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Ionospheric Behaviour Analysis over Thailand Using Radio Occultation Technique.

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ABSTRACT

With the advent in the development of science and technology in the field of space and atmospheric science in order to obtain accurate result, hence the use of radio occultation technique in the investigation of the amount of electron density and Total Electron Content presence in equatorial region particularly over Thailand. In this research, radio occultation data obtained from UCAR/CDAAC was used to observe daily, monthly, seasonal and the entire year 2013 Ionospheric TEC and electron density variation due to changes and instability of solar activities from time to time. It was observed that TEC was high (ionosphere was more disturbed or violent) in May and spread over a wide range of altitude and summer season has the highest TEC value for the year 2013 which means at this period GNSS measurements was more prone to error. It was noted that ionospheric variations or fluctuations was maximum between 200km and 450km altitude. The results of the study show that ionospheric perturbation effects or irregularities depend on season and solar activity.

Keywords - Electron Density, Equatorial Region, Ionosphere, Radio Occultation and TEC.

I. INTRODUCTION

A numerical model is one of the most realistic descriptions of the condition of the atmosphere called weather prediction. The reality of these models has reached a stage where their representation depends mainly on the available data to initialize the prediction computations more than just mathematical model. One way to achieve better and evenly distributed global data coverage is satellite observations of meteorological standard parameters [1]. A lot of efforts have been made to successfully model the atmosphere to determine the contributions of water vapour, temperature and total electron content (TEC) some years back. Largely, the efforts depend on the availability of global data that are provided by direct measurements from satellite based ionosondes on board satellite missions. This method is no more in vogue with the advent of radio occultation technique, which is the current and most suitable today [2].

The integration of the electron density along the signal path *S* is called Slant Total Electron Content (STEC). The quantity described can be interpreted as the total amount of free electrons in a cylinder with a cross sectional area of 1m^2 and measured in Total Electron Content Units (TECU), where 1 TECU is equivalent to 10^{16} electrons/m^2. The effect in meters of the ionised medium on phase and group signal propagation can be described with these equations:

$$d_{ph} = \int_s \left[\left(1 - \frac{40.28N_e}{f^2}\right) - 1\right] = -\frac{40.28}{f^2}\int_s N_e dS = -40.28.1016f2STEC$$
(1)

$$d_g = \int_s \left[\left(1 + \frac{40.28N_e}{f^2}\right) - 1\right]dS = \frac{40.28}{f^2}\int_s N_e dS = +40.28.1016f2STEC$$
(2)

where
f −carrier frequency in Hz.
N_e −free electron density in the medium.

GNSS radio occultation amounts to an almost instantaneous depiction of the atmospheric state. At radio frequencies the amount of bending cannot be measured directly; instead the bending can be calculated using the Doppler shift of the signal given the geometry of the emitter and receiver. The relative position between the GPS satellite and the Low-Earth Orbit satellite changes over time, allowing for a vertical scanning of successive layers of the atmosphere. The magnitude of the refraction depends on the temperature, pressure, water vapour and ions concentration in the atmosphere [3]. This probing technique though new is based on measuring the radio signals continuously broadcast by the GNSS satellites which could be GPS, GLONASS or Galileo revolving round the earth at an altitude of about

20,000km above the sea level [1]. Fig. 1 describes radio occultation principle.

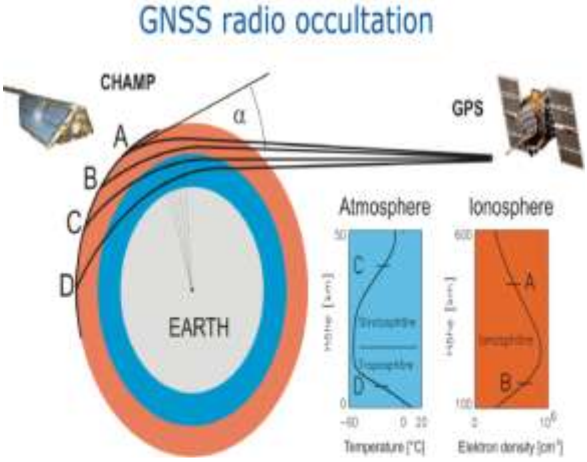


Figure 1: Schematic diagram illustrating radio occultation of GNSS signals [4].

