Navigation Satellite System (GNSS) receiver, International GNSS Service (IGS) and International Reference Ionosphere (IRI). There are many reports on the execution of different methods for the relationship and monitoring of the earthquake and ionospheric anomalies from ground and space measurements during seismic preparation period s before and after the main shock in a statistical (Shah & Jin, 2015, pp. 42-49; Shah et al., 2020, pp. 268-276). The researchers used the correlation for relationships between the earthquake events and the disturbance of ionosphere. For example, Afraimovich et al. (2004, pp. 339-354) studied the variations of the total electron content in the ionosphere from GPS data recorded during the Hector Mine earthquake of October 16th, 1999, California. Arikan et al. (2008, pp. 1-13) estimated the values of single station interfrequency receiver bias using GPS TEC. Cahyadi and Heki (2013, pp. 1777-1787) found the ionospheric disturbances of the 2007 Bengkulu and the 2005 Nias earthquakes, Sumatra, observed with a regional GPS network. Grawe and Makela (2015, pp. 472-483) investigated the ionospheric responses to the 2011 Tohoku, 2012 Haida Gwaii, and 2010 Chile tsunamis: Effects of tsunami orientation and observation geometry. Kakinami et al. (2021, pp. 1-12) studied the onset altitudes of co-seismic ionospheric disturbances determined by multiple distributions of GNSS TEC after the foreshock of the 2011 Tohoku earthquake on March 9th, 2011. Kenpankho et al. (2021, pp. 2152-2159) analyzed the real-time GPS receiver bias estimation. Kenpankho et al. (2013, pp. 1820-1826) compared the observed TEC values with IRI2007 TEC and IRI-2007 TEC with optional foF2 measurement predictions at an equatorial region, Chumphon, Thailand. In 2011, Kenpankho et al. (2011, pp. 365-370) made the comparison of GPS TEC measurements with IRI TEC prediction at the equatorial latitude station Chumphon, Thailand. Nishioka et al. (2021, pp. 1-12) analyzed the statistical analysis of TEC: long-term estimation of extreme TEC in Japan. The outcome of the statistical characteristics of seismo-ionospheric GPS TEC disturbances prior to global Mw was ≥ 5.0 earthquakes (1998–2014) (Shah & Jin, 2015, pp. 42-49). Ulukavaka and Inyurtb (2020, pp. 123-130) studied seismo-ionospheric precursors of strong sequential earthquakes in Nepal region. Moreover, Sharma et al. (2021, pp. 1-7) developed a monitoring system for ionospheric TEC variability before earthquakes.

According to study and investigation of the outcome of the statistical characteristics of seismo-ionospheric GPS TEC disturbances prior to global Mw was ≥ 5.0 earthquakes (1998–2014) (Shah & Jin, 2015, pp. 42-49), Ulukavaka and Inyurtb (2020, pp. 123-130) presented on seismo-ionospheric precursors of strong sequential earthquakes in Nepal region found that an acoustic gravity waves from earthquake significantly affected TEC values at magnitudes 2.0 to 2.5 less than pre-earthquake variations in the ionosphere. It has been observed that ionospheric anomalies might continue up to one month, 15 days prior to and following earthquakes. Pre-earthquake ionospheric TEC may plummet starting from five days till one day ago when earthquakes are at magnitudes equal to and higher than 6.0. Kenpankho et al. (2011, pp. 365-370) presented about comparison of GPS TEC measurements with IRI TEC prediction at the equatorial latitude station, Chumphon, Thailand, they found that the TEC derived from the IRI-2007 model agrees with the GPS TEC data mostly in the morning hours, but that it generally underestimates the GPS TEC. The maximum differences are about 15 TECU during the daytime and five TECU during the nighttime. The underestimation is more evident at daytime than at nighttime, and the development of a monitoring system for ionospheric TEC variability before the earthquakes (Sharma et al., 2021, pp. 1-7). The researchers applied and studied as the example research methodology to investigate the relationship between earthquake events and TEC of the ionosphere in Thailand during 2007-2020.

The research is aimed to study and analyze the relationship between earthquake events and the disturbance of ionosphere. This method focuses on the IGS TEC and IRI TEC and then finds the correlation between earthquake events and ionosphere. The researchers assumed that TEC results are to show a significant relationship with earthquake events, to guide the development of earthquake alarm, and to develop the telecommunication systems.

II. METHODOLOGY

A. Earthquake events data

For earthquake events, the earthquake data are received from Earthquake Observation Division, Thai Meteorological Department (TMD) site: https://earthquake.tmd.go.th/inside.html. The severity of an earthquake can be expressed in terms of both intensity and magnitude. The magnitude scale of earthquakes can be classified in Table 1.

Table 1: The magnitude scale of earthquakes.

