Studies on Equatorial Total Electron Content Near Solar Maximum Activity from 1998-2000

Wan Salwa Wan Hassan [(1)], Ahmad Faizal Mohd.Zain [(2)], Abdul Ghaffar Ramli[(3)], Ho Yih Hwa[(4)], Mardina Abdullah[(5)]

[(1)] Department of Electrical, Electronic and Systems Engineering, Faculty of Engineering, Universiti Kebangsaan Malaysia, 43600, Bangi,Selangor, Malaysia. Email: mhashim@pc.jaring.my

[(4)] As (1) above, but E-mail: hoyhwa@tm.net.my

[(2)] Faculty of Engineering, Kolej Universiti Teknologi Tun Hussein Onn, Parit Raja, 86400, Batu Pahat, Johor, Malaysia. Email: drfaizal@kuittho.edu.my

[(3)] STRIDE, Ministry of Defence, Jalan Padang Tembak, 50634, Kuala Lumpur, Malaysia. Email: agr.sst@mod.gov.my

[(5)]) Institute of Integrated Information Systems, School of Electronic and Electrical Engineering, The University of Leeds, University of Leeds, LS2 9JT, Leeds, United Kingdom. Email: eenmabd@leeds.ac.uk

INTRODUCTION

The irregularities in the electron density of the equatorial ionosphere can result in the performance of Global Positioning System (GPS) receivers to be compromised. These effects are more serious after sunset and during periods of high solar activity [1]. The formation and mechanism of the irregularities is attributed to the Rayleigh-Taylor Instability [2] which results in a distinct trough of depleted ionization in the bottomside and topside of the ionospheric F2 layer at the magnetic equator with crests of ionization at ~ 15 to 20° north and south of the geomagnetic equator. In addition to instabilities, there are large diurnal and seasonal variations in the ionosphere in step with solar activity which is almost cyclical every 11 years. At the equator, such variations peaks up during equinoxes in March and September.

In Malaysia, ionospheric studies is still a relatively new area of research. There are a few active research groups looking at the short-term spatial and temporal characteristics of local ionospheric condition [3], [4] and [5]. This paper describes a long-term study on the trend of equatorial TEC variations with increasing solar activity carried out at Marak Parak, Sabah, Malaysia (geographic co-ordinates : 6.31° N, 116.74° E ; geomagnetic lat 1.3° S, dip 3.8° S, declination 0.2°). The GPS receiver station is part of the network of GPS receivers described in more detail by [6].

This work analyses the correlations of TEC with solar ($F_{10.7}$ and SSN) and magnetic activities (A_p) using two indicators, namely TEC_{max} and TEC_{day} observed.

EQUIPMENT AND METHODS

Measurements of ionospheric TEC were done using a NovAtel MiLLennium GPSCard receiver with NovAtel 503 Survey Antenna and Choke Ring designed to minimize multipath interference. The dual frequency receiver has 12 channels permitting simultaneous collection of data from up to 12 satellites.

The dispersive nature of the ionosphere enables measurements of total electron content (TEC) using a dual-frequency GPS receiver. Ionospheric TEC is proportional to the time delay of the signals traversing the ionosphere. TEC is measured in units of 10^{16} electrons/m^2, denoted by TECU.

Both code and phase TEC are calculated from the data obtained at a rate of 0.5 Hz. However, the results reported here are derived from code TEC only due to complexity of dealing with phase ambiguities in

phase TEC. Vertical TEC is derived from slant TEC by correcting for each satellite's elevation angle assuming a thin shell of effective ionospheric height of 400km.

For the purpose of analysis two indicators of TEC are chosen to be TEC_{max} and TEC_{day}. TEC_{max} is the daytime maximum value of TEC, one value per day. TEC_{max}, an instantaneous reading of TEC at a maximum value is a commonly used parameter by most workers. Being an instantaneous value, TEC_{max} may be affected by short term value of solar activity. TEC_{day} is the integrated diurnal TEC, a summation of every minute TEC values, one value per day. Due to its integral nature TEC_{day} is representative of the ionospheric response to solar activity for the entire day including nocturnal behaviour.

VARIATION OF IONOSPHERIC TOTAL ELECTRON CONTENT

Diurnal variations of TEC

Typical variation of diurnal TEC at Marak Parak between 1998 to 2000 is shown in fig. 1. The maximum value of TEC (TEC_{max}) usually happens near mid-day while the minimum value (TEC_{min}) occurs at night. TEC_{max} increases from 40 TECU to 120 TECU over the 3 years while TEC_{min} increases from 10 TECU to 30 TECU over the same period. There is usually a deep pre-sunrise depression which becomes more prominent as TEC increases with the increasing solar activity.

