AGU100 ADVANCING EARTH AND SPACE SCIENCE

Space Weather

RESEARCH ARTICLE
10.1029/2017SW001762

Key Points:
- Multisatellite scintillations over a limited common ionospheric volume were simultaneously observed
- Detrended CNO fluctuations were compared for satellites of different constellations during intense scintillations from two different stations
- Differences in CNO fluctuations lie within the range of 1–2.5 dB Hz implying the interoperability of GPS, GLONASS, and GALILEO

Supporting Information:
- Supporting Information S1
- Data Set S1
- Data Set S2
- Data Set S3
- Data Set S4

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Citation:
Goswami, S., Paul, A., & Haldar, S. (2018). Study of relative performance of different navigational satellite constellations under adverse ionospheric conditions. *Space Weather*, *16*, 667–675. https://doi.org/10.1029/2017SW001762

Received 9 NOV 2017
Accepted 20 MAY 2018
Accepted article online 25 MAY 2018
Published online 15 JUN 2018

Study of Relative Performance of Different Navigational Satellite Constellations Under Adverse Ionospheric Conditions

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Abstract Detrimental effects of satellite signal outages during periods of intense equatorial ionospheric scintillations could be mitigated using multiconstellation satellites if provisions for interoperability of these satellite signals exist. In view of the sharp spatial gradient of ionization occurring in the equatorial region, comparison of satellite signal fluctuations from different constellations should be performed over limited spatial volume. This could be effective for maintaining and improving the performance of satellite-based communication and navigation without compromising the accuracy and integrity. This paper presents a comparative study of robustness of GPS, GLONASS, and GALILEO satellites over a common ionospheric volume during periods of ionospheric scintillations for the equinoctial months of 2014 and March 2016 from Calcutta (22.58°N 88.38°E geographic; 32°N magnetic dip) and for September 2016 from Siliguri (26.72°N, 88.39°E; 39.49°N magnetic dip), located near the northern crest of equatorial ionization anomaly in the Indian longitude sector. It is found that for all the cases, carrier-to-noise ratio fluctuations over limited ionospheric volume from satellites of different constellations are comparable, thereby rendering them interoperable.

1. Introduction

Global Navigation Satellite System (GNSS) provides collectively worldwide positioning, navigation, and timing determination capability using one or more satellite constellations. The reception of multiconstellation satellite signal can enhance the performance of satellite-based navigation system under conditions of intense ionospheric scintillations as experienced during equinoctial months of high sunspot number years at equatorial locations through application of the principles of spatial diversity (Paul et al., 2017), frequency diversity (Goswami et al., 2017), and interoperability. Presently, GPS, GLONASS, GALILEO, and Beidou/COMPASS are the operational GNSS. There are 31 operational GPS satellites, while GLONASS has declared full-operational constellation of 24 "healthy" satellites. GALILEO is scheduled to be fully operational by 2020. Combining GPS, GLONASS, and GALILEO constellations, an average 15 satellites are expected to be in view at any time from any point on the surface of the earth. Importance of multiconstellation observations in improving the accuracy of satellite-based navigation system has already been illustrated from the equatorial region by Paul et al. (2017).

Sharp latitudinal gradients of ionization are one of the important characteristics of equatorial ionosphere which exists for a major part of the day often existing till about 22:00 LT. Transionospheric satellite links operating near the crests of the equatorial ionization anomaly (EIA) experience unusually large range errors when the signal passes through such steep ionization gradients which may be particularly hazardous for reliable operation of high dynamic platforms like an aircraft (DasGupta et al., 2006). This sharp latitudinal gradient of ionization occurring during the daytime and intense space weather events in the postsunset hours are some of the major deterrents to successful implementation of satellite-based communication and navigation service, affecting transionospheric satellite links particularly in the equatorial region (Carrano & Groves, 2010; Das et al., 2014; Humphreys et al., 2010; Paul, Roy, et al., 2011; Roy & Paul, 2013).

During solar maxima at equatorial latitudes for GPS-only scenario, receivers can frequently experience loss of carrier tracking lock due to signal fading, which in turn significantly reduces the availability of navigation satellites. If the GNSS satellites (GPS, GLONASS, GALILEO, and Beidou/COMPASS) are interoperable, the impact of ionospheric scintillations on satellite-based navigation could be mitigated. Four satellites with good geometry are required to be tracked by the receiver for navigation (Kaplan & Hegarty, 2006). Therefore, if GNSS satellites are interoperable, the receiver can still track at least four satellites with good geometry even if it briefly loses some satellites simultaneously. In addition to the intensity of scintillations, the number of satellites affected by scintillations is also a very important factor, since a greater number of satellites under lower scintillation intensity may be more problematic for GNSS-based aviation than less number of satellites with much higher scintillation intensity (Paul et al., 2017; Seo et al., 2011). A comparative study in terms of statistics of scintillation occurrences for GPS L1, L2C and L5, GLONASS L1 and L2, and GALILEO E1 and E5a for equatorial Africa was done earlier (Hlubek et al., 2014).

