



# Quality analysis of GNSS-TEC measurements based on Smartphone and Septentrio receiver

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## Abstract:

The number of uses for the Global Navigation Satellite System, which includes American's GPS, European's GALILEO and Chinese BeiDou, has been growing in recent years. Aside from GNSS, regional navigation systems such as the Japanese QZSS and the Indians NavIC were also developed. One of the most common uses of GNSS is to investigate the behaviour of the ionosphere propagation medium by measuring and calculating TEC, Scintillations, and Faraday rotation of electromagnetic waves. The primary goal of this project is to study and estimate, evaluate TEC using signals from multiple GNSS constellations received at GPCET in Kurnool, India (15.79° N, 78.07° E). At this location, R&D lab is established, which was helped us for conducting this project and for this an multi-frequency GNSS receiver of Septentrio make and model of PolaRx5 receiver and PolaNt-x MF is a high-gain antenna which incorporates a low noise amplifier, experimental setup was done. With the help of Septentrio receiver and Smart phone Geo++ application, which is acting as receiver for mobile, Multi GNSS constellations (GPS, GALILEO and BeiDou) data was logged and stored in their default locations of PC and mobile on April 25, 2022. Finally GNSS-TEC of the ionosphere was analyzed using the Septentrio tools. The maximum TEC for Septentrio Rx was 104.63 TECu was observed along the BeiDou, C06 signals, The minimum TEC for Septentrio Rx was 0.67 TECu was observed along the Galileo and E33 signal. The maximum TEC for Geo ++ was 98.04 TECu was observed along the Galileo and E33 signal, The minimum TEC for Geo ++ was 1.37 TECu was observed along the Galileo and E19 signal. The values of TEC in both were considerably similar **Key words: TEC, TEC using mobile, mobile tec vs conventional antenna tec, gnss.**

along the signal path in the ionosphere medium, however, delay the radio signals from GNSS

## 1. Introduction

GNSS stands for Global Navigation Satellite System, which comprises GPS (Global Positioning System), GLONASS (Global Navigation Satellite System), GALILEO, and BeiDou (Global Navigation Satellite System). Following that, countries such as Japan and India built their own regional systems, dubbed QZSS (Quasi Zenith Satellite System) and NavIC (Navigation with Indian Constellation). Because signals are provided at no cost, all of these systems have a wide range of civilian and scientific research applications, including navigation, precise positioning, and surveying. The number of applications is growing all the time, and one of them is ionosphere TEC research. The electrons present

satellites. This delay may reduce the precision of the selected application. Estimation The use of Ionosonde, RADAR, and GNSS data can improve accuracy by removing the impact of group delay on radio signals. Table 1 lists the various GNSS signals currently available for TEC estimation over the Indian latitude. Total Electron Content, abbreviated as TEC, is the integration of free electrons throughout the radio signal channel. TEC is expressed in TECu (1TECu=10<sup>16</sup> electrons/m<sup>2</sup>) units. Furthermore, TEC is important for detecting scintillations and has been chosen as a characteristic metric to represent

ionosphere activity . The state of the ionosphere (TEC) fluctuates according on the amount of sun exposure, such as day versus night, and the time of year. Because of the Sunlight directions, TEC varies more from north to south. The TEC is also seasonally connected, peaking around the Equinox. Furthermore, the amount of TEC varies depending on where you are. The time delay of NavIC signals was calculated using code and carrier phase measurements at various latitudes across India. At individual stations, multi-GNSS data are also employed to determine ionospheric TEC and DCBs used single frequency and dual frequency data to calculate TEC and found little variation in the findings. TEC was calculated in this study using the following combinations: GPS (L1-C/A, L2 P(Y)) for 27 PRNs, GLONASS (L1-C/A, L2-C/A) for 23 PRNs, GALILEO (E-5a, E-5b) for 23 PRNs, and BeiDou (B1, B3) for 13 PRNs

