Analysis of Temporal Variations of TEC with Ionospheric Activity at Low-Latitude Station

Supraja Reddy. A and Haritha.G

Chaitanya Bharathi Institute of Technology (CBIT), Gandipet, Hyderabad

Abstract: *The performance of several critical services offered by GNSS is affected by large and sudden variations in ionosphere. A key limitation on the performance of such services is temporal variation of ionosphere. In this paper, temporal variation of ionospheric TEC is analyzed with respect to ionospheric activity in terms of two significant parameters ROT and ROTI. It is observed that the ionospheric temporal variations exhibit huge variability on storm days when compared to moderate and quiet days of ionospheric activity.*

Keywords: **GNSS, TEC, ROTI, Dst**

1. Introduction

The ionosphere, which extends from 50-1000 kms above the surface of the Earth is composed of four layers denoted as D, E, F1 and F2 (Klobuchar, 1996). Thus within the ionosphere, there exists large variations of electron densities with altitude. Also, the structure of the ionosphere changes continuously with variations in the intensities of solar radiations. Hence, the error introduced by ionosphere into GNSS signal as it traverses from the satellite to receiver varies with time, latitude of the receiver, location of the satellite, season and solar activity. Total Electron Content (TEC) is a quantity that describes the behavior of ionosphere. Variation of ionosphere with time (temporal variability/temporal gradients) is quantified in terms of two significant parameters, Rate of TEC (ROT) and Rate of TEC Index (ROTI). These two parameters help for auto detection of temporal gradients from scale lengths of a few kilometres down to less than hundreds of meters.
ROT is the differential TEC obtained at a receiver at every one minute.

$$\text{Rate of change of TEC } (\mathrm{ROT}(i)) = \frac{\mathrm{RTEC}(i+1)-\mathrm{RTEC}(i)}{t_{i+1} - t_i} \quad (1)$$

where i is the epoch, t_i is the time at ith epoch and t_{i+1} is the subsequent epoch of i.

ROTI is the standard deviation of ROT. Based on the sampling rate of TEC values, the ROTI calculation time intervals are decided (Jacobsen et.al, 2014). Usually ROTI > 0.5 indicates the presence of ionospheric irregularities at scale lengths of a few kilometers (Rungraengwajiake et.al, 2015).

$$\text{Rate of TEC Index } (\mathrm{ROTI}) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\mathrm{ROT}(i)-\overline{\mathrm{ROT}}\right)^2} \quad (2)$$

where N is the number of epochs.

2. Methodology

TEC data acquired from IRNSS-GPS-SBAS (IGS) receiver located at Chaitanya Bharathi Institute of Technology (CBIT), Hyderabad, India, is processed using the standard techniques (Mohd., et al., 2018). The temporal variations of TEC are calculated using Eqns. (1) and (2). ROT is calculated for every one minute time interval, whereas ROTI is calculated by considering a 5 minute time window. As the IRNSS data used has 1s sampling rate, 5 min interval is considered. The basis of 5 min interval can be used to compare low resolution data and high resolution data (Pi.et al, 1997). To obtain each ROTI, the standard deviation for 5 min interval of ROT is carried out. The analysis is carried out for days with different ionospheric activity. The ionospheric activity is characterized by Dst (Disturbance storm time). Based on Dst, the days are identified as quiet, moderate and storm days. Dst measured in nanoTesla (nT) is an index of geomagnetic activity derived from a network of four low-latitude observatories. During quiet days, it is between +20 to -20nT. It is between -50 to -100nT during moderate days and less than -100nT will indicate storm days (Cander. et al, 1998). The temporal variation of TEC for the IRNSS 1F satellite on a quiet day, moderate and storm day is presented.

3. Results and Discussion

The temporal variation of TEC for a typical quiet day (7^{th} April 2017, Dst: -15nT) for IRNSS 1F satellite is presented in Fig.1. ROT values are observed to be less than 0.5 and ROTI values are less than 0.15 during most part of the day, except for some variations observed during 23-24hours IST

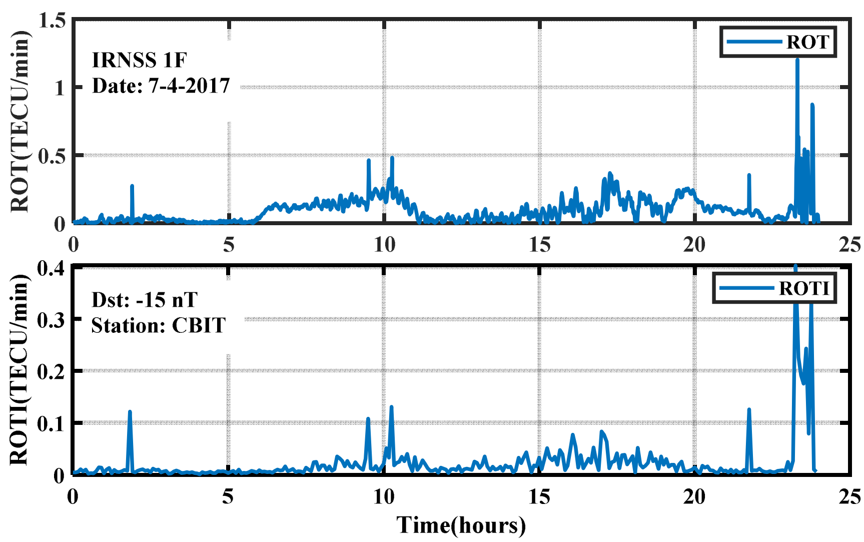

Fig.1 Temporal variation of TEC for a typical quiet day

The temporal variation of TEC for a moderate day is as shown in the Fig.2. On 28 October 2016, the Dst is observed to be -50nT, which represents it as a moderate geo-magnetic activity day. Strong TEC fluctuations mainly occurred during night time than during day. Maximum ROT of 0.975 and ROTI of 0.3793 TECU/min is observed on this day. It is inferred that when compared to quiet day the magnitude of temporal variations is high on a moderate day.