COSMIC was the first constellation of satellites dedicated primarily for radio occultation and delivering of radio occultation data in near real time. The use of an advanced signal tracking technique (open loop tracking) by COSMIC mission makes it more reliable and improves the radio occultation accuracy. This modern observation technique being versatile for imaging the earth's surface environments offers a new, highly precise, continuous, all-weather, better global coverage, higher vertical resolution and near-real-time remote sensing tool.

Radio occultation payload such as COSMIC, CHAMP, GRACE and SAC-C/D are equipped with dual frequency GPS receiver onboard. This offers a unique opportunity to improve measuring techniques and algorithms for determining the electron density. Knowledge of ionospheric behaviour and continuous monitoring of the actual condition of the ionosphere is enhanced [5]. Radio occultation investigations of the ionosphere uses the highly stable radio frequency signals transmitted at GPS frequencies f_1= 1575.42MHz and f_2=1227.60MHz from a GPS satellite and then received by the GPS receiver mounted on a LEO micro-satellite [6].

In this paper, section II discussed the COSMIC observations and methodology, section III analysed the results of the findings while section IV is the conclusion. Radio occultation COSMIC 2013 data were obtained from UCAR/CDAAC archive and then used. The processed data were used to monitor the daily, monthly, seasonal and year 2013 variations of electron density and total electron content in Thailand. It was observed that summer season has the highest TEC value for the year 2013. Therefore, at this period GNSS measurement was more prone to error. The results of the study show that ionospheric perturbation effects or irregularities depend on season and solar activity. Radio occultation has some advantages over the existing techniques. Despite that, observations have some error characteristics such as thermal noise mostly from the receiving antenna, orbit and clock errors and local multipath [7].

II. COSMIC Observations and Methodology

Radio occultation data from COSMIC 2013 made available by University Corporation for Atmospheric Research (UCAR) Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC). Data-set from January to December over Thailand during the year 2013 were analyzed. This accommodated all the three seasons in Thailand. The Solar Influences Data Analysis Center and also from Fig.5 classified year 2013 as an ascending phase of solar activity [8]. This classification results from comparing annual sunspot numbers of 2011 and 2012. The annual numbers in 2010 and 2011 are on the increase from 2010 to 2013. Solar cycle and sunspots number play a very important role in the variation of ionospheric characteristics like the electron density and Total Electron Content. Fig.5 gives details of the variations by NASA curve. The latest mission FORMOSAT-3/COSMIC is illustrated in Figure 2.

This research involved COSMIC ionospheric observations of TEC from the POD antennae and vertical electron density profiles obtained through the use of radio occultation method. The TEC from the POD antennae provide information on electron densities for altitude above 800km and for TEC obtained from GOX antennae that is through radio occultation provides electron density details of altitude up to 800km. The ionospheric profile from UCAR Community was in NC File format.

Figure 2: COSMIC Mission [4].

The technique is so efficient that data can be rapidly processed and analyzed for users with facilities provided in a continuous manner as shown in Fig.3. The structure also allows for elimination of error by a differencing scheme demonstrated in Fig. 4.

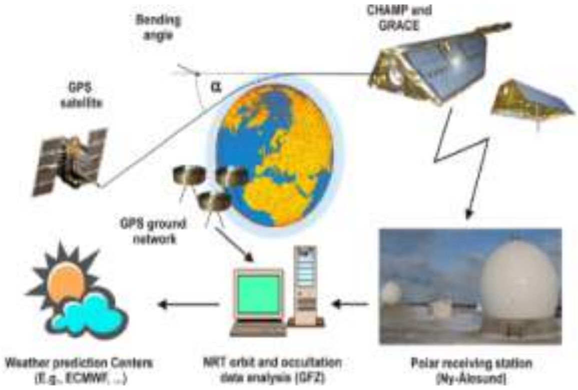


Figure 3: A Radio Occultation System Rapid Data Processing Scheme [4]

