Comparison of Ionosphere at Middle Latitude Zone during Solar Maximum and Solar Minimum

Tharapong Sukcharoen, Jingnong Weng, Teetat Charoenkalunyuta, and Falin Wu

***Abstract*—The impact of the satellite-based technologies is significantly increasing nowadays, while the satellite signal processing still imperfect. Especially when satellite signals travel through ionosphere layer since Total Electron Contents (TEC) flowing throughout ionosphere layer interrupt these signals. This paper purposes to investigate the characteristics of ionosphere as the temporal analysis during the equinox period which is extremely influence and during the solstice period which is slightly influence to TEC variation compared between solar maximum and minimum. The spatial analysis used the GPS data from different geographic latitude in the middle latitude region where the variation of TEC is pretty quiet and calm. The results show TEC distribution during solar maximum was greater and more violent than that in solar minimum. The peak values mostly occurred in April and September while the lowest value period occurred in June. Furthermore the exploration of the diurnal analysis during solar maximum increased regularly from noon until dusk while solar minimum also rose up at noon to dusk. Mostly TEC variation had the same pattern but only some latitude appeared unconventional.**

***Index Terms*—Equinox, TEC, solar activity, sunspot number.**

I. Introduction

In principle, Ionosphere is a layer of the Earth's upper atmosphere forming by high density of charge particles and gases, which introduces regularly the ionization. As a result the much number of ionized electrons will be distributed throughout the layer ranging from 50 km to more than 1,000 km altitude from Earth's surface. Normally, the electron density will be varied by spatial factors (altitude, latitude, longitude) and temporal factors (local time, season, solar cycle and magnetic activity) [1]. Mostly, this variation is introduced by the solar radiation generating free electrons from the Earth's atmospheric gases and charge molecule. However, the ionization will be occurred severely at the Equatorial Ionization Anomaly (EIA) region and Polar ionosphere region where there is a strong magnetic field compared relatively to gentle ionization in the middle latitude region. The great role of solar activity in the free electron disturbance is caused by the plasma blown from the solar storm [2].

Sunspot Number (SSN) can impact directly to the strength of solar storm [3]. The Solar activity follows a regular periodic variation as eleven year long known as solar cycle. The solar cycle is the periodic recurrence of Sunspot at Sun's surface [4]. However, the ionization process in the ionosphere is also mainly influenced by one of many factors known as solar zenith or the March equinox and September equinox. The equinox is period that Sun is perpendicular to the Earth's surface will occur twice a year. This period will be induced in March to April and September to October [5]. In recent years, the measurement of the actual value of the Total Electron Content (TEC) of the ionosphere has become key issue for effective correction because its troublesome can downgrade the service of space-based technology. Since it produces the errors embedded in the signal delay of satellite signal propagation. Recently, the evolution of navigation satellite technology achievement has been further understanding the TEC behavior that whenever the GPS signals transmit pass through ionosphere layer will be delayed by TEC causing signal refraction, diffraction and dispersion. Consequently, the pseudo-range must be farther than it should actually be which this can produce inaccuracy positioning calculation [6]. For this reason, the volume of the TEC variation can also be processed by the GPS satellite signals [7]. The TEC is a core parameter that can be valuable for studying the ionosphere and also improving the positioning accuracy of Global Navigation Satellite System (GNSS). This paper purposes to investigate the spatial and temporal variations of the total free electrons in ionosphere. It has been considered by the periodic solar activity between maximum and minimum solar activities via twelve month time frame data. Another investigating is the impact of solar phenomena as equinox and solstice at the middle latitude region which is the modest TEC variation region relatively compared against with the violent variation region in the equatorial and low-latitude regions [8].

II. Signal Processing Model

A. When GPS Signal though the Ionosphere

In general, each GPS satellite continuously transmit signal L band frequencies L1=1.57542 GHz and L2=1.2276 GHz, respectively. The properties of both signal frequencies can be delayed while transmitting to the Earth. It is affected by the ionospheric characteristics. But this delay error can be eliminated at the signal post processing step which can also determine the total electron content (TEC) along the signal path. The GPS receiver acquires its range to each satellite orbiting in space, then calculates the position. The range is determined from the time delay that satellite signal used to transmit from each satellite in space to the receiver on Earth's surface. So it is the difference between the

Manusript received December 8, 2015; revised May 8, 2016.

Tharapong Sukcharoen and Jingnong Weng are with International School, Beihang University, Beijing 100191, China (e-mail: beihangmasta2012@gmail.com).

Teetat Charoenkalunyuta is with the Department of lands, Bangkok, 10210, Thailand.

Falin Wu is with School of Instrumentation Science and Opto-electronics Engineering, Beihang University, Beijing 100191, China (e-mail: falin.wu@buaa.edu.cn).

DOI: 10.7763/IJET.2017.V9.982

transmit time at satellite and the reception time at receiver then multiplied by the speed of signal or equal to the speed of light. But this difference does not include the error of the receiver's clock and the satellite's clock. The distance calculated on the receiver is only approximate so called a pseudo range [9]. The different time is calculated from code synchronization with autocorrelation technique by technical function at receiver. Unfortunately, satellite signal will also be degraded by many other parameters before arriving receiver antenna. So, the accuracy of position calculation still depends on many parameters not only the ionosphere error [10].

