MAPPING OF THE MALAYSIAN REGIONAL TOTAL ELECTRON CONTENT (TEC) LATITUDE AND LONGITUDE PROFILE

Ahmad Faizal Mohd. Zain[1], Ho Yih Hwa[2] and Harlisya Harun[3]

[1]*Wireless and Radio Science Centre (WARAS), Kolej Universiti Teknologi Tun Hussein Onn, 86400 Parit Raja, Batu Pahat, Johor*

[2]*Department of Telecommunication Engineering, Faculty of Electronic and Computer Engineering*
Kolej Universiti Teknikal Kebangsaan Malaysia, Melaka

[3]*Department of Aerospace Engineering, Faculty of Engineering, Universiti Putra Malaysia 43400 UPM, Serdang, Selangor*

ABSTRACT

The ionosphere plays a vital role in radio communications whose usable frequencies for signals propagation are mainly affected by its electron content. Determination of the electron content in the ionosphere will aid in reliable and secure radio communications. Phase delays of the received frequencies at L1 (1575.42 MHz) and L2 (1227.6 MHz) of GPS signals has extensively been be used to determine the total electron content of the ionosphere. Using a network of dual frequency GPS receivers in the Malaysian Active GPS System (MASS) installed by the Jabatan Ukur dan Pemetaan Malaysia (JUPEM), a regional map of the Malaysian ionosphere is constructed. This will aid in correcting errors for geomatic and other GPS-based applications. In this paper, techniques to generate the TEC latitude and longitude profile map are discussed. A few sets of the Malaysian regional TEC latitude and longitude profile map have also been produced to demonstrate the dynamic structure of the ionosphere and equator phenomenon such as the famed equatorial anomaly.

Keywords : *Equatorial Ionosphere, GPS, Ionosphere, TEC Profile Mapping , Total Electron Content*

1.0 INTRODUCTION

The success of a radio communications link depends very much on understanding the transmission medium. In the heydays of shortwave radio communications, i.e., in the range of 3-30 MHz, the ionosphere plays a very important role in reflecting the radio signals allowing over the horizon communications. Its significance cannot be disregarded even with the advent of highly sophisticated satellite communications network, in the 1-40 GHz range. This is due to the fact that the ionosphere can cause scintillations to the satellite transmissions which degrades the signals. In land surveying, geomatic accuracy using GPS satellites is also dependent on ionosphere, which causes phase delays of the signal. This tantamounts to ionospheric errors. Hence, a very good knowledge of the medium, especially the ionosphere, through which the signal passes through is very important.

The ionosphere is a region in the earth's upper atmosphere, consisting of several electrified layers, which are capable of bending high-frequency radio waves and returning them to earth at great distances [1]. It is formed by ultraviolet radiation from the sun, and the intensity of this radiation changes radically with time and geographical location. The ionosphere can be thought of as a number of distinct layers, with some overlapping with the whole of the ionosphere having some level of ionisation. These layers are given designations 'D', 'E', 'F_1' and 'F_2' as shown in Figure 1.

The level of ionisation in the ionosphere varies according to a number of factors including the time of day, the season and the state of the sun. The intensity of ionising radiation that strikes the ionosphere varies with latitude, being considerably greater in equatorial regions, where the sun is more directly overhead, than in the northern latitudes. Malaysia's location, which is near to the equator, has made it good for the study of the ionosphere, particularly the equatorial anomaly and fountain effect [2, 3]. The equatorial anomaly is caused by the combined action of electric and magnetic fields. When the overhead sun creates intense ionisation in the region, the electric field starts these charges moving. The magnetic field (which only has an effect on moving charges) then causes them to drift upwards. Finally, the particle diffuse outwards following the geomagnetic field down to where it intersects the normal F-layer. This process starts immediately after sunrise and by mid afternoon the build up of ionisation is clearly present and persists until after sunset, when there is no more ionisation produced by the sun [1, 4].

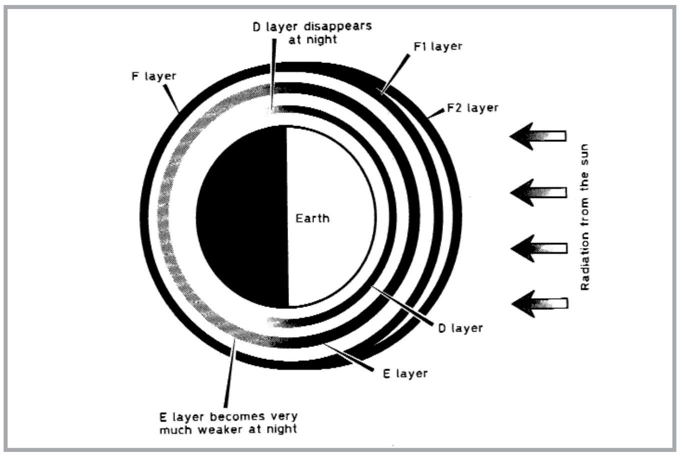

Figure 1: Simplified view of the layers of the ionosphere over the period of a day [4]