## 2. Literature Review

B. Zhang et al. [2018] Two cellphones, the Xiaomi Mi8 and the Huawei Mate20 X, were used to collect dual-frequency code and phase observations. Despite the fact that the Mate20 X's platform is based on the HiSilicon Kirin 980, both devices have the Broadcom BCM47755 dual-frequency GNSS chip, which can track GPS L1/L5, Galileo E1/E5a, QZSS L1/L5, GLONASS L1, and BeiDou B1 signals. Only the GPS and Galileo constellations are examined in this work, as dual-frequency signals are required to recover the TEC from phase observations in most cases. Geo++ GmbH in Garbsen, Lower Saxony, Germany, collected the information. Three distinct situations have been established. The initial set of data was gathered by securing the smartphone to a geodetic pillar on the company's rooftop. The observations in this case are similar to those in the previous scenario. As a result of multipath and nearby surfaces that can reflect signals, they are altered in reality. The smartphone and geodetic antennas, on the other hand, are about 10 metres apart and can be influenced by differing surface reflections. This configuration will be referred to as smartphone-antenna from now on. The second set of data was gathered inside an RF-enclosure on the roof, which was coupled to a geodetic antenna. The signals received by the geodetic antenna on the rooftop were re-transmitted inside the RF enclosure, which was housed inside the smartphone. We can assume that the reflections within the RF enclosure are all the same for a particular signal based on the double-difference and positioning analysis performed in

Darugna (e.g. L1). In fact, there is no additional bias in the data. This set creates an ideal condition in which distant and near-field phenomena, such as multipath, that can affect smartphone measurements are reduced. This configuration will be referred to as geodetic-antenna from now on. The third experiment was carried out in the same RF enclosure as the previous two, but with the addition of a 13 dB attenuator after the antenna. This last scenario provides carrier-to-noise values that are closer to real-world values while still limiting multipath effects. Hereafter, this configuration will be referred to as geodetic-antenna + attenuator. The various multipath impacts in each circumstance must be taken into account. As a result, no elevation mask is applied.

## 3. Proposed Method

### Calculating TEC

To estimate TEC using Multi GNSS (GPS, GLONASS, Galileo, and BeiDou) constellations data (or) signals, Multi-Frequency multi-GNSS receiver station was established at our institute, GPCET Kurnool, India. The receiver station equipped with Septentrio Pola Rx5 receiver and high gain multi band antenna (Model: PolaNt-x MF, Make: Septentrio) of RHCP that is mounted on the roof of our institute which is a 5 floor building. Both the antenna and receiver connected through a 25 meters RF cable .The antenna receives signals from satellites of Multiple GNSS and regional constellations. However, this paper mainly focuses on GNSS constellations to estimate the TEC using real-time observables of a typical day April, 25, 2022.



Fig. 3.1 Multi-Frequency Multi-GNSS signal receiving system

The raw data was recorded at 1Hz sampling rate which was in the form of Septentrio Binary Format (SBF). This SBF data was converted into the RINEX format using a graphical user



interface (GUI) named SBF converter. Then, SBF analyser was used to compute various parameters such as number of PRNs, elevation angle and TEC.

To compute TEC, ionospheric differential delay of two code or carrier phase observations measured on two different frequencies ( $f_1$  and  $f_2$ ) was used.

Code and carrier phase measurements between receiver 'p' and satellite 'i', for carrier k (k=1, 2,) & frequencies  $f_1$  &  $f_2$  can be formalized as equations given below. Pseudo range and carrier phase can be converted to distance multiplying by a wavelength  $\lambda_k$ .

$$\rho_{p,k}^i = D_p^i + c(\Delta t^i(t_e) - \Delta t_p(t)) + T_p^i + I_{p,k}^i + M_{p,k,g}^i - g_k^i + g_{p,k} + \epsilon_{p,k,g}^i(1)$$

$$\phi_{p,k}^i = D_p^i + c(2)$$

Where,  $D_p^i$  is pseudo range;  $D_p^i$  is geometric distance between satellite 'i' and receiver 'p';  $c$  is speed of light in free space ( $3 \times 10^8$  m/s);  $\Delta t^i(t_e)$  is satellite clock error at time of emission ;  $\Delta t_p(t)$  Receiver clock error at time of reception ;  $I_{p,k}^i$  is tropospheric delay;  $M_{p,k,g}^i$  is Ionospheric delay;