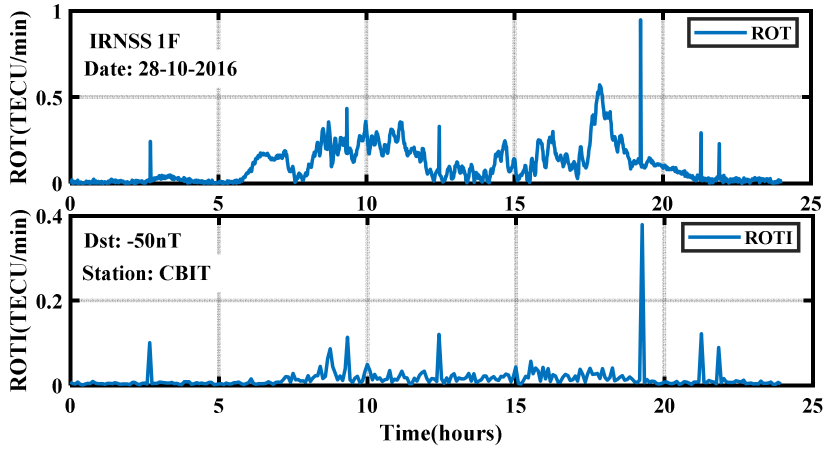

Fig.2 Temporal variation of TEC for a moderate day

The temporal variations for a typical storm day are presented as shown in the Fig.3. To examine the intensity of temporal variations on storm days, TEC corresponding to 14 October 2016 is considered. Dst of -104nT indicates the day as geo-magnetically storm day and the ROT values are observed to be very high when compared to a moderate day and quiet day. More TEC fluctuations are observed throughout the day indicating the large ionospheric activity, though the maximum values of ROT and ROTI are 0.6 and 0.125 TECU/min respectively.

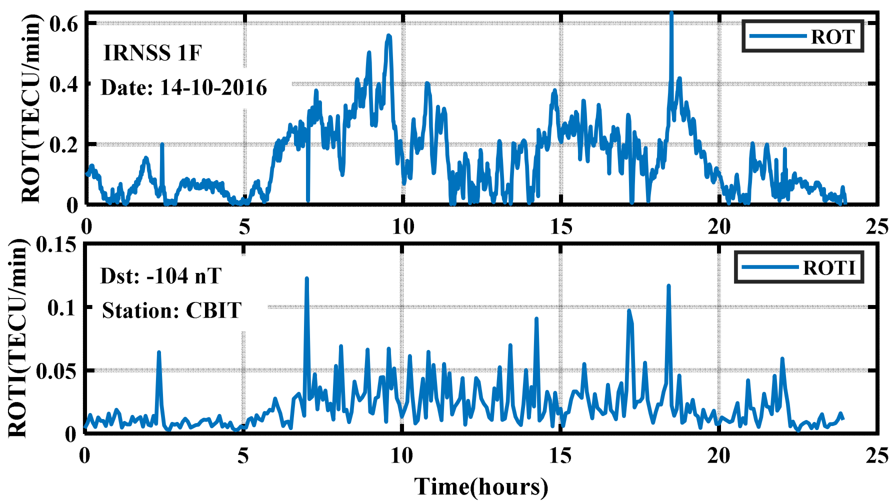

Fig.3 Temporal variation of TEC for a typical storm day

Several days of data has been analyzed and the maximum and minimum ROTI for some quiet, moderate and storm days are tabulated as follows.

Table 5.1 Temporal variations for typical quiet, moderate and storm days

S.No	Day	Dst (nT)	ROTI maximum (TECU/min)
1.	29 Jun 2017	-4	0.1039
2.	17 May 2017	-7	0.1087
3.	15 Dec 2016	-9	0.1108

4.	25 May 2017	-11	0.1134
5.	27 Oct 2016	-50	0.1239
6.	17 Jul 2017	-58	0.1278
7.	26 Oct 2016	-59	0.1297
8.	14 Oct 2016	-104	0.4638

Based on the data availability, ROT and ROTI are calculated for typical quiet days (29 Jun 2017, 17 May2017, 15 Dec 2016), moderate days (27 Oct 2016, 17 Jul 2017 and 26 Oct 2016) and for a storm day (14 Oct 2016). As the ionospheric activity increases, the standard deviation values of ROT also increase justifying the behavior of severity of ionosphere activity. The ROTI value has more variation for a storm day as compared to the moderate days presented above.

7. Conclusions

GNSS plays a crucial role in providing positioning and timing information to several applications. One of the errors that limits its performance is caused by severe ionospheric temporal variations. This problem is more in low latitudes regions where the ionosphere is severe and highly dynamic. Therefore, a thorough statistical analysis of temporal variations is carried out in terms of ROT and ROTI. Several days of data has been analyzed and the ROT and ROTI values are computed for quiet, moderate and storm days for different stations. It is observed that the temporal variations are high during ionospheric storm days when compared to quiet and moderate days. Also, from the analysis of data from several stations during several days, it is observed that temporal variations not only exhibit day-to-day variability but also exhibit seasonal and geographical variations.

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