Researchers have extensively done ionospheric research on tropical and equatorial area. The worldwide ionospheric mapping with GPS brings major improvement to ionospheric mapping. In Malaysia, research has been carried out on the ionospheric characteristics and dynamics using the Jabatan Ukur dan Pemetaan Malaysia (JUPEM) network [3, 5 - 8]. Analysis of TEC was made using the GPS station at Arau, Perlis in the northern part of Malaysia as reported [3, 5]. Short term TEC analysis has also been done using GPS station at Miri, Sarawak [3, 6]. Furthermore, they have made D region analysis from GOES-7 soft solar x-ray data at Universiti Kebangsaan Malaysia [3, 7]. While Ho et al. [3, 8] have reported on typical hourly variations for quiet ionosphere over Malaysia during 24 hours on July 14, 2000.

This paper focuses on the relative variations in TEC at Malaysia and equatorial region (Latitude 10^0 S to 16^0 N, Longitude 90^0 E to 120^0 E) with respect to a normal quiet day (stormwise). The observations of oblique TEC can be obtained from the delays of GPS radio signal on channels L1 (1575.42 MHz) and L2 (1227.6 MHz) under the assumption of an infinitesimal single-layer ionospheric model at fixed height $H = 450\ km$ and 20˚ elevation angle. It should be noted that the mapping involves the oblique to vertical TEC conversion, which in general may cause some degradation of the map accuracy, with distance away from GPS receivers. A few sets of Malaysian regional TEC latitude and longitude profile maps have been produced to demonstrate the dynamic structure of the ionosphere and equator phenomenon such as the equatorial anomaly. Techniques to produce the TEC latitude and longitude profile maps will also be discussed in this paper.

2.0. MALAYSIAN ACTIVE GPS SYSTEM (MASS)

2.A. THE NETWORK OF GPS RECEIVER STATION

MASS is the permanent Malaysian GPS station network, which is operated and maintained by Jabatan Ukur dan Pemetaan Malaysia (JUPEM). Figure 2 shows 15 Malaysian nationwide distributed JUPEM GPS tracking stations processed at present, the probed ionospheric regions indicated by blue circles when thin shell ionospheric model at height $H = 450\ km$ and 20˚ elevation angle were used.

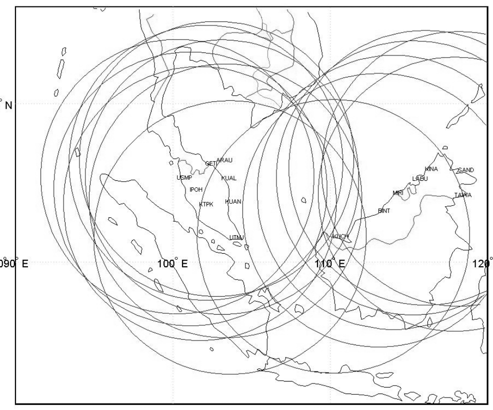

Figure 2: Malaysian nationwide distributed GPS tracking stations and GPS-probed ionospheric regions

Each station contains a TRIMBLE 4000 SSI or SSE receiver and TRIMBLE Universal Station Reference Software, which can be run on Windows NT platform. The antenna is the Trimble L1/L2 with earth surface and Choke Ring Trimble with radome. The radome protects the antenna from inclemental and bad weather and other disturbances, which may come from birds, trees, buildings etc. Each station records the data in TRIMBLE format and exchange it into RINEX format with C/A code, P-code or Y-code mapping and L1 and L2 phase carriers.