B. TEC Measurement Using GPS Signals

Since, the atmosphere along the satellite signal path is not a vacuum. There are a plenty of charge particles that can influence the GPS satellite signal frequencies, the speed and direction of the signal must be changed. The ionosphere can affect the GPS satellite signal which can be explained by the Ionospheric Refractive Index [11].

The Refractive Index (n) is defined by the ratio between the speed of the signal dissemination in vacuum (c) and the speed in the medium (v) [12].

$$n = \frac{c}{v} \tag{1}$$

c is the light velocity (m/s), v is the light velocity in the medium (m/s).

Equation (1) n will equal to 1 when the GPS signal transmits though a vacuum. But in actual condition the particles flown in the ionosphere layer can cause the L band signal refraction. So the Refractive Index varies inversely to signal frequency [13]. The dual frequency GPS receivers use two L band frequencies to compensate for the ionospheric delay to remove the errors. It is useful for the dispersive characteristic of satellite signal during in the ionosphere.

For the processing in this paper used the ionospheric time delay at the $L1$ carrier frequency of f_1 as given by [11]

$$t_1 = 40.3 \times \left({}^{TEC}/_{c.\,f_1^2} \right) \tag{2}$$

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

$$\Delta t = \left({}^{40.3}/_{C} \right) \times \frac{TEC}{\left[\left({}^{1}/_{f_2^2} \right) - \left({}^{1}/_{f_1^2} \right) \right]} \tag{3}$$

So, the time delay (Δt) calculated from the $L1$ and $L2$ frequencies is used to calculate the TEC along the signal path. If TEC calculation uses only the pseudo range, it can process a noisy result. The differential carrier phase allows a measurement of the relative TEC variation since the actual number of cycles of phase is unknown. So the absolute TEC cannot be achieved if pseudo range is not being used. The differential phase increases more accuracy [14].

In general, all receiver stations normally begin to receive visible satellite signals when they orbit over horizon at different azimuth. However, all TEC value cannot be detected at all along the paths. Before obtaining the TEC value derived from each PRN satellite, it will be eliminated the PRN bias and receiver bias by post processing function at receiver. Particularly, PRN bias consisted of satellite bias and inter-channel bias, after that all calculated TEC outputs will be averaged as the ideal TEC value [15].

In this paper, the slant TEC $(STEC)$ measurement was the sum of the real slant TEC calculated from phase and group delay which was downgraded by GPS satellite differential delay b_S (satellite bias) and the receiver differential delay b_R (receiver bias). Hence, the ideal slant TEC is

$$STEC_{ideal} = STEC + b_R + b_{RICH} + b_S \tag{4}$$

$STEC$ is the calculated slant TEC, b_R is the satellite bias, b_{RICH} is the inter channel receiver bias, b_S is the satellite bias. The obliquity factor (E) is defined as [16]:

$$S(E) = \frac{1}{\cos(Z)} = \frac{1}{\sqrt{1-\left(\frac{R_E \times \cos(E)}{R_E + h_S}\right)^2}} \tag{5}$$

R_E is the mean radius of the Earth in km, h_S is the ionosphere height over the Earth's surface, z is the zenith angle and E is the elevation angle in degree.

$$VTEC = \frac{STEC - (b_R + b_S)}{S(E)} \tag{6}$$

$VTEC$ is the vertical TEC, $STEC$ is the slant TEC, E is the elevation angle of the satellite in degree, $S(E)$is the obliquity factor with zenith angle z at the Ionospheric Pierce Point (IPP).

III. Methodology

This paper mainly used GPS satellite signal data in the RINEX format with sampling interval 30s derived from four continuous GPS receiver stations, namely IRYM (34°S), BEUA (35°S), ARAT (37°S), and CRES (38°S). All stations are located in Victory state, Australia. The distance among each station is about 110-190 km and total distance along geographical longitude is 450 km. The study area covers latitude 34°13'11.03"S to 38° 1'41.52"S and longitude 142°11'28.36"E to 143°38'23.06"E (See Fig. 1).

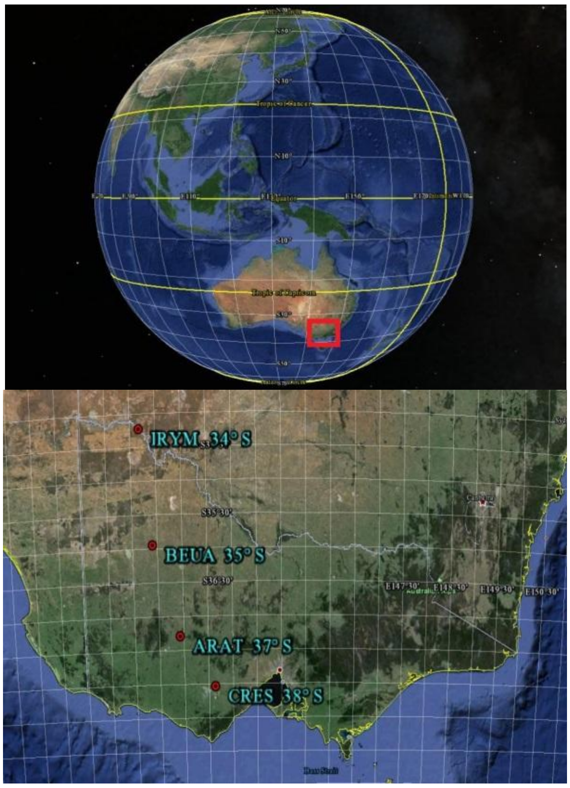

Fig. 1. Location of study area in Victoria, Australia (Google Earth).

