GPS OBSERVATIONS OF IONOSPHERIC TEC VARIATIONS OVER NEPAL DURING 22 JULY 2009 SOLAR ECLIPSE

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Abstract
As the study of ionospheric behavior during various solar activities is an important task, various studies of ionospheric changes during eclipse events have been widely performed in the different regions of the globe. This paper investigates the ionospheric responses to the solar eclipse on 22 July 2009 over Nepal using the total electron content (TEC) measured by dual-frequency Global Positioning System (GPS) receivers. The time-averaged Vertical TEC (vTEC) of ten GPS stations from Nepal is analyzed and it is found that the value of ionospheric TEC decreases due to the reduction of ionizing radiation. In addition, the deviation in the TEC value on eclipse day from the mean vTEC value of the top five quietest days is found to lie in the range ~1–5 TECu at those regions which were associated with the partial eclipse shadow. On the other hand, the region with the total eclipse (BRN2 and RMTE) faced ~6–7 TECu on average reduction in the TEC value. Considering that the eclipse of 22 July 2009 occurred just at sunrise in the Nepalese zone, a maximum reduction of about 5 TECu is very significant. Higher deviation in TEC is therefore linked with the path of totality and the obscuration rate. This study reveals that the ionospheric TEC over Nepal was altered by wave-like energy and momentum transport, as well as obscuration of the solar disc due to the partial and total solar eclipse. Furthermore, the cross-correlation results presented similar type signatures of the eclipse-induced ionospheric modification over Nepal. This research work serves a crucial future reference for the comparative study of change of ionospheric TEC variability over the Nepal region during eclipse events.

Keywords: Solar Eclipse, Global Positioning System, Total Electron Content, Cross-Correlation.

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1. Introduction

The importance of GPS in various fields of atmospheric science has grown dramatically over the last few decades [1, 2]. TEC is one of the most important parameters of the ionosphere that is possible to track using GPS [3], allowing to conduct extensive research on the ionosphere and thus study a variety of phenomena such as precursory effects of an earthquake [4, 5], modification in ionospheric signatures during high, moderate or low solar activities [6] and geomagnetic storms [7].

Several research works have been carried out to study the response of the ionosphere during a solar eclipse with the help of TEC measurements [8–11]. Changes in the ionization of the D-layer, E-layer as well as the F layer of the ionosphere have been observed during an eclipse [10–13]. The electron density in regions D, E and F1 is commonly considered to be governed by the equilibrium between photoionization and chemical recombination [10, 12]. As a result of the hiding of the optical rays, photoionization is reduced directly, the previous photochemical equilibrium is destroyed, and electron density is depleted. These studies point out a significant decrease in the TEC during eclipse time which is recovered within an hour [14], or sometimes the eclipse led to an apparent decrement in TEC that lasted for six to eight hours [11, 15]. In this paper, we analyzed the variation of ionospheric TEC during 22 July 2009 solar eclipse by using TEC data archived at ten GPS stations installed in Nepal by UNAVCO.

Since the GPS satellite and receiver might not always be in a position of perpendicularity, the number of electrons in a unit square area between a satellite and receiver is obtained in the form of Slant Total Electron Content (sTEC) which is given (1):

\[
sTEC = \int_{\text{receiver}}^{\text{satellite}} N ds.
\]

The Vertical Total Electron Content (vTEC), which is an overhead projection of sTEC, was obtained from the relation, given by [16]:

\[
vTEC = sTEC \times \cos \left( \sin^{-1} \left( \frac{R_E \cos \theta}{R_E + h} \right) \right),
\]

where \( R_E \) is the earth’s radius, \( \theta \) is the elevation angle at the ground station, and \( h \) is the height of the ionospheric layer, which generally assumes is 350 km. Both sTEC and vTEC are estimated in a unit called TECu, in which 1 TECu = \( 10^{16} \) electron/m\(^2\) [17].

