

# Correlation analysis of Ionospheric Total Electron Content (TEC) and Tide Data observed at Port Blair, India during 2013-2016

M. Ravi Kumar, M. Sridhar, V. V. D. Dharani Kumar, Sarat K. Kotamraju, D. Venkata Ratnam

**Abstract:** In this paper, an effort was made to study the variations of ocean tides and Total Electron Content (TEC) with respect to the position of sun, moon, and earth. The analysis is carried out for both new moon and full moon events in the year 2013-16 at Port-Blair (geographic latitude: 11.62°N; longitude: 92.72°E). Tide data was taken from the Port-Blair inlet, while the Total Electron Content (TEC) data was taken from GPS station-6 receiver at Port-Blair (PBR2) by using the SOPAC (Scripps Orbit and Permanent Array Center) site. It is observed that during the new moon and full moon events there is a substantial rise and fall in normalized TEC values along with position ratio of sun and moon respectively. Further, the correlation analysis is carried out between normalized TEC and the normalized ratio during the new moon and full moon. The normalized TEC and the normalized ratio will maximum correlate in the year 2014-15 for new moon event and 2013-14 for full moon event.

**Index Terms:** Total Electron Content, GPS, New moon, Full Moon, Correlation Analysis

## I. INTRODUCTION

Investigation on the relation between Total Electron Content (TEC), tide and positions of sun and moon is paramount of significance for earth-space weather conditions. Total electron content (TEC) remains as most important factor of ionosphere, space climate concern. TEC is defined as the total number of electrons in square meter cylindrical cross section from the satellite to GPS receiver. TEC can be measured by dual frequency GPS receivers. The low and high water point caused due to the gravitational attraction of the sun, moon through the earth rotation around the sun is called tides phenomena [1]. The ionosphere changes with the season, solar cycle Geographic latitude and time of day. At the time of solar activity, the maximum total electron content (TEC) around noon, while minimum total electron content (TEC) is around at post-midnight [2]. The diurnal seasonal ascent and fall in the sea water level are called a "Tide". Generally, the tide is determined by the physical parameter of the earth-moon and sun revolution system. Tide on earth is the outcome of the combination of gravitational force applied by

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sun, moon at the time of oceanic water masses. Centrifugal forces are resulting from the revolution of the earth-moon system through its regular center of gravity [3]. For the monthly variation with the daily patterns, the tidal theory is determined by the changeability in the gravitational pull on earth because of the following reason: 1.Changing aspect of the moon 2.Declination of the moon 3. Earth-moon distance changes because of lunar orbit. During lunar month, the earth and moon distance varies up to 11%, resulting in a 35% variation in the tidal height [4]. Lunar tides and solar tides are the tides formed due to the tidal forces of the Moon and the Sun exerted on the Earth, respectively. Lunar tides are more predominant than solar tides though the distance between the Earth and Sun is larger than Earth-Moon distance [5]. Nurul Syafiqah Mohamad and Kalaivani Chellappan, 2015 [6] have investigated that the relationship between TEC and tide at Port Klang station for the year 2013-14 during the full moon and new moon conditions. It is found that sun and moon position ratio is not correlated well with TEC measurements [6]. TEC values are decreasing during full moon along with position ratio values. It is also found that TEC values are increased during new moon occurrence.

In this paper, the GPS-TEC and tide data at Port-Blair station (latitude: 11.62° N; and longitude: 92.72°E) and a detailed correlation analysis is carried out for the three years data from 2013-2016. TEC is an important factor not only for an ionospheric study as well as for an amendment of ionosphere impact, which destroys the GNSS position [7]. Total electron content (TEC) is described by observing carrier phase delays of received radio signals transmitted from satellites, it is situated over the ionosphere by utilizing the Global Positioning System (GPS), and then the total electron content is firmly influenced by the solar activity. It portrays time delay in the trans-ionospheric radio spread and it can cause blunders in the application of Global Navigation Satellite System such as GPS (Global positioning system) [8].