All data files were processed for the Vertical TEC by using GPS-TEC version 2.2 developed by Institute for Scientific Research, Boston College, MA, USA. To make perceptively understanding to the TEC variation during solar maximum and solar minimum period, so this paper used GPS data in 2012 year representing solar maximum analysis and 2008 year representing during solar minimum analysis. However, there was a considerable concern of processing TEC value that has been processed from all visible PRN satellite. Especially this processing model has processed only GPS system.

IV. Result and Analysis

A. Annual Analysis Related with Sunspot Number

Fig. 2-Fig. 5 illustrate the annual TEC variation derived from four GPS receiver stations representing the four different latitude zones, ranging from IRYM, BEUA, ARAT, and CRES. All plots showed clearly different amount of TEC value in solar maximum greater than that of the TEC value in solar minimum. It can be noticed that the trend of TEC movement pattern at every station displayed the same direction (Black line: the averaged trend calculated by polynomial equation). Another interesting point is that the TEC value in solar maximum had a dominantly fluctuated variation, while solar minimum was pretty quiet and peaceful. In the entire year, the total number of TEC value in solar maximum was total approximately about 10–40 TECU and about 5–20 TECU in solar minimum. Especially the peak value was mostly occurred in April and September while the lowest value period was in June. It is because the equinox phenomena incurred the TEC value significant increment and depletion in four times a year known as March equinox, June solstice, October equinox, and December solstice. However in the period of solar minimum had a noticeable remark of TEC value between higher latitude (CRES, 30°S) and lower latitude (IRYM 34°S) and (BEUA, 35°S) that its trend seems to be the increasing values and more variability.

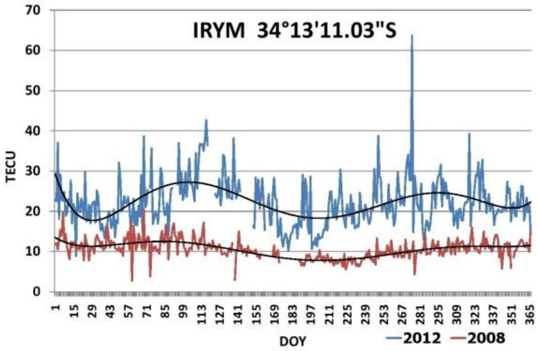

Fig. 2. Annual TEC variation at IRYM station.

Fig. 6, International SSN in solar maximum plotted with solar minimum which was processed by Royal Observatory of Belgium, Brussels, Belgium. It presented accordingly with the research results. Firstly in solar maximum, SSN in February (DOY 032-060) relatively depressed, while during March to May (DOY 65–DOY 166) SSN increased. But in June (DOY 173–DOY 175) was a low value of SSN accounted for all TEC value in these months appeared the same variation as all investigation above. In October (DOY 320), the SSN was the outstanding high (SSN 97) which made TEC value during this period was reasonably increased. During solar minimum, it was the highest in March (DOY 86), so during this month the TEC variation increased significantly. The SSN from DOY 175–DOY 235 was curiously scarce value. It was identically concordant with investigated results. So the SSN was one of factors influenced TEC variation.

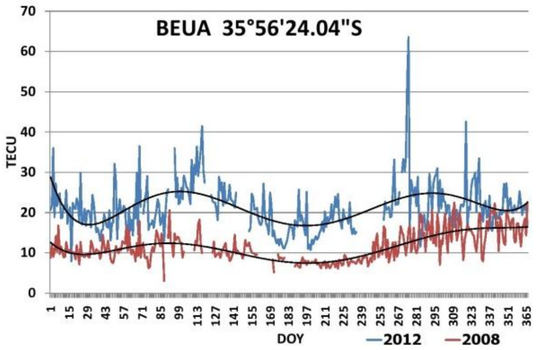

Fig. 3. Annual TEC variation at BEUA station.

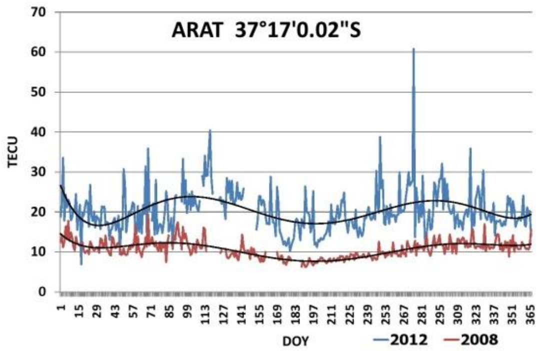

Fig. 4. Annual TEC variation at ARAT station.

