Impact of multi-constellation satellite signal reception on performance of SBAS under adverse ionospheric conditions

Ashik Paul[1,2] and Aditi Das[2]

[1]Institute of Radio Physics and Electronics
University of Calcutta
Calcutta
India
ashik_paul@rediffmail.com

[2]S. K. Mitra Center for Research in Space Environment
University of Calcutta
Calcutta
India

ABSTRACT

Application of multi-constellation satellites to address the issue of satellite signal outages during periods of equatorial ionospheric scintillations could prove to be an effective tool for maintaining the performance of SBAS without compromise in accuracy and integrity. A receiver capable of tracking GPS, GLONASS and GALILEO satellites is operational at the Institute of Radio Physics and Electronics, University of Calcutta, Calcutta, India located virtually underneath the northern crest of the Equatorial Ionization Anomaly (EIA) in the Indian longitude sector. The present paper shows increased availability of satellites from Calcutta compared to GPS-only scenario and estimates scintillation-free or mildly affected ($0.2<S_4<0.4$) satellite vehicle look angles at different hours of the post-sunset period 13:00-19:00UT (19:00-01:00LT) during March 2014. A representative case of March 1, 2014 is highlighted in the paper to indicate quantitative advantages in terms of scintillation-free satellite vehicle look angles that may be utilized for planning communication and navigation channel spatial distribution under adverse ionospheric conditions.

1. INTRODUCTION

Multiconstellation satellite signal reception capability has provided an important tool for enhancing 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. The equatorial ionosphere is characterized by sharp latitudinal gradients of ionization for a major part of the day existing till about 22:00LT. Transionospheric satellite links operating near the crests of the Equatorial Ionization Anomaly (EIA) experience unusually large range errors and range error rates through such steep ionization gradients which may be particularly hazardous for reliable operation of high dynamic platforms like an aircraft [*DasGupta et al.*, 2006]. One of the major deterrents to successful implementation of SBAS may be linked to sharp latitudinal gradients of ionization occurring during the daytime and intense Space Weather events in the post sunset hours, affecting transionospheric satellite links particularly in the equatorial region [*Carrano and Groves*, 2010; *Humphreys et al.*, 2010a; *Roy et al.*, 2013; *Das et al.*, 2014]. It has been observed through studies conducted earlier 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 TEC measured in 2004 along a chain of stations located more-or-less along 77°E meridian under the Indian SBAS program GAGAN that the median grid scale for TEC variation less than 3TECU (for an acceptable range error of 50cm) varied from (0.64°-0.87°)×(0.23°-0.49°) at elevation angles greater than 70° [*Paul et al.*, 2011]. It should be borne in mind that these figures were arrived at during a moderate sunspot number period. Thus more stringent requirements may be imposed during the upcoming solar maximum period during 2014-2015. With the increased number of satellites under GNSS resulting in large number of ionospheric pierce points, availability of sufficient satellite links at varying elevation angles may result in improved accuracy and hence less stringent requirement for grid size even under the highly dynamic equatorial ionosphere.

2. OBSERVATIONS

A multiconstellation GNSS receiver capable of tracking GPS, GLONASS, GALILEO and SBAS at L1 (1575.42MHz), L2 (1227.6MHz) and L5 (1176.45MHz) frequencies is operational at the Institute of Radio Physics and Electronics (IRPE), University of Calcutta (22.58°N 88.38°E geographic; magnetic dip: 32°N), Calcutta, India since April 2013. It provides at its output elevation, azimuth, time (UTC), carrier-to-noise ratios (CNO) and amplitude scintillation index S_4 at a sampling interval of 1minute. Analyses of CNO and S_4 for all satellite vehicles observed from Calcutta have been done for March 2014. The paper presents a representative case for March 1, 2014 to stress the importance of application of spatial diversity technique to plan communication and navigation signal distribution in space under periods of ionospheric scintillations which may result in severe outages resulting in compromise of performance of SBAS.

3. RESULTS

Availability of multi-constellation satellites was studied from Calcutta during different periods since April 2013. Figure 1 shows the availability of GPS, GLONASS and GALILEO satellites from IRPE during October 9-25, 2013. Significantly larger number of transionospheric satellite links, 18, were available instantaneously in comparison to 12 normally observed under GPS-only scenario thereby providing scope for application of spatial diversity techniques to improve navigation position solutions during ionospheric scintillations.

