Investigation of the Annual Solar Eclipse by using Total Electron Content (TEC) Measurements

Norsuzila Ya'acob[1], Azita Laily Yusof[1], Mohd Tarmizi Ali[1], Mohd Khairul Mohd Salleh[1], Idnin Pasya[1] and Sari Yusmidar Mohamed Sharihuddin[1]

[1] Faculty of Electrical Engineering,
Universiti Teknologi MARA (UiTM),
40450 Shah Alam, Selangor, Malaysia

norsuzila@salam.uitm.edu.my, azita968@salam.uitm.edu.my, mizi732002@salam.uitm.edu, khairulsalleh@ieee.org , idnin@salam.uitm.edu.my,yusmidar_starz@yahoo.com

***Abstract*—This research investigates the ionosphere response to the annual solar eclipse on 26th January 2009 over Indonesia and Singapore. During solar eclipse, ionosphere will be affect due to the partial or complete obstruction of solar emission. It makes the number of electrons and ions decreases. There are several factors that will contribute to the ionosphere response which are the level of solar and geomagnetic disturbances, geographical latitude and longitude and local time. There are some methods that use to determine the behavior of ionosphere response during solar eclipse. It includes ionosonde measurements, incoherent scatter radar (ISR) and Global Positioning System (GPS) satellite. In this research, GPS satellite is use in order to investigate the ionosphere response. This research focuses on the measurement of Total Electron Content (TEC) obtained from two GPS station which are Bako in Indonesia and Ntus in Singapore. The location of these three GPS stations from the path of solar eclipse occur is different. The data is obtained a day before and during solar eclipse. From the findings it shows that TEC level will reduce during solar eclipse due to the reduction of ionizing radiation.**

Keywords-Ionosphere; Solar Eclipse; GPS; TEC

I. INTRODUCTION

Solar eclipse is a unique phenomenon. It occurs when the moon passes between earth and sun. During solar eclipse, ionosphere will be affect due to the incomplete or complete obstruction of solar radiation. It makes the number of electrons and ions decreases. There are several factors that will contribute to the ionosphere response which are the level of solar and geomagnetic disturbances, geographical latitude and longitude and local time [1,2]. During a solar eclipse there is changing in temperature and lights. Due to this condition, electrical wave and magnetic energy have the opportunity to reach the earth [3]. This condition will impact our earth and life. It happens because during that time, the increasing of light is outside the normal cycle. Besides that, solar eclipse also can effect food and life gestation. Through investigation the behaviour of ionosphere response during solar eclipse it can help to predict the time of solar eclipse occur.

Solar eclipse can occur at new moon when the moon passes between Earth and Sun. If the moon's shadow happens to fall upon Earth's surface at that time, some portion of the sun's disk covered or 'eclipsed' by the moon. Even new moon occurs every 29 1/2 days, but a solar eclipse about doesn't happen once a month. It's because the moon's orbit around Earth is tilted 5 degrees to Earth's orbit around the Sun. As a result, the Moon's shadow usually misses Earth as it passes above or below our planet at new moon. At least twice a year, the geometry lines up just right so that some part of the moon's shadow falls on Earth's surface and an eclipse of the Sun is seen from that region. The moon's shadow actually has two parts which are penumbra and umbra [4]. Annular eclipse happens when the moon and Sun are precisely in line, but the evident size of the moon is smaller than that of the Sun. therefore the Sun emerges as a very vivid ring, or annulus**,** adjoining the summarize of the moon[5].

This study is to investigate the ionosphere effect to the solar eclipse based on GPS data due to TEC measurement. This research focuses on the measurement of TEC level during solar eclipse. The data is obtained a day before and during solar eclipse. The variation of TEC is use to discover the prediction of the solar eclipse.

II. SOLAR ECLIPSE CONDITION

According to NASA the eclipse will be seen in the larger path of the moon's penumbral shadow, which includes the southern third of Africa, Madagascar and many parts of Australia (except Tasmania), south-east India, south-east Asia

and Indonesia, on 26th January 2009[6]. According to Harrington (1997), the cities of Kotabumi and Telukbetung in Indonesia will experience more than six minutes of annularity while Krakatoa (or Krakatau), which will be closer to the shadow's edge, will experience less than five minutes of annularity. The town of Sampit, in Indonesia's central Kalimantan province, and Samarinda, the capital of the Indonesian province of East Kalimantan, will witness a lopsided ring-of-fire sunset eclipse as they will be located near the southern extreme of annularity. The annual eclipse's path from central track continues north-east where it finally encounters land in the form of the Cocos Islands and onward to southern Sumatra and western Java in Indonesia. At 09:40 UT, the central line duration is six minutes and 18 seconds and the sun's altitude at 25 degrees. In its final minutes, the antumbral shadow cuts across central Borneo and clips the northwestern edge of Celebes before ending just short of Mindanao, Philippines at 09:52 UT [7].