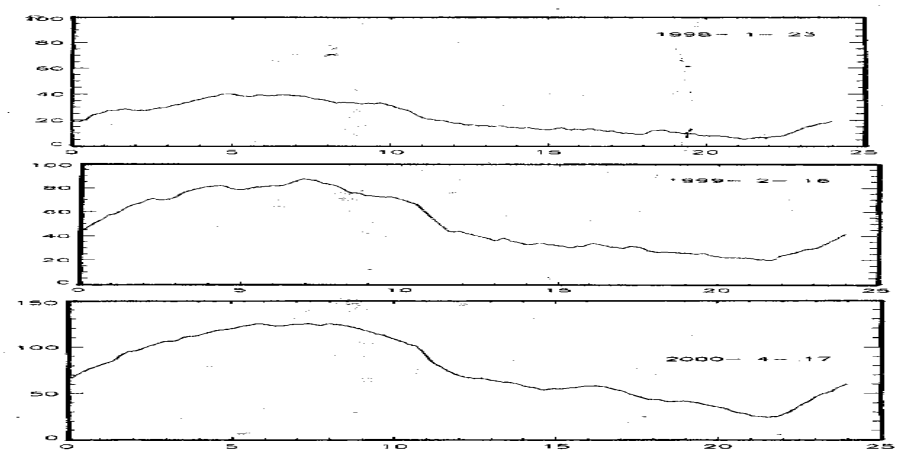

Fig 1 : Typical diurnal variation of TEC for 1998 (top), 1999 (middle) and 2000 (bottom). (LT=UT+8hrs)

There appears to be a prominent secondary peak after sunset (hereafter called post-sunset secondary maximum; PSSM) throughout the 1998-2000 data. PSSM normally happens in the evening before midnight and are more pronounced around equinoxes during high solar activity. In 1998, 90% of the days near equinoxes exhibit PSSM while only 50% of days near solstices have PSSM.

The mechanism of PSSM could be caused by irregularities developed by Raleigh-Taylor instability due to the influence of gravitational, electric, and magnetic fields**.** This anomaly is typical of measurements made at and near the magnetic equator. An alternative explanation offered by [7] indicates the PSSM is due to ExB drift from the equatorial anomaly region. These observations need a further study to ascertain the true cause of the very frequent occurrence of PSSM.

Seasonal variation of TEC

The averaged TEC_{max} shows an increase with solar activity from 38.9 ± 3.4 TECU in Jan 1998 to 109.0 ± 7.6 TECU in Oct 2000. During the period of 1998 when solar is relatively quite, a few months (Mac, Apr, May and Aug) show a bigger spread of TEC. This spread is due to the occasional occurrences of solar flares pushing for higher TEC. In the period of high solar activity even though the average absolute

monthly TEC increases the spread is relatively low showing that TEC values within the month are consistently high.

Fig.2 shows the variations of TEC with increasing solar activity indicated by $F_{10.7}$ and Zurich sunspot number (SSN). TEC_{max} values increases in step with solar activity peaking at equinoxes. We observed a general increasing trend of TEC_{max} in step with the increase in solar activity between 1998 and 2000. There is also a hint of a seasonal variation in TEC_{max}, although this is not so obvious due to the absence of data over relatively long periods of time due to equipment failure.