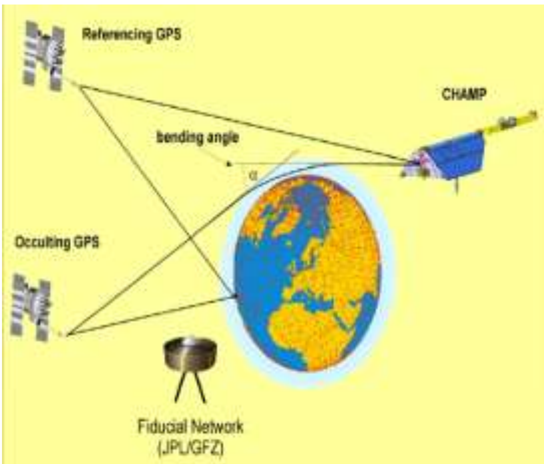


Figure 4: Differencing Scheme [4].

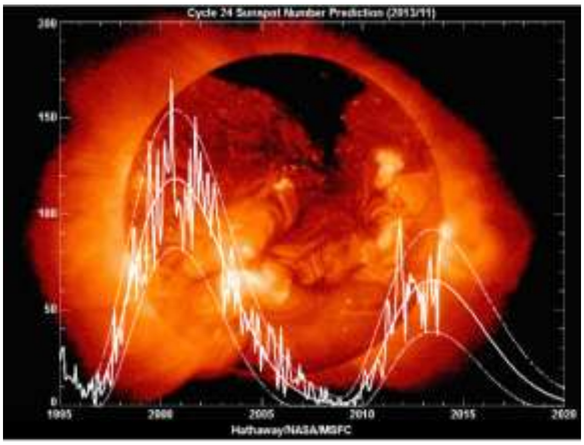


Figure 5: Solar Cycle and Sunspots number [9].

III. Results and Discussions

Using the COSMIC data for the year 2013 over Thailand, the daily, monthly and seasonal variations of the statistical characteristics of ionospheric variation have been studied. Analysis of the occurrence of Total Electron Content and electron density was made. The correlation between electron density and Total Electron Content was studied in this region. The TEC effects have been violent being an equatorial zone and thereby results in GPS measurement error. The region involved has three seasons which are the winter, summer and rainy. The winter period includes the month of October, November, December and January while the summer period is February, March, April and May. The rainy season starts in June and ends in September. Therefore, ionospheric TEC and electron density variations was monitored and analysed as shown below.

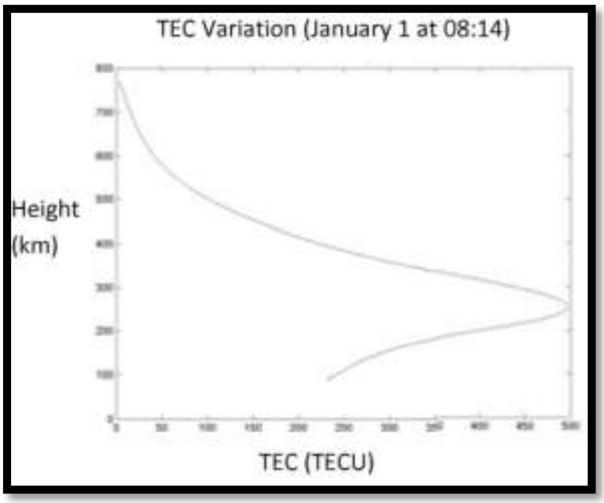
3.1. Daily Ionospheric TEC Variation Analysis in Thailand

The daily analysis of COSMIC 2013 data for Thailand was carried out. One day was chosen from each season representative of the entire season. It means that the day chosen represent the season. Table1 summarized the whole daily ionospheric TEC variation phenomenon for first of January, May and September for the year 2013.