III. METHODOLOGY

The path of annual solar eclipse of 26th January through Indonesia and Singapore was investigate at three GPS stations which are Bako and Ntus as shown in Figure 1. The data obtained includes a day before and during solar eclipse. The studied of TEC is based on data taken from SOPAC data center [8]. All GPS data that used is belonging to international GNSS services (IGS) station. The data obtained in the form of Receiver Independent Exchange (RINEX) format.

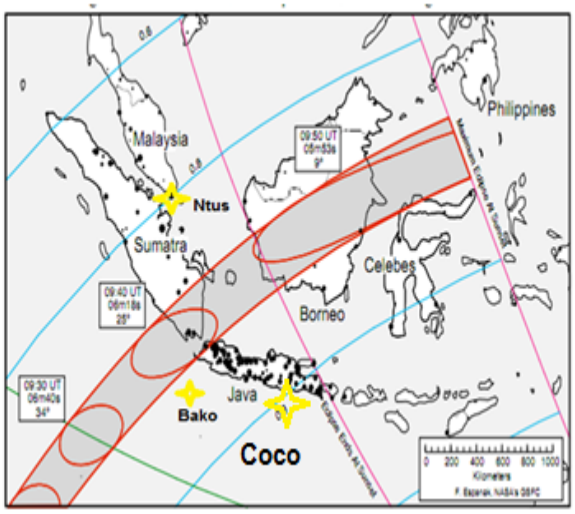

Figure 1. Path of Annual Solar Eclipse of 26th January through Indonesia and Singapore.

Figure 2 show the flow chart of method during investigation on ionosphere response on 26th January 2009 over Indonesia and Singapore.

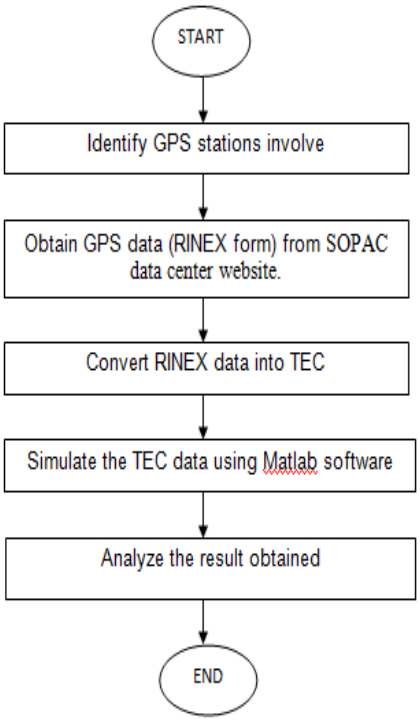

Figure 2. Flow chart of research methodology

The data obtained in RINEX format had been convert to TEC data by using GPS Tool Kit (GPSTk). In order to evaluate TEC, GPSTk made assumption that ionosphere which surrounding by earth is situated at a height about 350 or 450 km. In this study 450 km used in the corresponding area of the equator. It is recognized as the single layer model (Single Layer Model, SLM). The procedures to calculate the TEC is starting by identifying the cycle slip and eliminate it by using DiscFix application. The RINEX data that processed by the DisFix stored in RINEX continued format. The ResCor used to evaluate Vertical TEC (VTEC) and the geographic position from Ionospheric Pierce Point (IPP).

The ResCor applications require navigation data or SP3 data in order to ensure the position of the GPS satellite orbits The data is obtained from International GNSS Service). The ResCor use to remove the error from satelite. Then RinexDump is use to provide data in the boxed column format. The TEC calculation by GPSTk still contain error until the value of TEC be a relative value.

The method for calculating TEC is by developing a matlab software to assist in the analysis of data. The ionosphere response during solar eclipse will be determined by analyze the result from simulation. The comparison of TEC measurements a day before and during solar eclipse will be observed. From the graph on simulation part, the variation of TEC measurement will be observed.

IV. RESULT AND DISCUSSION

The measurements of TEC level at each GPS data chosen had been analyzed during solar eclipse occurs on 26th January 2009 and it compared with a day before which are on 25th January. The analysis had been done starting from 06:00 until 11:00 (UT). The location of GPS station is referring to the path of solar eclipse over Indonesia and Singapore as shown in Figure 1.

According to Figure 3, it shows that the variation level of TEC at Ntus station a day before and during solar eclipse on 25th January and 26th January 2009 respectively. The variation level of TEC on 25th January and 26th January 2009 are observed to analyze the comparison between TEC level a day before and during solar eclipse. On 26th January 2009, the solar eclipse begins at 08:30:01 (UT). By referring to the Figure 3, during solar eclipse, the TEC is less compare to a day before solar eclipse especially on the time of solar eclipse occurs. It happens according to the theoretical part which state that during solar eclipse the TEC will reduce due to the declining of ionizing radiation. From observation, there is a sharp reduction of TEC during solar eclipse starting from 08:30 (UT). Its shows that the TEC level during solar eclipse decrease about 6.43614 TECU starting from 08:30 until 10:57 (UT).