$g_k^i$  is multipath effect;  $g_{p,k}$  are delays produced by receiver and satellite hardware;  $\epsilon_{p,k,g}^i$  is measurement noise in code;  $T_p^i$  is carrier phase;  $I_{p,k}^i$  are delays produced by receiver and satellite

hardware and  $\epsilon_{p,k,g}^i$  is measurement noise in carrier phase. The STEC for the 'i<sup>th</sup>' satellite at any time 't' is calculated as below

$$STEC_i(n) = \frac{1}{40.3} \left( \frac{f_1 f_2}{f_1 - f_2} \right) (\rho_{p,f_2}^i - \rho_{p,f_1}^i) (3)$$

VTEC can also be obtained by taking the projection from slant to vertical using thin shell model assuming a ionosphere height at 350Kms, by the following technique (Feess and Stephens, 1987).

$$SF = 1 + 2 \left[ \frac{96^\circ - \text{elevation angle}}{90^\circ} \right]^2 (4)$$

By using all the above equations TEC is calculated internally in septentrio software the data is collected using mobile phones and septentrio Pola NT-X MF

## Measuring, Tabulating TEC Values

Septentrio has tools like SBF Logger, SBF Analyzer, SBF Converter RINEX, Rx Upgrade, Rx Planner, Rx Download, Rx Control. From these tools, SBF Logger will log the data and the GNSS data from the Septentrio and Mobile receivers are stored in default locations of the memory. These data are of Totally RINEX raw type data along with some observation and navigation files. To analyse these data SBF Analyser has used. Logged data from Septentrio Rx and Smart phone Rx, was imported to SBF analyzer. Our Project is based on Comparing and Measuring TEC values so TEC Ionospheric will be selected in SBF analyzer. Multiple signals like (GPS, Galileo and Beidou) Raw data will be uploaded and through this SBF analyzer Maximum and Minimum TEC values are observed and tabulated. For comparing TEC values of the both receivers, we need to select common signals of the different constellations, Such that comparing of the TEC values can be done easily. Based on the tabulated and studied values of TEC from the both receivers, plots for different constellations is generated and also compared TEC values with respect to time.

### 4. Result

This study presents a qualitative analysis for measuring the ionospheric total electron content. The novel two-step quality check method introduced in this paper significantly improves the quality of the data by discarding TEC measurements coming from rapidly fluctuating phase observations. Smartphone measurements in different setups have been gathered. An open-sky scenario on the rooftop and an ideal scenario within an RF enclosure where multipath effects are mostly removed are considered.

The results obtained from the comparison between sTEC differences retrieved from smartphone and geodetic receivers in the open-sky scenario show excellent agreement with the results obtained with the geodetic-antenna setup, when any of the filtering techniques is applied.

The difference between constellations is also noticeable, with more observations discarded for GPS

than for Galileo in all scenarios using both smartphones. This shows the higher quality and phase stability of the Galileo signals.