2.B. RINEX AND SP3 (DATA) FORMAT

Two types of information are needed to process TEC, which are the GPS pseudo range data and the orbital data of satellite. The GPS pseudo range data comes in the form of RINEX and the orbital data of satellite in the form of SP3. RINEX (Receiver INdepent Exchange format) is the international standard format for the GPS geodetic data exchange, which was proposed in 1989 during the fifth International Geodetic Symposium on Satellite Positioning [9]. The RINEX format is used because it can simplify the GPS data exchange that involves the different types of GPS receivers. RINEX contains three types of different files, which are observation, navigation and meteorology data files. Each file consists of header section that has information on receiver station and antenna in ASCII code for easy exchange between different platforms. There are three important parameters for RINEX format observation file, such as time, phase and range. Figure 3 is an example of the typical RINEX file.

```
     2              OBSERVATION DATA                        RINEX VERSION / TYPE
DAT2RIN 2.35a       DSMM                18JUL00  1:01:20 GMTPGM / RUN BY / DATE
DSMM                DSMM                                    OBSERVER / AGENCY
00021566            TRIMBLE 4000SSI     Nav 7.29 Sig 3.07   REC # / TYPE / VERS
02201071            DORNE MARGOLIN TRIM                     ANT # / TYPE
------------------------------------------------------------ COMMENT
Offset from BOTTOM OF ANTENNA to PHASE CENTER is 110.0 mm   COMMENT
------------------------------------------------------------ COMMENT
ARAU                                                        MARKER NAME
ARAU                                                        MARKER NUMBER
 -1131050.5638  6236311.4461   711749.5158                  APPROX POSITION XYZ
        0.0640        0.0000        0.0000                  ANTENNA: DELTA H/E/N
*** Above antenna height is not corrected.                  COMMENT
     1     1     0                                          WAVELENGTH FACT L1/2
     4    L1    C1    L2    P2                              # / TYPES OF OBSERV
    30                                                      INTERVAL
  2000     7    17     0     0   30.000000                  TIME OF FIRST OBS
  2000     7    17     1     0    0.000000                  TIME OF LAST OBS
     9                                                      # OF SATELLITES
     2   120   120   120   120                              PRN / # OF OBS
     4   120   120   118   118                              PRN / # OF OBS
     7   120   120   120   120                              PRN / # OF OBS
     8    39    39    26    26                              PRN / # OF OBS
     9    96    96    58    58                              PRN / # OF OBS
    10   105   105   101   101                              PRN / # OF OBS
    13   110   110    72    72                              PRN / # OF OBS
    16    67    67    63    63                              PRN / # OF OBS
    24   120   120   120   120                              PRN / # OF OBS
                                                            END OF HEADER
  0  7 17  0  0 30.0000000  0  7  2  4  7  8 13 16 24
  26522566.44900  20179071.43300  19960290.65140  20179077.49940
  33310509.87000  21364927.31900  25730195.21240  21364933.69040
  65151864.67100  22631652.10200  10992065.62140  22631659.23040
  76375979.76900  23995724.83300  59012865.30140  23995734.66940
   3263987.39500  24116419.27400   1409173.13940  24116426.66640
  42109009.44400  22870181.31400  32690703.20340  22870189.47640
  17248696.30400  21685192.07100   2844174.69340  21685198.31440
  0  7 17  0  1  0.0000000  0  8  2  4  7  8 10 13 16 24
  26656071.70500  20204476.66800  20064320.63740  20204482.42340
  33477100.42900  21396628.54400  25860005.93540  21396633.58340
  65245091.42700  22649392.55900  11064709.78240  22649400.42440
  76577916.11000  24034152.24000  59170218.05040  24034157.57340
      6841.85910  23036966.05300
   3350709.63700  24132922.05800   1476748.80940  24132927.78040
  42304006.70000  22907288.22900  32842648.95040  22907297.15640
  17375020.06000  21709230.74900   2942608.67840  21709236.69940
  0  7 17  0  1 30.0000000  0  7  2  4  7  8 13 16 24
  26790167.58500  20229994.31400  20168810.84840  20230000.54940
  33643894.56200  21428368.46100  25989975.28140  21428373.49540
  65338237.49900  22667117.70900  11137291.04340  22667124.15640
  76779685.12000  24072547.84500  59327440.50640  24072554.78740
   3437221.22500  24149384.73600   1544160.35740  24149389.93240
  42499416.06900  22944473.48300  32994915.79640  22944483.24140
  17501676.88300  21733332.80500   3041302.20540  21733338.71240
  0  7 17  0  2  0.0000000  0  7  2  4  7  8 13 16 24
```

Figure 3: Example of a RINEX data format

The time of the measurement is the receiver time of the received signals, which is expressed in GPS time (not Universal Time). The pseudo-range (PR) is the distance from the receiver antenna to the satellite antenna including receiver and satellite clock offsets. The phase is the carrier-phase measured in whole cycles at both L1 and L2. The IGS orbital format SP3 (Standard Product # 3) for Global Positioning System (GPS) satellites as proposed by Remondi from Institute of Navigation in 1985 [10].

The main purpose of using SP3 format is for easy exchange satellites orbit data between different platforms. A few important parameters in SP3 file which are x-y-z coordinates position in kilometer, clock record in microsecond, x-y-z coordinate velocities and clock rates-of-change. The SP3 format is chosen because it can provide the GPS orbit data with the maximum precision error of 0.05 m, compared to the orbit data in RINEX format navigation file, which gives the maximum precision error of 2.5m. RINEX in ASCII format is highly flexible in exchanging data. Since it is such a difficult task to process data using the observation file, the binary files are being used instead. This can be implemented using the Bernese GPS software.

2.C. BERNESE GPS MODEL

The Bernese GPS software was developed as a tool for the highest accuracy requirement for GPS geodetic usage and applications. This software can transform all the RINEX files from the 15 JUPEM GPS receiver stations into four different types of binary files. The first file is the phase header file, which contains information on station, receiver, antenna, ambiguity and other information. The second file is the phase observation file, which consists of phase observation data. The third file is the code header file, which has information that is similar to the phase header file, but it does not contain ambiguity information. The last file is the code observation file, which contains the code observation data.