Magnitudes	Interpretation
1.0-2.9	Hanging objects may swing.
3.0-3.9	The vibrations may be like a passing truck.
4.0-4.9	Windows may be broken, cause small or unstable objects to fall.
5.0-5.9	Furniture moves, chunks of plaster may fall from walls.
6.0-6.9	It damages to well-built structures, severely damages to poorly built ones.
7.0 or more	Building is displaced from foundations, things crack in the earth, and underground pipes broken.

In this research, according to the earthquake magnitude 1.0-2.0 as a rarely effective on TEC, researchers focused on the earthquake magnitude starting at 3.0 and above for comparing with TEC. We collected data on 472 earthquake events from 2007-2020 (Thai Meteorological Department [TMD], 2007, Online). There is classified by regions of Thailand as follows in Figure 1.

For investigating the relationship between earthquake events and TEC disturbance over Thailand during 2007-2020, researchers used the data from four regions of Thailand following as 1) Southern of Thailand and Andaman Sea; Phuket, Phangnga, Ranong, Suratthani, Chumphon, Trang, and Andaman sea; 2) Western of Thailand and Andaman sea; Kanchanaburi, Tak, and Andaman sea; 3) Northern of Thailand are Maehongson, Chiangmai, Lamphun, Chiangrai, Payou, Lampang, Phrae, Nan, and Uttaradit; and 4) Northeast of Thailand are Nakhon ratchasima, and Loei.

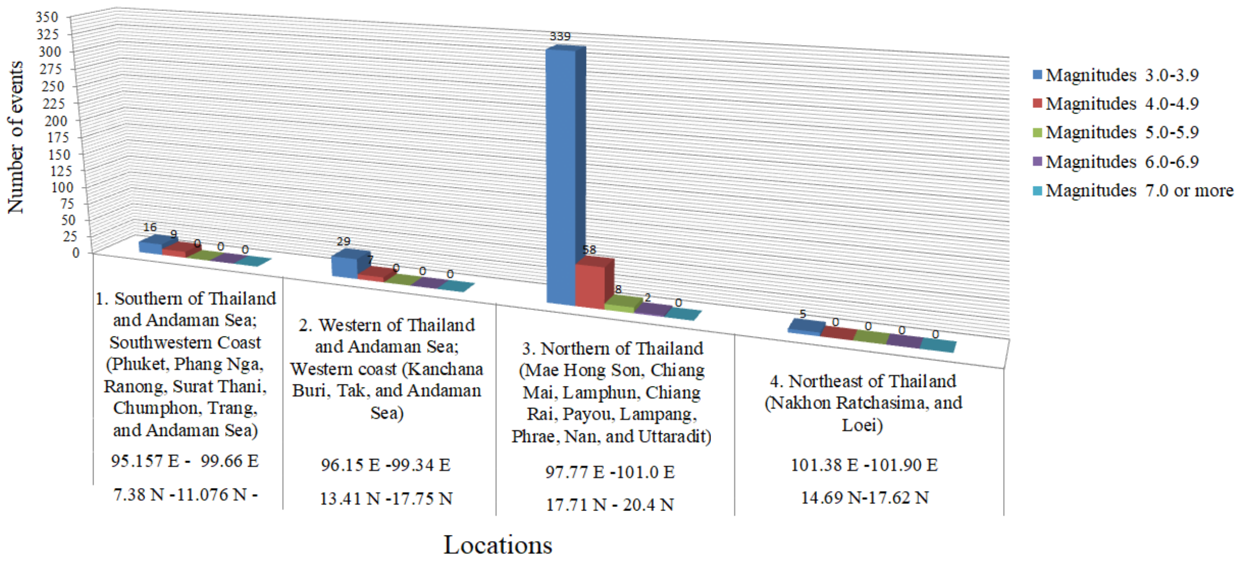

Figure 1: Earthquake events classified by magnitudes and regions of Thailand.

According to the information in Figure 1, the results of the earthquake events data in Thailand from 2007 to 2020 of 472 earthquake events of 3.00 Magnitudes upward as follows: 1) 389 earthquake events of magnitude 3.00 to 3.99, 2) 74 earthquake events of magnitude 4.00 to 4.99, 3) eight earthquake events of magnitude 5.00 to 5.99, 4) one earthquake event of magnitude 6.00 to 6.99, and 5) The event of magnitude 7.00 and upward does not exist.

B. Total Electron Content (TEC)

The TEC is the total electron content along a signal ray path between satellite and receiver which is assumed to include all the electrons in a column with a cross section of 1 m^2 and extending from receiver to satellite. TEC is measured in TECU with 1 TECU = 10^{16} el/m^2.