Table 1: Summary of Daily Ionospheric TEC variation in Thailand

Day	**Season**	**Peak TEC**	**Height km**	**Lowest TEC**	**Height km**
Jan. 1st	Winter	496.66	253.41	0.58	804.82
May 1st	Summer	725.45	327.82	1.30	787.56
Sept. 1st	Rainy	486.15	227.07	0.74	830.18

COSMIC 2013 (data of ionospheric electron density profile) for the selected three days were plotted and ionospheric TEC variations profiles were displayed. For the purpose of understanding and simplicity, few ionospheric TEC profiles were selected to showcase ionospheric TEC phenomenon. Some of the ionospheric TEC profiles are shown in Fig. 6, 7 and 8 to display the characteristics behaviour of ionospheric TEC for the days selected. On January 1st during winter, it was observed that TEC has its highest value of 496.6555TECU and lowest to be 0.5805TECU at corresponding altitudes 253.411km and 804.8207km respectively. On May first during summer, the highest TEC value recorded was 725.4481TECU while the lowest was 1.3TECU at altitudes 327.8175km and 787.5607km respectively. During the rainy season on first September, 2013, the peak value for ionospheric TEC variation on this day was 486.1525TECU while on the other hand; the least value of TEC was 0.7370TECU with their respective altitudes of 227.0688km and 830.1833km. From the result obtained, it was observed that the highest TEC value was in May during the summer season and it was also discovered that TEC spread wide towards the evening time than the other two days in winter and rainy seasons.



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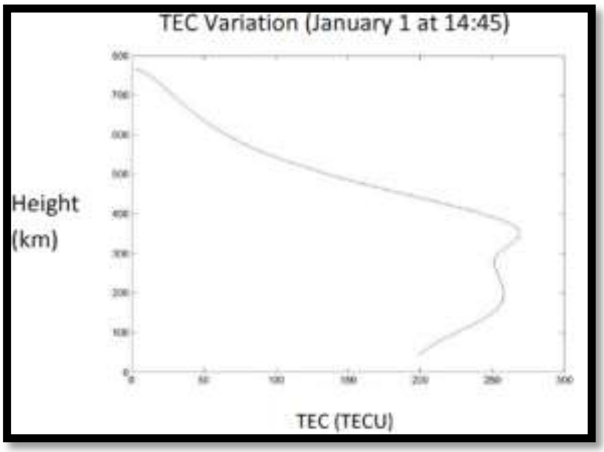

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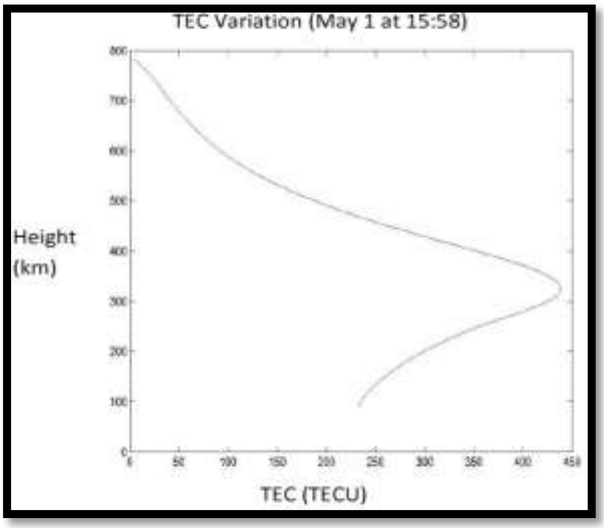
Figure 6: Ionospheric TEC Variation on January 1, 2013



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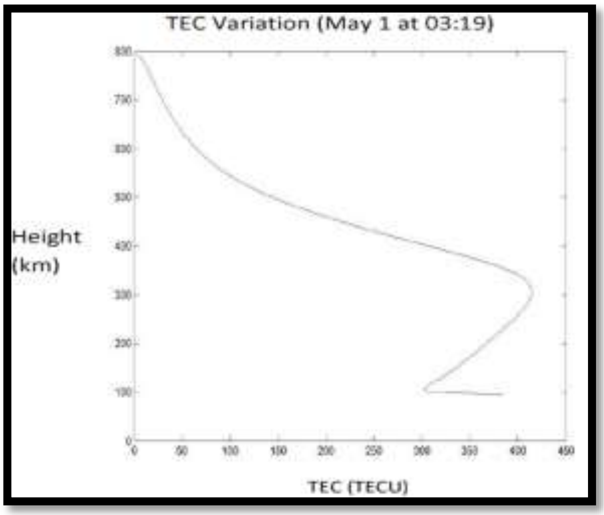

