Scintillation Effects related to Propagation Geometry as applicable to Indian SBAS

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Abstract

The propagation geometry involving the satellite-to-receiver ray path and the magnetic field line plays an important role in determining the effects of equatorial ionospheric irregularities. An extensive study has been conducted involving eighteen GAGAN Reference Stations extending from the magnetic equator through the northern crest of the EIA and beyond in the Indian longitude sector. Propagation angle maps have been generated using IGRF models for each station. GPS scintillation observations show effects of links viewing irregularities 'end-on' resulting in intense scintillations ($S_4 \geq 0.6$) at regions of maximum propagation angle even with reduced irregularity intensity.

1. Introduction

It is well known that the propagation of Global Navigation Satellite System (GNSS) signals is severely affected by the ionosphere. Particularly, ionospheric amplitude scintillations cause signal fading and when the depth of fading is greater than the receiver fade margin, message errors in satellite communication are introduced. Phase scintillation introduces cycle slips and may cause loss of lock in phase locked loops in GPS receivers. This paper presents a study of the effect of geometry of GPS signal ray-path propagating through the ionosphere, with respect to the geomagnetic field line, on low latitude amplitude scintillations observed from stations in the Indian longitude sector.

It has been established from statistical studies of geostationary L-band ionospheric amplitude scintillation observations from Kolkata (22.58°N, 88.38°E geographic, 17.23°N magnetic) [1, 2] that equatorial scintillations is essentially an equinoctial phenomena with high occurrence frequency and intensity around the sunspot number maximum years. During the equinoxes of solar maxima, scintillations occur practically daily. Under extreme conditions of scintillations, position-fixing by GPS may become impossible. [3] showed that during periods of intense scintillations observed at Kolkata, even in the sunspot number minimum period 1994-1995, the accuracy of position-fixing was degraded. In the high sunspot number years 1999–2002, it has frequently been observed that eight GPS/GLONASS satellite links may simultaneously show scintillations in excess of 10 dB. The largest position deviation observed during this period of intense scintillations, was of the order of 11m in latitude and 8m in longitude [4].

For a station like Kolkata situated near the northern crest of the Equatorial Ionization Anomaly (EIA), it has been observed that there are two regions of enhanced scintillations: i) one around the crest of the EIA due to a high ambient ionization [5], and ii) the other in the direction looking towards the magnetic equator [4]. During high solar activity period (1999-2002), the SNRs of many GPS and GLONASS links, particularly in the southern sky and near overhead, have been found to scintillate frequently in between the local sunset and midnight hours. Scintillations of satellite signals near overhead are caused by irregularities in electron density distribution in an environment of high ambient ionization occurring near the crest of the equatorial anomaly. For the links at lower elevation angles in the southern sky, scintillations occur when the field aligned plasma bubbles are viewed 'end-on' by the satellite [4]. Some case studies on the effects of equatorial ionospheric irregularities causing intense amplitude scintillations observed at low elevation angles looking south from a station like Kolkata during the abnormally low solar cycle 24 during the period 2008-2010 are available in literature [6].

The Indian SBAS, GPS and Geo Augmented Navigation (GAGAN) is being set up by the Indian Space Research Organization (ISRO) in collaboration with the Airports Authority of India (AAI). Under the GAGAN program, eighteen stations distributed all over the Indian subcontinent are located covering a geographic latitude range

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from 08.47°-31.09°N and longitude range from 72.18°-92.72°E. The corresponding magnetic latitude range extends from 03.66°-27.65°N. The morphology of equatorial scintillations depends extensively on magnetic latitude of a station as the plasma bubbles responsible for scintillations are field-aligned. The station Trivandrum and Port Blair are situated near the magnetic equator (0^o-5^oN magnetic latitude) at the trough of the EIA, Bangalore, Agatti just to the north of the trough (5^o-10^oN magnetic latitude). Hyderabad, Mumbai and Visakhapatnam between the magnetic equator and the northern crest of EIA (10^o-15^oN magnetic latitude), Bhopal, Ahmedabad, Kolkata, Aizwal and Raipur near the northern crest of EIA (15^o-20^oN magnetic latitude), Jodhpur, Lucknow, Bagdogra, Guwahati just beyond the northern crest of EIA (20^o-25^oN magnetic latitude). Delhi and Shimla are well beyond the northern crest of EIA ($\gtrsim 25^o$N magnetic latitude).

The effects of the propagation geometry involving the interplay between the transionospheric satellite link and the geomagnetic field line are usually quantified in terms of the propagation angle. The propagation angle at a subionospheric point for a particular station at the mean ionospheric height is the angle made by the satellite ray path, directed from the station to the satellite, with the geomagnetic field line (directed north) at that point. This paper presents maps of propagation angle calculated using International Geomagnetic Reference Field (IGRF) models and experimental validation of the theoretically computed zones of maximum propagation angle with GPS scintillation data from a number of stations over the Indian longitude sector during the moderate sunspot number year 2004.