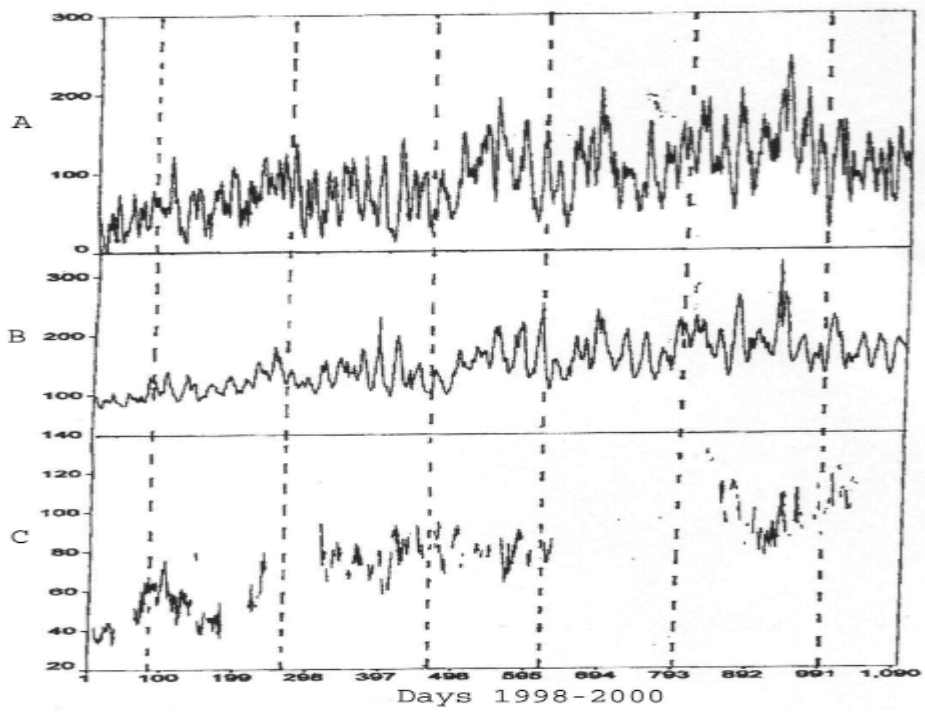

Fig.2 : Variations of TEC for 1998-2000. The vertical dotted lines indicate equinoctial occurrences. A, B, and C represent $F_{10.7}$, Zurich SSN and TEC_{max} respectively.

EFFECTS OF SOLAR ACTIVITY ON TOTAL ELECTRON CONTENT

Although the absolute values of TEC_{day} increase in step with the increasing solar activity the behavior of the increment is different when observed separately each year. In 1998 when the solar is quiet the TEC_{day} increases proportional to solar flux $F_{10.7}$ up to approximately about 70 000 TECU after which saturation commences. Data for 1999 and 2000, although exhibiting an increasing trend, TEC_{day} versus $F_{10.7}$ in fig.5 shows there is considerably more scatter. The possible reason for this could be due to geomagnetic flux since the later years have higher incidences of geomagnetic storms. Fig.6 shows the values of TEC_{day} plotted against $F_{10.7}$ with indicative values of geomagnetic index, A_p. It can be observed that at higher A_p the TEC_{day} appears lower than the expected value if the relationship were linear.

SOLAR INDICATORS

Throughout our work we have used various indicators of solar activity and representation of ionospheric TEC. For solar activity we have used Zurich SSN, $F_{10.7}$ and a local measurement of sunspot number. For the ionospheric TEC we have chosen TEC_{max} and TEC_{day}. Our results indicate that $F_{10.7}$ is a better indicator of solar activity while TEC_{day} provides the best representation of TEC.

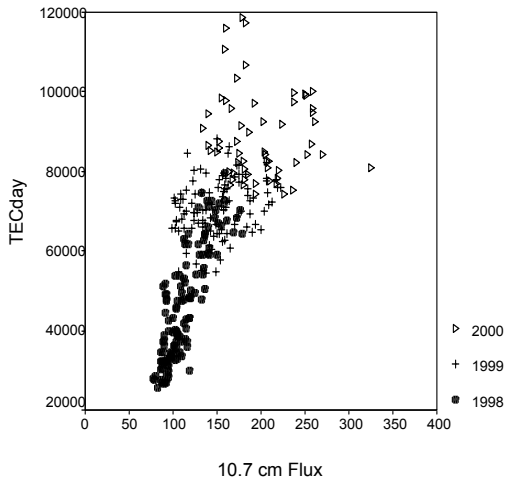

Fig.5 : TEC_{day} versus $F_{10.7}$ for 1998-2000.

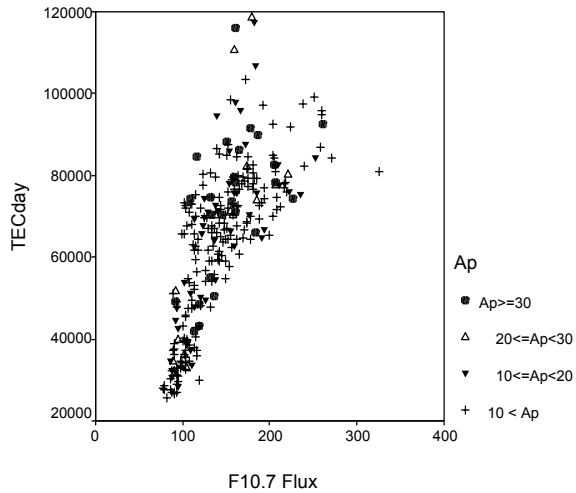

Fig.6 : TEC_{day} versus $F_{10.7}$ for 1998-2000 for various A_p.

CONCLUSION

Observation over 1998 to 2000 indicates absolute TEC_{max} and TEC_{day} values increase with increasing solar activity peaking at equinoxes. There is an almost daily presence of PSSM and also a deep pre-sunrise depression becoming more prominent as TEC increases with the increasing solar activity. During quiet solar period TEC_{day} increases almost proportional to solar flux $F_{10.7.}$ However during active solar period the linear relationship breaks down and TEC_{day} appears lower than the expected value if the relationship were linear. A possible reason for this could be due to higher A_p as TEC_{day} also exhibits similar relationship at high A_p values.

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