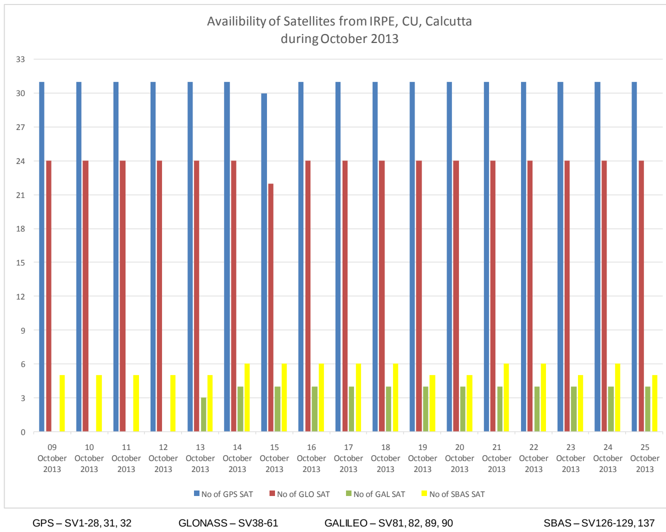


Figure 1

During March 2014, it is extremely important to note that 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°. On March 1, 2014, intense amplitude scintillations (S_4>0.6) and associated fluctuations in carrier-to-noise ratios (CNO) were noted on 6 GPS and 8 GLONASS links above an elevation mask of 15° during 13:00-19:00UT. Sky plots corresponding to 350-km subionospheric tracks of the satellites affected by amplitude scintillations during that time interval were plotted to understand the changing look angles affected by different levels of amplitude scintillations every hour, namely, mild ($0.2<S_4<0.4$), moderate ($0.4<S_4<0.6$) and intense (S_4>0.6) during that time period. The different levels of scintillations are indicated by different colours on the subionospheric tracks.

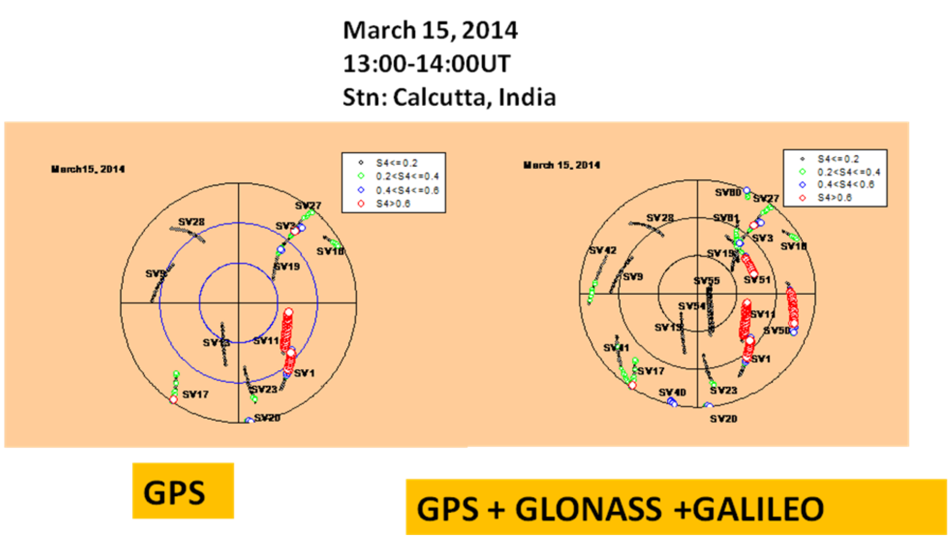
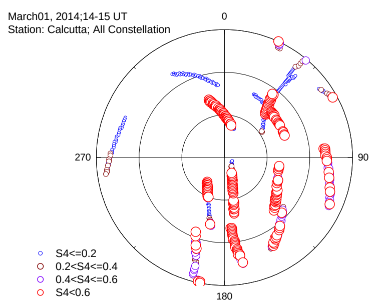
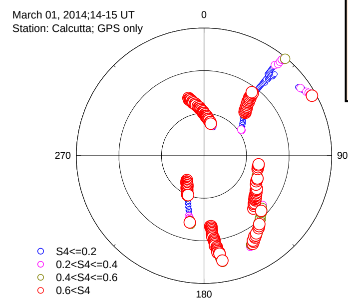


Figure 2: (a) (b)

Figure 2 shows the sky plots of SV links affected by different levels of scintillations during 13:00-14:00UT (19:00-20:00LT) of March 15, 2014 for (a) GPS and (b) combining GPS, GLONASS and GALILEO. The different colors marked on the 350-km subionospheric tracks of the satellites indicate different scintillation intensities. It could be understood that the number of SV links either unaffected or mildly affected ($0.2<S_4<0.4$) are much more when combining GPS, GLONASS and GALILEO observations as shown in Figure 2(b).