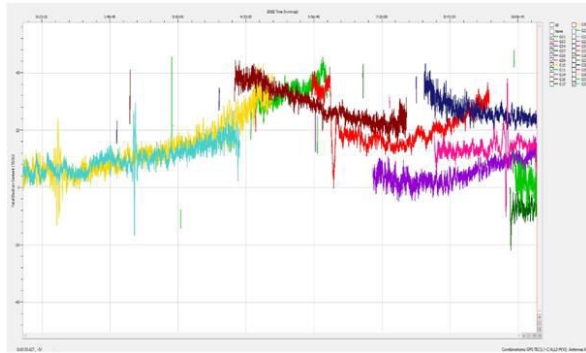


Fig. 4.1 TEC values of mobile receiver of GPS

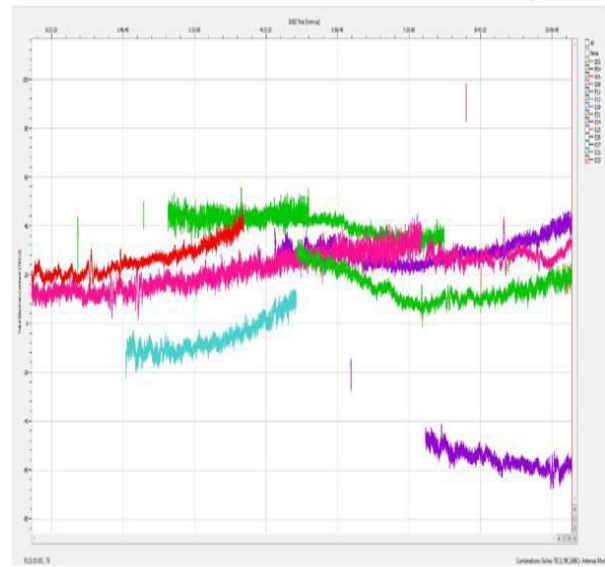


Fig. 4.3 TEC values of mobile receiver of Galileo



Fig. 4.2 TEC values of septentrio receiver of GPS

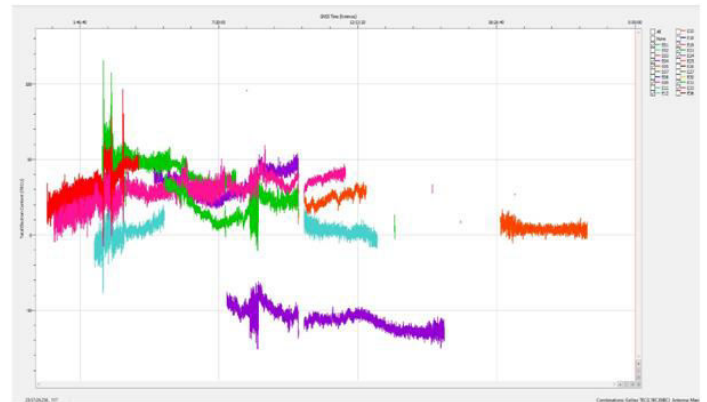


Fig. 4.4 TEC values of septentrio receiver of Galileo

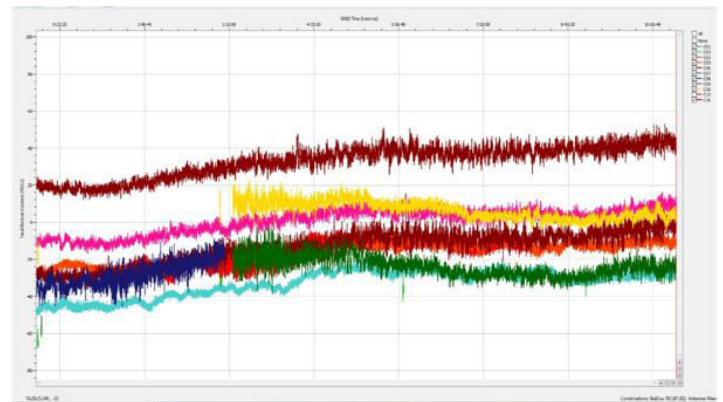


Fig. 4.5 TEC values of mobile receiver of BeiDou

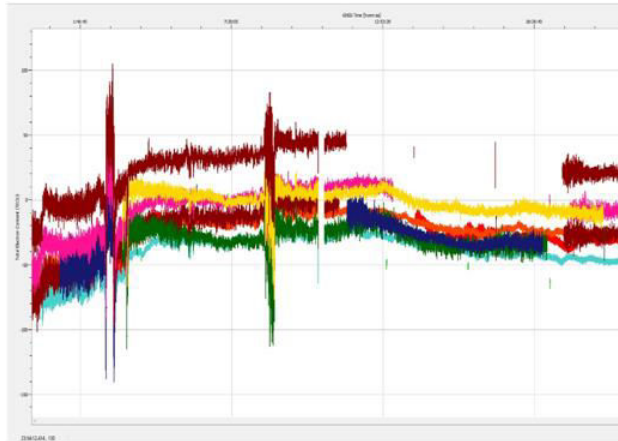


Fig. 4.6 TEC values of septentrio receiver of BeiDou

8	1	3	2		3			
G0	37.7	9:5	-	9:51	45.7	8:49	-	8:37
9	4	3	10.2		5		12.19	
			6				4	
G1	41.9	4:4	-	00:4	48.0	5:00	-29.8	00:41
0	1	8	12.4	1	5			
			6					
G1	24.7	6:0	-	10:2	31.4	6:01	-	03:31
1	8	0	10.3	8			12.84	
			3					
G2	44.1	4:2	17.6	7:28	49.6	4:41	19.56	22.05
6	7	5	1		4			