During 1999–2002, combined GPS-GLONASS receivers were operated at some locations in India where it was reported that availability of GLONASS satellites was limited from equatorial locations (Banerjee et al., 2002). Studies conducted earlier have reported that the detrimental effects of the sharp latitudinal gradients of ionization occurring in the equatorial region may be limited if sufficient number of satellite links are available at high elevation angles in excess of 60° (Paul et al., 2005). It has been observed using total electron content (TEC) measured in 2004 along a chain of stations located more or less along 77°E meridian under the Indian Satellite-Based Augmentation System (SBAS) program GPS-aided Geo Augmented Navigation (GAGAN) that the median grid scale of latitude and longitude for total electron content variation less than 3 TECU (for an acceptable range error of 50 cm) varied from (0.64°–0.87°) × (0.23°–0.49°) at elevation angles greater than 70° (Paul, Das, et al., 2011). It should be kept in mind that these figures were arrived at during a moderate sunspot number period. Thus, more stringent requirements may be imposed during solar maximum period. As the number of satellites tracked increase in GNSS compared to GPS-only, it results in larger number of ionospheric pierce points and availability of sufficient satellite links at varying elevation angles. This in turn may result in improved accuracy and hence less stringent requirement for grid size even in the highly dynamic equatorial ionosphere. Thus, studying the availability and interoperability of multiconstellation satellites from the anomaly crest location will provide important inputs for satellite navigation system designers. It is important to note that issues of interoperability of signals from different satellite constellations have not been extensively reported in literature, particularly from the Indian longitude sector.

To ascertain the feasibility of interoperability of satellite signals, relative performance of signals from the different constellations is needed to be understood, particularly during periods of ionospheric scintillations. This will ensure an efficient handling of air navigation signals under adverse ionospheric conditions using different combinations of constellations as GNSS is expected to be used for future air navigation. In order to avoid sharp latitudinal gradients of ionization affecting comparative study of performance from different constellations, common spatial extent of scintillation observation zone from two different constellations should be limited. The present paper reports cases of relative signal fluctuations from different constellations over limited common ionospheric volume during ionospheric scintillations for the equinoctial months of 2014 and March 2016 from Calcutta and for September 2016 from Siliguri located near the anomaly crest region.

2. Data and Methodology

Multiconstellation GNSS receivers which are capable of tracking GPS, GLONASS, and GALILEO satellites at L1 (1575.42 MHz), L2 (1227.6 MHz), and L5 (1176.45 MHz) frequencies are operational at the Institute of Radio Physics and Electronics, University of Calcutta (22.58°N 88.38°E geographic; magnetic dip: 32°N), Calcutta since April 2013 and North Bengal University, Siliguri (26.72°N, 88.39°E geographic; magnetic dip 39.49°N) in Indian longitudes since October 2015. It provides SVID (Satellite Vehicle ID), elevation, azimuth, time (UTC), and carrier-to-noise ratio (CNO) at 50-Hz sampling rate (0.02 s) and amplitude scintillation index S_4 at a sampling interval of 1 min as output. The receiver logs the data in binary format which can be converted to RINEX or ASCII format in postprocessing actions.

The SVID identifies the satellites. The range of values for SVID is as follows: 1–37 PRN number of a GPS satellite; 38–61 slot number of a GLONASS satellite, with an offset of 37; and 71–106 PRN number of GALILEO satellite, with an offset of 70. The CNO is defined as the ratio of the received modulated carrier signal power to the received noise power. The S_4 index is defined as the standard deviation of the 50-Hz raw signal power normalized to the average signal power over the last minute. Analyses of amplitude scintillations measured by the S_4 index and CNO have been done for all satellites observed from Calcutta during 13:00–19:00 UT (19:00–01:00 LT) of March and September 2014 and 2016 and from Siliguri during 13:00–19:00 UT (19:00–01:00 LT) of March and September 2016. For further analyses, days and time intervals were selected when a pair of satellites from different constellations (GPS, GLONASS, and GALILEO) exhibited intense ionospheric scintillations ($S_4 > 0.6$) over a common ionospheric volume of 5° × 5°. This volume was selected so as to reduce the detrimental effects of sharp spatial gradients of ionization occurring in the equatorial region. An elevation mask angle of 15° has been chosen to eliminate the effects of multipath on the GPS and GNSS observations (Parkinson & Spilker, 1996). It is important to note that cases of intense scintillations affecting satellites from different constellations over a common ionospheric volume of 5° × 5° are few.

In this paper, the numbers of available satellites of GPS, GLONASS, and GALILEO from Calcutta for the whole month of March 2014 and from Siliguri for the whole month of March 2016 have been illustrated. It is extremely important to note that during March 2014, intense GPS scintillations with $S_4 > 0.6$ were recorded on all 31 nights from Calcutta on SV links above an elevation mask of 15°. Sky plots corresponding to 350-km subionospheric tracks of the satellites affected by amplitude scintillations during that time interval were made for both Calcutta and Siliguri to understand the changing look angles affected by different levels of amplitude scintillations every hour, namely, mild ($0.2 < S_4 \leq 0.4$), moderate ($0.4 < S_4 \leq 0.6$), and intense ($S_4 > 0.6$) during that time period. The different levels of scintillations are indicated by different colors on the subionospheric tracks.