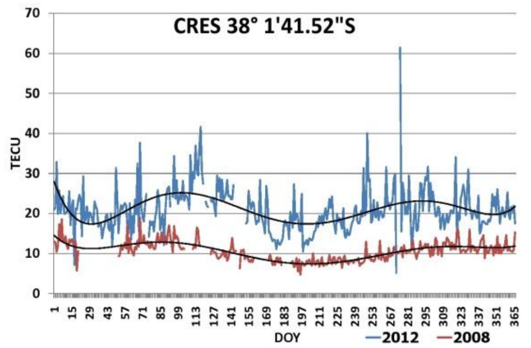

Fig. 5. Annual TEC variation at CRES station.

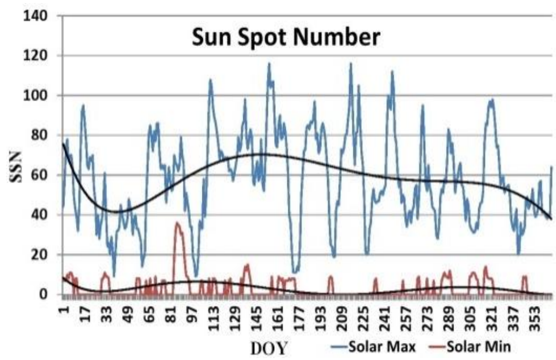

Fig. 6. Sunspot number in 2012 and 2008. (http://www.ngdc.noaa.gov/stp/space-weather/solar-data/solar-indices/sunspot-numbers).

B. *Diurnal Analysis Investigated by Local Season*

This analysis results illustrate diurnal variations of TEC from CRES station comparing relatively between solar maximum (2012) and solar minimum (2008) by means of using three typical periods of DOY to be a representative of Sun activity. It began with DOY 109-DOY 111 in solar maximum and DOY 111-DOY 117 in solar minimum delegating March equinox. During DOY 187- DOY 197 in solar maximum and DOY 188 - DOY 197 in solar minimum delegated June solstice. During DOY 290-DOY 300 in solar maximum and DOY 290-DOY 300 in solar minimum delegated September equinox. During DOY 35-DOY 360 in solar maximum and DOY 350 - DOY 360 in solar minimum delegated December solstice. In general, these plots can describe that the diurnal TEC variation during solar maximum was in the highest in March equinox of April (considered on the average), while the lowest diurnal during solar maximum was in June solstice of July. Meanwhile the highest TEC diurnal variation during solar minimum was coincide with those of solar maximum. However, the highest TEC value was in March equinox and the lowest TEC value was in June solstice.

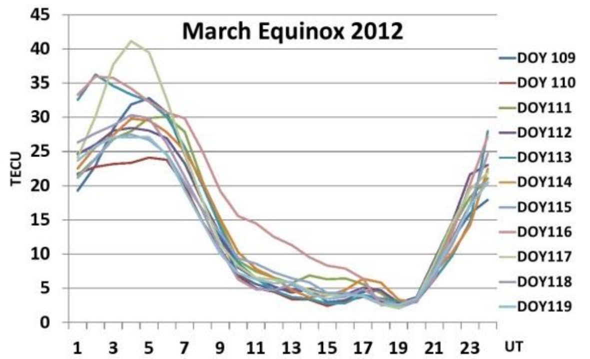

Fig. 7. TEC variation in March equinox in 2012.

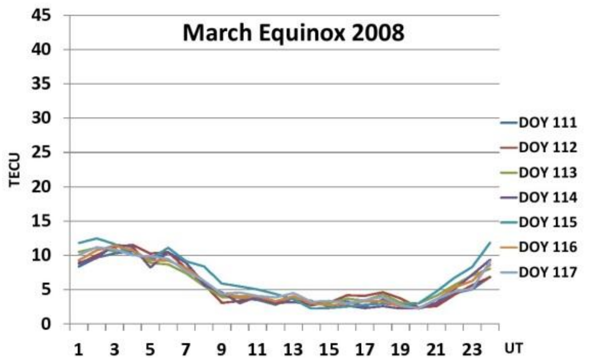

Fig. 8. TEC variation in March equinox in 2008.

Fig. 7 illustrates that TEC distribution in March equinox during solar maximum (2012) increased around 0200-0600 UT or 1300-1700 LT (GMT+11) (23-42 TECU) which was during daytime from noon to dusk in local time. The maximum value was at 0400-0500 UT then kept dramatically decreasing until 0900 UT (5-10 TECU) at night time. It was lowest at 1900 UT (3-4 TECU) at dawn in local time then enhanced significantly up again. If compared with similar phenomenon during solar minimum (2008). Fig. 8 illustrates that TEC value increased highly about 0200-0600 UT (10 TECU) and it was peak at 0300-0400 UT then decreased until 0800 UT (3-4 TECU) however from this time point was a tiny variation as flat until 1900 UT at dawn then clearly raised up. Fig. 9 shows that TEC value in June solstice during solar maximum (2012) increased around 0200-0600 UT (13-27 TECU) post midday and the maximum value was at 0200-0400 UT. It kept dramatically decreasing until 0900 UT (3-7 TECU) after sunset, then kept being low until 2000 UT (3-7 TECU) at early morning then increased up again. If compared with the same solstice during solar minimum (2008).