However, only the code header and observation files are used for the further process. SP3, which is in ASCII format contains precise ephemeredes data and include position, velocities and clock for each satellite. Both the GPS code observation data and GPS satellite ephemeredes data are needed for the GPSEST program to generate the Spherical Harmonics coefficients of Global Ionosphere Map parameters for specific epoch. The resultant SH coefficients are applied to the regional TEC representative Equation 1 to produce TEC value for specific geographical position.

$$F_v(\beta, s) = \sum_{n=0}^{n_{max}} \sum_{m=0}^{n} \tilde{P}_{nm}(\sin\beta)\left[\tilde{C}_{nm}\cos(ms) + \tilde{S}_{nm}\sin(ms)\right] \quad (1)$$

where,

β	- geographical latitude for ionospheric pierce point
$s = \lambda - \lambda_0$	- sun-fixed longitudinal for ionospheric pierce point
λ	- longitude for ionospheric pierce point
λ_0	- longitude for sun
n_{max}	- maximum degree for SH expansion
$\tilde{P}_{nm} = N_{nm}P_{nm}$	- normalised Lagendre function for n degree and m order
N_{nm}	- normalised function
P_{nm}	- Lagendre function
$\tilde{C}_{nm}$, $\tilde{S}_{nm}$	- estimated SH coefficient or Global Ionosphere Map, GIM parameters

The normalised function can be written as follows [11]:

$$N_{nm} = \sqrt{\frac{(n-m)!(2n+1)(2-\delta_{0m})}{(n+m)!}} \quad (2)$$

with δ as Kronecker delta.

3.0. MAPPING METHODOLOGY – TEC PROFILE MAPPING

The mapping toolbox in Matlab version 5.3 software had been used to generate the Malaysian regional TEC map. The TEC values are arranged in matrices form (latitude and longitude) for each epoch before being projected on Malaysian regional map. Furthermore, Malaysian regional map (9˚ to 16˚ latitude, 90˚ to 120˚ longitude) is generated for each epoch using the world map database, which is available in the Matlab toolbox. The TEC information quantified by the high density electron being represented by dark grey and black for low density electron following a graduation of values for a specific epoch (Figure 4). A generic system for regional Malaysian TEC mapping has been produced. Hence, a variety of Malaysian regional TEC map can be produced based on certain purposes.

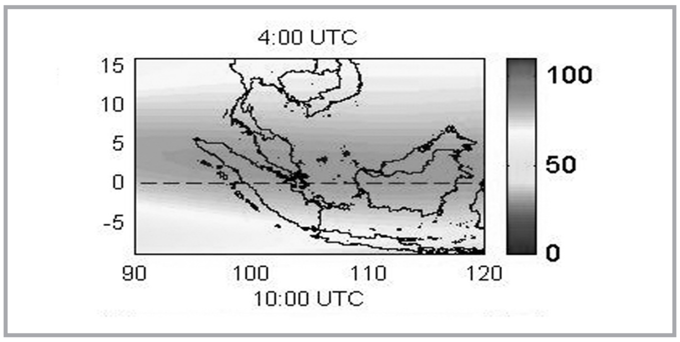

Figure 4: The TEC information quantified by the high density electron being represented by red and blue for low density electron following a graduation of values for a specific epoch

3.A. MALAYSIAN MAP OUTLINE

The generic system for regional Malaysian TEC mapping had been produced to study and facilitate research in ionospheric dynamic activities. In the Malaysian region, the daily (24 hours) longitude and latitude TEC profile map (Figures 5 and 6) for Malaysian region is produced by redimensioning the TEC values matrices (produced by the GPSEST program). Figure 7 summarises the techniques used to generate the Malaysian Regional latitude and longitude profile map.

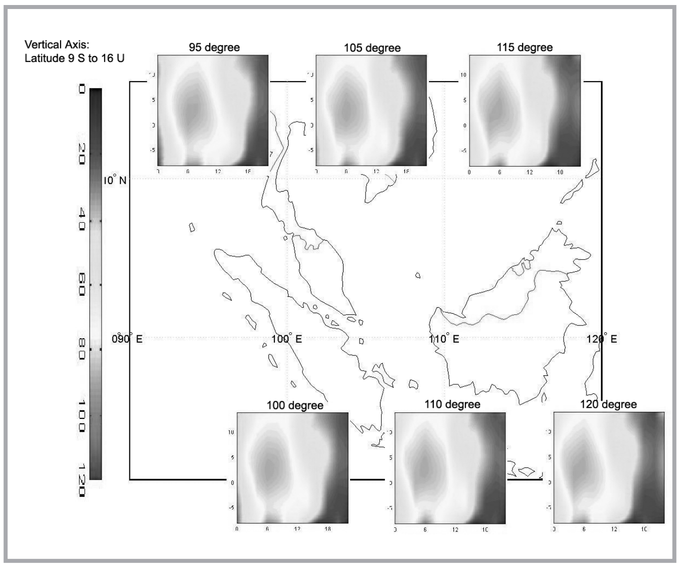

Figure 5: Daily latitudinal profile map for Malaysia region at July 13, 2000 at longitude 95 E, 100 E, 105 E, 110 E, 115 E and 120 E.

