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Performance Analysis of GAGAN and Trimble RTX Satellite Based Augmentation Services in Respective to Equatorial Ionospheric Conditions

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ABSTRACT

The effect of trans-ionospheric satellite signal propagation diminishes the positional accuracy of GNSS observations to a high extend in the equatorial region. Differential GPS (DGPS) technique is applied to overcome ionospheric issues by providing locally generated corrections. The increasing use of Satellite Based Augmentation Systems (SBAS) provides DGPS correction data via geostationary satellites with accessible bandwidths by all GNSS receivers without requirement of additional hardware. The Indian SBAS GPS Aided Geo Augmented Navigation (GAGAN) and the Trimble RTXIO (Real Time eXtended – Central Asia) are available over Sri Lankan region. The first is a free service covering the entire Indian region by three geostationary satellites and the second is a globally available paid service with a restricted access even for Trimble GNSS users. Continuous observations of four days were carried out to analyses the performance of these correction services under varying ionospheric conditions. For the experiment, one GNSS receiver was configured with GAGAN and the other with RTX CenterPoint augmentations, while a third receiver was set to perform standalone GNSS observation. Both GAGAN and CenterPoint RTX shows similar positioning accuracies varying between zero to 130cm and observed to be changing

with the variation of the Total Electron Content (TEC) depending on time of the day. Standard deviation (SD) values were investigated for four different time periods covering certain times during day and night. The TEC declining phase during late afternoon from 4:30 to 20:30 Local Time (LT) resulted in highest SD, depicting a degraded system performance than during the high TEC period from 10:30 am to 16.30 LT. However, SD were minimum during quiet TEC phase at night from 20:30 to 5:30 LT. CenterPoint RTX was marginally outperforming compared to GAGAN services during both the disturbed and quiet ionospheric conditions.

KEYWORDS: GAGAN, Trimble RTXIO, Ionosphere, Total Electron Content (TEC), Equatorial Region

1 Introduction

Global Navigation Satellite System (GNSS) has emerged an important tool in the modern world through providing un-interrupted timing, positioning and navigational solution to the rapidly increasing GNSS users around the world. Usage of GNSS is well known for many types of applications for defense, security and other commercial applications like transportation, surveying, timing, aviation, maritime, precision agriculture etc. (Jeffrey, 2010). Currently, United States' GPS and Russia's GLONASS are full operational satellite systems and there are also European Union's Galileo and China's Beiduo, are being implemented and expected to reach its full operational capabilities by 2020. Along with these Global satellite systems, GNSS also includes regional satellite systems like Indian Regional Navigation Satellite System (IRNSS) and Japan's Quasi Zenith Satellite System (QZSS) (B. Langley et al., 2017; Hofmann-Wellenhof et al., 2007).

GNSS satellites, orbiting at an approximate altitude of 20,200km continuously broadcasts electromagnetic signals to receivers on or near the ground which the receivers can perform precise range measurements. On the way from satellite to receivers, the signals traverse through the upper atmospheric layer of the earth. This layer known as ionosphere, contains highly varying ionospheric plasma made of free electrons which are formed due to ionization of atoms and molecules by the primary solar emissions, extreme ultra-violet (EUV) and ultra-violet (UV) (Anderson & Fuller-Rowell, 1999; Jensen & Mitchell, 2011). Existing plasma exerts a signal delay by refracting the trans-ionospheric satellite signals which diminish the positional accuracy of GNSS system applications. Despite the ionospheric error having greater influence on positional accuracy, there are also several other sources of errors such as tropospheric delay, satellite and receiver clock drifts, ephemeris errors, receiver noise, multipath etc. impacting on the positional accuracy (Carter, 1997).

GNSS positioning involves wide range of users including professionals and scientists requiring high level of positional accuracy. The technique known as Standard Positioning Service (SPS), based only on C/A code provides a horizontal accuracy up to 13 m as stated in GPS Interface Document (Kaplan & Hegarty, 2005). Even though this accuracy is adequate for satellite navigation, requirement for better precision and accuracy paved the way for the modified correction techniques such as Precise Point Positioning (PPP) and Differential GPS (DGPS). The PPP technique provides centimeter level accuracy by generating model-based corrections using global reference stations and distributing them through satellite or internet. Even though

PPP provides freely available worldwide coverage, the requirement of longer convergence time is a major drawback (Jeffrey, 2010; Leandro et al., 2011).