2. Data

Data from the eighteen GAGAN reference stations sampled at 1Hz were available in a processed form. The S_4 indices corresponding to patches of amplitude scintillations observed on GPS links from different GAGAN stations during August through October 2004 were scaled at 1 minute interval for the time interval 13-21UT. Since data availability for each hour for the station Port Blair falls below 20% of the total number of 92 days in the chosen season, the station Port Blair has not been included in the present study.

The IGRF model is upgraded every 5 years by the International Association of Geomagnetism and Aeronomy (IAGA) and is available at http://www.ngdc.noaa.gov/IAGA/vmod/igrf.html.The propagation angles have been calculated using IGRF-9 (2000) coeffecients for the period August through October 2004 (mean smoothed sunspot number: 39). To avoid multipath effects, the propagation angle maps are for zone of reception above 15^o elevation angle for each station.

3. Results

Figure 1 shows the locations of GPS receivers on a map of India under the GAGAN program. The locations of the magnetic equator and the northern crest of the EIA have been shown.

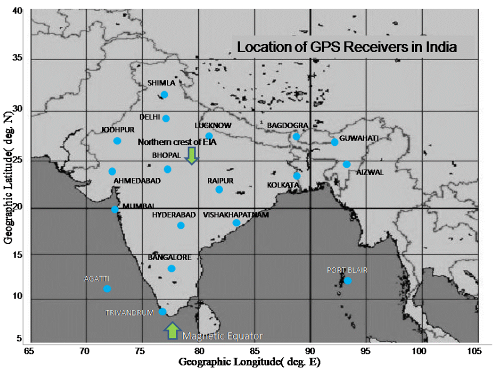
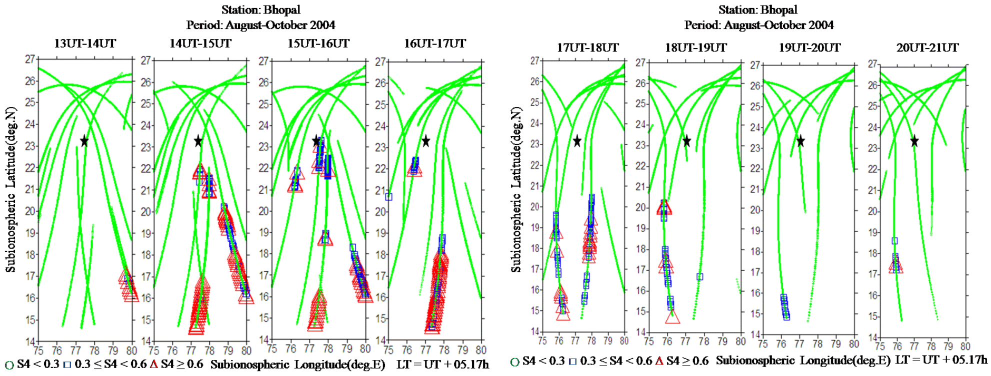


Figure 1: GAGAN Reference Stations

Figures 2(a) and (b) show plots of amplitude scintillation occurrences on 350 km subionospheric tracks of different GPS satellites observed from Bhopal (23.28°N, 77.34°E geographic; 19.20°N magnetic) during 1300-2100 UT of the period August through October 2004. Different sections of the tracks have been colored differently to indicate varying levels of S_4 indices computed at 1-minute interval over each 1 hour period for the entire 3 months. The portions of the track with green circles indicate S_4<0.3, i.e. no scintillations, the blue squares $0.3 \leq S_4 < 0.6$, moderate scintillations and the red triangles $S_4 \geq 0.6$, intense scintillations. The 350 km subionospheric longitude swath for the tracks has been restricted to 75°-80°E in order to reduce the local time effects as far as possible. The local time at the center of the 5^o longitude swath is LT=UT+05.17h. The location of the station is indicated with a star in each plot. It is important to note that Bhopal is located near the crest of the equatorial anomaly and intense scintillations were observed only on 5 out of 75 nights during August-October 2004. During early evening hours 1400-1700 UT, intense scintillations occurred in patches extending from subionospheric latitude 14^o-22^{o}N subionospheric longitude 77^o-78^{o}E during 1400-1500 UT; from 14^o to the station overhead at 23^{o}N, over the entire longitude swath of 75^o-80^{o}E during 1500-1600 UT; and again from 14^o-22^{o}N in 76^o-78^{o}E during 1600-1700 UT [Figure 2(a)]. The equatorial irregularity belt causing intense scintillations proceeded to the north towards the anomaly crest location in the early evening hours till 1600 UT and then receded to the south. In the late evening hours till midnight (1700-1900 UT) [Figure 2(b)], the irregularity belt moved more towards the south with near absence of scintillations post-midnight..