2. Materials and methods

The GPS-derived TEC data of ten stations used in this work was obtained from UNAVCO, which is freely available on the website of UNAVCO [18]. These data can be used to study ionospheric related phenomena especially when there is no GNSS receiver installed in the country. Table 1 presents the GPS stations that lie under partial eclipse and Table 2 presents the stations that witnessed total eclipse. The available data was in the RINEX (Receiver Independent Exchange) format v2.1, a standard ASCII format, which was further processed using the software [19]. The software converted the RINEX files into ASCII files by taking the TEC bias error calculations into account, eventually giving the values of vTEC throughout a day in 30-second intervals in an ASCII format.

Geomagnetic indices (\( Ap, Kp, Dst, \) and \( AE \)) data were downloaded from Operating Mission as Nodes on the Internet Web System [20]. These indices are remarkable parameters to distinguish geomagnetically disturbed and quiet events.

We adopted various methods to observe the variation in vTEC in the ionosphere during a solar eclipse. First, let’s note the start time, maximum time, and end time of the eclipse along with obscuration rate for the stations mentioned in Tables 1, 2 [21]. Then, the minute averaged vTEC during the eclipse day is compared with the mean of the top five quietest days of the month. Our primary focus is to find the temporary variation in vTEC by dividing the study into three different scenarios, viz. pre-eclipse hour, eclipse hour, and post-eclipse hour. The principle behind the use of this approach is to reveal signatures of the eclipse-induced ionospheric modification with high spatiotemporal resolution [22, 23]. Fig. 1 shows a network of the GPS receiver stations within the map of Nepal utilized in this study.

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Earth and Planetary Science
Table 1
Information of stations with partial eclipse for TEC measurements

<table>
<thead>
<tr>
<th>Station</th>
<th>Code</th>
<th>Geog. Latitude</th>
<th>Geog. Longitude</th>
<th>Start of partial eclipse (UT)</th>
<th>End of partial eclipse (UT)</th>
<th>Maximum Obscuration rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bayana</td>
<td>BYNA</td>
<td>29.4742</td>
<td>81.2007</td>
<td>00:03:14.2</td>
<td>01:57:38.7</td>
<td>84.75 %</td>
</tr>
<tr>
<td>Chilime</td>
<td>CHLM</td>
<td>28.2072</td>
<td>85.3141</td>
<td>00:01:31.0</td>
<td>02:00:42.0</td>
<td>94.74 %</td>
</tr>
<tr>
<td>Ghermu</td>
<td>GHER</td>
<td>28.375</td>
<td>84.41</td>
<td>00:01:45.6</td>
<td>01:59:57.6</td>
<td>92.98 %</td>
</tr>
<tr>
<td>Kawasaki</td>
<td>KAWA</td>
<td>27.648</td>
<td>84.13</td>
<td>00:01:17.4</td>
<td>01:59:27.2</td>
<td>94.40 %</td>
</tr>
<tr>
<td>Kirtipur</td>
<td>KIRT</td>
<td>27.682</td>
<td>85.288</td>
<td>00:01:09.8</td>
<td>02:00:28.9</td>
<td>96.64 %</td>
</tr>
<tr>
<td>Kakani 4</td>
<td>KKN4</td>
<td>27.8007</td>
<td>85.2788</td>
<td>00:01:16.5</td>
<td>02:00:30.8</td>
<td>96.01 %</td>
</tr>
<tr>
<td>Koldana</td>
<td>KLDN</td>
<td>27.7669</td>
<td>83.6033</td>
<td>00:01:27.1</td>
<td>01:58:58.8</td>
<td>94.28 %</td>
</tr>
<tr>
<td>Simikot</td>
<td>SMKT</td>
<td>29.9694</td>
<td>81.8065</td>
<td>00:03:31.2</td>
<td>01:58:17.1</td>
<td>83.57 %</td>
</tr>
</tbody>
</table>

Table 2
Information of stations with full eclipse for TEC measurements

<table>
<thead>
<tr>
<th>Station</th>
<th>Code</th>
<th>Geog. Latitude</th>
<th>Geog. Longitude</th>
<th>Start of partial eclipse (UT)</th>
<th>Maximum Obscuration rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biratnagar</td>
<td>BRN2</td>
<td>26.5797</td>
<td>87.2722</td>
<td>00:00:18.0</td>
<td>100 %</td>
</tr>
<tr>
<td>Ramite</td>
<td>RMTE</td>
<td>26.991</td>
<td>86.5971</td>
<td>00:00:38.1</td>
<td>99.91 %</td>
</tr>
</tbody>
</table>