By inducing precisely surveyed reference stations to generate the differential corrections, the DGPS technique reduces or eliminates the common sources of errors at rover stations providing meter level positional accuracy depending on the distance between the rover and reference station. The DGPS technique can be used for post processing kinematics and real-time kinematics (RTK), in which the corrections are provided through a radio link or through the internet. But the positional accuracy of this technique highly depend on the quality of the differential corrections generated by the reference receiver, which degrades with the increment of baseline distance (Charoenkalunyuta et al., 2012). As an alternative solution, to provide the differential correction covering a wide area, independent on the baseline distance and geographical location, the technique called Wide Area Differential GPS (WADGPS) was initiated. State-Space Domaine approach of WADGPS technique is used with a Satellite Based Augmented System (SBAS).

SBAS use geo-stationary communication satellites commonly to provide corrections for GNSS satellite orbits and clock data along with the ionospheric propagation delay (B. Langley et al., 2017; Dammalage et al., 2017a). Currently, US Wide Area Augmentation System (WAAS), the European Geo Stationary Navigation Overlay Services (EGNOS), Japan’s Multi - Functional Satellite Augmentation System (MTSAT), India’s GPS Aided Geo Augmented Navigation (GAGAN) and Trimble RTX (Real-Time eXtended) Satellite Based Augmentation Systems are in full operation. Out of which GAGAN and Trimble RTXIO (Real-Time eXtended – Central Asia) are available over Sri Lankan region as SBAS services.

1.1 GPS Aided Geo Augmented Navigation (GAGAN)

GPS Aided Geo Augmented Navigation (GAGAN) is a collaborative implementation of Satellite Based Navigation System (SBAS) over Indian airspace by Indian Space Research Organization (ISRO) and Airports Authority of India (AAI) (Acharya et al., 2005; Prasad & Achanta, 2007). The aim of the implementation was to provide high positioning accuracy and integrity to the civilian aircrafts in Indian space while landing. But the system can be used for vast range of user application such as railways, security, surveying etc. (Acharya et al., 2005; K. Rao, 2007).

The GAGAN system consists of several implements such as Indian Reference Station (INRES) at 15 locations across India, two Indian Master Control Centers (INMCC), three Indian Land Uplink Stations (INLUS) and three geostationary satellites namely GSAT - 8, GSAT - 10 and GSAT - 15 as an orbit spare. The IRNES collects data from all the GPS and geostationary satellites in view and forwards them in real time to INMCC, where it is processed for generation of correction and integrity parameters in SBAS message format. The SBAS messages are uplinked in C – Band to the geostationary satellites through INLUS, which are downlinked in L1 and L5 bands to users (Ganeshan et al.; K. Rao, 2007). GAGAN compatible receivers perform the received corrections to augment the calculated positioning.

The equatorial ionospheric region over India shows very unique characteristics such as Equatorial Anomaly (EA), Eqatorial ElectroJet (EEJ) etc., showing high spatial and temporal variation in ionospheric contents (Acharya et al., 2007; Reddy, 1986). In order to meet the required GAGAN performance fitting this kind of ionospheric variations, known as ISRO GIVE Model - Multi - Layer Data Fusion (IGM - MLDF) was developed by ISRO and operational in the implemented GAGAN system (Dammalage et al., 2017b; Ganeshan et al.).

This model provides GIVE (Grid Ionospheric Vertical Error) and GIVD (Grid Ionospheric Vertical Delay) by capturing the ionospheric variability at 2 different ionospheric shell heights at 250 km and 450 km and provides a value at 350 km shell height using a weighted average method. A data fusion is applied at vertical Ionospheric Grid Points (IGPs) at $5x5^0$ interval using a Kriging algorithm at designated shell heights (Ganeshan, 2011; Ganeshan et al.; Srinivasan et al.).