(a) (b)

Figure 2: GPS satellite tracks observed from Bhopal during August to October 2004 for (a) premidnight (13-17UT) and (b) postmidnight (17-21UT)

The theoretically computed propagation angle maps for Bhopal in Figures 3(a) and (c) using IGRF-9 Model above 15^o zone of reception with the station centrally show two zones of maximum propagation angle in the range 175^o-180^o, with a maximum value of 176.21^o corresponding to a subionospheric latitude 14.84^o-16.98^{o}N, 76.06^o-76.52^{o}E longitude geographic [Figure 3(a)], 10.42^o-12.66^{o}N magnetic [Figure 3(c)], and the other around 14.81^o-16.55^{o}N latitude, 77.82^o-78.43^{o}E longitude geographic [Figure 3(a)], 10.08^o-11.94^{o}N magnetic [Figure 3(c)], located in between the trough and the northern crest of the EIA. Figure 3(b) showing GPS tracks observed from Bhopal for the hour 1700-1800UT on October 28, 2004 showing intense scintillations passed through 15^o-16^{o}N subionospheric latitude near 76^{o}E longitude. The track passed through the first region of maximum propagation angle as observed from Figure 3(a) with a magnetic latitude of 10^o-13^{o}N [Figure 3(c)]. GPS signals measured at Bhopal, situated near the northern anomaly crest experienced enhanced scintillations both from relatively high ambient ionization near overhead during 1400-1600UT (1900-2100LT) [Figure 3(a)] and when viewing irregularities 'end-on' particularly during late evening hours 1700-1900UT (2200-0000LT) when the satellite ray-path traversed a maximum propagation angle at a region located in between the trough and the northern crest.

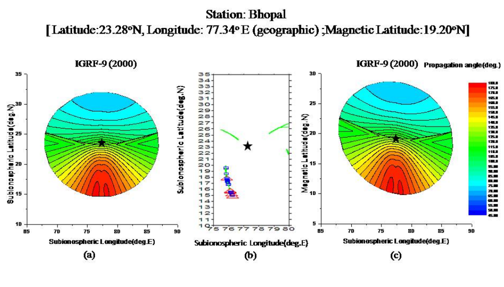


Figure 3: (a) Propagation angle map in terms of Subionospheric Latitude and Longitude for Bhopal. (b) Scintillation observed from Bhopal during 1700-1800UT on October 28, 2004. (c) Propagation angle map in terms of Magnetic Latitude and Subionospheric Longitude for Bhopal.

Propagation angle maps for the other GAGAN stations have been generated and regions of enhanced scintillation during midnight and post-midnight hours of August through October 2004 have been identified in the same way as illustrated for Bhopal.

4. Conclusion

From scintillation data analysis of the seventeen GAGAN reference stations in the Indian longitude sector, it has been observed that for stations with magnetic latitude within 25^{o}N, enhanced scintillations due to field-aligned propagation are recorded in the midnight and post midnight hours when the irregularities causing scintillations at L-band are in their decaying phase. The portion of the zone of reception for each station where enhanced scintillation activity due to field aligned propagation during these hours were observed occur in the region of maximum propagation angle corresponding to the station as long as the region lies within the equatorial irregularity belt (±20^{o} magnetic latitude).

However we observe for stations like Bangalore and Agatti that the zone of the maximum propagation angle is about the magnetic equator and since the irregularities are field-aligned and the field has minimum curvature at the magnetic equator, the ray path thus traverses a shorter path length through the irregularities in this zone and the irregularities could not be viewed ‘end-on’. Thus, no enhanced scintillation activity due to field-aligned propagation was observed from these stations.

For a station with magnetic latitude greater than 25^{o}N, as in the case of Shimla enhanced scintillation due to field-aligned propagation has been observed not in the region of maximum propagation angle but in a region of high propagation angle within the zone of reception of the station which overlapped with the equatorial irregularity belt.

Transionospheric satellite links passing through the region of maximum propagation angle are experiencing intense scintillations as the irregularities responsible are aligned along the geomagnetic field lines and hence the satellite ray path views the irregularities ‘end-on’ and pass through a greater length of the field tube. Maps of propagation angles for different stations under GAGAN will inform the system designers about the probable zones of outages of transionospheric satellite signals within the GAGAN service area. Experimental validation of the theoretically computed regions of maximum propagation angle with GPS scintillation data will help to quantify the intensity of such effects at different stations under the GAGAN program.

5. References

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