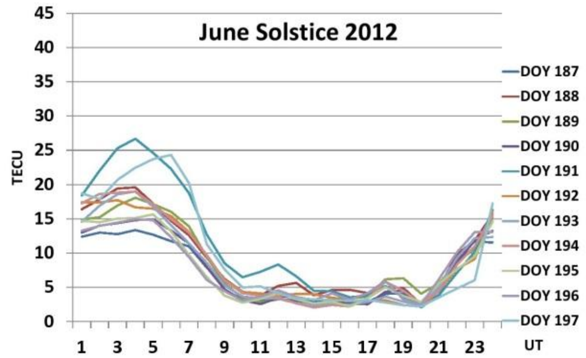

Fig. 9. TEC variation in June solstice in 2012.

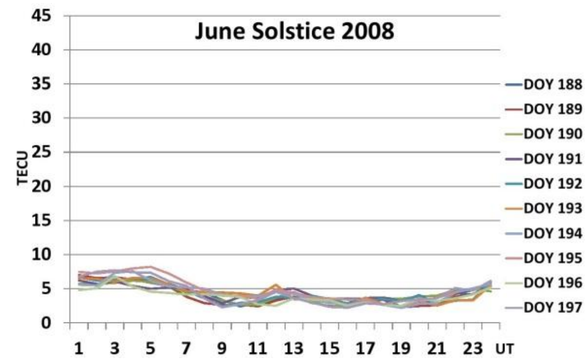

Fig. 10. TEC variation in June solstice in 2008.

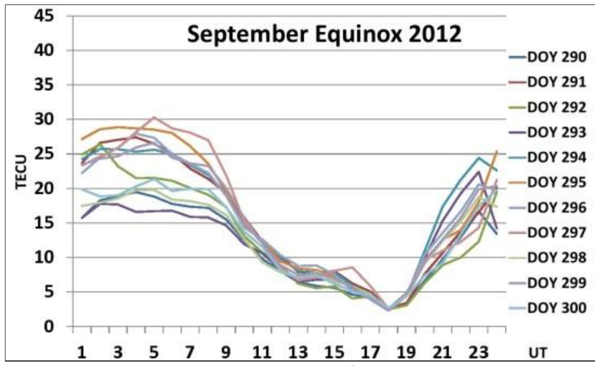

Fig. 11. TEC variation in September equinox in 2012.

Fig. 10 illustrated that TEC was obviously less than during solar maximum. It increased highly around 0300-0500 UT after lunchtime (5-7 TECU). It was peak at 0400 UT then decreased around 0800 - 1000 UT (3-5 TECU) or twilight in local time. From this time TEC values were lightly varied until 2000 UT at early morning then increased higher. Fig. 11 illustrates that TEC value in September equinox during solar maximum (2012) increased around 0200-0600 UT (16-30 TECU) after noon. The maximum value was at 0400-0500 UT twilight time then obviously decreased until 0900 UT (15 TECU). It was lowest at 1700 UT (3-4 TECU) at dawn then grew directly higher again. If compared with similar equinox period during solar minimum (2008).

Fig. 12 illustrated that the TEC value increased highly around 0200-0600 UT (7-13 TECU) after noon. It was peak at 0400 UT then decreased until 1100 UT (3-4 TECU) nighttime. From this time, TEC value was likely little fluctuating until 1900 UT at sunrise then also increased again. Fig. 13 illustrates that TEC value in December solstice period during solar maximum (2012) increased around 0200-0800 UT (15-25 TECU) from after midday to dusk. The maximum value was at 0700-0800 UT then deeply decreased until lowest at 1700 UT (3 TECU) at dawn after that raised directly up higher again. If compared with similar solstice period during solar minimum (2008). Fig. 14 illustrates that it increased highly around 0100-0800 UT (7-14 TECU) at midday to dusk. It was peak at 0100 UT then decreased until 1100 UT (3-7 TECU). From this time, TEC value was likely little fluctuating until 1800 UT at sunrise time and it was also the lowest (3-4 TECU) then also newly increased.

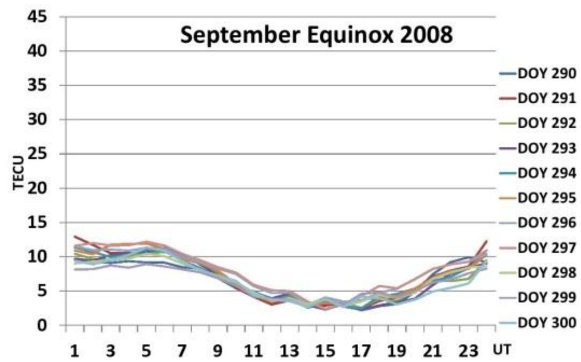

Fig. 12. TEC variation in September equinox in 2008 .