1.2 Trimble RTX

Trimble RTX (Real-Time eXtended) is a set of GNSS correction services that provides high accurate positioning correction solutions to Trimble customers all over the world through satellite or internet. RTX correction services includes CenterPoint RTX, FieldPoint RTX, RangePoint RTX, ViewPoint RTX and XFill Premium. These services have a specific initialization time, accuracy, performance and require separate subscription for the services (INC, 2019; Zhang et al., 2013). Trimble RTX employs the CenterPoint RTX services since mid of 2011 to provide centimeter-accurate positions to Trimble users in real time for static and kinematic applications. CenterPoint RTX system uses globally distributed RTX tracking stations which are composed of more than 100 stations equipped only with Trimble NetR5, NetR8 and NetR9 receivers, tracking multiple GNSS satellite systems (Leandro et al., 2011; Zhang et al., 2013). Collected data are streamed in real time to RTX control centers where the precise correction parameters are generated using high accurate models and algorithms and compressed in messages complaint with especially designed CMRx format for compact transmission of satellite information. The CMRx correction stream comprises several information, such as precise satellite positioning, precise satellite clock, ionospheric and tropospheric data and additional biases valid in a global scale (Chen et al., 2011; Leandro et al., 2011). The generated corrections are then forwarded to either a satellite uplink station to be uploaded to satellites or made directly available to customers through internet protocols and mobile phone links (NTRIP). The corrections are also downlinked through six geostationary satellites via L-band communication signals (Chen et al., 2011; INC, 2019). A single-layer global ionospheric model was introduced to RTX service in 2013 based on a spherical harmonic expansion aiming to reduce the convergence time (Brandl et al., 2019; Rodriguez-Solano et al., 2015). This was supportive to reduce the convergence time in both, the dual and single frequency mode and reduce positional error.

2 Research Problem and Objective

Sri Lankan GNSS users are been provided with two options within Sri Lankan region, (i) GAGAN, providing freely available regional based corrections over Indian region and (ii) Trimble RTX, a global commercial service providing several regional based correction services where RTXIO (Central Asia) at 1545.53 MHz is commercially available over Sri Lanka. Trimble RTX claims less than decimetre positioning accuracy, while GAGAN is a GPS based C/A code-based augmentation with capable of only 50cm to 1 meter performance. Therefore, this study comparatively analyzes the on-field performances of both the systems over Sri Lanka during varying ionospheric conditions.

3 Field Experiment and Analysis

An experimental setup was established with three GNSS receivers as shown in Figure 1. The experiment was designed as it could cover a 24 - hour period continuously covering four days of static observation from 12th to 15th of September 2019, which the days were magnetically quiet (geomagnetic activity index Kp < 3).

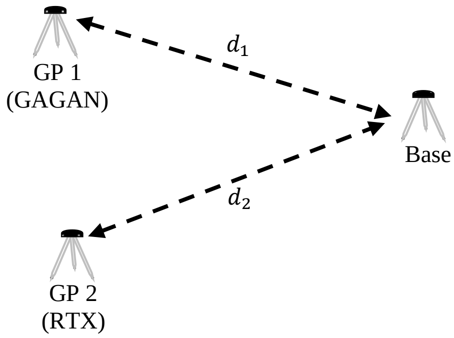

Figure 1 Pictorial depiction of field experiment

A Trimble R5 GNSS receiver was used as base station and two SPS 986 receivers were used as rover stations with augmented positioning. The SPS 986 receiver at reference point GP 1 was enabled with GAGAN augmentation and the other SPS 986 receiver at GP 2 was enabled with RTX augmentation. These stations were selected carefully so that the multipath effect has a minimum influence. The reference distances d_1 and d_2 were precisely measured using an EDM instrument. Using the precise coordinates of the base station, the distance between the base and rover stations were calculated (${d_t}^{GAGAN}$, ${d_t}^{RTX}$) at 180 seconds interval. Then the time series analysis on distance deviation between base and GP 1 ($\Delta {\in_t}^{GAGAN}$) was done using equation 1 and the analysis on distance deviation between base and GP 2 ($\Delta {\in_t}^{RTX}$) was done using equation 2. GPS and GLONASS satellites were considered for this analysis.

$$\Delta {\in_t}^{GAGAN} = d_1 - {d_t}^{GAGAN} \quad \textit{Equation 1}$$

$$\Delta {\in_t}^{RTX} = d_2 - {d_t}^{RTX} \quad \textit{Equation 2}$$

TEC estimations were done using the *Ciaralo* methodology by applying carrier phase measurements of GPS and GLONASS using GNSS_VShell (Ciraolo et al., 2007). The height of the ionospheric Single Layer Model (SLM) was selected to be at 350 km. A mapping technique depending on elevation was introduced to map the STEC into vertical TEC (VTEC) for the modelling of TEC using the following equation:

$$F(z) = \frac{STEC}{VTEC} \quad \textit{Equation 3}$$

Elevation mask angle of 50^0 was applied in order to eliminate the low elevation angle effects and topo scatter, due to multipath and water vapor on measured TEC values (P. R. Rao et al., 2006; V. S. Rama Rao et al., 2006).