The comparative study of robustness of GPS, GLONASS, and GALILEO satellite signals present in a common ionospheric volume during periods of ionospheric scintillations as determined from relative fluctuations of detrended CNO and S_4 indices was studied. CNO deviations have been calculated by subtracting the moving averaged values over a running time interval of 10 min from the instantaneous measurement of CNO. Detrended CNO fluctuations at L1 frequency were studied on days for time intervals when a pair of satellites from different constellations (GPS, GLONASS, and GALILEO) exhibited intense ionospheric scintillations over a common ionospheric volume of 5° × 5° for both Calcutta and Siliguri. To compare the detrended CNO fluctuations from different constellations, the differences in 99 percentile of CNO deviation values were determined for satellites sharing a common ionospheric volume for a common time period. If this difference value is less, then it can be concluded that those satellites are interoperable during intense scintillations.

The cases analyzed in the present paper have been for geomagnetic quiet conditions for the equinoctial months of 2014 and 2016 which is evident from Figures 1a and 1b where the geomagnetic activity indices (*Dst* index and *Kp* index) for the period of analyses have been provided. The *Dst* index is an index of magnetic activity derived from a network of near-equatorial geomagnetic observatories that measures the intensity of the globally symmetrical equatorial electrojet (the “ring current”). The *Dst* index values and plots are available at http://wdc.kugi.kyoto-u.ac.jp/dstdir/. The *Kp* index quantifies disturbances in the horizontal component of earth’s magnetic field with an integer in the range 0–9 with 1 being calm and 5 or more indicating a geomagnetic storm. It is derived from the maximum fluctuations of horizontal components observed on a magnetometer during a three-hour interval. The *Kp* indices are available at http://www.swpc.noaa.gov/products/planetary-k-index.

3. Results

Figures 2a and 2b show the availability of GPS, GLONASS, and GALILEO satellites from Calcutta for March 2014 and Siliguri for March 2016, respectively. During March 2014, it is found from Figure 2a that at any instant of time, at least 8 GPS, 6 GLONASS, and 1 GALILEO satellites are visible from Calcutta above an elevation of 15° during every hour over a 24-hr period from 00:00 UT. Significantly larger numbers of transionospheric satellite links were available at an instant, particularly during 12:00–13:00 UT when 12 GPS, 12 GLONASS, and 2 GALILEO satellites were tracked in comparison to 10–12 satellites normally observed under GPS-only scenario normally. Similarly, from Figure 2b, at least 7 GPS, 6 GLONASS, and 1 GALILEO satellites are visible from Siliguri above an elevation of 15° during every hour over a 24-hr period from 00:00 UT at any instant of time. This improved geometry thereby provides scope for application of spatial diversity techniques to improve navigation position solutions during ionospheric scintillations (Paul et al., 2017).

Intense GPS and GLONASS scintillations ($S_4 > 0.6$) were noted on several days mainly during local premidnight hours of March 2014. In addition, intense scintillations on GALILEO SV 81, 82, 89, and 90 were observed on 12, 25, and 26 March 2014 from Calcutta. These are perhaps some of the first reports of ionospheric scintillation on GALILEO links from India. As representative cases, the sky plots for 1 March 2014 from Calcutta and for 12 September 2016 from Siliguri are shown in Figures 3a and 3b, respectively. The satellite tracks