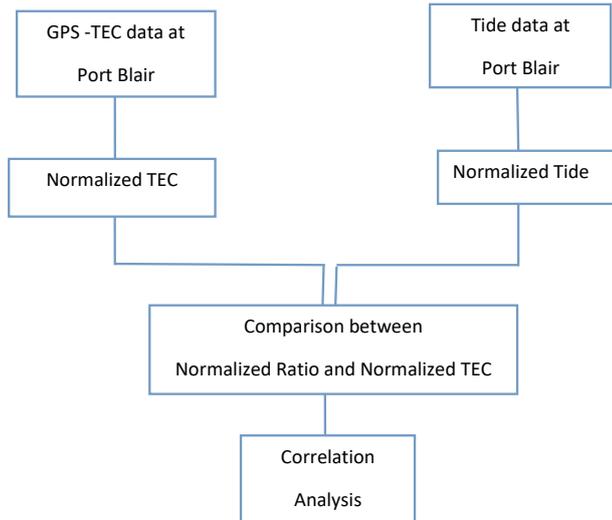
## II. METHODOLOGY

The Earth and the moon are adequately near to sun and thus the moon's orbit near to earth is considerably by the gravitational attraction of the sun [9]. When earth, moon, and sun are nearly aligned during a full moon and new moon the tides are higher (spring tides). If a moon is at 90° (quadrature)



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from the sun with respect to earth, the tides are reduced to a low (neap tides). Neap tides occur during a half moon (or)



first

Fig.1 Block Diagram of the Tide, Total electron content (TEC) throughout the new moon and full moon.

quarter and third (last) quarter moon [10]. In the earth, moon and sun system there are a lunar eclipse and solar eclipse. The moon passes through sun and the earth, at that time there will be a solar eclipse [11]. To identify the relation between tide and total electron content (TEC), the sun distance, moon distance, tide data and TEC data is used. The block diagram of the Tide and Global positioning system-Total electron content (GPS -TEC) as shown in Fig. 1 during the new moon and full moon. Both Tide information and Total electron content (TEC) information are normalized. After the completion of the normalization, the comparison between normalized ratio and normalized Total electron content (TEC) is observed. Correlation analysis is carried out for the normalized ratio and normalized total electron content (TEC).

## A. GPS-TEC Estimation

The TEC characteristics during the year (2013-2016) throughout the new moon and full moon are considered over Port Blair (PBR2) receiver with the latitude of 11.62°N and

(<http://sopac.ucsd.edu>) [12].The data was obtained in the form of Receiver Independent Exchange Format (RINEX).RINEX observation data are extracted to Slant TEC (STEC) measurements using GPS -TEC software. Single layer estimation is amended to change over STEC values into vertical TEC (VTEC) values, where the Ionospheric Pierce Point (IPP) is considered at an elevation of 350km over the earth's surface.

$$vTEC = p(v_s, dl) \times sTEC \quad (1)$$

$$p(v_s, dl) = \left[ 1 - \left( \frac{R_e \times \cos(el)^2}{R_e + h_s} \right) \right]^{-1/2} \quad (2)$$

where,

999

$p(v_s, dl)$  is a thin shell mapping function

$v_s$  is height of the thin shell(350km)

$dl$  is elevation angle of the satellite

$R_e$  is earth radius(6378km)

## B. Tide-Gauge Data

The Tide-Gauge taken from the year (2013-2016) throughout the new moon and full moon are considered over Port Blair (PBR2) receiver with the latitude of 11.62°N and with the longitude of 92.72°E in India. The study of the tide-gauge data is considered from Ispra Site (<http://webcrtech.jrc.ec.europa.eu/SeaLevelsDb/Home/TideChart/100062>) [13].

Generally, the measurements of changes in sea-level have a two type of techniques one is a tide gauge and another is a satellite altimetry. For estimating a change in the ocean-level the tide gauge is utilized. Tide gauge provides ocean level variations in terms of tide gauge land. Tide gauge will provide an opportunity for measuring sea-level variations when vertical land movements are accurately observed because of the global positioning system (GPS) [14].