4 Results and Discussion

The performance of the GAGAN and Trimble Centerpoint RTX satellite-based correction services over Sri Lanka is analyzed with the use of four days continuous observations from 12th to 15th of September in 2019. Deviation of distance between a high accurate base station and the coordinates of GP1 and GP2 which were calculated using augmented GNSS positioning with GAGAN and RTX, respectively, are shown in Figure 1. Moreover, the distance deviations of GAGAN in blue and RTX in red on 12th and 13th of September 2019 are shown in Figures 3 and 4. Accordingly, both systems have shown the same trend of variation pattern throughout 24-hour observation periods; however, GAGAN and RTX augmented observations during 13:00 to 17:00 LT on 12th of September was not recorded due to an instrumental breakdown.

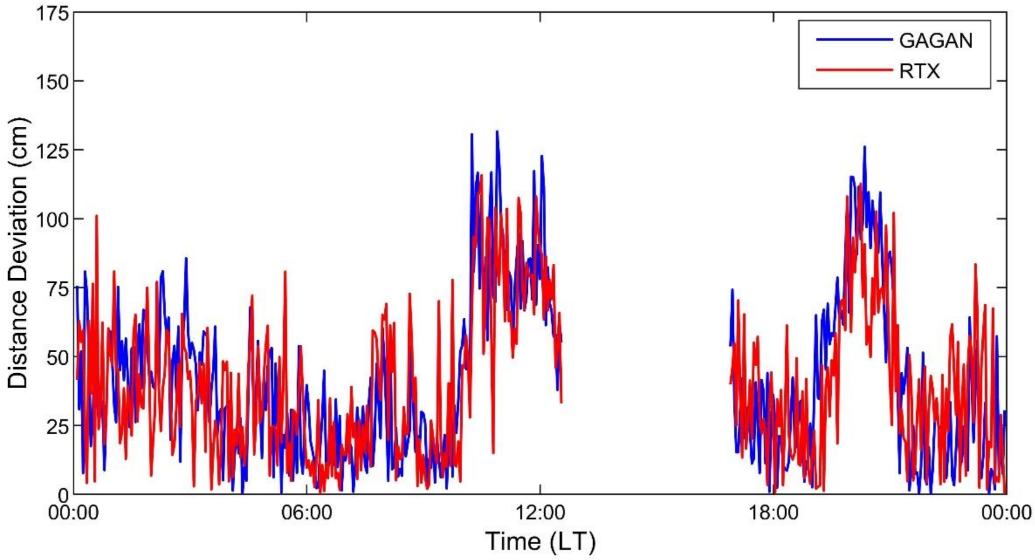

Figure 2 Variations of distances of GAGAN (blue) and RTX (red) on 12th of September.