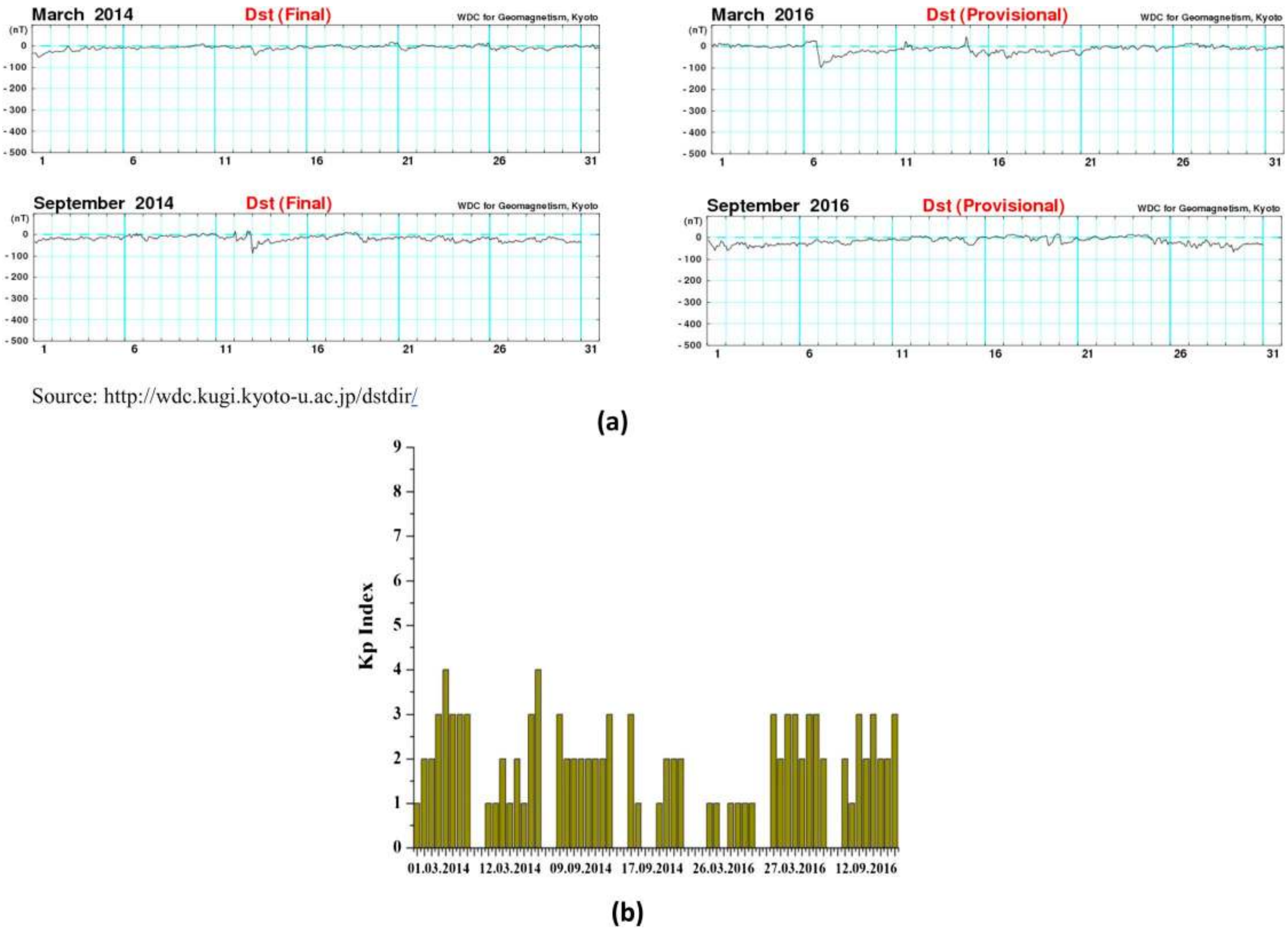

Figure 1. The geomagnetic activity indices (*Dst* index and *Kp* index) for the period of analyses.

are affected by different levels of amplitude scintillations, namely, mild ($0.2 < S_4 \leq 0.4$), moderate ($0.4 < S_4 \leq 0.6$), and intense ($S_4 > 0.6$) during that time period. The different levels of scintillations are indicated by different colors on the subionospheric tracks. In Figure 3a, it can be observed that six GPS satellite links and six GLONASS satellite links are affected by intense scintillation during premidnight hours

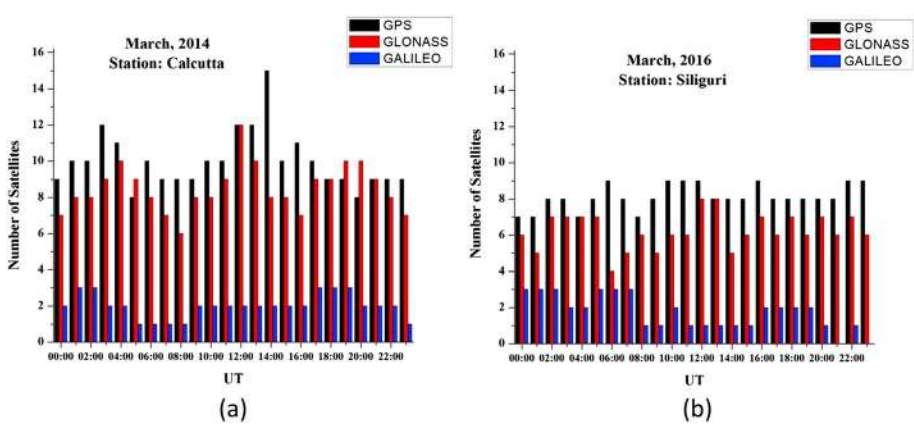

Figure 2. Availability of satellites from different constellations (a) from Calcutta for March 2014 and (b) from Siliguri for March 2016.

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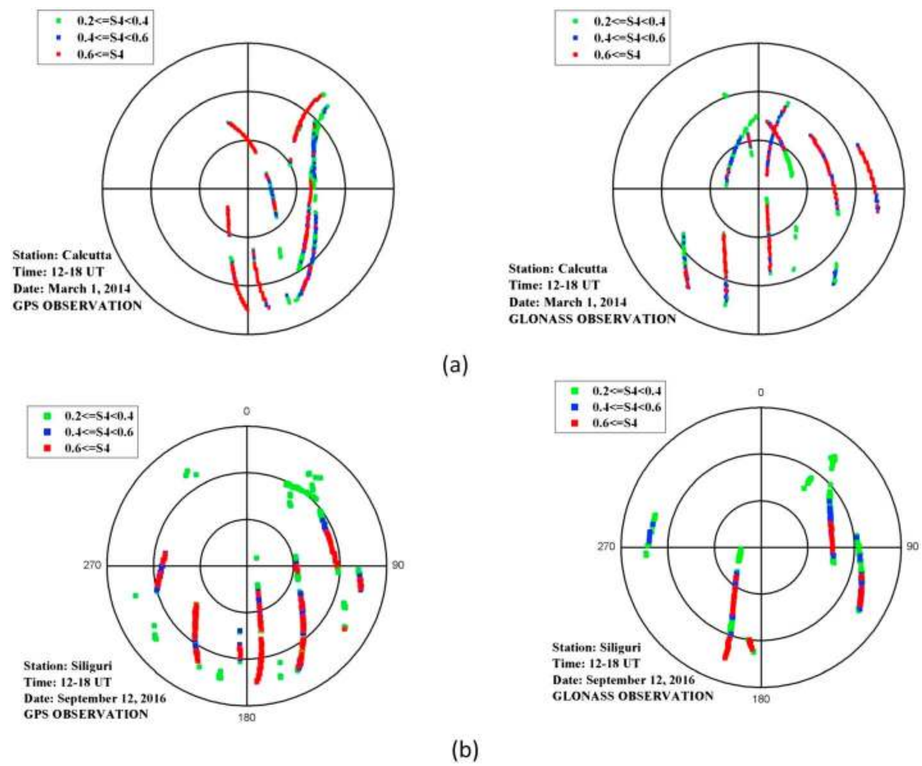

Figure 3. Sky plots of satellites affected by amplitude scintillations (a) for 1 March 2014 from Calcutta and (b) for 12 September 2016 from Siliguri.

from Calcutta. In Figure 3b, it can be observed that that intense scintillation affected seven GPS satellite links and four GLONASS satellite links from Siliguri.