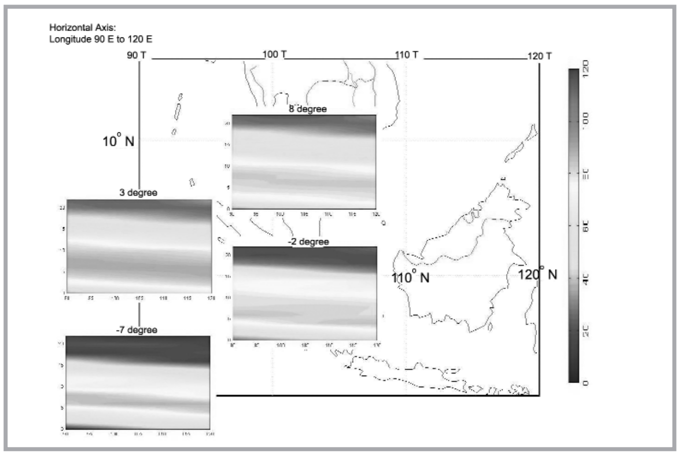

Figure 6: Daily longitudinal profile map for Malaysia region at July 13, 2000 at latitude 8 N, 3 N, 2 S, and 7 S

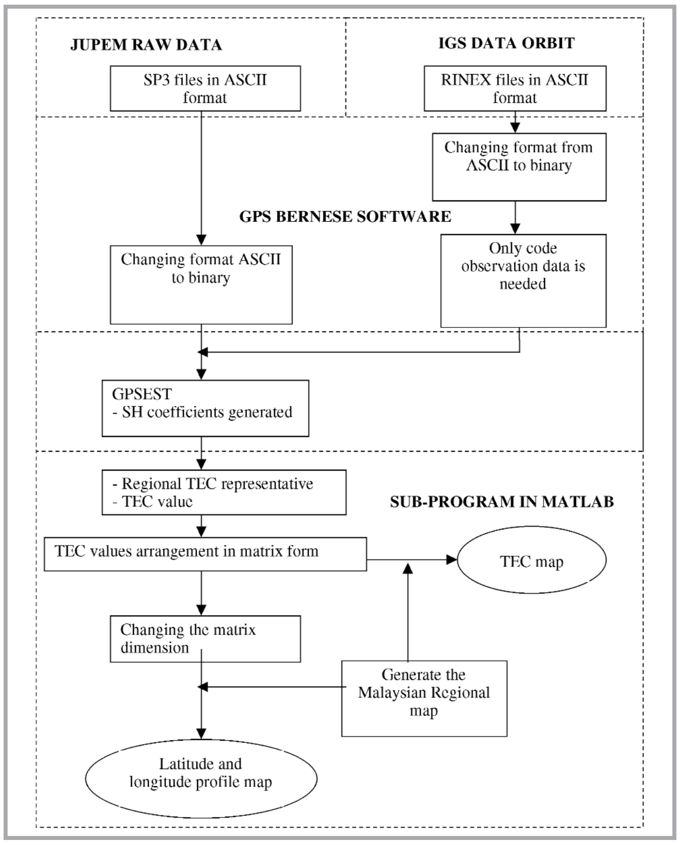

Figure 7: Flowchart for Generation of TEC Map

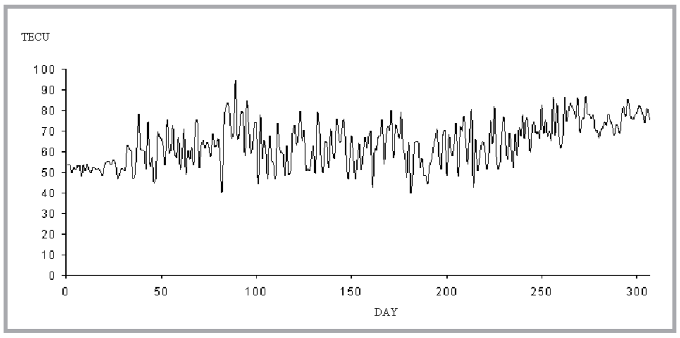

Figure 8: The mean Malaysian regional daily TEC for 365 days in 2001

A parameter, which is used to characterise the Malaysian ionosphere is the mean regional TEC, $\bar{E}$. The mean regional TEC is obtained from Equation 3, which is

$$\overline{E} = \frac{\sum \cos \beta E_{\beta,\lambda}}{\sum \cos \beta} \qquad \text{(Equation 3)}$$

where,

$E_{\beta,\lambda}$ - TEC values at geographical coordinate (β, λ)

$\cos \beta$ - load function for geographical latitude β

The $\bar{E}$ value from the Equation 3 is referred to the specific epochs. Hence, the mean Malaysian regional daily TEC is obtained from the mean values for the whole epochs for each day (24 hours) within the Malaysian region (Figure 8). The maximum mean Malaysian regional daily TEC is obtained from the maximum mean values for the whole epochs for each day (24 hours) within the Malaysian region (Figure 9). The minimum mean Malaysian regional daily TEC is obtained from the minimum mean values for the whole epochs for each day (24 hours) within the Malaysian region (Figure 10).