## C. Tide-Gauge Specifications

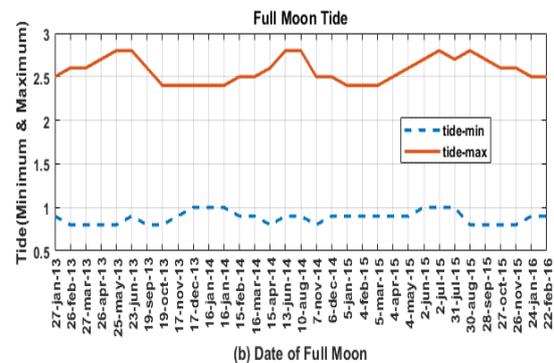
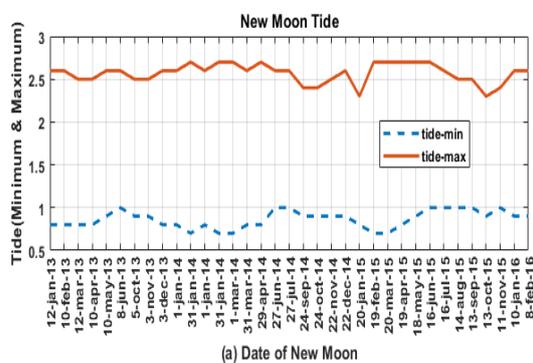


Fig. 2. Tide Minimum and Tide Maximum during (a) Date of New Moon (b) Date of Full Moon

with the longitude of 92.72°E in India. The study of Total electron content (TEC) is based on data and considered from Scripps Orbit and Permanent Array Center (SOPAC)

The tide-gauge system consists of two parts one is a transmitter and another is a



receiver, which communicates by using a radio link. To measure accurate variations in tide levels, the transmitter is used as a sensitive pressure transducer. The tide-level for a particular ocean is shown at the transmitter panel and also the tide-level data is stored in transmitter memory. The

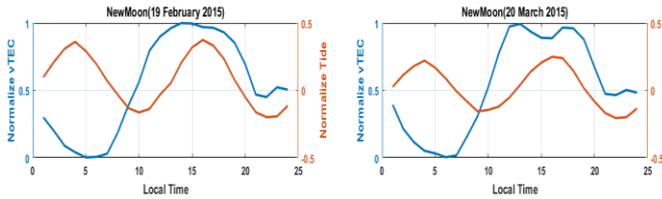


Fig. 3 Tide data during perigee and new moon for the days 19 February 2015 and 20 March 2015.

details of tide levels will be transmitted to the remote receiver. At the receiver end, the readings of the tide levels will be displayed along with the time and identification code of the transmitter.

At the time of New Moon, it can observe that from the year 2013-2014 the minimum value (0.7) and a maximum value (2.7) of tide happened on 31 January 2014. From the year 2014-2015, the minimum value (0.7) of a tide and the maximum value (2.7) of tide happened on 1 March 2014. From the year 2015-2016, the minimum value (0.7) of the tide and the maximum value (2.7) of tide happened on 19 February 2015 and 20 March 2015 as shown in figure 2(a). From figure 2(b), it can observe that during the year 2013-2014 the minimum value (0.8) and the maximum value (2.8) of tide happened on 25 May 2013. During the year 2014-2015, the minimum value (0.9) and the maximum value (2.8) of tide occurred on two days that is 13 June 2014 and 10 August 2014. During the year 2015-2016, the minimum value (0.8) and the maximum value (2.8) of tide occurred on 30 August 2015 at full moon days. The sun position and the moon position are nearest to the earth when contrasted with all other new moon and full moon days.

During the analysis data, the normalization process was used. The formula for normalization technique can be given as

$$v_i = \frac{p_i - \min(p_i)}{\max(p_i) - \min(p_i)} \quad (3)$$

A Relationship between Ratio of sun and moon with total electron content (TEC) during new moon and full moon: The ratio can be calculated by using the distance of the sun divided by the distance of the moon for that month.

$$\text{Ratio} = \text{Distance of the Sun} / \text{Distance of the Moon} \quad (4)$$

### III. RESULTS AND DISCUSSION

GPS-TEC and tide gauge data are collected at Port-Blair (geographic latitude of 11.62°N and longitude of 92.72°E for the year 2013-2016). The day wise TEC and tide gauge profiles are identified based on new moon and full moon details for the three years. The TEC and tide levels are normalized by using equation (3). In order to understand the relationship between TEC and tides, the sun and moon distance are calculated for both new moon day and full moon

day as given in Table 1. In addition to this, the solar and geomagnetic indices (F10.7 and AP Index) which are major influence on TEC variations are also collected from the website <https://omniweb.gsfc.nasa.gov/form/dx1.html>.