In order to quantify the relative advantage of using multi-constellations compared to GPS-only situation particularly under ionospheric scintillation condition, proportion of satellite vehicle (SV) look angles unaffected by intense scintillations every hour during 13:00-19:00UT (19:00-01:00) were estimated to assess the improvement, if any, and applicability of the principle of spatial diversity for ionospheric scintillation mitigation. Figures 3(a) and 3(b) represent sky plots of GNSS (GPS, GLONASS and GALILEO combined) and GPS-only SV links respectively affected by different levels of scintillations during 14:00-15:00UT (20:00-21:00LT) on March 1, 2014 from Calcutta.



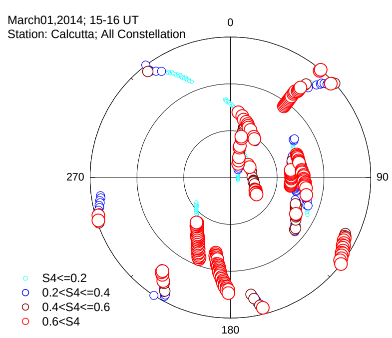


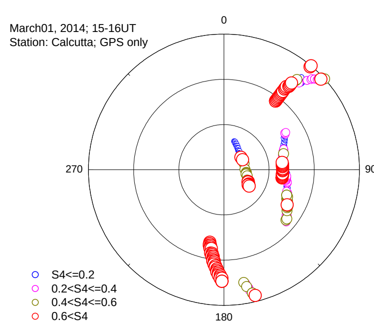
March 1, 2014 Station: Calcutta

14:00-15:00UT (20:00-21:00LT)

Figure 3: (a) GNSS (b) GPS-only

The 99 percentile values of elevation range of SVs unaffected by scintillations during 14:00-15:00UT were found to be 30.45° using multi-constellaton compared to 23° using GPS only. The 99 percentile values of azimuth range of SVs unaffected by scintillations during 14:00-15:00UT were found to be 10° using multiconstellaton compared to 7° using GPS only. Thus increased availability of SV look angles unaffected or mildly affected by scintillations when using GNSS compared to GPS-only case will definitely help in planning alternative strategies for diversion of communication and navigation traffic during periods of signal outages.





March 1, 2014 Station: Calcutta

15:00-16:00UT (21:00-22:00LT)

Figure 4: (a) GNSS (b) GPS-only

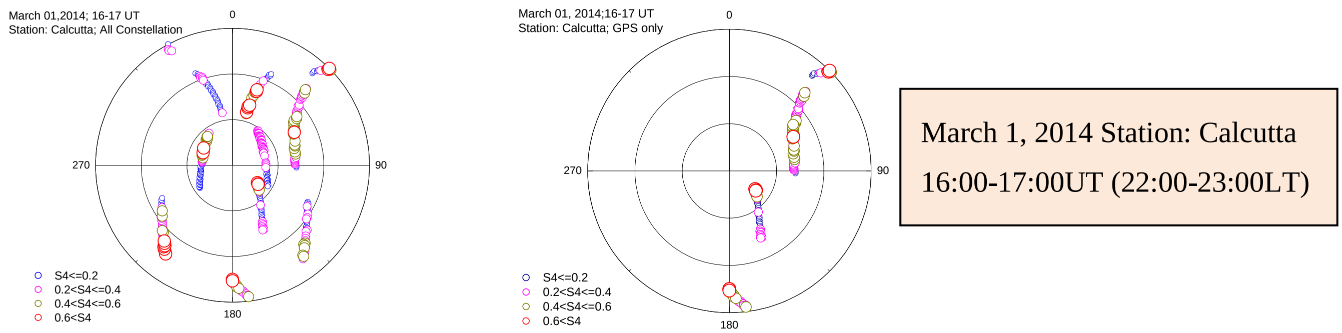


Figure 5: (a) GNSS (b) GPS-only

The 99 percentile values of elevation range of SVs unaffected by scintillations during 15:00-16:00UT and 16:00-17:00UT were found to be 29.38° and 32.62° using multi-constellations compared to 14.3° and 28.62° when using only GPS as depicted in Figures 4 and 5 respectively. The corresponding range of unaffected azimuth values at 99 percentile level showed improved values of 26° and 22.38° using GNSS in contrast to 24.68° and 10.38° when using GPS.