The Slant Total Electron Content (STEC) from a satellite to a receiver can be obtained from the differences among dual GNSS frequencies (f_1 and f_2), the pseudoranges (P_1 and P_2), and the difference between the carrier phases (L_1 and L_2) of the two methods as follows; (Blewitt, 1990, pp. 199-201; Ma & Maruyama, 2003, pp. 2084-2085).

$$TEC = \frac{2(f_1 f_2)^2}{k(f_1^2 - f_2^2)}(P_2 - P_1) \qquad el/m^2 \tag{1}$$

or

$$TEC = \frac{2(f_1 f_2)^2}{k(f_1^2 - f_2^2)}(L_1\lambda_1 - L_2\lambda_2) \qquad el/m^2 \tag{2}$$

In equations (1) and (2), f_1 is 1575.42 MHz, f_2 is 1227.60 MHz, P_1 and P_2 are the pseudoranges (P_1 measured on L_1, and P_2 measured on L_2), λ_1 and λ_2 are the wavelengths corresponding to f_1 and f_2 (λ_1 = 0.1904 m, λ_2 = 0.2444 m), L_1 is the phase of f_1 and L_2 is the phase of f_2, and k = 80.62 m^3/s^2.

Once STEC is known, we use STEC to find the Vertical Total Electron Content (VTEC). Where VTEC, in el/m^2, can be calculated and analyzed (Ma & Maruyama, 2003, pp. 2084-2085) as follows;

$$\mathrm{VTEC}=\mathrm{STEC}\times\cos\chi \quad (3)$$

where χ the zenith angle x is expressed as

$$\chi=\arcsin\left(\frac{R_E\cos\alpha}{R_E+h}\right) \quad (4)$$

where α is the elevation angle of the satellite, R_E is the mean radius of the Earth ≈ 6,378 km, and h is the height of the ionospheric layer, which is assumed to be 400 km (Ma & Maruyama, 2003, pp. 2084-2085).

C. IGS TEC data

The researchers used the TEC values from the IGS which are maintained and monitored by the International GNSS Service (IGS). The IGS relies on an international network of over 514 continuously operating dual frequency GNSS stations (International GNSS Service [IGS], 1998, Online). The IGS collects, archives, and distributes GNSS observation data sets. It provides the TEC map data available on the Internet, and these data can be accessed from the File Rapid and Final ionospheric TEC grid site: https://igs.org/, and then click link https://igs.org/products/#ionosphere. Ionospheric products are available through CDDIS website: https://cddis.nasa.gov/archive/gnss/products/ionex/YYYY/DDD/. Next, we searched TEC from IGS on selected seismic events of magnitude 3 and above according to earthquake events data from 2007 to 2020. The IGS information must be the same location, date, and times as the earthquake events were selected. We selected IGS station locations are available in Thailand and the closest distances to earthquake sources were Chiang Mai (18.761 N, 98.932 E), Chumphon (10.725 N, 99.374 E), and Chulalongkorn University (13.736 N, 100.534 E). We collected IGS TEC data five days before earthquake events and five days after earthquake events, there are 11 days in total. Finally, the IGS TEC values and the group magnitude scale of earthquakes data which classified by vibration near the epicenter were analyzed and displayed. The IGS TEC data collecting process is shown as a Figure 2.

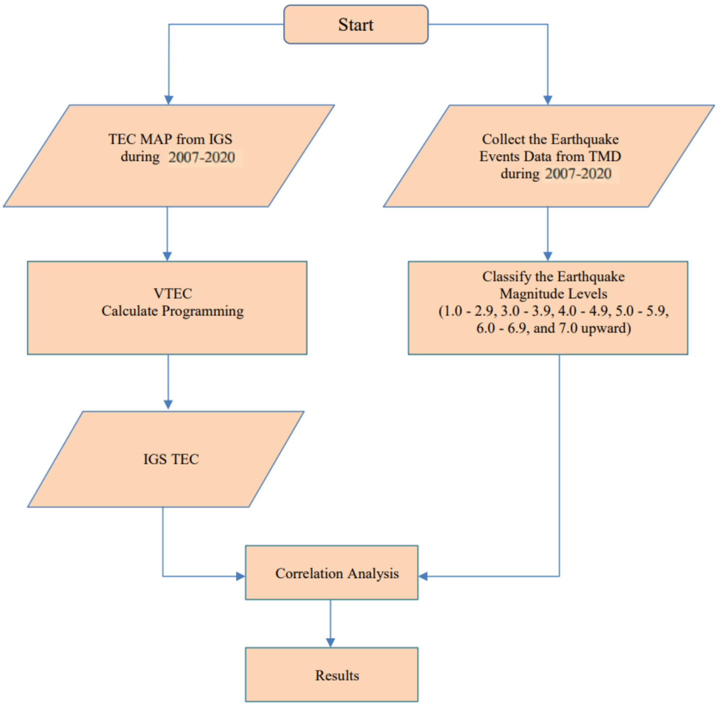

Figure 2: IGS TEC data collection and data analysis process.

The IGS station locations are available in Thailand is shown Figure 3.