Table 1 contains the distance of the sun (km), a distance of

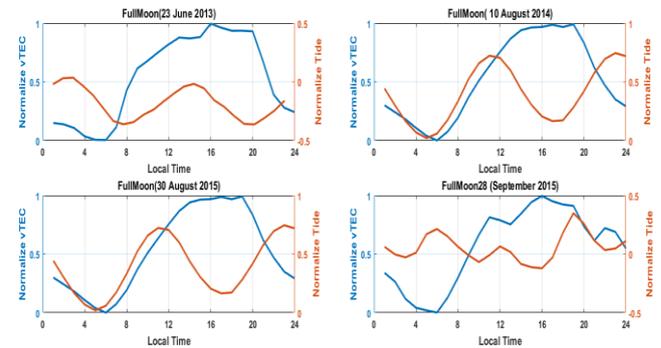


Fig. 4. Tide data during perigee and full moon for the days 23<sup>rd</sup> June 2013, 10<sup>th</sup> August 2014, 30<sup>th</sup> August 2015, and 28<sup>th</sup> September 2015.

the moon (km) and maximum, minimum estimation of tide,

normalized TEC, AP Index and F10.7 based on the new moon days for three years (2013-2016). The relationship between the masses of the earth, sun and moon and there distances to each other play a crucial role in affecting the tides. One of the major forces is gravity to create the tides. It is well known that the moon and the sun also raise tides on earth. From the table 1, it is clearly noticed that tide levels are enhanced up to 2.7m during 19<sup>th</sup> February 2015. The day corresponding to new moon where earth is closest to the sun (147875627 km) and increases gravitation forces are resulted in both tides and TEC values at perihelion conditions. The TEC and tide values are shown in figure 3. It can be observed from the figure (3) that TEC and tide levels are in opposite phase during early morning hours. It is evident that geomagnetic influences (24) are stronger on 13<sup>th</sup> October 2015. It is noticed that solar influence (148.6) is higher on 10<sup>th</sup> April 2013 in summer season during solar maximum years. Three solar eclipse events (29<sup>th</sup> April 2014, 20<sup>th</sup> March 2015 and 13<sup>th</sup> September 2015) are noted from Table 1 to investigate the relation between TEC and sun, moon distances. It is observed from the tide and TEC results that TEC values are decreased about 0.63. At the same time, tide level enhancement about 2.7m is observed from Table 1. It is obvious to known that sun and moon distances are closer for solar eclipse days. Table 2 contains the sun distance (KM), the moon distance (KM), and maximum, minimum estimation of the tide, normalized TEC, AP index and F10.7 based on the full moon days for three years (2013-2016).



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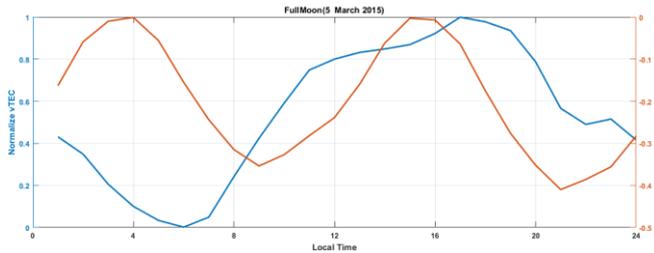


Fig. 5. Tide data during apogee and full moon for the day 5 March 2015.

The perigee full moon days are identified (23<sup>rd</sup> June 2013, 10<sup>th</sup> August 2014, 30<sup>th</sup> August 2015, and 28<sup>th</sup> September 2015 are shown in figure 4. It is observed that maximum tide values are reached up to 2.8m at 3:29 am. The increase in tide levels is due to coincidence of perigee and perihelion. Further the moon distance is closest about (357037 km) as shown in Table 2 indicating the influences on significance on ionosphere. The full moon days and apogee conditions are shown in figure 5 for the 5<sup>th</sup> March 2015. It is observed maximum tide values are reached up to 2.4m at 3:50 am. The corresponding normalized TEC value (0.95 TECU) as shown in fig 5.