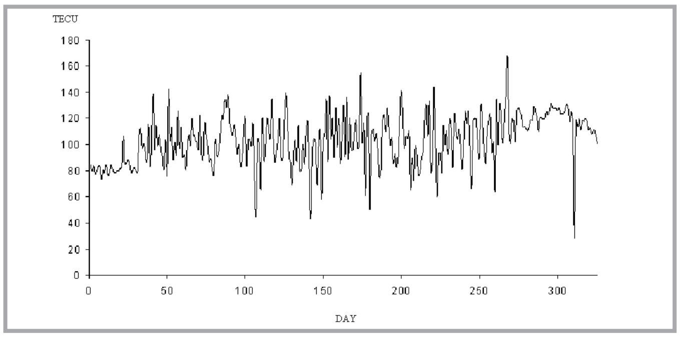

Figure 9: The maximum mean Malaysian regional daily TEC for 365 days in 2001

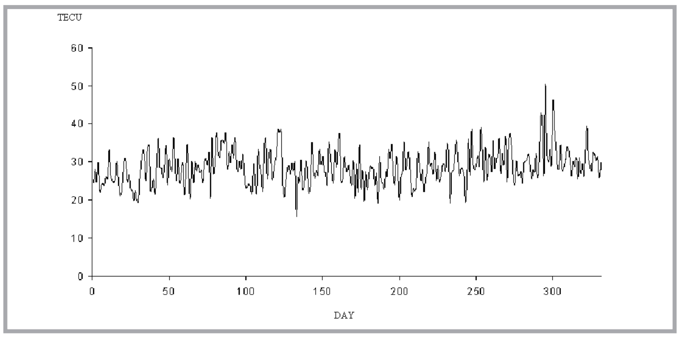

Figure 10: The minimum Malaysian regional daily TEC for 365 days in 2001

4.0. DISCUSSIONS

4.A. LATITUDINAL AND LONGITUDINAL TEC VARIATION PROFILE

A series of six latitudinal TEC profile Malaysian maps (Figure 5) were generated on July 13, 2000 at longitudes of 95˚ E, 100˚ E, 105˚ E, 110˚ E, 115˚ E and 120˚ E. For illustration purpose, July 13, 2000 is chosen because it is a normal quiet day (storm wise). From the figure, the equator anomaly effect can be seen. The effect was first seen at 05:00 UT or 13:00 LT (lunch hour). The effect was obviously seen at 06:00 UT or 14:00 LT and disappeared at 07:00 UT or 05:00 LT.

Figure 6 shows a series TEC longitude profile Malaysian maps which were obtained on July 13, 2000 at particular latitude which are 7˚ S, 2˚ N, 3˚ N and 8˚ N. Qualitatively, the TEC peak begins

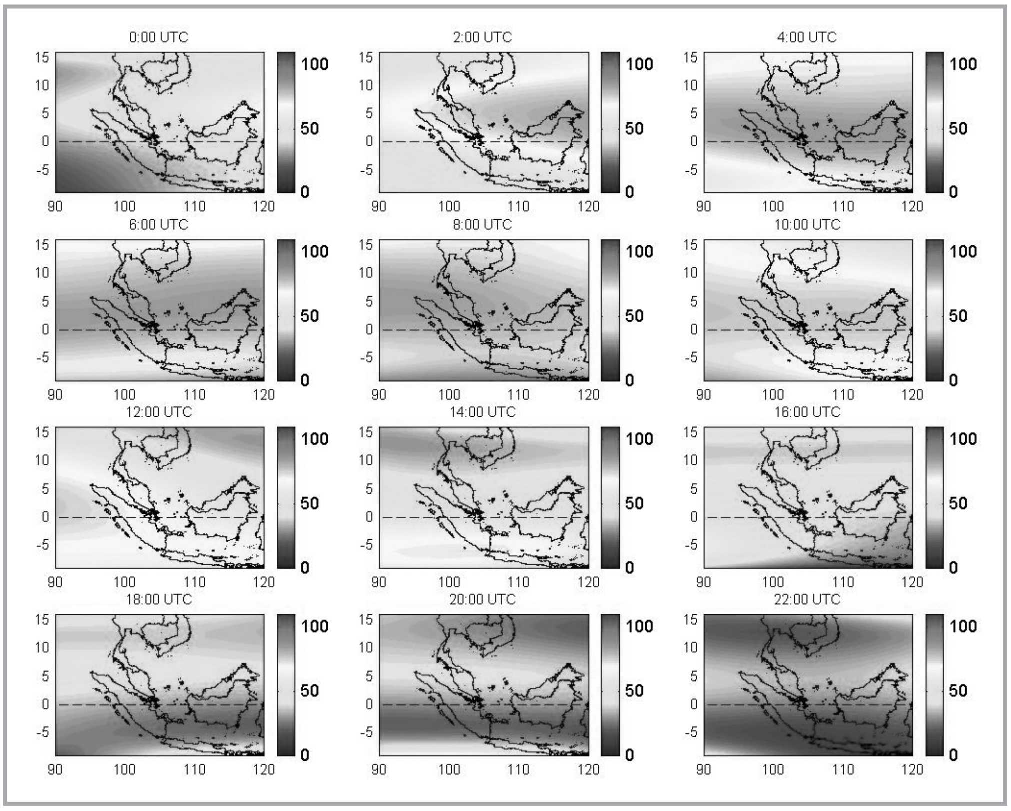

Figure 11: TEC maps snapshot with 2 hours interval on July 14, 2000

at 120° longitude and moves towards 90° longitude, which is the TEC dynamic structure movement from east to west in accordance to sun movement.