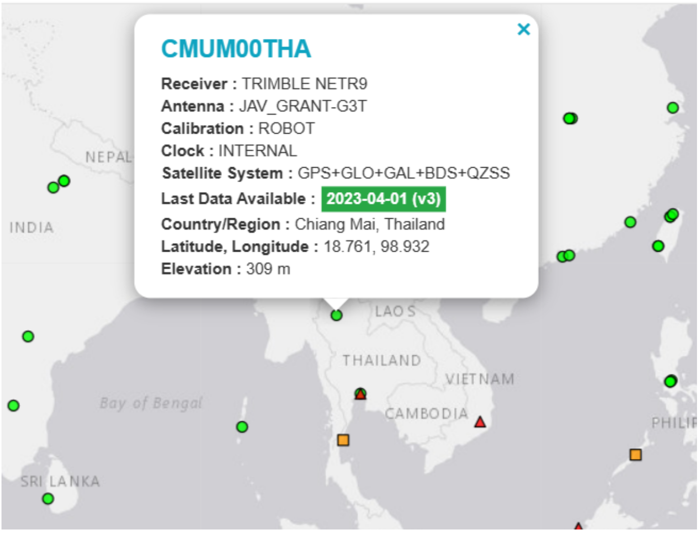

Figure 3: The locations of IGS station are available for Thailand.

D. IRI TEC data

The International Reference Ionosphere (IRI) is an international project sponsored by the Committee on Space Research (COSPAR) and the International Union of Radio Science (URSI). The IRI TEC can be found from IRI model version 2016 site: ttps://ccmc.gsfc.nasa.gov/modelweb/models/iri2016_vitmo.php. Several steadily improved editions of the model have been released. For given location, time, and date, IRI provides monthly averages of the electron density, electron temperature, ion temperature, and ion composition in the ionospheric altitude range. You can select desired output parameters of the model for example: independent variables (Year, Month, Day of month, Day of year, Hour of day, Height, etc.) and IRI model parameters (Electron density, Ratio of Ne and F2 peak density, TEC, Electron Temperature, Height of F2 peak, etc.).

For finding IRI TEC data, select the entered parameters as follows; date and time, coordinates (coordinates type, latitude, longitude, and height), profile type and range, optional input, and desired output parameters which can be selected as TEC output (National Aeronautics and Space Administration [NASA], 2022, Online). The IRI input parameters must be the same location, date, and times as the earthquake event were selected. We collected data five days before earthquake events and five days after earthquake events, there are 11 days in total. The procedure for calculating IRI TEC model is shown in Figure 4 and the process of data collection and analysis of IRI TEC as shown in Figure 5.

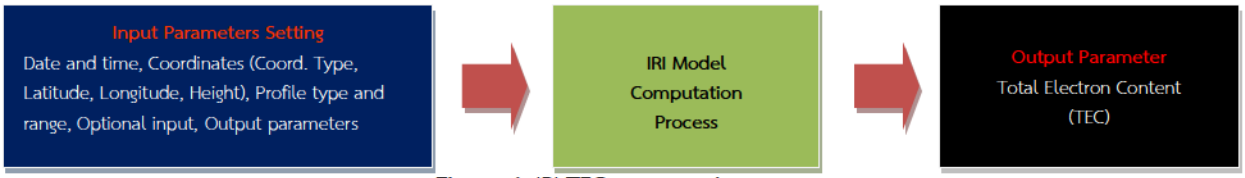

Figure 4: IRI TEC computation process.

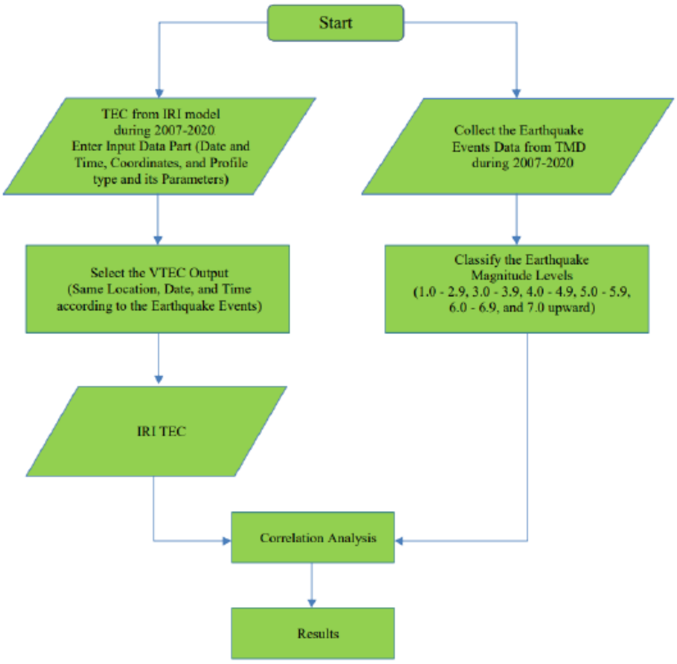

Figure 5: IRI TEC data collection and data analysis process.