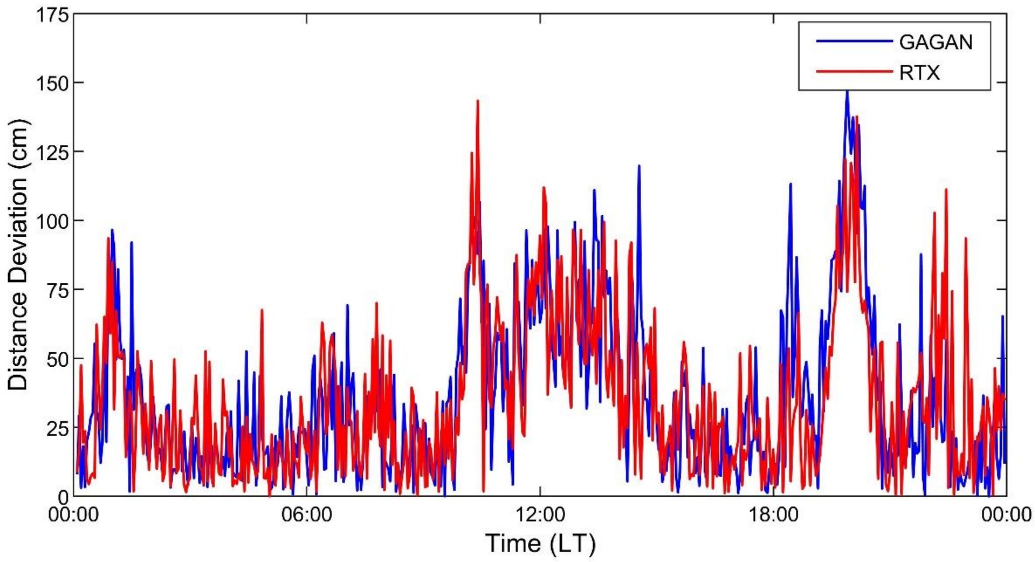

Figure 3: Variations of distances of GAGAN (blue) and RTX (red) on 13th of September.

The distance deviation varies around zero to 75 cm throughout the night period from 22:30 to 08:30 LT in the morning. Higher positional accuracy variation depicting the degraded system performances, could be seen during noon time from 10:30 to 14:30 LT, where the distance shift

jumps up to 150 cm and varies around 50 cm to 125 cm in average. The same distance deviation could be noticed for a comparatively shorter period around 20:30 and 23:00 LT. Still the distance deviation jumps to a higher 75 cm to 130 cm variation on average. In order to study the ionospheric impact on the GAGAN and Trimble CenterPoint RTX system performance, the ionospheric TEC variation during these four ionospheric quiet days (Kp < 3) are calculated and shown in Figure 4.

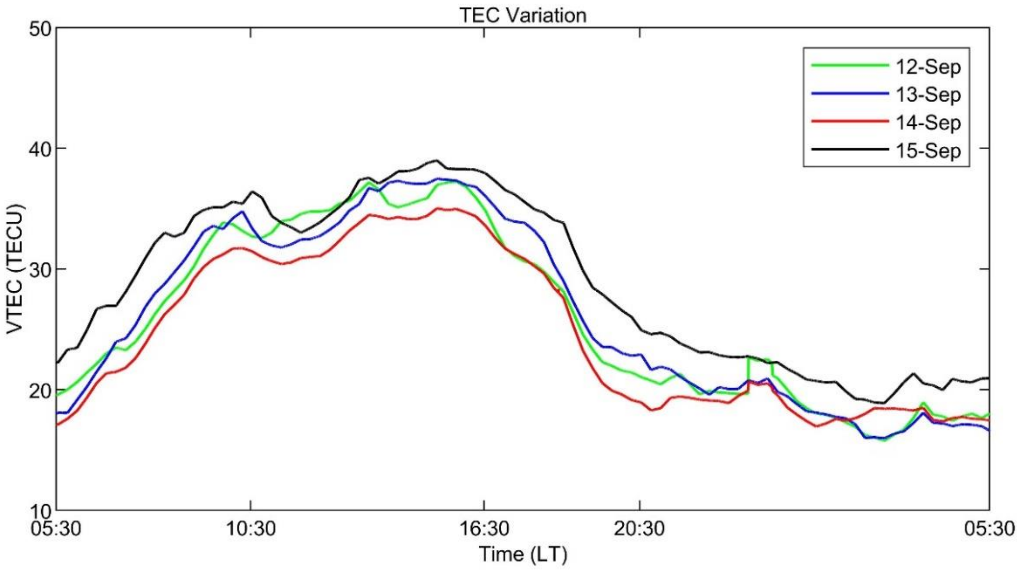

Figure 4: TEC variation during the observation days

The VTEC variations over Sri Lanka during these days follows almost same diurnal variation trend. Considering these variations of VTEC, it could be divided into four time slots of variations as T1, T2, T3 and T4. The ascending phase of VTEC shows a stable increment from around 20 TECU at 05:30 LT to reach a short-lived maximum of 36 TECU at around 10:30 LT is classified as T1. The local time slot T2, from 10:30 could be described as high TEC phase which maintains maximum value throughout the noon period peaking around 14:00 LT with a maximum of 35 to 38 TECU and begins to decrease at around 16:30 LT. Continuing from here, the slot T3 which could be mentioned as descending phase of TEC, shows a sudden decrement of TEC which reaches a minimum TEC units of those respective days at around 20:30 LT. From here ionospheric TEC has become comparatively stable until 05:30, next morning which this variation could be mentioned as quiet phase of TEC variation.