This process of estimating scintillation-free SV look angles when using multi-constellation was performed every evening during March 2014 thereby providing system designers with figures to validate the suggestion of the concept of spatial diversity for scintillation mitigation. Variabilities were noted in the scintillation-free look angle ranges at different hours which may be attributed to the temporal behavior of equatorial ionospheric scintillations.

4. CONCLUSIONS

In the next decade, the GNSS environment is going to undergo a major transformation. First, two more GNSS core constellations are expected to be launched/augmented, GALILEO and COMPASS over the existing GPS and GLONASS. When these constellations are in their final operational capability, there will be three times more ranging sources. Secondly, GPS and the new core constellations will broadcast signals in two frequencies L1 and L5 (E5a or b for GALILEO). These signals will be available for civil aviation, allowing users to cancel the pseudorange errors due to the ionosphere. The relative robustness of these different frequencies need to be assessed under intense scintillation conditions. Many studies suggest that it could be possible to achieve global coverage of vertical guidance using multi-constellation under certain assumptions on the constellation performance.

The concept of vertical guidance needs to be developed for the Indian subcontinent to achieve worldwide precision approach (LPV 200) without an extensive ground infrastructure (unlike SBAS and GBAS). Potential of this technique to provide vertical guidance needs evaluation under several constellations, multiple frequencies in the highly dynamic Equatorial Ionization Anomaly (EIA) crest region where the station Calcutta is located. In this process, when it is assumed that at most one satellite suffers outage, it is assumed that there exists a subset of N-1 satellites within the nominal expectations (N being the total number of satellites in view). The results of the studies conducted earlier are conditional on specific constellation assumptions, namely User Range Errors (URE) below one meter and prior probabilities of satellite outages, the latter may be due to ionospheric scintillations. These assumptions may be difficult to satisfy at locations around the EIA crest.

ACKNOWLEDGEMENTS

This research has been sponsored in part by the University Grants Commission (UGC), Govt. of India through the Center of Advanced Study (CAS) program at the Institute of Radio Physics and Electronics, University of Calcutta, Calcutta, India.

REFERENCES

Carrano, C. S., and Groves, K. M. (2010). Temporal decorrelation of GPS satellite signals due to multiple scattering from ionospheric irregularities, *Proc. of the 2010 Institute of Navigation ION GNSS Meeting*, pp. 361–374, Institute of Navigation, Portland, Oreg.

Das, A., Paul, K.S., Halder, S., Basu, K. and Paul, A. (2014). Characteristics of equatorial ionization anomaly (EIA) in relation to transionospheric satellite links around the northern crest in the Indian longitude sector, *Ann. Geophys.*, 32, 91-97, doi:10.5194/angeo-32-91-2014.

DasGupta, A., Paul, A., Ray, S., Das, A. and Ananthakrishnan, S. (2006). Equatorial bubbles as observed with GPS measurements over Pune, India, *Radio Sci.*, *41*, RS5S28, doi:10.1029/2005RS003359..

Humphreys, T. E., Psiaki, M. L., Ledvina, B. M., Cerruti, A. P. and P. M. Kintner Jr. (2010a). Data-driven testbed for evaluating GPS carrier tracking loops in ionospheric scintillation, *IEEE Trans. Aerosp. Electron. Syst.*, 46(4), 1609–1623.

Paul A., Das, A., Chakraborty, S.K. and DasGupta, A. (2005). Estimation of satellite-based augmentation system grid size at low latitudes in the Indian zone, *NAVIGATION*, *52*, 15-22.

Paul, A., Das, A. and DasGupta, A. (2011). Characteristics of SBAS grid sizes around the northern crest of the equatorial ionization anomaly, *J. Atmos. Sol. Terr. Phys.*, 73, 1715–1722.

Roy, B., DasGupta, A. and Paul, A. (2013). Impact of space weather events on satellite-based Navigation, *Space Weather*, 11, 680–686, doi:10.1002/2013SW001001.