E. Correlation coefficient

The correlation coefficient can be calculated (Mukaka, 2012, p. 69) following as

$$r = \frac{\sum_{i=1}^{n}(x_i - x)(y_i - y)}{\sqrt{\left[\sum_{i=1}^{n}(x_i - \bar{x})^2\right]\left[\sum_{i=1}^{n}(y_i - \bar{y})^2\right]}} \quad (5)$$

where, r is the correlation coefficient of the linear relationship between the variables x and y, x_i is the value of the magnitude of earthquake in a sample, $\overline{X}$ is the mean of the value of the magnitude of earthquake, y_i is the values of the TEC in a sample, and $\overline{y}$ is the mean of the values of the TEC.

The correlation coefficient meaning is as below;

the correlation coefficient value closes to -1 means having an inverse relationship, the correlation coefficient value closes to +1 means having a direct relationship, and

the correlation coefficient value closes to 0 means no relationship.

This dataset is used to analyse the relationship between earthquake events and TEC changes in Thailand. For earthquake magnitudes of 5.0-5.9, 6.0-6.9, and 7.0 and above, as categorized previously, due to the limited occurrence of earthquakes, the researchers divided them into three groups for analysis. In this research, Earthquake magnitudes were divided into 3 groups: 3.0-3.9, 4.0-4.9, 5.0 and above. This allows us to compare daily TEC values from IGS TEC and IRI TEC.

III. RESULTS AND DISCUSSION

A. IGS TEC data results

The results show 472 earthquake events of magnitude at 3.0 and above compared with IGS TEC by data collecting from 2007-2020 as shown in Figure 6.

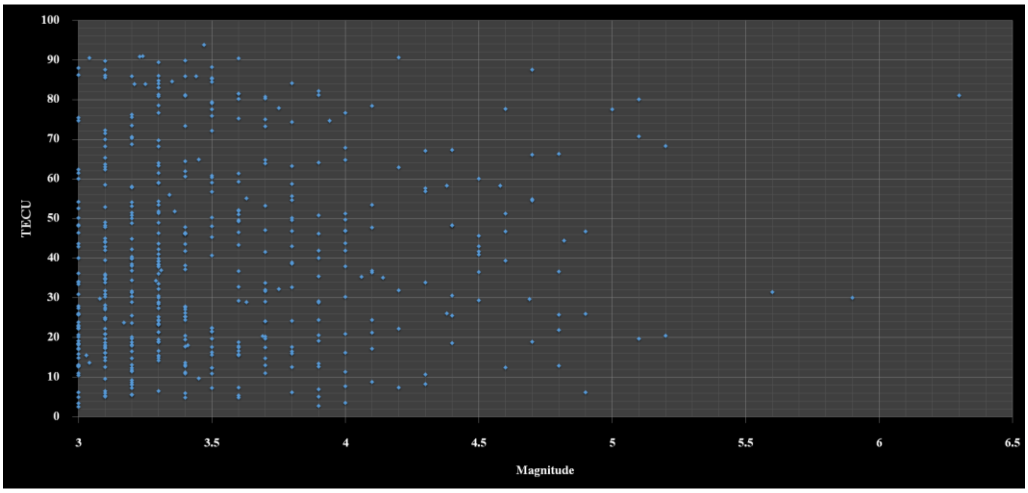

Figure 6: 472 earthquake events of magnitude at 3.0 and above compared with IGS TEC.

In Figure 6, this result can be implied that the magnitude above 4.1 gives the TEC value mostly above 10 TECU. The results show that the number of earthquake magnitude is high, the amount of TEC increases. At the results, there are the significant events that the earthquake is related to the disturbance of ionosphere.

B. IRI TEC data results

Moreover, the researchers investigated more on the comparison between the earthquake events and the disturbance of ionosphere by using the IRI TEC and earthquake events during 2007-2020 as shown in Figure 7.

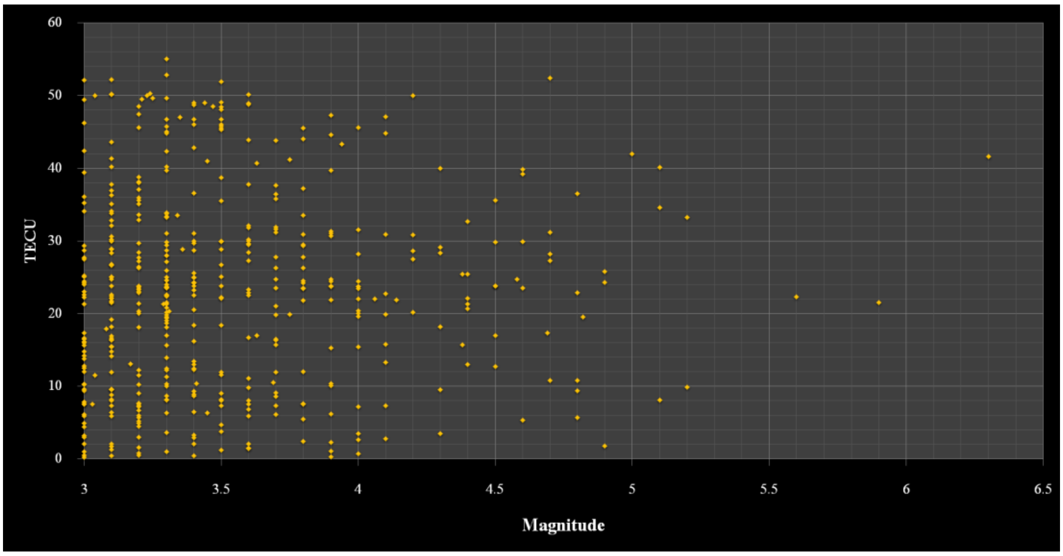

Figure 7: 472 earthquake events of magnitude at 3.0 and above comparing with IRI TEC.