In order to investigate the variation of distance deviation, which depicts the system performances with respect to the ionospheric variations, the behavior of Vertical Total Electron Content (VTEC) on the respective days are plotted along with the distance deviation for the respective days. Figures 5 and 6 depict the variation of the distance deviation from the right along with the VTEC behavior from the left side on 14^{th} and 15^{th} of September 2019.

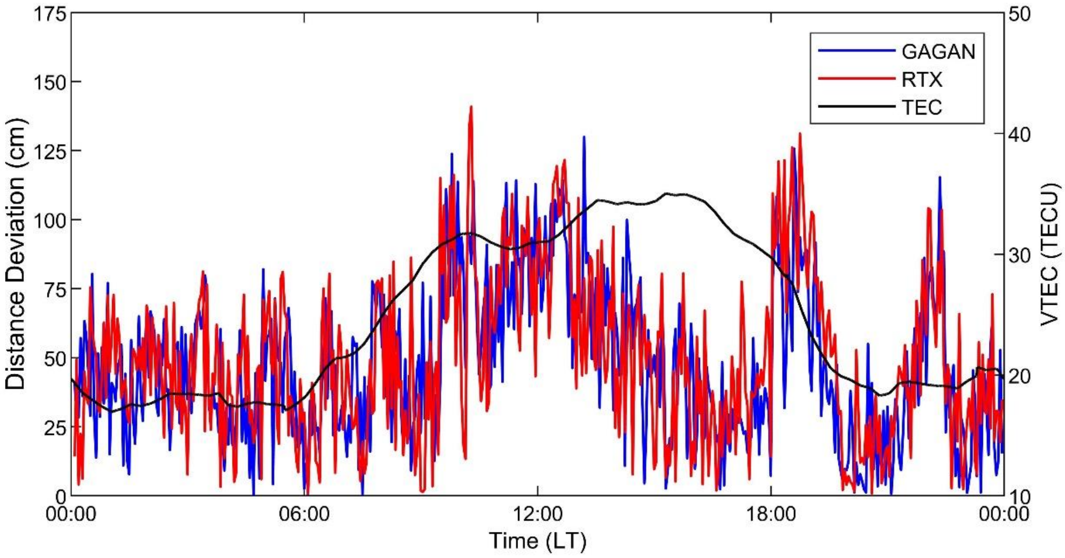

Figure 5: Variations in distances of GAGAN (blue) and RTX (red) along with VTEC variations (black) on 14th of September.

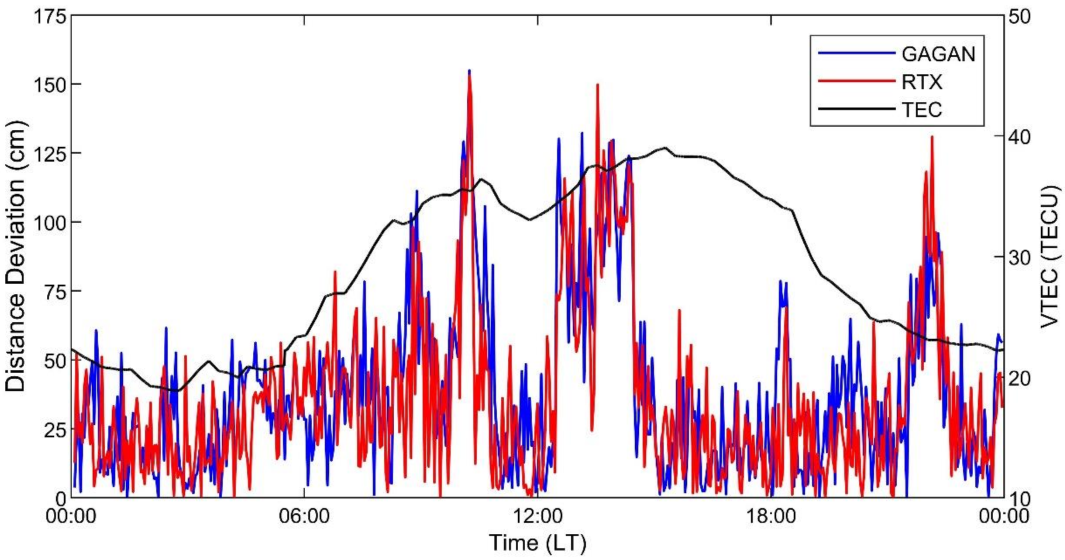

Figure 6: Variations in distances of GAGAN (blue) and RTX (red) along with VTEC variations (black) on 15th of September.