In contrast, the tide levels are decreased up to 2.4m on 5<sup>th</sup> March 2015 during full moon as observed in figure(5). The decrement of tide levels because of coincidence of apogee,

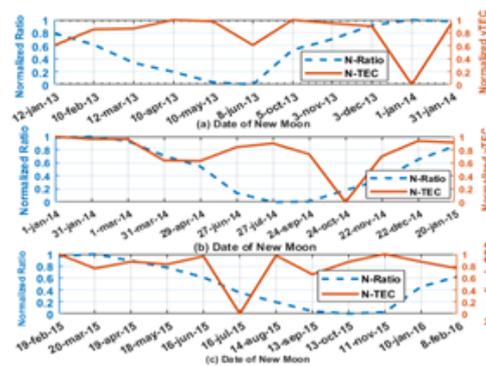


Fig. 6 Ratio of Sun, Moon along with Total Electron Content during New Moon (a) 2013-2014 (b) 2014-2015 (c) 2015-2016.

carried out from the year 2013 to 2016 at the time of new moon as presented in figure 6(a), 6(b), 6(c). It can be seen from fig.6 (a) that the normalized TEC values are not following well with ratio values for the new moon events in the year 2013-14.

It is evident that normalized TEC values are well correlated with ratio values for the year 2014-15 as observed in fig.6b by indicating the influence of gravitational forces on TEC measurements. It is also noticed that the TEC values are reasonably correlated with ratio values for the year 2015-16 (fig.6c).

The maximum correlation of 0.44 is observed for the year 2014-15 as observed in fig.7 (b) and the negative correlated value of 0.34 is observed for the year 2013-14(fig.7a). The reasonably correlated value of 0.10 is observed at the year 2015-16 as shown in fig.7c.

A Relationship between Ratios of sun, moon with total electron content (TEC) at the time of full moon: For monthly full moon days, the Normalized Ratio and Normalized TEC data were carried out from 2013 to 2016 and presented in figure 8(a), 8(b), 8(c). From fig.8a, it can be observed that the normalized TEC values are well correlated with the ratio

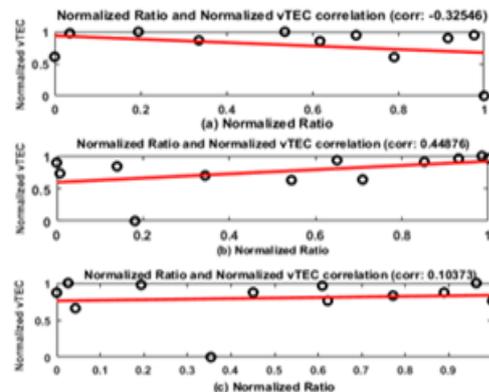


Fig.7 Scatter Plots of Normalized Ratio versus Normalized TEC values during the New Moon Month (a) 2013-2014 (b) 2014-2015 (c) 2015-2016.

aphelion. The moon is farthest to the earth about 406362km. The Normalized Ratio and Normalized TEC value are

values in the year 2013-14, due to the influence of

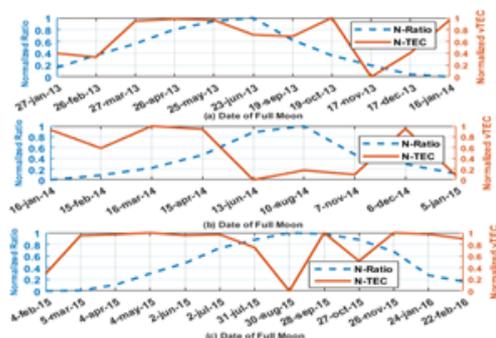


Fig. 8 Ratio of Sun, Moon with Total Electron Content during Full Moon (a) 2013-2014 (b) 2014-2015 (c) 2015-2016