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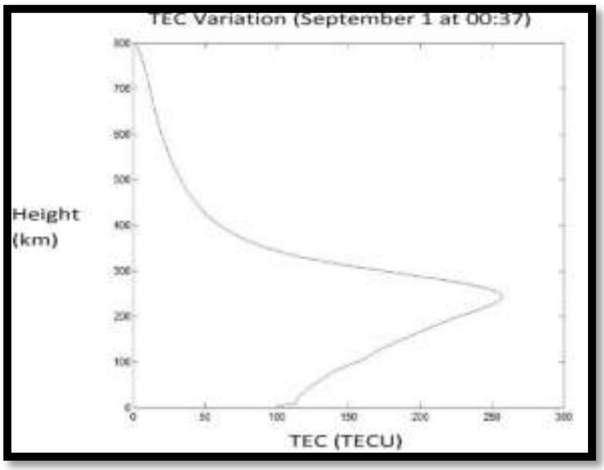
Figure 7: Ionospheric TEC Variation on May 1, 2013



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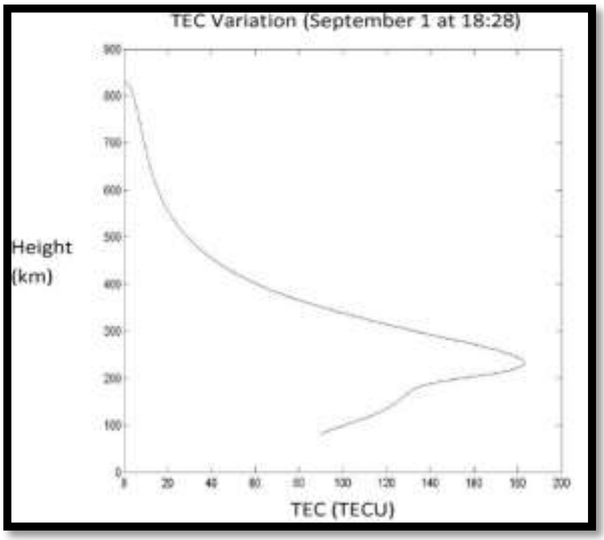


(b)

Figure 8: Ionospheric TEC Variation in September 1, 2013.

3.2 Monthly Ionospheric TEC and Electron Density Variation Analysis in Thailand

Table 2 summarized the monthly ionospheric TEC variation activity. It was observed from the analyzed data as shown in Fig. 9 that the month of May had the highest mean TEC and the month of February had the least mean TEC value. This confirmed the vigorous activity of the sun during the month of May and the sun activity being gentle in the month of February and hence, the ionospheric mean TEC value was above 500 TECU in May and less than 200 TECU in February at height 300km. Also Fig.10 shows the corresponding monthly ionospheric mean Electron Density from January to December indicating that the mean Electron Density was at peak value of 400km above the sea level in the month of May. Table 3 summarized the monthly ionospheric electron density variation in 2013.

Table 2: Summary of Monthly Ionospheric TEC Variation in 2013

TEC	**Mean Value(TECU)**
January	241.8542
February	196.3513
March	376.0470
April	339.9245
May	552.7481
June	244.7126
July	242.1549
August	347.9868
September	248.1855
October	289.1186
November	322.3167
December	254.5740

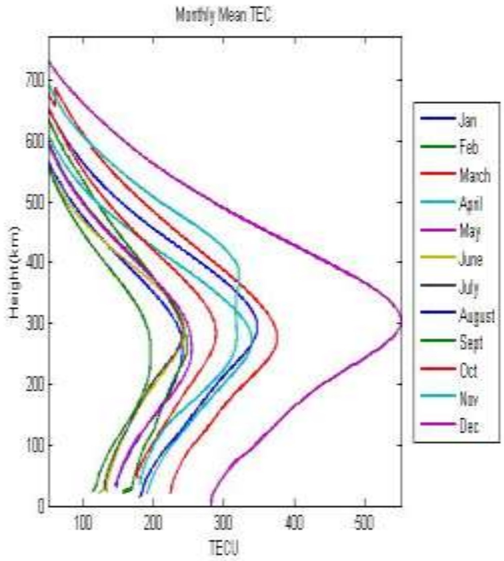


Figure 9: Monthly Ionospheric TEC Variation in 2013 [Calculated Mean value from 44 data].