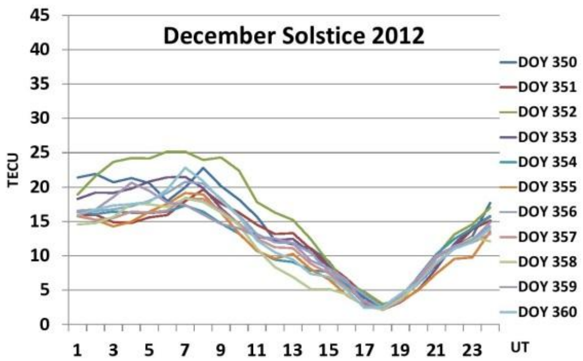

Fig. 13. TEC variation in December solstice in 2012.

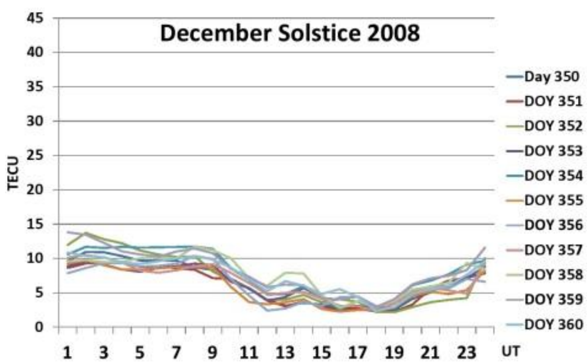

Fig. 14. TEC variation in December solstice in 2008.

C. Diurnal Analysis Investigated by Geographic Location

Fig. 15-Fig. 18 show the spatial analysis of TEC distribution from all the GPS receiver stations according to different geographic latitude in middle latitude. The TEC analyzed comparatively in these plots by selecting 15th day of four months during solar maximum and solar minimum. There was interesting point during March equinox period. The TEC value in March in solar maximum was extremely high (28 TECU) ranging from 0000-0800 UT then suddenly decreased until low value ranging from 1600-1900 UT (3 hours). BEUA (35°S), ARAT (37°S), and CRES (38°S) likely had much more TEC value than IRYM (34°S). Meanwhile in solar minimum, the high TEC value ranged from 0100 to 0800 UT. BEUA (35°S) latitude location had the lower than other latitude locations and the low TEC values decreased from 1100-1900 UT which at 1900 UT had the lowest TEC value (3 TECU).

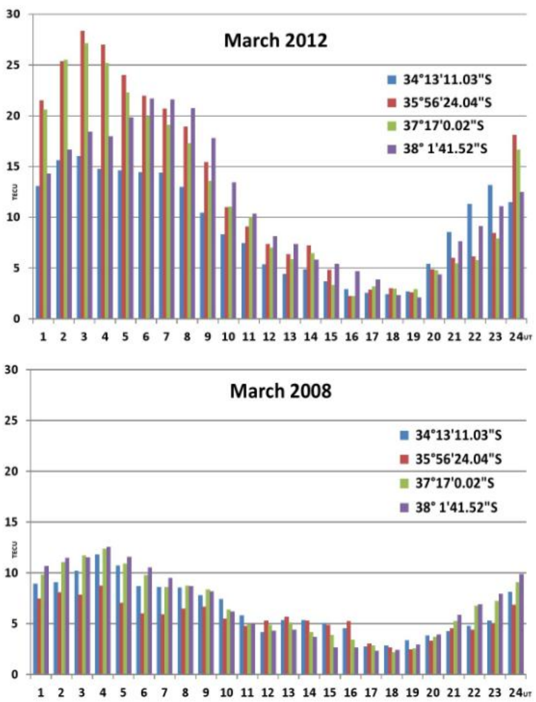

Fig. 15. Diurnal TEC variation analyzed by geographic latitude in March 2012 and 2008.

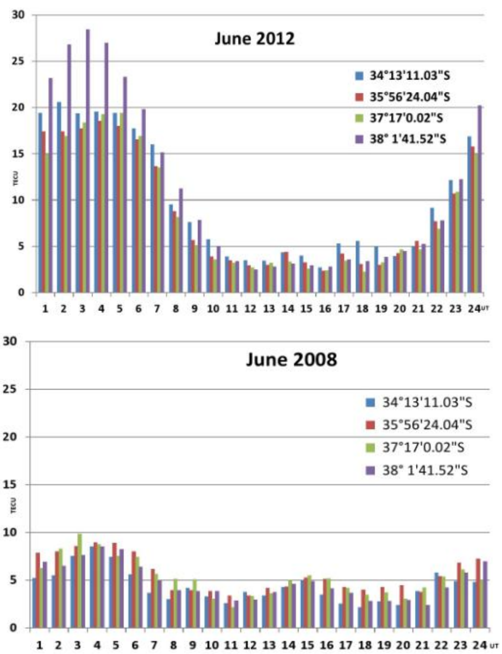

Fig. 16. Diurnal TEC variation analyzed by geographic latitude in June 2012 and 2008.