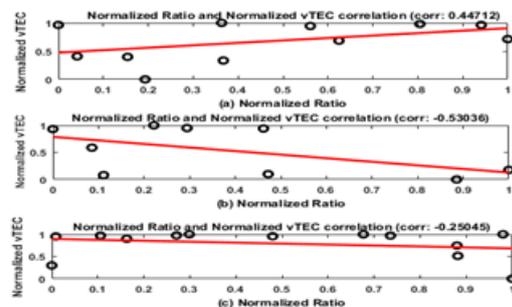


Fig. 9 Correlation Scatter Plot of Normalized Ratio and Normalized TEC during the Full Moon Month (a) 2013-2014 (b) 2014-2015 (c) 2015-2016



gravitational forces on TEC measurements. It is evident that the normalized TEC values are not correlated well with ratio values for the years 2014-15 and 2015-16 observed in fig.8b and fig.8c during the full moon event.

From fig.9a, it is evident that the maximum correlation value is occurred at the year 2013-14 with the value of 0.44, and also it can be noticed that from fig.9b and 9c the TEC and ratio values are correlated as negative with the values of -0.5 and -0.2.

The correlation analysis method that the relation between TEC, ratio of new moon and full moon events are inversely proportional for the years 2013-16 at Port Blair region.

#### IV. CONCLUSIONS

In this paper a relation among the sun distance, moon distance, and total electron content and tidal during the full moon as well as the new moon is investigated. An investigation of the correlation analysis, amongst the ratio of total electron content (TEC), has been carried out for the year 2013-2016 at the time of new moon and full moon. From the result of correlation analysis, it can be observed that the ratio and TEC were much lower in the year 2013-2014 and 2015-2016 than the corresponding year of 2014-2015 during a new moon. At the time of full moon, results of correlation analysis indicate that the sun ratio, as well as moon ratio with total electron content (TEC), was lower in the year 2014-2015 and 2015-2016, than the comparing year of 2013-2014. The relationship amongst the total electron content (TEC) with a ratio of sun and ratio of moon throughout the full moon and new moon is dissimilar. At Port-Blair station, the relation between ratio and TEC are inversely proportional for the years 2013-16 during the new moon and full moon events. The outcome of this reference work would be useful to understand the TEC affects due to the gravitational changes of earth, moon and sun.

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**APPENDIX**

New Moon							
Month	Sun Distance	Moon Distance	Tide(m)		TEC	AP Index	F10.7
	(KM)	(KM)	min	max	Normalized		
12-Jan-13	147129598	362919	0.8	2.6	0.60	4	163
10-Feb-13	147627881	370096	0.8	2.6	0.85	4	103.2
12-Mar-13	148654891	382878	0.8	2.5	0.87	5	121.5
10-Apr-13	149879666	391685	0.8	2.5	1.00	4	148.6
10-May-13	151061958	402010	0.9	2.6	0.98	4	127.3
08-Jun-13	151845578	405740	1	2.6	0.61	8	106.3
05-Oct-13	149597992	379854	0.9	2.5	1.00	0	105.9
03-Nov-13	148398058	370833	0.9	2.5	0.95	7	141.1
03-Dec-13	147465033	360932	0.8	2.6	0.90	7	131.9
01-Jan-14	147101424	357124	0.8	2.6	0.00	11	113.9
31-Jan-14	147385766	358101	0.7	2.7	0.95	1	99.7
01-Jan-14	147101424	357124	0.8	2.6	0.00	11	113.9
31-Jan-14	147385766	358101	0.7	2.7	0.95	1	99.7
01-Mar-14	148224010	362626	0.7	2.7	0.96	6	161.6
31-Mar-14	149439564	373749	0.8	2.6	0.64	6	152.1
29-Apr-14	150648461	382702	0.8	2.7	0.63	4	121.8
27-Jun-14	152073988	401555	1	2.6	0.84	3	107.6
27-Jul-14	151925033	406385	1	2.6	0.90	4	125.2
24-Sep-14	150078166	400321	0.9	2.4	0.73	21	145.6
24-Oct-14	148804330	389722	0.9	2.4	0.00	9	215.4
22-Nov-14	147759890	380636	0.9	2.5	0.70	9	162.6
22-Dec-14	147159853	368203	0.9	2.6	0.93	19	173.4
20-Jan-15	147201442	361414	0.8	2.3	0.91	2	121.6
19-Feb-15	147875627	356996	0.7	2.7	1.00	8	116
20-Mar-15	148961315	357766	0.7	2.7	0.76	22	111.8
19-Apr-15	150236482	364610	0.8	2.7	0.87	8	153
18-May-15	151307167	372158	0.9	2.7	0.83	15	117.6
16-Jun-15	151965431	381038	1	2.7	0.96	10	140.5
16-Jul-15	152055269	393433	1	2.6	0.00	7	102.9
14-Aug-15	151550789	400346	1	2.5	0.98	2	95.7
13-Sep-15	150539013	405958	1	2.5	0.66	11	100
13-Oct-15	149277007	405434	0.9	2.3	0.87	24	95.2
11-Nov-15	148124447	401376	1	2.4	1.00	22	102.9
10-Jan-16	147113840	378581	0.9	2.6	0.87	8	105.4
08-Feb-16	147555905	369928	0.9	2.6	0.76	17	112.1