In Figure 7, this result can be implied that the magnitude above 5.1 gives the TEC value mostly above 10 TECU. The results show that the number of earthquake magnitude is high, the amount of TEC increases. At the results, there are the significant events that the earthquake is related to the disturbance of ionosphere.

C. The relationship between earthquake events and the TEC of the ionosphere over Thailand during 2007-2020.

The results of the relationship between the earthquake events and the disturbance of ionosphere by using the IGS TEC, IRI TEC and 472 earthquake events during 2007-2020 as shown in Table 2.

Table 2: The relationship between the earthquake events and the IGS TEC and IRI TEC disturbance in ionosphere.

Correlation Coefficient / Magnitude of Earthquake	IGS TEC Earthquake Event Day	IRI TEC Earthquake Event Day
3.0 - 3.9	0.09170	0.03463
4.0 - 4.9	0.02426	0.00781
5.0 and upward	0.29561	0.27341
Correlation Coefficient in Total	**0.08926**	**0.05634**

Refer to Table 2, results of the relationship between the earthquake events and the TEC disturbance in ionosphere by using the IGS TEC, IRI TEC and 472 earthquake events during 2007-2020 as follows: 1) the correlation coefficient of earthquake events and ionosphere TEC anomalies using the IGS data is 0.089, 2) the correlation coefficient of earthquake events and ionosphere TEC anomalies using the IRI model is 0.056. For classification by the magnitude of the earthquake caused, there are correlation coefficients as follows: magnitude of 3.0-3.9 ($r_{IGS\ TEC}$ = 0.092, $r_{IRI\ TEC}$ = 0.092), magnitude of 4.0-4.9 ($r_{IGS\ TEC}$ = 0.024, $r_{IRI\ TEC}$ = 0.008), and magnitude of 5.0 and upward ($r_{IGS\ TEC}$ = 0.296, $r_{IRI\ TEC}$ = 0.273) respectively. The correlation coefficient curve is shown in Figure 8.

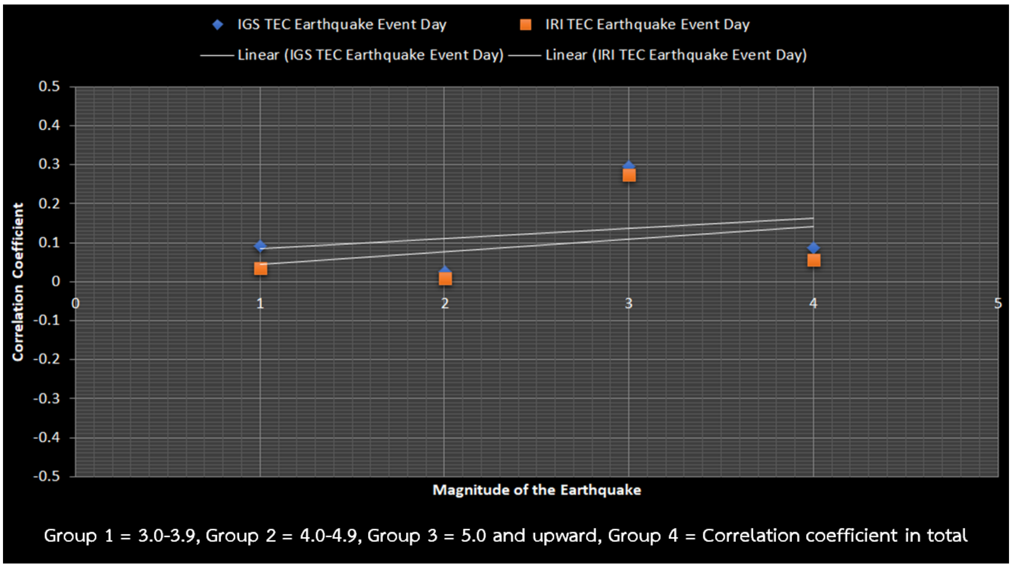

Figure 8: The correlation coefficient of the relationship between the earthquake events and the disturbance of ionosphere.