Comparing Figures 5 and 6, it can be observed that it is easier to see the TEC variations from the longitudinal profile map (Figure 6). A series of 12 TEC maps on July 14, 2000 was constructed with 2 hours each intervals, that is 0000, 0200, 0400, 0600, 0800, 1000, 1200, 1400, 1600, 1800, 2000, 2200 UT as shown in Figure 11. Figure 11 combines both the latitude and longitude profile maps. The data is taken from all satellites are visible within $\theta > 20^\circ$ to observation stations at the moment in order to reduce the error in TEC values.

An interesting feature that can be easily seen in Figure 11 is a shift in TEC structures. It indicates the correlation between the propagation of electron content drift in the ionosphere and the sun's movement from east to west. The maximum TEC value occurred around 0600 UT equivalent to 1400 LT (Malaysia). It is consistent to high solar energy input to the ionosphere and cause highly ionisation process. However minimum TEC value occurred just before sunrise at 2200 UT, which is equivalent to 0600 LT. The ionospheric shell is thicker and ionisation process has stopped. Recombination processes and dispersion of electrons is dominant during this time.

B. EXAMPLE OF MAPPING DURING GEOMAGNETIC STORM

The discussion before is focused on a normal quiet day (storm wise). Another factor that can affect the TEC variations is the geomagnetic storm. A geomagnetic storm is the result of constant explosions on the searing surface of the Sun. These explosions throw off an incredible amount of highly energetic particles, which stream into space at velocities of thousand of miles an hour. When these particles hit our atmosphere, the consequences may be drastic

A sudden storm commencement occurred at 1440 UT on July 15, 2000 when a powerful interplanetary shock wave struck the earth's magnetosphere. Significant geomagnetic disturbances were caused which consequently induced a major magnetic storm which exceeded Kp = 9 for over 9 hours starting at about 1500 UT on July 16, 2000. Kp is the principle planetary geomagnetic disturbance index obtained from the H component of the earth magnetic field and divides activity into ten levels. The letter K was selected by Julius Bartels to stand for the word "kennziffer", meaning the index of the logarithm of a number [12].

This was the second largest geomagnetic storm observed since 1989, and one of the most intense solar proton event ever recorded. The proton event reached S4 on the NOAA Space Weather Scales, and the geomagnetic storm reached G5 levels. The most significant x-ray event in the sequence was the R3 level event on July 14, 2000 [13]. The storm commencement is followed by an initial or positive phase lasting for an hour. During this time the geomagnetic field intensity is increased. This is probably due to the compression of the geomagnetic field by the solar plasmas. The time interval between 1700 and 2100 UT on July 15, 2000 was the main phase of the storm. During the main phase of the storm, the Dst index reached a low of –300 nT and the Kp index reached its maximum value of 9. After 2100 UT, it was the recovery phase as Dst was returned to its regular value gradually in the next 48 hours. There was still significant substorm activity during the early recovery phase.

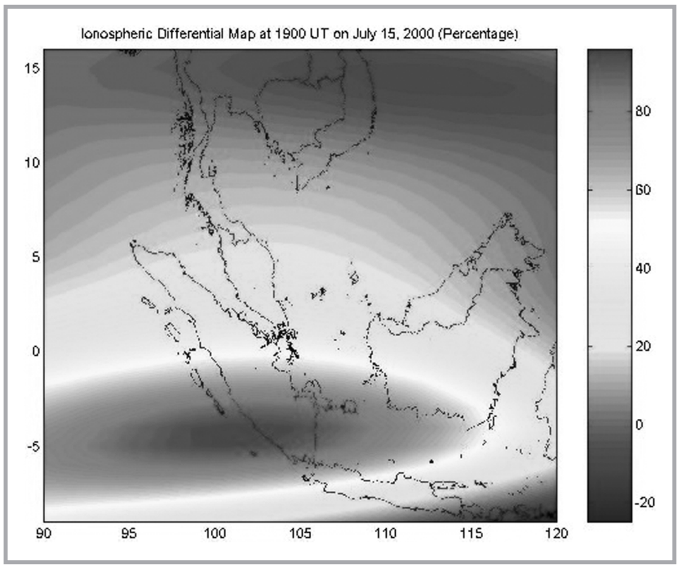

Figure 12: The Main Phase of the Storm at 1900 UT on July 15, 2000

Figure 12 shows the TEC variations over Malaysia and equatorial region during the three days of the storm times. The percent changes relative to the quiet time profiles are calculated. The three days (July 12 – 14, 2002 with low geomagnetic activity) of TEC average have been used as the quiet time reference. The ionospheric storm phases along these three days are obviously shown in the figure. Over this region the positive phase started two hours after the arrival of fast CME from Sun.