G3	29.2	2:1	-	2:16	45.6	2:46	-35.7	3:01
2	5	7	16.1		3			
			6					

Table. 4.1 Maximum and Minimum TEC values of GPS signals

RECEIVER_1(MOBILE)					RECEIVER_2(SEPTEN TRIO)			
GP S	Ma x Tec	Tim e	Min Tec	Tim e	Max Tec	Tim e	Min Tec	Time
G01	45.37	3:02	16.77	4:39	54.33	12:10	23.9	5:45
G03	41.25	6:15	-0.32	6:20	62.04	4:37	2.4	8:51
G04	24.34	5:58	-4.92	7:40	34.4	8:44	-31.8	8:52
G07	41.78	6:56	-21.44	9:57	32.224	6:56	-15.24	9:57
G0	42.5	8:1	19.2	9:37	71.3	8:42	-9.7	8:52

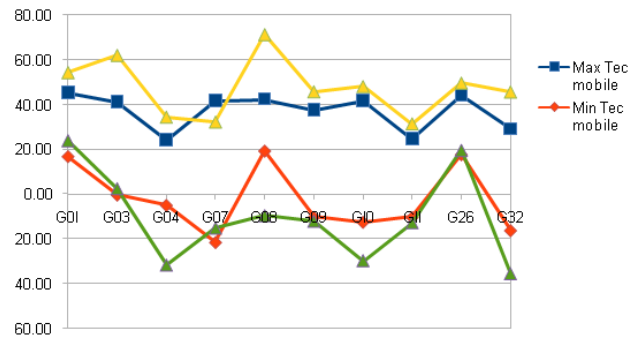


Fig. 4.7 plot of maximum and minimum values of GPS signals of both septentrio and mobile receiver

Table. 4.2 maximum and minimum TEC values of Galileo signals

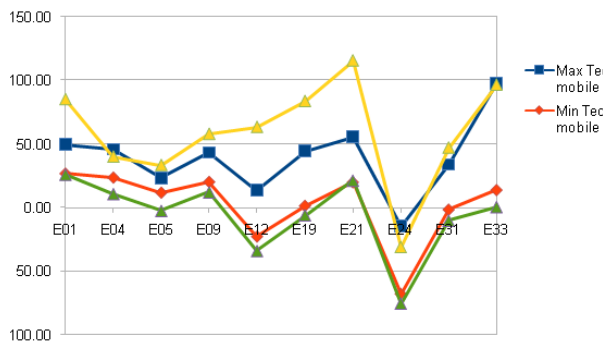
RECEIVER_1(MOBILE)					RECEIVER_2(SEPTE NTRIO)			
GALIL EO	Ma x Tec	Ti me	Mi n Tec	Ti me	Ma x Tec	Tim e	Min Tec	Tim e