Detrended CNO fluctuations at L1 frequency were studied on days when ionospheric scintillations on a pair of satellites from different constellations were observed over a common ionospheric volume of 5° × 5° and a comparative study of the robustness between those pair of satellites were done for the month of March and September 2014 and 2016 for Calcutta and March and September 2016 for Siliguri. It should be noted that no such cases were found in September 2016 from Calcutta and in March 2016 from Siliguri. It was found that these conditions were fulfilled on 1 and 12 March and 9 and 17 September 2014 and 26 and 27 March 2016 from Calcutta and on 12 September 2016 from Siliguri. The dates used for analyses of common period scintillations at a particular station from two different constellations correspond to geomagnetically quiet conditions when intense ionospheric scintillations were observed at L-band during postsunset hours. It is important to note that intense ionospheric scintillations are observed at locations around the northern crest of the EIA like Calcutta and Siliguri even on geomagnetic quiet conditions, unlike midlatitudes where such phenomena are usually associated with geomagnetic disturbed conditions. Two representative cases, one each from Calcutta (1 March 2014) and Siliguri (12 September 2016), are discussed in detail in this paper.

The tracks of SV19 (GPS) and SV53 (GLONASS) for 1 March 2014 from Calcutta and the tracks of SV10 (GPS) and SV45 (GLONASS) for 12 September 2016 from Siliguri are plotted for the common period of scintillation observation in Figures 4a and 4b, respectively. The plots clearly indicate that those satellites were sharing the defined common ionospheric volume while experiencing scintillation during the time interval 14:31–15:18 UT from Calcutta and 14:20–14:53 UT from Siliguri. The different colors indicate the different levels of scintillation index (S_4); the color green represents mild scintillation ($0.2 < S_4 \leq 0.4$), whereas the colors blue and red represent moderate ($0.4 < S_4 \leq 0.6$) and intense ($S_4 > 0.6$) scintillations, respectively.

In Figure 5a CNO fluctuations at L1 frequency with respect to time were plotted for time intervals when SV19 (GPS) and SV53 (GLONASS) exhibited intense ionospheric scintillations over a common ionospheric volume of 5° × 5°(22.5°N–27.5°N and 90°E–95°E). Then the CNO fluctuations were plotted as histogram in Figure 5b, which shows that on 1 March 2014, SV19 showed 28.6% more fluctuation in CNO amplitude for 64% of the

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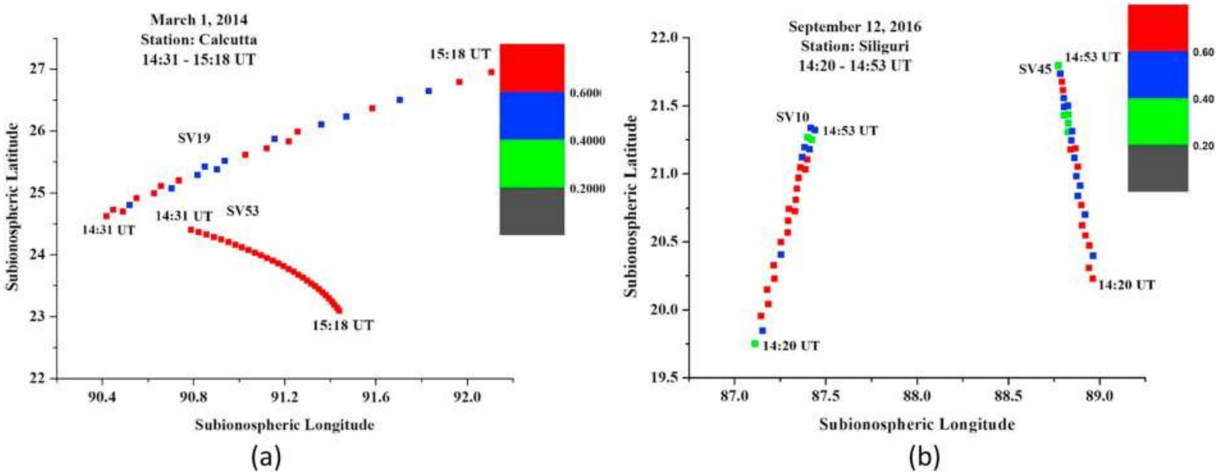

Figure 4. (a) Tracks of SV19 (GPS) and SV53 (GLONASS) and (b) tracks of SV10 (GPS) and SV45 (GLONASS) where the colors indicate different levels of scintillation index (S_4).