Fig. 1. The geographical position of receiver stations in the map of Nepal

Cross-correlation is a technique of studying different parameters to measure similarities and draw similar relative characteristics, which can reveal new information [23–25]. The cross-correlation is useful in aligning two-time series, one of which is delayed relative to the other, since its peak occurs at the lag at which the two-time series are best correlated [26]. The curve towards ±1 indicates a very strong correlation, whereas the curve around zero represents a moderate or less correlation [27]. The cross-correlation technique was used to detect the stations’ similarity pattern those lines in the northern crest of Equatorial Ionization Anomaly (EIA).

3. Results and discussions

Fig. 2 depicts the path of the total solar eclipse on July 22, 2009, where the umbral shadow of the Moon begins in India and passes through Nepal. With a maximum duration of 6 min 39 s, it was the longest solar eclipse in the 21st century. The partial eclipse began at 21 July, 23:58:17 UT (22 July, 05:43:17 NST) and ended at 22 July, 05:12:21 UT (22 July, 10:57:21 NST) with maximum eclipse at 22 July, 02:35:18 UT (22 July, 08:20:18 NST). The eastern regions of Nepal witnessed the northern limit of the total eclipse, which started at 22 July, 00:01:10 UT (22 July, 05:46:10 NST) and ended at 22 July, 02:00:31 UT (22 July, 07:45:31 NST). Detailed information on the eclipse can be seen in the work of Espenak and Anderson [28].

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3.1 Geomagnetic activity on the event day

Fig. 3 shows the plots of global geomagnetic indices ($Ap$, $Kp$, $Dst$, and $AE$) for the period of 21–23 July 2009. During the eclipse hour (red shaded region), it can be observed that the $Ap$ value does not exceed 20 nT ($Kp*10$–30), the $Dst$ index lies near zero with small negative values, and the $AE$ index is below 200 nT. According to [29], geomagnetic storms can be classified as: weak ($-50 < Dst \leq -30$ nT), moderate ($-100 < Dst \leq -50$ nT), intense ($-250 < Dst \leq -100$ nT), and very intense ($Dst \leq -250$ nT). Thus, the geomagnetic indices have low values, characterizing the eclipse hour as a quiescent period. The eclipse hour, however, was followed by a 10-hour geomagnetic storm.

![Fig. 3. $Kp$, $Ap$, $Dst$, and $AE$ indices on 22 July 2009](image-url)
As shown in Fig. 3, a medium magnetic storm occurred on 22 July; its main phase was 02:30–12:00 UT. Furthermore, its peak of $D_{st}$ index was up to $-80$ nT, and $Kp\times10$ index up to $-60$. Meanwhile, the total solar eclipse occurred during 00:53–04:18 UT. So, the beginning time of the magnetic storm lagged behind the solar eclipse, and the magnetic storm faded away gradually in several hours after the ending of the eclipse. Thus, unlike solar eclipses in the past, which often have been followed by no magnetic storm, solar eclipse and magnetic storm synchronism characterized this eclipse [30]. The detailed study of TEC variation during geomagnetic storms is left for future work.

### 3. 2. TEC variation during eclipse day compared to international quiet days

The diurnal variations of the ionospheric vTEC over Nepal during the eclipse day are compared with the mean of the top five international quiet days for July 2009. The study has been divided into two parts: short term response of ionosphere towards the:

a) Partial Eclipse;

b) Full Eclipse.

BRN2 and RMTE witnessed total solar eclipse with an obscuration rate of 100 % and 99.91 % among the ten GPS stations, respectively. The rest of the stations faced partial solar eclipse. A more detailed description of the events and stations can be found in Tables 1, 2.