TEC enhancements reached their maximum during the main phase of the storm (1900 UT on July 15, 2002), whose change ratio exceeds 25%. There is a clear negative phase, which started after 0000 UT on July 16. These TEC depressions reached their minimum between 1400 – 2100 UT on July 16, 2002 whose change ratio exceeds –20%. After 0000 UT on July 17, 2002, the entire ionosphere gradually recovered to normal.

5.0. SUMMARY

This paper has discussed on using JUPEM GPS network to map the Malaysian ionosphere. We have shown that it is possible to generate a map of the TEC profile using Bernese model and Matlab. The map gives a visual indication of the state of the ionosphere. An example is given during the geomagnetic storm on July 12 – 14, 2002 (Figure 12).

From the Malaysian regional latitude profile map, the equatorial anomaly effect can be observed during the local noontime and start disappearing at the morning time. Based on the Malaysian regional longitude profile map (Figure 5), dynamic structure movement of TEC can be seen from east to west in accordance to sun movement. In the series of Malaysian regional TEC map (Figure 6), the electron movement in the ionosphere layer can be studied.

It should be noted that the mapping involves the oblique to vertical TEC conversion, which in general may cause some degradation of the map accuracy with distance away from GPS receivers. Further studies should involve mapping error analysis with distance away from GPS receivers.

EPILOGUE

Since the aftermath of the tsunami of 26 December, 2004, and the Nias earthquake of 28 March, 2005, the importance of TEC studies in relation to earthquakes has increased. Ionospheric parameters are currently being monitored at the WARAS Centre, KUiTTHO in Batu Pahat.

ACKNOWLEDGMENTS

The authors would like to acknowledge the Jabatan Ukur dan Pemetaan Malaysia for graciously providing the RINEX data. ■

REFERENCES

[1] G. Jacobs and T. J. Cohen, *The Shortwave Propagation Handbook*, 2nd Ed., USA: CQ Publishing, Inc, 1982.

[2] J. W. Wright, "Vertical Cross Sections of the Ionosphere across the Geomagnetic Equator", *NBS Tech. Note*, U.S. Dept. of Commer., Washington D.C., 1962.

[3] A. F. M. Zain, H. Y. Hwa and M. Abdullah, "Enabling GPS Technology on Equatorial Ionosphere Monitoring During Geomagnetic Storm of July 15 – 17, 2000", ION GPS 2002, Portland, 24 – 27 September, 2002.

[4] I. Poole, *Your Guide to Propagation*, Great Britain: Radio Society of Great Britain, 1998.

[5] A. F. M. Zain and M. Abdullah, "Initial Results of Total Electron Content Measurements over Arau, Malaysia", *Proc. 4th IEEE Malaysia International Conference on Communications*, Vol. 1, pp. 440 – 443, Nov., 1999.

[6] A. F. M. Zain and M. Abdullah, "Measurements of Total Electron Content Variability at Miri, Sarawak: Short Term Analysis", *Proc. 2nd ICAST*, Putrajaya, Malaysia, Vol. 2, pp. 1967 – 1975, 15 – 17 August 2000.

[7] M. Abdullah and A. F. M. Zain, "Determination of D-region Electron Densities from GOES-7 X-Ray Detector Measurement", *Journal-Institution of Engineers*, Vol. 61, No. 3, pp. 67 – 80, 2000.

[8] H. Y. Hwa, A. F. M. Zain and M.Abdullah, "Hourly Variations Total Electron Content, TEC, for Quiet Ionosphere Over Malaysia", *In Proceeding of the Annual Workshop National Science Fellowship (NSF) 2001*, Petaling Jaya, Malaysia, pp. 77 – 79, 14 – 15 January 2002.

[9] A. Evans, "Summary of the Workshop GPS Exchange Formats", *Proc., of the Fifth International Geodetic Symposium on Satellites System*, 1989.

[10] B. W. Remondi, "Distribution of Global Positioning System Ephemerides by the National Geodetic Survey", *1st Conference on Civil Applications of GPS – Institute of Navigation*, CR-ROM, 1985.

[11] D. D. McCarthy, "Atmospheric Tides in the Ionosphere.I. Solar Tides in F2 Region", *Proc. Roy. Soc.,* pp. 1 – 18, 1947.

[12] W. H. Campbell, Introduction to Geomagnetic Fields, USA: U.K.: Cambridge University Press, 1997.

[13] SEC, "Space Environment Center", *URL: http://sec.noaa.gov or ftp://ftp.sec.noaa.gov*, Boulder, Colorado, USA, 2000.

PROFILE

Ir. Prof. Dr Ahmad Faizal Mohd. Zain
Wireless and Radio Science Centre (WARAS), Kolej Universiti Teknologi Tun Hussein Onn, 86400 Parit Raja, Batu Pahat, Johor Darul Takzim

Ho Yih Hwa
Department of Telecommunication Engineering, Faculty of Electronic and Computer Engineering, Kolej Universiti Teknikal Kebangsaan Malaysia, Jalan Ayer Keroh, Melaka

Harlisya Harun
Department of Aerospace Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor Darul Ehsan