time compared to SV53 during 14:31–15:18 UT when the two satellites shared common ionospheric volume of 22.5°N–27.5°N and 90°E–95°E. The difference in 99 percentile values of CNO fluctuation of SV19 and SV53 is found to be only 1.43 dB Hz, and hence, those satellites could be interoperable during intense scintillation. Similarly, from Figures 6a and 6b, it is observed that on 12 September 2016 SV 10 (GPS) showed 58% more fluctuations in CNO compared to SV 45 (GLONASS) for 74.2% of common scintillation interval when sharing

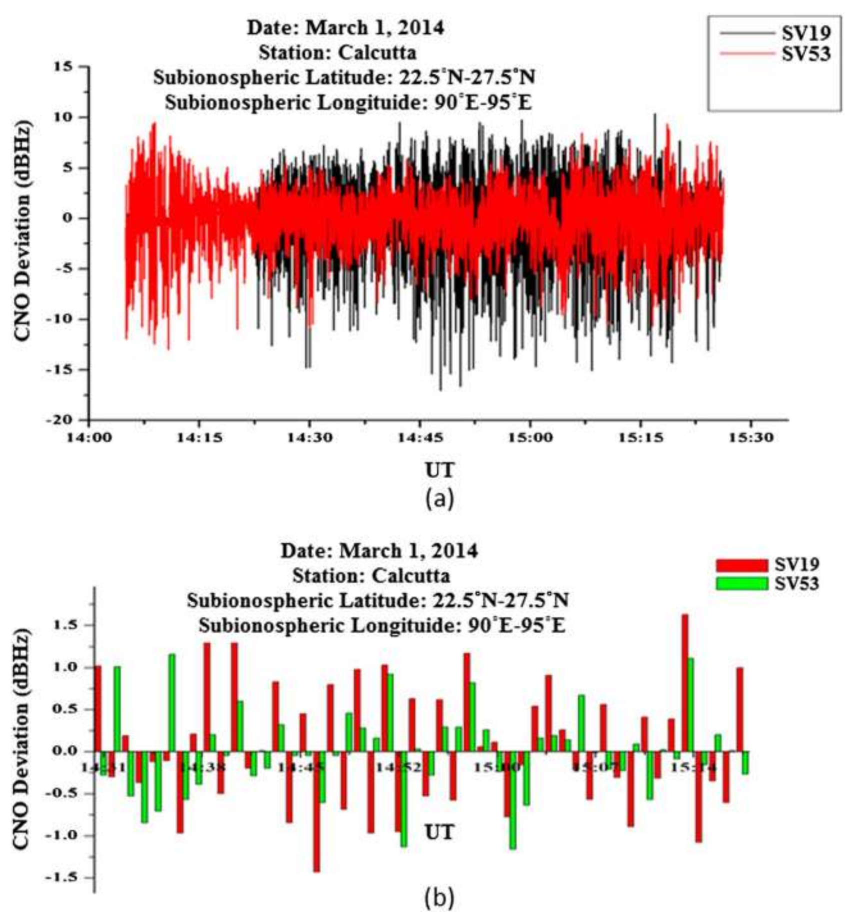

Figure 5. (a and b) Comparative study of carrier-to-noise ratio deviation of SV 19 and SV 53 observed from Calcutta on 1 March 2014.

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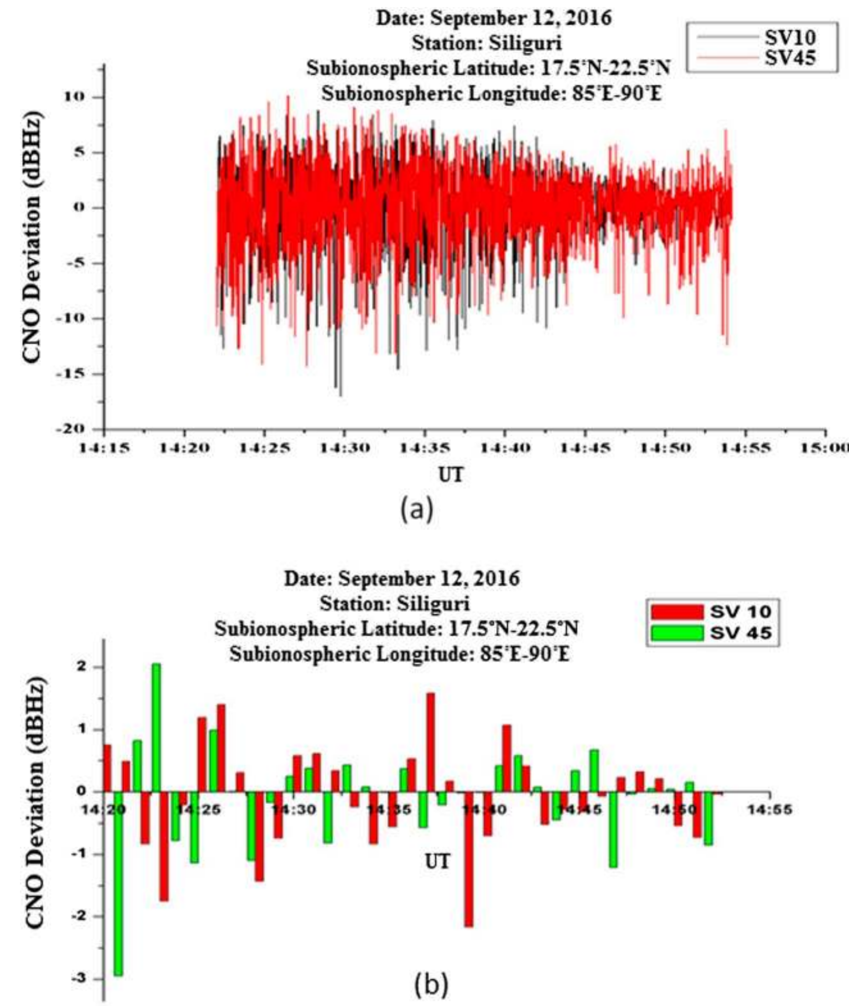