Table 1 and Table 2 show the variation level of TEC at Ntus station on 25th January 2009 and 26th January 2009 respectively. The data tabulated are starting from 06:00 until 11:00 (UT) for each single 30 minutes.

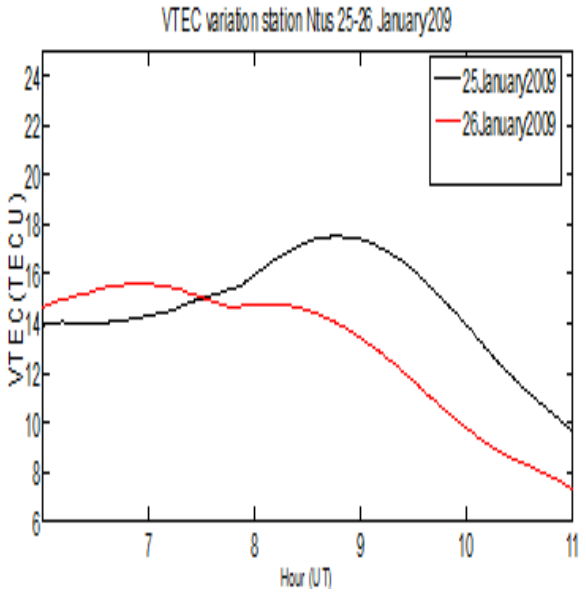

Figure 3. The measurements of TEC level on 25th January and 26th January 20009 at Ntus station

TABLE 1. THE VARIATION LEVEL OF TEC AT NTUS STATION ON 25th JANUARY 2009

Time (UT)	TEC (TECU)
06:00	13.95048
06:30	13.98109
07:00	14.3121
07:30	15.0154
08:00	15.95546
08:30	17.28609
09:00	17.40727
09:30	16.17231
10:00	13.9495
10:30	11.55777
11:00	9.683192

TABLE 2. THE VARIATION LEVEL OF TEC AT NTUS STATION ON 26th JANUARY 2009

Time (UT)	TEC (TECU)
06:00	14.64906
06:30	15.33792
07:00	15.59665
07:30	15.05953
08:00	14.70666
08:30	**14.54285**
09:00	13.40831
09:30	11.655
10:00	9.753859
10:30	8.381515
11:00	7.291434

According to Table 2, the value of TEC obtained from Ntus station at 6:00 until 08:00 average 14.64906 to 14.70666 TECU which is higher comparing to the value of TEC at 08:30 until 11:00 which is 14.54285 to 7.291434 TECU. It's because solar eclipse is start to occur on 08:30 (UT).

Figure 4 perform the variation level of TEC at Bako station a day before and during solar eclipse on 25th January and 26th January 2009 respectively. The comparison of TEC between these two days show that gradually decrease of TEC level on 26th January 2009 compared to the 25th January 2009. From the observation, on 26th January 2009 the decreasing of TEC is starting from 08:30:00 (UT). Its due to the time of solar eclipse begins at 08:30:01 (UT). At this time, the declining of ionizing radiation occurs. From analysis, the depletion of TEC is about 2.6878 TECU starting from 08:30 until 10:57 (UT).

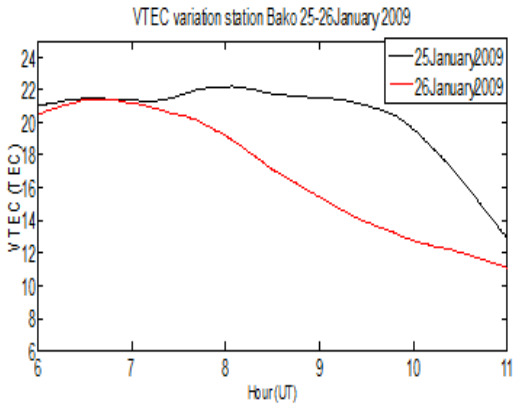

Figure 4. The measurement of TEC level on 25th January and 26th January 20009 at Bako station.

In Table 3 and Table 4, it shows the variation level of TEC at Bako station on 25th January 2009 and 26th January 2009 respectively. The data tabulated are starting from 06:00 until 11:00 (UT) for each single 30 minutes.

TABLE 3. THE VARIATION LEVEL OF TECAT BAKO STATION ON 25TH JANUARY 2009

Time (UT)	**TEC (TECU)**
06:00	21.03279
06:30	21.45175
07:00	21.32416
07:30	21.61627
08:00	22.15888
08:30	21.74722
09:00	21.47778
09:30	21.02747
10:00	19.56649
10:30	16.55722
11:00	12.92608

TABLE 4. THE VARIATION LEVEL OF TEC AT BAKO STATION ON 26TH JANUARY 2009.