Figure 8 shows the evidence of correlation between earthquake events and the TEC values. The relationship among IGS TEC, IRI TEC, and earthquake events shows positive values as the direct evidence of correlation on earthquake magnitudes and ionosphere. The correlation values for 5.0 and upward magnitudes are 0.296 for IGS TEC and earthquake events and 0.273 for IRI TEC and earthquake events. The researchers found that the relationships among IGS TEC, IRI TEC, and earthquake events at 5.0 and upward magnitudes are significantly correlation values as direct relationship. According to the results of correlation at 5.0 and upward magnitudes, the TEC disturbances in ionosphere are significantly related to earthquake occurrence in Thailand.

According to the study and analysis on the TEC and earthquake events in Thailand, the researchers found that the seismo-ionosphere coupling occurs in the investigation during the years 2007-2020. This results evidence and support Ulukavaka and Inyurtb (2020, pp. 123-130) who studied the seismo-ionospheric precursors of strong sequential earthquakes in Nepal region. They found that the disturbance of ionosphere was likely related to the process of seismic connection with the ionosphere that occurred on April 25th, 2015. The significantly affected TEC values at magnitudes 2.0 to 2.5 less than pre-earthquake variations in the ionosphere. It has been observed that ionospheric anomalies might continue up to one month, 15 days prior to and following earthquakes. Pre-earthquake ionospheric TEC may plummet starting from five days till one day ago when earthquakes are at magnitudes equal to and higher than 6.0. The results were the ionospheric anomaly that occurs before an earthquake and ionosphere anomalies caused by aftershocks may be caused by large earthquakes. In addition, Shah and Jin (2015, pp. 42-49) investigated using the TEC of GPS global ionosphere maps (GIM). Statistical analysis of 10-day TEC data before global Mw ≥ 5.0 earthquakes shows significant enhancement 5 days before an earthquake of Mw ≥ 6.0 at a 95% confidence level. The finding of earthquakes with a focal depth of less than 60 km and Mw ≥ 6.0 is presumably the root of deviation in the ionospheric TEC because earthquake breeding zones have gigantic quantities of energy at shallower focal depths. Increased anomalous TEC is recorded in cumulative percentages beyond Mw = 5.5. Sharpness in cumulative percentages is evident in seismo-ionospheric disturbance prior to Mw ≥ 6.0 earthquakes. Seismo-ionospheric disturbances related to strike slip and thrust earthquakes are noticeable for magnitude

Mw 6.0-7.0 earthquakes. The relative values reveal high ratios (up to 2) and low ratios (up to - 0.5) within 5 days prior to global earthquakes for positive and negative anomalies. The anomalous patterns in TEC related to earthquakes are possibly due to the coupling of high amounts of energy from earthquake breeding zones of higher magnitude and shallower focal depth. Moreover, Sharma et al. (2021, pp. 1-7) developed a monitoring system for ionospheric TEC variability before the earthquakes which integrated TEC, geomagnetic storm, and solar flare data. They carried out a TEC anomaly study before earthquakes occurred. In the present study, an earthquake monitoring by using the observations of the ionosphere conditions before an earthquake may help in understanding earthquake precursors and space weather conditions.

IV. CONCLUSION

At the results and discussion, the relationships among IGS TEC, IRI TEC, and earthquake events at 5.0 and upward magnitudes are the significant events that the earthquake is related to the disturbance of ionosphere which shows the evidence of correlation on earthquake events and the TEC values monitoring in Thailand. The relationship among IGS TEC, IRI TEC, and earthquake events shows the direct evidence of correlation on earthquake magnitudes and ionosphere. The researchers found that TEC results are significant relationship with earthquake events at 5.0 and upward magnitudes which can be guided the development of earthquake alarm and developed the telecommunication systems as such Global Navigation Satellite Systems (GNSS).

ACKNOWLEDGEMENT

The researchers would like to thank International GNSS Service (IGS) for TEC Map data and International Reference Ionosphere (IRI) for TEC calculation results and various parameters. We would like to thank the staff members of Earthquake Observation Division, Thai Meteorological Department (TMD), and EIDA Data Archives for sharing the earthquakes event data.

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Research Journal Paper Name

Aaaaa Lastname *, Bbbbb Lastname and Ccccc Lastname

Received: October 15, 2022
Revised: November 20, 2022
Accepted: December 1, 20,2022

ABSTRACT

---Only One Paragraph 250-300 words---

Keywords: Firstword; Secondword; Thirdword; Soonword

I. INTRODUCTION

--First Paragraph for important introduction--

------------------------Second Paragraph for research literature review with reference in context, APA 7th------------
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------------------------Third Paragraph for main idea from research review with reference in context, APA 7th ------
----

---Fourth Paragraph for objective---

Corresponding author e-mail: first@firstandname.com*
Organization name, Country.