Figure 6. (a and b) Comparative study of carrier-to-noise ratio deviation of SV 10 and SV 45 observed from Siliguri on 12 September 2016.

common ionospheric volume of 17.5°N–22.5°N and 85°E–90°E for the time interval 14:20–14:53 UT. The difference in 99 percentile values of CNO fluctuations for SV 10 and SV 45 is found to be 1.64 dB Hz, which implies the interoperability of these satellites during periods of intense scintillations.

The two representative cases highlighted in this paper correspond to two different dates of collocated satellites affected by intense scintillations, one from Calcutta on 1 March 2014 and the other from Siliguri on 12 September 2016. These cases are not similar but have been highlighted to understand the interoperability of satellites from two different locations at two different times.

Two cases of scintillations on satellites from different constellations, namely, SV8, SV49 and SV60, SV82 over a common ionospheric volume were found on 12 March 2014. In the first case, amplitude of CNO fluctuations for SV 8 (GPS) was 36.6% more for 52% of the common scintillation time compared to SV49 (GLONASS) during 14:23–14:46 UT when the two satellites shared common ionospheric volume (22.5°N–27.5°N and 85°E–90°E). In another case for the same day, CNO fluctuations for SV 60 (GLONASS) were 60% more for 59% of the common scintillation time compared to SV82 (GALILEO) during 14:04–14:31 UT when the two satellites shared common ionospheric volume (17.5°N–22.5°N and 85°E–90°E). The differences in 99 percentile values of CNO fluctuation for these two cases were found to be 2.5 and 2.17 dB Hz, respectively, asserting that the satellites from different constellations are affected to nearly the same level during ionospheric scintillations.

Similar exercise was performed for September 2014. On 9 September 2014 CNO fluctuations for S24 (GPS) are 37.7% more for 55% of the common scintillation time compared to SV49 (GLONASS) during 14:06–14:26 UT

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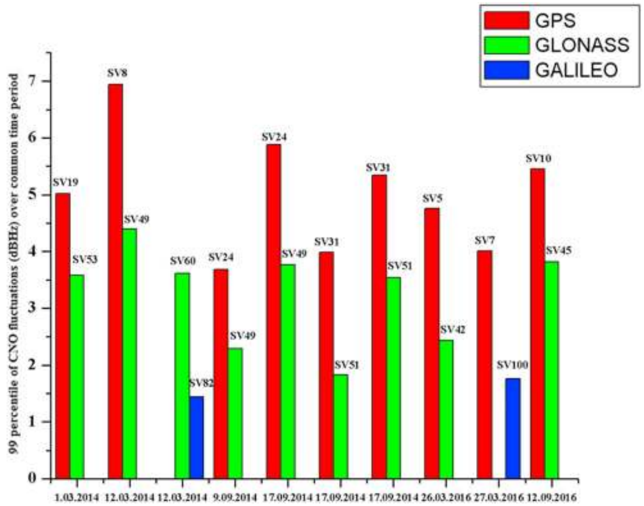

Figure 7. Comprehensive plot showing results for all the cases from Siliguri and from Calcutta.

when the two satellites shared common ionospheric volume (17.5°N–22.5°N and 90°E–95°E). For this case, the difference in 99 percentile values of CNO fluctuation is found to be 1.39 dB Hz. On 17 September 2014 three such cases were observed. In the first case, SV24 (GPS) showed 35.9% more fluctuation in CNO for 69% of common scintillation period compared to SV49 (GLONASS) during the time interval 14:17–15:02 UT when the two satellites shared common ionospheric volume (22.5°N–27.5°N and 90°E–95°E) and the difference in 99 percentile values of CNO fluctuations is 2.11 dB Hz. On this date for the second case, SV31 (GPS) showed 54.1% more fluctuation in CNO for 51% of common scintillation interval compared to SV51 (GLONASS) during 16:14–16:51 UT when the two satellites shared common ionospheric volume (17.5°N–22.5°N and 85°E–90°E) and the difference of 99 percentile values of CNO fluctuation for this case is 2.15 dB Hz. On the same day for third case, SV31 (GPS) showed 33.7% more fluctuation in CNO for 57% of the common scintillation time compared to SV51 (GLONASS) during 15:19–15:35 UT when the two satellites shared common ionospheric volume (13.5°N–18°N and 85°E–90°E). The difference of 99 percentile values of CNO fluctuation for SV31 and SV51 is found to be 1.8 dB Hz.