It could be seen that during slot T4, when the ionospheric TEC variations are quiet with TEC vales are around 18 TECU, the distance deviation is varying between zero to 75 cm, depicting a higher system performance. Though the TEC shows a steady increment during the slot T1 to reach up 90 TECU at around 10:30 LT, the distance deviation maintains the same precision. The effect of the steep TEC increment could be seen during the phase of T2 as the distance deviation jumps up 75 cm to 130 cm between 10:00 to 14:20 LT. VTEC during this period varies dramatically with the peak TEC value of 39 TECU at around 15:15 LT, begins to drop reaching 35 TECU at around 16:30 LT which the drop continues throughout the slot T3 to reach 23 TECU at around 20:30 LT. Despite the decrement in the VTEC during the final stage of slot T2 and early stage of slot T3 the distance deviation continues to be low during the final stage of the slot T2 and the early period of slot T3. But, a short and sudden eruption in system

performance during 18:30 LT of slot T3 could be noticed for the observations of both the systems. Similarly, a short-lived eruption could also be noticed during the slot T4 at around 10:10 LT, where the ionospheric variations has been very quiet. In order to derive a statistical solution, for the system performance and its dependence on time based ionospheric behaviors, standard deviations of distance variations (SD) during the respective time slots of the four days of observations were derived as shown in Table 1.

Table 1: Standard deviations in [cm] of GAGAN and Trimble RTX during seperate time slots.

Time slot of Day	12th Sep		13th Sep		14th Sep		15th Sep	
	GAGAN	**RTX**	**GAGAN**	**RTX**	**GAGAN**	**RTX**	**GAGAN**	**RTX**
Slot T1	24.9	26.1	24.6	26.7	27.8	31.6	30.3	29.0
Slot T2	21.7	21.0	28.2	26.4	27.3	29.9	39.9	38.5
Slot T3	33.6	28.2	41.5	32.9	30.6	35.6	19.3	13.6
Slot T4	24.2	22.9	19.8	22.0	21.9	21.7	21.7	22.9

Minimum SD of day
Maximum SD of day

The overall SD values of distance deviation of both the systems varies between 19 to 42 cm during these four days of observations. The higher SD could be observed at slot T3, during the descending phase of ionosphere for the first three days of observation. The SD has been low varying between 19 to 23 cm during the nighttime (slot T4) when the ionosphere is quiet, where the recombination process of electrons is occurring. The Trimble CenterPoint RTX has performed well during, the disturbed and quiet ionospheric conditions evident that the variation of SD between Trimble RTX and GAGAN have a difference of around a mere 2 to 4 cm only during quiet ionospheric conditions and a difference of 6 to 8 cm during disturbed ionospheric conditions.

5 Conclusion

This study comparatively analyzed the performance of GPS Aided Geo Augmented Navigation (GAGAN) and the Trimble RTX systems providing satellite-based correction services under diurnally varying ionospheric conditions through continuous observations of four days from 12th to 15th of September in 2019. The performance of both systems shows almost a same variation pattern throughout a complete day which the positional accuracy is varying between zero to 75 cm from 20:30 to 05:30 LT, throughout the night. Comparatively lover system performance could be seen around 10:30 to 14:30 LT where the positional inaccuracy reached up to 75 to 130 cm. Though both systems show better precision during ionospheric quiet period over Sri Lankan region, the accuracy is not adequate for surveying and mapping applications. The analysis on standard deviation of both the systems indicates that the Trimble RTX has marginally outperformed GAGAN SBAS services during quiet and disturbed ionospheric conditions. Though this study reveals a comparative analysis of GAGAN and Trimble RTX over Sri Lankan region, however, it is recommended to perform further the analysis covering a longer period under varying ionospheric conditions to obtain a better understanding.

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