Correlation Analysis of Geomagnetic Activity and TEC in Detection of MSTIDs

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This project focuses on revealing the detection of Travelling Ionospheric Disturbances (TIDs) during geomagnetic storms event at Malaysia ionosphere. The essential parameter to be studied is Total Electron Content (TEC) that extracted using Global Positioning System (GPS) dual frequency data which in RINEX format that supplied by Department Of Survey and Mapping Malaysia (JUPEM). The data was analysed from 11 March 2007 to 15 March 2007 and observed from receiver station located at Universiti Teknologi Malaysia, Johor (Latitude (N) 1.6º Longitude (E) 103.6º). The values of TIDs are compared base on variability value of daily Kp index prepared by World Data Centre System for Geomagnetism (WDC), Kyoto, Japan.

1. Introduction

Travelling Ionospheric Disturbances (TIDs) viz. travelling wave packets (TWPs) are a wave like motion in the ionosphere. TIDs appears as waves in the electron density (and consequently in the TEC) due to interactions between the neutral atmosphere and the ionosphere and also influenced by gravity waves on plasma distribution especially in the F layer. TID is part of disturbance that occurs at ionospheric and effects on radio communication and the spread of GPS signal. The irregularities TIDs with a typical spatial size ranging from 100 to 1000 km, and a time period in the range of 20–120 minutes and can be categorized in 3 scales; i.e. large scale TIDs (LSTIDs), medium scale TID (MSTIDs), and small scale TID (SSTIDs) [1].

2. Methodology

TEC is an important descriptive quantity for the ionosphere, which is defined as the height of electron density along the ray path from the receiver to the satellite. TEC will be measured by using GPS receivers.

i. Calculation of Slant and Vertical TEC

Slant TEC is a measure of the total electron content of the ionosphere along the ray path from the satellite to the receiver, as the quantity TECs. Vertical TEC, TECv enables TEC to be mapped across the surface of the earth [2] (see figure 1).

Figure 1: Geometry of Satellite-Receiver Link
The absolute TEC, from equation (1) can be calculated using GPS signal [3].

\[
TEC = \frac{\Delta \rho \cdot c}{40.3 \left( \frac{f_1^2 f_2^2}{f_1^2 - f_2^2} \right)}
\]  

(1)

where \( \Delta \rho \) is the difference between time delays measured by the L1 and L2, \( C \) is the light velocity (m/s), \( f_1 \) (1575.42 MHz) is the frequency of the L1 wave and \( f_2 \) (1227.6 MHz) is the second frequency of the L2 wave.

The slant TEC, TECs also can be written as in equation (2) [3]:

\[
TECs = \frac{1}{40.3 \left( \frac{f_1^2 f_2^2}{f_1^2 - f_2^2} \right)} (P_2 - P_1)
\]

(2)

Equation (3) is to convert slant TEC (TECs) to vertical TEC (TECv) [3].

\[
TECv = TECs \cos \chi'
\]

(3)

where TECs is the value of slant TEC, \( \chi' \) is the difference between 90° and zenith angle (90°-\( \chi \)).

In this TEC research, to get more precise mapping, the Modified-Single Layer Model, M-SLM is use as define in equation (4) [1]:

\[
\sin \chi' = \frac{Re}{Re + hm} \sin(a \chi)
\]

(4)

where \( Re \) = Mean earth radius, 6371 km, \( hm \) = maximum height of electron density, 450 km, \( a \) = correction factor, 0.9782, \( \chi \) = zenith angle and \( \chi' = (90^\circ - \chi) \).

**ii. Detection of Irregularities in TEC**

TIDs and scintillation effects cause of high frequency changes in the TEC. Consequently, these phenomena can be monitor from time variation of the TEC, \( \Delta TEC(t_k) \), as in equation (5) [4].

\[
\Delta TEC^i(t_k) = \frac{TEC(t_k) - TEC^i(t_{k-1})}{(t_k - t_{k-1})}
\]

(5)

Where \( \Delta TEC^i(t_k) \) is value TEC for satellite (i) on time (k) and it is measured in TECU/min

In order to detect the present of TIDs, choice of \( [0.1] \)TECU/min from \( \Delta TEC \) consider as threshold value. This threshold value of \( [0.1] \) TECU/min is large enough to avoid interpreting multipath effects as ionospheric phenomena [4].

**3. Result and Discussion**

The results of the observed variation \( \Delta TECv \) presented in this section. The results amount of TIDs detected were compared between the chosen dates (see Table 1).
The project was recognized types of TIDs were from medium-scale TIDs (MSTIDs). The analysis was done for 15 minutes intervals to compute the ionospheric variability due to the fact that most of the MSTIDs have periods ranging from 5 to 30 minutes. If the time intervals too short period, the TID will not have time to cause TEC changes large enough to be detected. On the other hand, if the interval is too long, the large residuals in ∆TECv due to TID will be lost among the other residuals [4].

Table 1: Comparison of Amount TIDs Detected

<table>
<thead>
<tr>
<th>Date</th>
<th>Kp Index</th>
<th>TIDs</th>
</tr>
</thead>
<tbody>
<tr>
<td>11 March 2007</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>12 March 2007</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>13 March 2007</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>14 March 2007</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>15 March 2007</td>
<td>10</td>
<td>12</td>
</tr>
</tbody>
</table>

Figure 2 and 3 are the variations of ∆TECv on 11 and 12 March 2007 correspondingly. Both days referred as quite day (no geomagnetic activity) since the Kp index are Kp 1. Also both had same amount TIDs detection (see Table 1) from the analysis ∆TECv was more than |0.1| TECU/min. The maximum ∆TECv for both figures occurred around LTC 10.00 to 10.30 am and the values are 0.1811 and 0.226 TECU/min respectively. The minimum values ∆TECv are 0.014 and 0.0026 TECU/min around at LTC 11.15 to 11.30 am.
Figure 4, 5 and 6 are ΔTECv variations for 13 to 15 March 2007 with value of Kp index 5, 3 and 1 respectively. The greatest TIDs detected on 13 March 2007 with high Kp index, Kp 5 where the starting of geomagnetic storm is observed. The values of TIDs are continuously detected keep strong for two or three days after the event of geomagnetic disturbance. This is due to the magnetic storms usually last 24 to 48 hours, but some may last for many days. From the analysis, the maximum ΔTECv occurred on 13 March 2007 which 0.4 TECU/min at LTC 08.45 am represented in Fig. (4), and followed the next day after event also recorded high maximum values of ΔTECv at early observation. The minimum values ΔTECv recorded at LTC 11.30 am around value 0.1 TECU/min.

4. Conclusion

Presence of TIDs can be detected by using dual frequency GPS data during variation geomagnetic activities. This is due to the solar activity is active on that day had geomagnetic disturbance and contribute for changes in Total Electron Content (ΔTEC) and the values of earth’s Kp index are strongly influenced with the occurrence of geomagnetic storm.

References

Figure 5: ΔTECv on 14 March 2007