II. LITERATURE REVIEW (This name can be changed)

--First Paragraph for more details on literature review from second and third paragraph in INTRODUCION with reference in context, APA 7th ---

--Second Paragraph for the assumption (if any) --

III. METHODOLOGY

-- Paragraphs are depended on the author --There are some pictures here. --

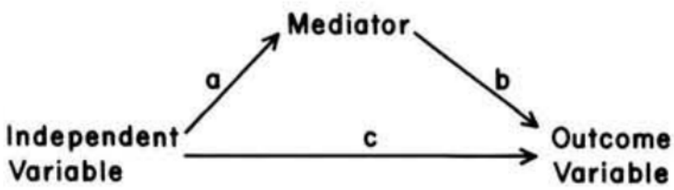

Figure 1: Independent variable model
Source: Baron and Kenny (1986, p. 1176)

IV. RESULTS

--- Paragraphs are depended on the author -- There are some tables here. --

Table 1: The factor on independent variable

Path	Effects on each variable
a	Independent Variable -> Mediator
b	Mediator -> Outcome Variable
c	Independent Variable -> Outcome

Source: Baron and Kenny (1986, p. 1176)

V. CONCLUSION AND DISCUSSION

--- First Paragraph for conclusion --

-- Second Paragraph for discussion, any references, APA 7th --

AKNOWLEDGEMENT (If any)

--Only One Paragraph---

REFERENCE

---APA 7th reference---

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Part 1 consists of	
1.1 Title	Thai and English should be shortly represented on the research goals
1.2 Authors	Responded author and co-authors in Thai and English giving first name and last name but no title and referring by number.
1.3 Abstract	Thai and English should be shortly focused and directly scoped on the research objective, research methodology and the research summary. It should not exceed 250 - 300 words.
1.4 Keywords	Thai and English should choose keywords related to article.

Part 2 Contents
- Introduction It is very important part and reason to guide the readers to understand of the research. It should be directly and shortly present the contents, objectives, methodologies, and the results of the research. It should not be written more than 250-300 words.
- Objectives
- Hypothesis (if applicable)
- Scope of Research
- Research Methodology
- Results (It should show the results in statistically significant according to objectives.)
- Discussion (It should present the reasons of the results as it is or compare to other writer's results.)
- Conclusion (Give the conclusion based on the results and the discussion.)
- Acknowledgement (If applicable) No needs to put the number for this content and use the same size letter
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3. Printed Format

3. Printed format

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- Font Th SarabunPSK only
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3.2 Titles

In Thai and English. For English, using the Upper case (18 Bold inch)

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It should write in all righted authors. Identify the responded author with email. (15 Bold inch)

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- Abstract is written in 14 bold inch and place it on the left side.
The word Abstract, only letter A is upper case and others are in 14 inches with 1 column.
- Contents are in 1 column with the headline in 16 bold inches and sub headline is in 14 bold inch. The contents are in 14 inches and given in 5 spaces.

3.5 Keywords): Fonts size 14 inches.

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1. Leaving 1 row before inserting the table and giving 1 row before writing the information for the table in details.
2. Uses "Table **...**" at the left corner with font 12 bold inch.
3. Table name is in font 12 inches and if the table detail is longer than 1 row, it should be started with new row by the same starting column.
4. Using only in column table as opened the left and right alignments.

Table 1 (Table name is in 12 inches.)

Title (12 bold inch.)	**Title**	**Title**	**Title**	**Title**
Content (12 inches.)	Content	Content	Content	Content
Content	Content	Content	Content	Content

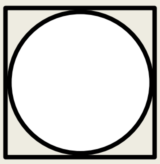

Figure 1 **................** (Font is in 13 inches with in center column)

3.7 Discussion part in 16 inches.

At left column for contents. For first row in each paragraph, it has to give 4 word-spaces (font in 14 inches.)

3.8 Conclusion part in 16 inches.

At left column for contents. For first row in each paragraph, it has to give 4 word-spaces (font in 14 inches.)

3.9 Acknowledgement in 16 inches. Without putting number in front of topic (Font in 14 inches.)
No needs to put the number for this content (font in 14 inches.)

3.10 References title font in 16 inches.

(Content font is in 14 inches.)

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1.1 Sub title (6 word-spaces in 14 font inches.)

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1.1.1.1 Third sub title

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(1.1) sub title of (1)

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1.2 The original or submitted paper must be only formatted as the Journal of Industrial Education printed format. **If NOT follows as directions, <u>the author is informed and the paper will NOT be stepped any forward.</u>**

1.3 Paper is needed to be clear in contents and pictures.

1.4 Paper is Not published or Not printed in any sources such as journal, conferences, so on.

1.5 The author is fully responsibility to prove the correction of any requirement of Journal of Industrial Education format.

1.6 Typing or writing journal application form and attach transfer receipt.

1.7 Filling and signing on form to submit industrial education journal article. The first name is the author name, then the second to sixth are advisor names and so on.

1.8 Preparing and submitting paper is noted as forms. URL/ http://www.tci-thaijo.org/index.php/JIE

1.8.1 SCAN PDF FILE AND MICROSOFT WORD(.doc. or .docx.) to database and naming the files separately.

1.9 Competely fill out the member form of Journal of Industrial Education.

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