Table 3: Summary of Monthly Ionospheric Electron Density Variation in 2013

Electron Density	Mean Value **(10^5)cm^{-2}**
January	6.862
February	5.557
March	9.669
April	9.633
May	14.853
June	7.629
July	6.770
August	9.720
September	6.298
October	7.882
November	9.719
December	7.046

Tables 4 and 5 summarized the ionospheric TEC and electron density behaviour for the seasons in 2013 respectively.

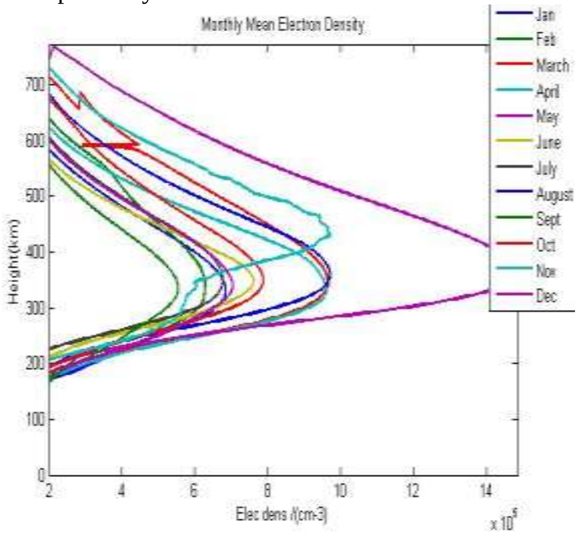


Figure 10: Monthly Ionospheric Mean Electron Density Variation in 2013.

3.1.3 Seasonal Ionospheric TEC and Electron Density Variation Analysis in Thailand

TEC values change dynamically from season to season but it was observed that the ionospheric mean TEC was at peak during the summer period and the least ionospheric mean TEC was experienced during the rainy season from Fig. 11a. These results comply with the theoretical background that solar activity has a great influence on the value of either TEC or Electron Density presence in the earth's atmosphere [10]. During the winter the amount of energy received from the sun is insignificant unlike during the summer when there was vigorous solar activities and this gave rise to high concentration of ions in the ionosphere. Fig. 11b buttressed ionospheric phenomenon which was initially analyzed by Fig. 21a.

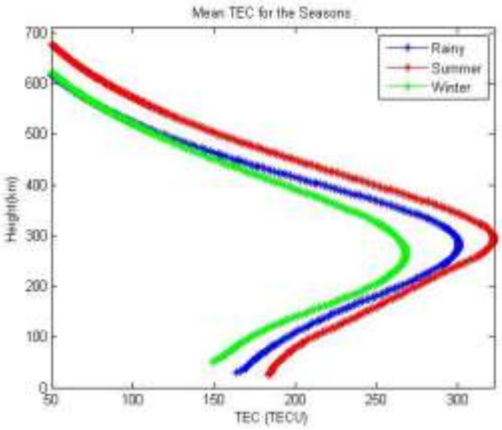
Table 4: Summary of Seasonal Ionospheric TEC Variation in 2013

TEC	Mean Value (TECU)
Summer	**322.2950**
Rainy	300.9523
Winter	267.9723

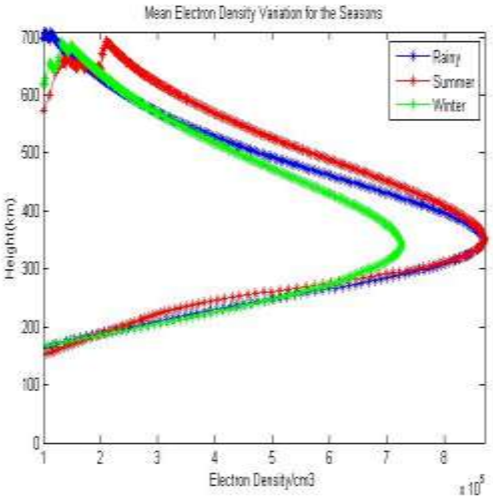
Table 5: Summary of Seasonal Ionospheric Electron Density Variation in 2013

Electron Density	Mean Value $(10^5)cm^{-2}$
Summer	8.7031
Rainy	8.6760
Winter	7.2586

Comparing the two graphs in Fig.11a and b, it shows that ionospheric TEC was directly proportional to Electron Density and hence, more occultations in the ionosphere during the summer than both the rainy and winter seasons.