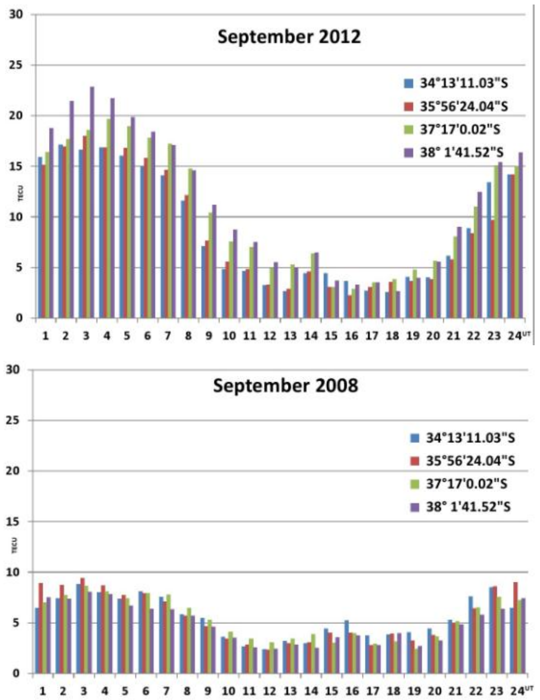

Fig. 17. Diurnal TEC variation analyzed by geographic latitude in September 2012 and 2008.

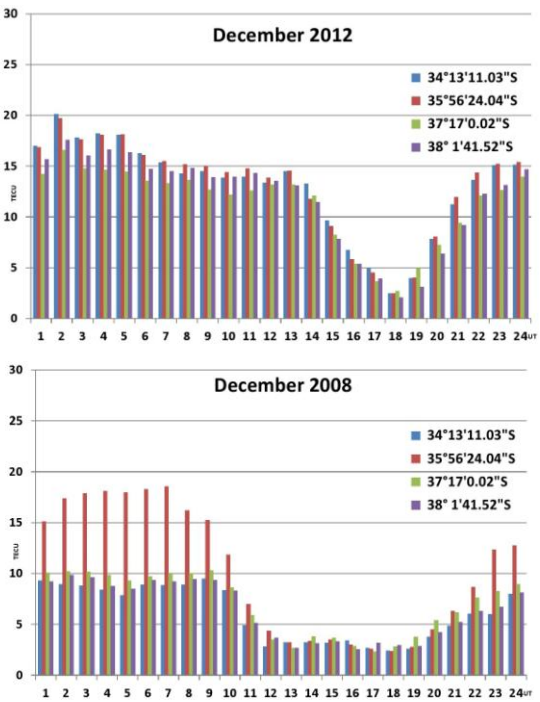

Fig. 18. Diurnal TEC variation analyzed by geographic latitude in December 2012 and 2008.

In June or in June solstice during solar maximum CRES (38 ° S) had the distinguishing high TEC value (28 TECU) while the others still were as normal (20 TECU). In September or in September equinox the high TEC value in solar minimum ranged from 0100–0600 UT or from afternoon to twilight higher value (3-9 TECU). In solar maximum, only CRES (38 ° S) TEC value set in outstanding high (23 TECU) at 0300 UT while the other latitude locations remained the same high TEC value (15-20 TECU). In December displayed increasing TEC value (3-19 TECU) at BEUA (35 °S) dominantly increased if compared with other latitude stations (3 - 13 TECU). The low TEC value gradually decreased to 1700 UT (3 TECU) but the low TEC value period in December from 0100-0900 UT (3-4 TECU) or from midday to dusk. The low TEC value seemingly covered longer time as December solstice again during solar maximum. TEC value became lower as well.

V. Conclusion

The results are summarized as during solar maximum was greater than that of the TEC value in solar minimum. TEC value in solar maximum was a dominantly fluctuated variation, while the variation in solar minimum was pretty quiet and peaceful. The peak value mostly occurred in April and September while the lowest value period was in June. It is consistent with the SSN which is one of factors can influence TEC variation. The diurnal variation during solar maximum increased around noon to dusk and lowest value at dawn while solar minimum was highly increased about noon to dusk and lowest value at dawn. The peak was in March equinox. During March equinox and September equinox had high value. The spatial analysis of TEC distribution from the middle latitude location was not significantly appeared the difference.

In general, TEC variation is not affected by only Sunspot Number (SSN) but also Solar Flux ($F_{10.7}$), Disturbance Storm Time Index (Dst) and Planets magnetic Index (Kp) [17] as well. In future study might investigate about other factors for other discovery because the TEC characteristic still be top issue to study for space-based technology improvement.

References

[1] C. C. Wu, C. D. Fry, J. Y. Liu, K. Liou, and C. L. Tseng, “Annual TEC variation in the equatorial anomaly region during the solar minimum,” *J. Atmos. and Solar-Terr. Phys.*, vol. 66, pp. 199-207, 2004.

[2] A. Ozgue, T. Atac, and R. Pektas, “Examination of the solar variation of foF2 for cycle 22 and 23,” *J. Atmos. Sol. Terrs. Phys.*, vol. 70, pp. 268-276, 2007.

[3] Solar Cycle 24 – Predictions lowest for 100 years. (June 5, 2013). [Online]. Available: http://solarwatch.wordpress.com/2012/05/03/solar-cycle-24-predictions-lowest-for-100-years/

[4] N. Balan, G. J. Bailey, and Y. Z. Su, “Variations of the ionosphere and related solar fluxes during solar cycles 21 and 22,” *Adv. Space Res.*, vol. 18, pp. 11–14, 1996.