#### 3. 2. 1. Variation of TEC at partial eclipse occurrence regions

In Fig. 4, 5, the left side depicts the comparison of the 24 h TEC variation of the eclipse day with the mean vTEC of the five quietest days of the month. As it is known, the TEC variations during the obscuration period can be observed for a relatively short time, the zoom-in behavior of the eclipse effect for consecutive epochs by highlighting the eclipse period shown on the right side of Fig. 4, 5 is provided. Moreover, the solid blue lines indicate the moment of the first contact, the end of the eclipse, whereas the solid black line indicates the moment of maximum eclipse.
Fig. 5. Depletion of diurnal TEC at the remaining four GPS stations during the solar eclipse of 22 July 2009 and its comparison with mean TEC of top five quietest days of the month, July 2009. The Left panel shows the variation of vTEC for the whole eclipse day, and the right panel shows the variation between 00:00 to 02:00 UT, highlighting the eclipse period. The region between the solid blue line represents the eclipse hour, and the bold black solid line represents the maximum phase of the eclipse.

As expected, the temporal variation in vTEC followed the evolutionary pattern, i.e., the depletion in TEC commences at the initial phase of the eclipse and slowly achieves the recovery after the end of the phase. It can be seen from Fig. 4 that the eclipse leads to apparent TEC depression on a large scale of sub-ionospheric points. This kind of depression occurred on the neck of the first contact of the eclipse [15]. Then the negative deviation became more profound with the area of optical disk obscured getting larger. However, in most of the stations, the maximum decrement time did not agree with the time of the middle of the eclipse. The trend of depression continues after the middle of the eclipse. As observed from the highlighted eclipse hour (right panel of Fig. 4, 5), on the day of the eclipse, the ionospheric vTEC decreased about ~4 TECu on average, in comparison with those observed on the quiet days in the interval 0 UT to 2 UT, respectively. TEC reductions ranging from 0.2–4 TECu to 3 TECu have been identified in previous studies [8, 9]. The TEC level depression is found to be proportional to the obscuration rate and path of totality. Moreover, it can be seen from the stations the TEC recovery phase, the time for restoration was also delayed compared with the time of the last contact.

3.2.2. Variation of TEC at full eclipse occurrence regions

The mean values of vTEC on the eclipse day, especially during the eclipse hours, are plunked down compared to the quiet days. From Fig. 6, it can be observed that the eclipse effect occurs as a trough-like depression. As expected, with respect to the quiet day, the eclipse’s effect was more pronounced at BRN2 station than at RMTE station because the solar obscuration at the BRN2 was more (100 %) whereas it was 99.96 % at RMTE. The TEC values attained their minimum around the maximum phase of the eclipse for each station. The findings of the previous studies suggest that the minimum value of TEC persists around an hour to 6–8 hours [8, 15, 31] slowly recovers for the following last hours. The recovery of vTEC occurs faster than expected due to the positive effect of the geomagnetic storm that occurred on the same day right after the eclipse hour.
3.2.3. Deviation in vTEC for partial eclipse occurrence regions

To show more clearly the variation of vTEC during the passage of the Moon’s umbral shadow, we presented the deviation in the vTEC, which has been defined as the difference in vTEC of the eclipse day and the mean vTEC of the quiet days, at each instant of time. The value of the $\Delta$vTEC seen during the eclipse hour (Fig. 7) showed a clear dip in the vTEC for all the stations mentioned in Table 1.

Fig. 6. Depletion of diurnal TEC at two GPS stations during the solar eclipse of 22 July 2009 and its comparison with mean TEC of top five quietest days of the month, July 2009. The left panel shows the variation of vTEC for the whole eclipse day, and the right panel shows the variation between 00:00 to 02:00 UT, highlighting the eclipse period.

The region between the solid blue line represents the eclipse hour, and the bold black solid line represents the maximum phase of the eclipse.