(a) Mean TEC Variation for the Seasons



(b) Mean Electron Density Variation for the Seasons
Figure 11: The Seasonal Ionospheric TEC and Electron Density Variation in 2013[Calculated Mean value from 356 data].

3.1.3 Annual Ionospheric TEC Analysis in Thailand

Table 6 is the summary of the annual ionospheric TEC variation values and standard deviation. Annual ionospheric TEC variation for the year 2013 is displayed in Fig.12 with the peak value above 300TECU at height 300km and the least TEC value below 200TECU at altitude 100km. The ionospheric mean value represent the actual variation in TEC. The trend shows that there was more concentration of TEC from 200km to 500km height. From 700km in height, the TEC value was rapidly increasing until 300km and then dropped drastically till below 100km height under the period observed. The characteristic of TEC variation were influenced by solar seasonal activities. Also from the same Fig.12 is the standard deviation plot which measures the dispersion from the ionospheric mean value. The graphs were almost even but there was a little deviation. This deviation could be as a result of error from radio occultation observation data. The observation data could incur error due to thermal noise mostly from the receiving antenna, orbit and clock errors, cycle slips and local multipath.

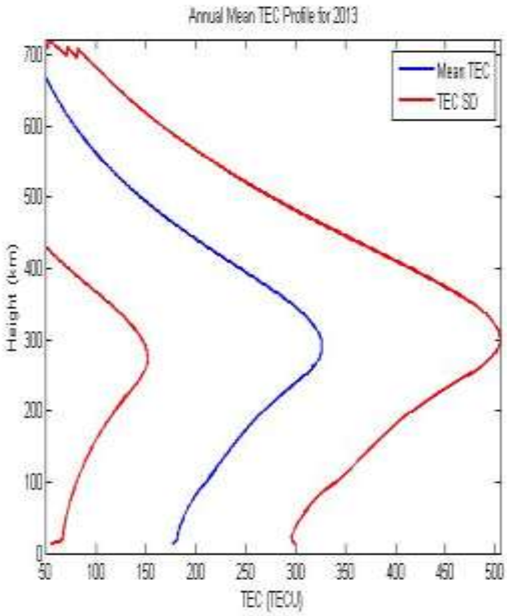


Figure 12: Annual Ionospheric TEC Variation and Standard Deviation in 2013[Calculated mean value from 694 data].

Table 6: Summary of Annual Ionospheric TEC Variation and Standard Deviation (2013).

TEC / Year	Mean Value (TECU)	Standard Deviation (TECU)
2013	326.8190	182.9545

IV. Conclusion

Recent developments of the GNSS radio occultation (RO) technique have offered an exciting potential for space and meteorological researches. It has become clear that RO has caused a revolution in ionospheric and atmospheric sounding. No other observing system provides such high quality, global observations of the ionosphere and atmosphere for effective weather prediction, climate change and the precise value of total electron content on daily basis globally.

This paper has investigated the characteristics of ionospheric TEC variation in Thailand. Ionospheric TEC variation was observed daily, monthly, seasonally and for year 2013 due to variation in solar activities from time to time. The result showed ionospheric TEC value in summer was obviously higher and most importantly at peak while the value of ionospheric TEC during the winter was the lowest. A little deviation was observed between the annual ionospheric mean TEC variation and the standard deviation which could be error from the observation data.

The implication here is that telecommunication, aviation industries, security agency and other users of space related application would have to take the advantage of this clue by avoiding the summer period or more care must be taken in measurements to prevent catastrophic situation.

V. Acknowledgements

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