E01	49.53	2:10	26.68	7:36	85.00	3:28	26.26	7:04
E04	45.81	10:26	23.58	6:24	39.98	15:00	11.00	19:58
E05	23.23	8:43	11.77	10:23	33.28	10:28	-2.3	20:24
E09	43.23	9:10	20.17	10:03	57.76	9:10	12.4	8:53
E12	13.54	5:06	-22.70	1:50	63.29	3:01	-33.87	2:42
E19	44.35	7:29	1.37	2:04	83.6	2:43	-5.76	2:42
E21	55.57	4:04	19.89	00:53	115.4	2:42	21.61	2:41
E24	-14.95	6:12	-67.62	10:07	-31.07	8:54	-75.35	8:55
E31	33.78	5:12	-1.54	7:35	47.03	3:35	-9.91	8:52
E33	98.04	8:26	13.78	1:07	96.44	3:28	0.67	2:42

Fig. 4.8 plot of maximum and minimum values of Galileo signals of both septentrio and mobile receiver

Table. 4.3 maximum and minimum TEC values of BeiDou signals

BeiDou	RECEIVER_1(MOBILE)				RECEIVER_2(SEPTENTRIO)			
	Max Tec	Time	Min Tec	Time	Max Tec	Time	Min Tec	Time
C01	-27.12	3:02	-40.03	9:00	-22.5	10:01	-68.27	19:01
C02	-20.92	5:00	-50.20	00:00	1.73	8:33	-98.49	2:42
C03	-4.47	4:30	-33.92	2:09	-7.25	14:09	-81.05	2:42
C05	-6.11	6:25	-30.10	1:14	13.76	8:32	-89.02	2:42
C06	5.53	10:14	-35.86	00:50	104.63	2:57	-128.97	3:01
C07	-0.89	3:36	-38.80	3:51	29.54	8:41	-115.13	3:28
C08	15.22	6:03	-44.53	1:17	80.76	2:57	-138.05	2:43
C09	15.05	6:03	-15.03	1:08	66.52	2:58	-93.52	3:01
C10	21.11	3:15	-4.85	10:19	43.68	8:41	-76.84	8:54





C16	52.16	10:10	12:59	00:24	100.64	2:58	-95.69	3:00
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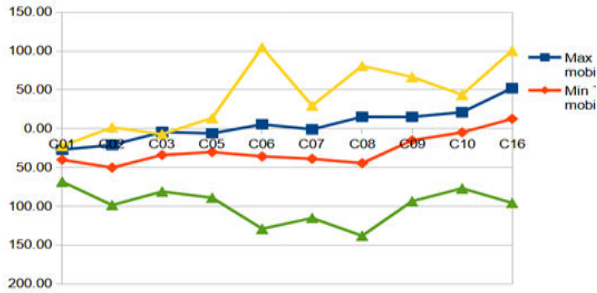


Fig. 4.9 plot of maximum and minimum values of BeiDou signals of both septentrio and mobile receiver

## 6. conclusion

Variations in TEC owing to several GNSS constellation (GPS, GALILEO, and BeiDou) signals over the receiver positioned at GPCET (15.79 0 N, 78.07 0 E) on April 25, 2022 have been presented in this work. GALILEO measured a maximum TEC value of 190.52 TECu (E08). Throughout the day, it was observed that the trend of TEC measured by several PRNs of all constellations follows the obvious behaviour of the ionosphere TEC. For the measurement of ionosphere impact on radio signals, data from numerous constellations on different frequencies (GPS (L1-C/A, L2 P(Y)), GLONASS (L1-C/A, L2-C/A), GALILEO (E-5a, E-5b), and BeiDou (B1, B3) can be employed.

This work has demonstrated that smartphone devices can be used to monitor ionospheric TEC. The method proposed in this research can be used to a variety of cellphones, settings, and ionospheric circumstances if these parameters are taken into account. This could make low-cost ionospheric monitoring instruments more widely available around the world.

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