Time (UT)	TEC (TECU)
06:00	20.47526
06:30	21.3888
07:00	21.18734
07:30	20.45798
08:00	19.18609
08:30	**17.09537**
09:00	15.41054
09:30	13.88113
10:00	12.75506
10:30	12.0285
11:00	11.08978

By referring Table 2, the comparison of TEC value obtained from Bako station is different. Starting from 6:00 until 08:00 the value of TEC are 20.47526 to 19.18609TECU .This value is higher comparing to the value of TEC at 08:30 until 11:00 (**17.09537** to 11.08978) TECU. The values of TEC decrease due to the declination of ionization since solar eclipse starting at 08:30.

Figure 5 illustrate the measurement of TEC at Coco station a day before and during solar eclipse on 25th January and 26th January 2009 respectively. On 26th January 2009, a sharp depletion had been identified starting from solar eclipse occur at 08:30. The reduction of TEC on 26th January 2009 starting from 08:30 until 10:50 is about 5.07835 TECU.

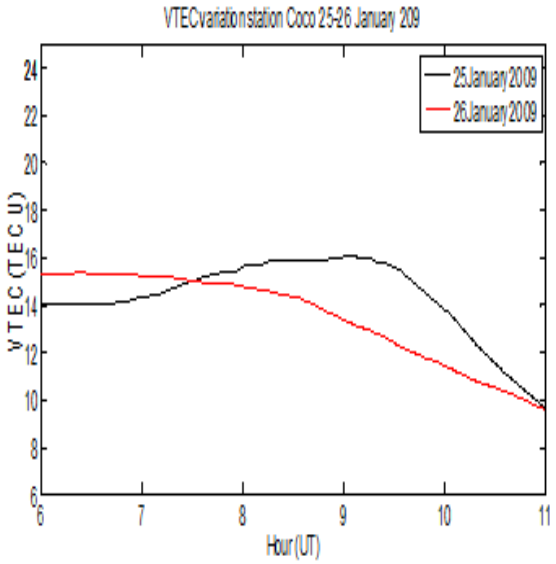

Figure 5. The measurement of TEC level on 25th January and 26th January 20009 at Coco station.

The variation level of TEC a Coco station on 25th January 2009 and 26th January 2009 had tabulated in Table 5 and Table 6 respectively. The data tabulated are starting from 06:00 until 11:00 (UT) for each single 30 minutes.

TABLE 5. THE VARIATION LEVEL OF TEC AT COCO STATION ON 25TH JANUARY 2009.

Time (UT)	**TEC (TECU)**
06:00	13.94321
06:30	13.95420
07:00	14.45872
07:30	15.03958
08:00	15.96378
08:30	15.98785
09:00	16.02783
09:30	15.94580
10:00	13.88579
10:30	11.65887
11:00	9.72597

TABLE 6. THE VARIATION LEVEL OF TEC AT COCO STATION ON 26TH JANUARY 2009.

Time (UT)	TEC (TECU)
06:00	15.32132
06:30	15.37151
07:00	15.24209
07:30	15.04735
08:00	15.04735
08:30	**14.33665**
09:00	13.36749
09:30	12.4067
10:00	11.43807
10:30	10.50638
11:00	9.546655

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In Table 6, the comparison of TEC value obtained from Coco station was observed. Starting from 6:00 until 08:00 the value of TEC are 15.32132 to 15.04735 TECU .This value is higher comparing to the value of TEC at 08:30 until 11:00 (14.33665 to 9.546655) TECU. The values of TEC decrease due to the declination of ionization since solar eclipse starting at 08:30.

V. CONCLUSION

This research investigates on ionosphere response to the Annual Solar Eclipse on 26th January 2009 by using GPS data over Indonesia and Singapore. The variation level of TEC had been observed by analyzed the TEC data on a day before and during solar eclipse occur. There are comparisons between a day before and during solar eclipse at the different GPS station. The analysis had been done starting from 06:00 until 11:00 (UT). From the observation TEC will reduce during solar eclipse compare to the value of TEC a day before eclipse. It's due to the declining of ionizing radiation during solar eclipse condition . On 26th January 2009 the value of TEC gradually decrease starting from time of solar eclipse occurs at 08:30.

There are some methods that use to determine the behavior of ionosphere response during solar eclipse. It includes ionosonde measurements, incoherent scatter radar (ISR) and GPS satellite. In this research, GPS satellite is use in order to investigate the ionosphere response. This method is use because the result can easily extract from GPS station. In future, the behavior of ionosphere response during solar eclipse will be determined by using incoherent scatter radar (ISR). By comparing more than one method, the investigation on ionosphere response to the annual solar eclipse will perform better result.

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