[5] G. Y. Ma and T. Maruya, “A super bubble detected by dense GPS network at East Asian longitudes,” *Geophysical Research Letters*, L21103, 2006.

[6] D. Odijk, “Fast precise GPS positioning in the presence of Ionospheric delays,” PhD thesis, Delft University of Technology, The Netherlands, 2002.

[7] R. P. Kane, “Irregular variations in the global distribution of total electron content,” *Radio Sci.*, vol. 15, pp. 837–842, 1980.

[8] K. Davies, “Recent progress in satellite radio beacon studies with particular emphasis on the ATS-6 Radio beacon experiment,” *Space Sci. Rev.*, vol. 25, pp. 357–430, 1980.

[9] N. Ackroyd and R. Lorimer, *A GPS User'S Guide*, Lloyd's of London Press, 1990.

[10] B. Hofmann-Wellenhof, H. Lichtenegger, and J. Collins, *Global Positioning System: Theory and Practice*, 5th ed. Berlin: Springer, 2001.

[11] J. A. Klobuchar, “Ionospheric effects on GPS,” in *Global Positioning System: Theory and Applications*, B. W. Parkinson and J. J. Spilker, Eds. 1996, vol. 164, p. 485.

[12] P. Misra and P. Enge, *Global Positioning System: Signals, Measurements, and Performance*, Lincoln, Massachusetts, USA: Ganga-Jamuna Press, 2006.

[13] R. Langley, “Propagation of the GPS Signals,” *GPS for Geodesy*, pp. 103-140, 1996.

[14] K. Davies and G. K. Hartmann, "Studying the ionosphere with global positioning system," *Radio Sci.*, vol. 32, pp. 1695–1703, 1997.

[15] P. V. S. R. Rao, S. G. Krishna, K. Niranjan, and D. S. V. V. D. Prasad, "Study of spatial and temporal characteristics of L-band scintillations over the Indian low latitude region and their possible effects on GPS navigation," *Ann. Geophys*., vol. 24, pp. 1567–1580, 2006.

[16] R. Langley, M. Fedrizzi, E. Paula, M. Santos, and A. Komjathy, "Mapping the low latitude Ionosphere with GPS," *GPS World*, vol. 13, no. 2, pp. 41–46, 2002.

[17] R. P. Kane, "Solar EUV and ionospheric parameters: A Brief assessment," *Adv. Space Res.*, vol. 32, no. 9, pp. 1713–1718, 2003.

Tharapong Sukcharoen was born in 1980 in Pissanulok, Thailand. He graduated with a bachelor degree in survey engineering at Chulachomklao Royal Military Academy, Nakornnayok, Thailand in 2005. He works as a pilot in Aerial Survey Department, Royal Thai Survey Department in Bangkok, Thailand. He graduated with a master degree (MASTA2012) on major space technology applications at Beihang University, Beijing, China in 2014. Currently, He is a Ph.D. candidate at International School, Beihang University. He is interesting in the phenomena of the electron variation in the ionosphere using GPS satellite signals by focusing on the influence came from the solar storm and how it effected on GPS signals measurement.

Weng Jingnong was born in Zhejiang province, China and received his bachelor, master and doctoral degrees in computer software and theory separately in Beihang University in China. Since 1990s, he has been working on the research in GIS and software engineering and finished several nation level project in this field. He had visited in the United States for one year. Since 2005, he has been focused his research on the technologies and its application of GIS and digital earth. He has published more 50 papers in the Journal of Science of China, and international conference of ISDE, Geoinfomatics, Geocomputation and so on. He has 14 software copyrights and 1 technical invention patent.

He is also an international cooperation expert of Beidou office and actively participate ICG meeting and has repeatedly delivered a presentation on GNSS education and training in the resent years. He teaches introduction to GIS course for undergraduate students and GIS and GNSS applications course for postgraduates.

Falin Wu graduated with a bachelor degree of electronic engineering and navigation at Dalian Maritime University in Dalian, China in 1995. He graduated with a master degree of maritime information system at Dalian Maritime University in Dalian, China in 1998.

He graduated with PhD about satellite positioning and navigation at Tokyo University of Marine Science and Technology in Tokyo, Japan in 2004. He is an associate professor of satellite navigation and remote sensing in the School of Instrumentation Science and Opto-electronics Engineering at the Beihang University, Beijing, China. His research interests include satellite positioning and navigation, multi-sensor integration for ubiquitous positioning, GNSS atmospheric sounding and space geodesy.

Teetat Charoenkalunyuta was born in Suphanburi, Thailand in 1973. He graduated with a bachelor degree in survey engineering, Chulalongkorn University in Bangkok, Thailand in 1997 and graduated with a master degree about technology (remote sensing & GIS) at National Institute of Technology in Warangal, India. He graduated with a PhD degree in survey engineering at Chulalongkorn University, Bangkok, Thailand in 2012. Nowadays he works as a measurement expert engineer in the Department of Lands, Bangkok, Thailand. His research interests include the investigation of the effect of Ionospheric models on performance of Network-Based RTK GPS in Thailand. He investigates on the performance of NRTK with the aid of the Global Ionospheric Maps (GIM) and the Thai Ionospheric Maps (THIM) in various different reference stations.