A similar study was done for the equinoctial period of March 2016 from Calcutta. On 26 March, SV5 (GPS) showed 48.8% more fluctuation in CNO compared to SV 42 (GLONASS) for 68% of common scintillation observation period over a common ionospheric volume of 17.5°N–22.5°N and 90°E–95°E during 16:32–17:00 UT. The difference of 99 percentile values of CNO fluctuation for SV 5 and SV 42 is found to be 2.32 dB Hz. On 27 March 2016 SV7 (GPS) showed 55.9% more fluctuation in CNO compared to SV 100 (GALILEO) for 72.4% of common scintillation interval when these two SVs were sharing common ionospheric volume of 12.5°N–17.5°N and 75°E–80°E during 13:36–14:03 UT. For this case the difference in 99 percentile values of CNO fluctuation for SV 7 and SV 100 is found to be 2.24 dB Hz.

The results from all the cases of March and September 2014 and March 2016 from Calcutta and the case of September 2016 from Siliguri are shown in Figure 7 as a comprehensive plot. In this plot, 99 percentile of CNO fluctuations (dB Hz) for two satellites from different constellations which were sharing a common ionospheric volume of 5° × 5°are compared over common scintillation interval. It is found that the 99 percentile values of CNO fluctuation for satellites from different constellations sharing a common ionospheric volume during intense scintillation is close to each other and the difference values lie in the range 1.4–2.5 dB Hz, which indicates that CNO fluctuations experienced by different constellations are close to each other.

It should be noted that the focus of the paper was not directed toward evaluating the cause behind the generation of the irregularities, rather study their impact on two satellites from different GNSS constellations sharing a common ionospheric volume and thereby estimate their relative robustness during periods of intense scintillations.

4. Discussions and Conclusions

For GNSS-based navigation, the satellite links should be available and should not experience intense ionospheric scintillations for accurate position determination by the receiver. The accuracy of position fixing by a receiver will be improved if the numbers of available satellites are high. From the standpoint of GPS receivers, it has been frequently observed from stations like Calcutta situated in the northern anomaly crest region that 6–8 satellite links are affected by intense scintillations, leaving only 3–4 usable links, which in turn, reduce the accuracy of position-fixing. If the receiver can receive signals from satellites of different constellations relatively less unaffected by intense scintillation, the position accuracy can be improved. If an effective strategy of interoperability of satellites across different constellations could be developed using GNSS receivers capable of receiving signals from GPS, GLONASS, and GALILEO simultaneously, this problem could be solved.

From the present study, it is found that the number of satellites tracked is increased when using GNSS compared to GPS-only scenario. Two satellites from two different constellations which were sharing a common ionospheric volume of 5° × 5° during intense scintillation have been compared in the present study spread over equinoctial months of 2 years from two stations. Ten cases were found over equinoxes of 2 years from two stations where two satellite signals from two different constellations experienced intense scintillations when sharing a common ionospheric volume of 5° × 5°. In eight cases out of these ten, CNO for GPS satellite signals showed more fluctuations compared to GLONASS, while in one case, CNO fluctuation for GLONASS satellite signal was more than that of GALILEO. In another case, CNO fluctuation for GPS satellite signal was more than that of GALILEO. For all the cases the differences in CNO fluctuations lie within the range of 1–2.5 dB Hz, which is evident from Figure 6. Hence, we can conclude that for the satellites from different constellations, the CNO fluctuations are very close to each other and comparable within a common ionospheric volume and therefore GPS, GLONASS, and GALILEO could be interoperable during periods of intense ionospheric scintillations. The relative robustness of signal of different constellations needs to be assessed in order to combat intense ionospheric scintillations using interoperability of satellites from different constellations to improve the performance of SBAS. This kind of comparative study of GPS, GLONASS, and GALILEO in terms of detrended CNO has not been reported from the northern crest region of equatorial ionosphere to the best of our knowledge.

Larger number of usable satellite links provides greater number of satellite combinations and hence better optimization possibilities for the receiver while determining its position (Kaplan & Hegarty, 2006). It had been understood that availability of satellite links will be increased once multiconstellation GNSS signals are being received. However, the exact number of satellites and their variability in terms of availability at different hours of a day has not been extensively studied from the geophysically sensitive Indian longitude sector post 2002 when GLONASS constellation had degenerated to a few satellites only. Availability of satellite links (which follows a predetermined orbital geometry) is more when using multiconstellations compared to GPS-only condition. Observation of ionospheric scintillations (caused by intersection of drifting ionospheric irregularities with satellite links) follows an established morphology of irregularity occurrence. Although the number of satellite links affected by scintillations may be more when using multiconstellation, the number of links unaffected may be also more. Further, the values available from Calcutta situated near the northern crest of the EIA provide some of the worst-case figures of satellite signal outages associated with intense scintillations and could serve as a benchmark for the international space weather community. The study of interoperability of satellites involving Beidou/COMPASS is intended to be done in future.

Acknowledgments

This research is sponsored in part by the Centre for Advanced Study (CAS) in Radio Physics and Electronics, University of Calcutta. One of the authors (Samiddha Goswami) acknowledges the support provided in the form of Research Fellowship by the Science and Engineering Research Board (SERB), Department of Science and Technology (DST), Government of India. The authors thank Centre for Advanced Study (CAS) and Department of Science and Technology (DST) for providing the GNSS receivers and the data. The GNSS data used in the study are available as supporting information. The *Dst* index values and plots are available at http://wdc.kugi.kyoto-u.ac.jp/dstdir/. The *Kp* indices are available at http://www.swpc.noaa.gov/products/planetary-k-index.

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