Fig. 7. Deviation of TEC: $a$ – at BYNA, CHLM, KLDN, and KKN4 (from top to bottom); $b$ – KIRT, GHER, SMKT, KAWA (from top to bottom) on 22 July 2009 eclipse day during 0–6 UT. The light blue region between the black dotted line represents the eclipse hour. The bold solid line represents the maximum phase of the eclipse.
One of the noteworthy findings of our study is the reduction of vTEC according to the obscuration rate. As seen from Fig. 7, the eight GPS stations used in the study, viz. KIRT, KKN4, KAWA, CHLM, KLDN, GHER, BYNA, and SMKT, the station KIRT with the highest obscuration rate (96.64 %), showed a maximum deviation of ~5 TECu and the station SMKT having the lowest obscuration rate (83.57 %) showed the minimum deviation of 1.5 TECu. All other stations followed a similar trend, i.e., the deviation in vTEC decreases with the decrease in obscuration rate. Thus, estimations from all the stations that witnessed partial eclipse demonstrated a decrease in the measure of approaching sun-based radiation during the eclipse onset. The size of the reduction is firmly identified with the obscuration rate [23, 32]. The maximum TEC deviation and the time delay of the maximum decrement for the GPS stations that lie under partial eclipse are presented in Table 3.

### Table 3
The maximum TEC deviation and the time delay of the maximum decrement for partial eclipse regions

<table>
<thead>
<tr>
<th>Stations</th>
<th>Maximum Deviation (TECu)</th>
<th>Delay of TEC max. decrement</th>
<th>Percent Obscuration, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>BYNA</td>
<td>–1.20</td>
<td>00:02:31</td>
<td>84.75</td>
</tr>
<tr>
<td>CHLM</td>
<td>–2.80</td>
<td>00:02:38</td>
<td>94.74</td>
</tr>
<tr>
<td>GHER</td>
<td>–1.60</td>
<td>00:02:16</td>
<td>92.98</td>
</tr>
<tr>
<td>KAWA</td>
<td>–3.03</td>
<td>00:03:07</td>
<td>95.40</td>
</tr>
<tr>
<td>KIRT</td>
<td>–5.23</td>
<td>00:02:03</td>
<td>96.64</td>
</tr>
<tr>
<td>KKN4</td>
<td>–5.03</td>
<td>00:02:21</td>
<td>96.01</td>
</tr>
<tr>
<td>KLDN</td>
<td>–1.62</td>
<td>00:03:18</td>
<td>94.28</td>
</tr>
</tbody>
</table>

### 3.2.4. Deviation in VTEC for full eclipse occurrence regions

When we analyzed ΔvTEC across two GPS stations of Nepal where the total eclipse was observed, we found that the deviation was relatively higher than that of the deviation in vTEC at partial eclipse stations. It is of interest to notice that the deviation is negative due to the solar eclipse of both stations, indicated in the y-axis. It is evident from Fig. 8 that negative deviation (red bars) starts increasing during the progress of the eclipse, demonstrating the exhaustion of TEC. The negative deviation of TEC during the main phase to one hour after the end of the solar eclipse was in the range of ~4–7 TECu at BRN2 and ~2–6 TECu at RMTE, as observed from Fig. 8. This indicates that the depression in vTEC is closely related to the obscuration rate in total eclipse regions. In a region where equatorial ionospheric anomaly (EIA) is not present, we expect the values of VTEC to decrease during an eclipse in comparison to days where there is no eclipse. This was due to $E \times B$ drift that transports a high number of ions to equatorial areas [23, 32]. The maximum TEC deviation and the time delay of the maximum decrement for the GPS stations that lie under total eclipse are presented in Table 4.

![Fig. 8. Deviation of TEC: a – at BRN2; b – and RMTE on 22 July 2009 eclipse day during 0–6 UT. The light blue region between the black dotted line represents the eclipse hour. The bold solid line represents the maximum phase of the eclipse](image)
Table 4
The maximum TEC deviation and the time delay of the maximum decrement for the total eclipse region

<table>
<thead>
<tr>
<th>Stations</th>
<th>Maximum Deviation (TECu)</th>
<th>Delay of TEC max. decrement</th>
<th>Percent Obscuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRN2</td>
<td>–6.94</td>
<td>00:02:21</td>
<td>100 %</td>
</tr>
<tr>
<td>RMTE</td>
<td>–6.10</td>
<td>00:02:18</td>
<td>99.91 %</td>
</tr>
</tbody>
</table>