**Table 1 New moon event results**



**Table 2 Full moon event results**

Full Moon
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Month	Sun Distance	Moon Distance	Tide(m)		TEC	AP Index	F10.7
	(KM)	(KM)	Min	Max	Normalized		
27-Jan-13	147314599	396216	0.9	2.5	0.40	7	94.7
26-Feb-13	148126242	384349	0.8	2.6	0.33	5	96.8
27-Mar-13	149279295	375309	0.8	2.6	0.94	20	92.6
26-Apr-13	150541208	364170	0.8	2.7	0.98	18	123.5
25-May-13	151525606	359004	0.8	2.8	0.96	37	124.5
23-Jun-13	152047833	357037	0.9	2.8	0.71	18	132.4
19-Sep-13	150275563	373866	0.8	2.6	0.69	13	108.9
19-Oct-13	149000860	386740	0.8	2.4	1.00	1	131.6
17-Nov-13	147905603	395066	0.9	2.4	0.00	6	172.9
17-Dec-13	147213393	403651	1	2.4	0.41	3	153.9
16-Jan-14	147160313	406523	1	2.4	0.96	2	117.1
16-Jan-14	147610313	406523	1	2.4	0.96	2	117.1
15-Feb-14	147761446	402982	0.9	2.5	0.59	9	158.1
16-Mar-14	148806530	397105	0.9	2.5	1.00	1	134.2
15-Apr-14	150080441	385376	0.8	2.6	0.94	5	163
13-Jun-14	151925872	364815	0.9	2.8	0.00	4	157.5
10-Aug-14	151645809	357134	0.9	2.8	0.18	7	111.3
7-Nov-14	148258490	376699	0.8	2.5	0.10	11	142.9
6-Dec-14	147405300	385762	0.9	2.5	0.95	11	125
5-Jan-15	147100135	397378	0.9	2.4	0.08	15	137.2
4-Feb-15	147466323	404746	0.9	2.4	0.30	8	150.1
5-Mar-15	148362303	406385	0.9	2.4	0.95	5	137.9
4-Apr-15	149600311	403318	0.9	2.5	0.97	11	122.4
4-May-15	150828264	394672	0.9	2.6	1.00	7	125.4
2-Jun-15	151711316	386432	1	2.7	0.96	2	103.9
2-Jul-15	152092890	373605	1	2.8	0.97	2	117.6
31-Jul-15	151862669	365725	1	2.7	0.75	13	103.8
30-Aug-15	151066008	358431	0.8	2.8	0.00	4	93.4
28-Sep-15	149919927	356907	0.8	2.7	1.00	3	124.5
27-Oct-15	148692962	358929	0.8	2.6	0.51	3	108.7
26-Nov-15	147653626	367162	0.8	2.6	1.00	1	101.2
24-Jan-16	147252798	388360	0.9	2.5	0.98	10	100.6
22-Feb-16	147963889	396457	0.9	2.5	0.90	2	91.7