In the latter stage of the eclipse, TEC was affected by the positive phase magnetic storm. Compared with the solar eclipse, the magnetic storm had a larger influence on TEC. Thus, the successive geomagnetic storm was responsible for the whole-day rise in TEC values. Interestingly, the Dst index became negative only after 02:30 UT. Furthermore, magnetometer data from the study areas showed storm-related changes in the ground magnetic field only after 04:00 UT. As a consequence, the findings presented here are essentially unaffected by the July 22 geomagnetic storm. This validates the previous findings [22, 30].

3.3. Cross-Correlation Analysis
Results in Fig. 9, a represent the cross-correlation between the ionospheric TEC measured at eight GPS stations of Nepal, which witnessed partial eclipse. Each line achieved the highest positive cross-correlation coefficient of 1 at lag 0, reflecting a strong positive correlation between all these stations in Nepal during the eclipse hour. This signifies that the variation of TEC exhibits a similar pattern all over Nepal during the event day. The results of cross-correlation reveal that an apparent effect on the ionosphere can be witnessed as a result of the solar eclipse over Nepal.

Fig. 9. The above Figure shows the cross-correlation versus time (minutes) for ionospheric TEC measured at different stations, occurred during the time of eclipse event, 22 July 2020 among all the stations of Nepal: a – having partial eclipse; b – full eclipse
Similarly, in Fig. 9, b, the cross-correlation between the vTEC of two stations with the highest obscuration rate (full eclipse) is presented. Again, one can observe the highest correlation coefficient (>0.9) at lag 0, which presented similar type signatures of the eclipse-induced ionospheric modification over Nepal. This result is in good agreement with past research works [11, 23].

3. 4. Limitations of the Study

The resulting analysis showed that the Ground-based GPS observation provides data with better accuracy, both in time and space, and hence keeps good track of eclipse-induced ionosphere modification even if it happened for a short period of time. Comparative study of many other stations at different latitudes over several countries around the eclipse path could be considered. However, this study covers the results of Nepal region only. Thus, similar study can be performed at other regions using this technique to have a better understanding of ionospheric changes in wide regions. Radio occultation data and GNSS flying formation are crucial suggested methods to study the ionospheric variation due to different events in the future ahead [33, 34].

4. Conclusion

In this study, GPS L-band TEC data over the Nepal region from ten GPS stations were used for tracking the effect of the solar eclipse condition of 22 July 2009 on the ionospheric electron density concentration. The preliminary remarks in this analysis can be summarized.

The results show that TEC depletion was observed during the early morning eclipse hour at (00:00 to 02:00 UT) at all the mentioned stations. The TEC at eight stations within the partial eclipse regions decreased by (1–5) TECu, then recovered gradually. On the other hand, the stations with Moon’s Umbra (total eclipse) show a significant reduction of >5 TECu as extreme reduction observed by the TEC during the solar eclipse is proportional to the magnitude of the eclipse. All of the stations’ measurements showed a decrease in the amount of incoming solar radiation. The scale of the reduction is proportional to the totality direction and the rate of obscuration. The eclipse caused a decrease in photoionization movement in the ionosphere due to changes in spectral solar irradiance.

The cross-correlation coefficient between ionospheric TEC measured within the same region (either partial eclipse or full eclipse) peaks with a very high value of 1 for a zero lag, suggesting that the response of the ionosphere to the solar eclipse over Nepal is quite similar. As a result, this method aids in determining the similarity pattern associated with stations during natural phenomena such as solar eclipses.

Solar eclipse provides a unique opportunity to investigate the ionospheric response to the change in the solar flux emission towards the Earth. In addition, ionospheric behavior and its effect on positioning and communication is an important concern. By virtue of GPS-derived TEC, the ionospheric response towards the solar eclipse can be monitored effectively.

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References


[20] OMNI Web Data Explorer. Available at: https://omniweb.gsfc.nasa.gov/


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