GPS Scintillation effects as observed from a location beyond the anomaly crest in the Indian longitude sector

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ABSTRACT

Extensive measurements of GPS amplitude scintillations have been performed all over India for the past decade especially under the GAGAN program from stations near the magnetic equator, in between the equator and the anomaly crest, and near the anomaly crest. Scintillation observations from a station beyond the anomaly crest is rare. A dual frequency GPS receiver is being operated by the University of Calcutta at Palampur (32.11°N, 76.53°E geographic; 30.25°N magnetic latitude) since April 2014. It has been observed that intense scintillations are mainly controlled by the geometry of propagation when observed from locations beyond the anomaly crest in the Indian longitude sector.

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 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 Calcutta (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] show that during periods of intense scintillations observed at Calcutta, 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 Calcutta 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 Calcutta 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) have been 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 recording GPS scintillations covering a geographic latitude range 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, Calcutta, 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 (>25^oN magnetic latitude). The GAGAN Reference Stations provide an excellent platform for studying GPS scintillations from different locations in the equatorial anomaly and beyond. Since April 2014, University of Calcutta is also operating a dual frequency GPS receiver at Sri Sai University, Palampur (30.11^oN, 76.53^oE geographic, 30.25^oN magnetic).

This paper presents cases of scintillations observed from Palampur, Shimla and Delhi, located well beyond the crest of the equatorial anomaly during moderate and high sunspot number years.

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. The receiver located at Palampur also gives *S*4 at 1 minute interval as output. Data recorded during April 2014 for 13-21 UT have been used in the present paper.

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. Maps of propagation angle are generated using International Geomagnetic Reference Field (IGRF) models. 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) and IGRF-10 (2010) for April 2014 (mean smoothed sunspot number: 82).

3. RESULTS AND DISCUSSIONS

Figure 1 shows the occurrence of scintillations on April 02, 2014 during 18-19UT (23.1-00.1LT) observed from Palampur. The tracks of GPS satellites during this hour indexed according to S4 have been plotted in Figure 1. The red portion of the track experienced intense scintillations (S4>0.6). The position of the station is marked with a star. The other hours for the night of April 02, 2014, have not been plotted as no scintillations were observed during those hours.

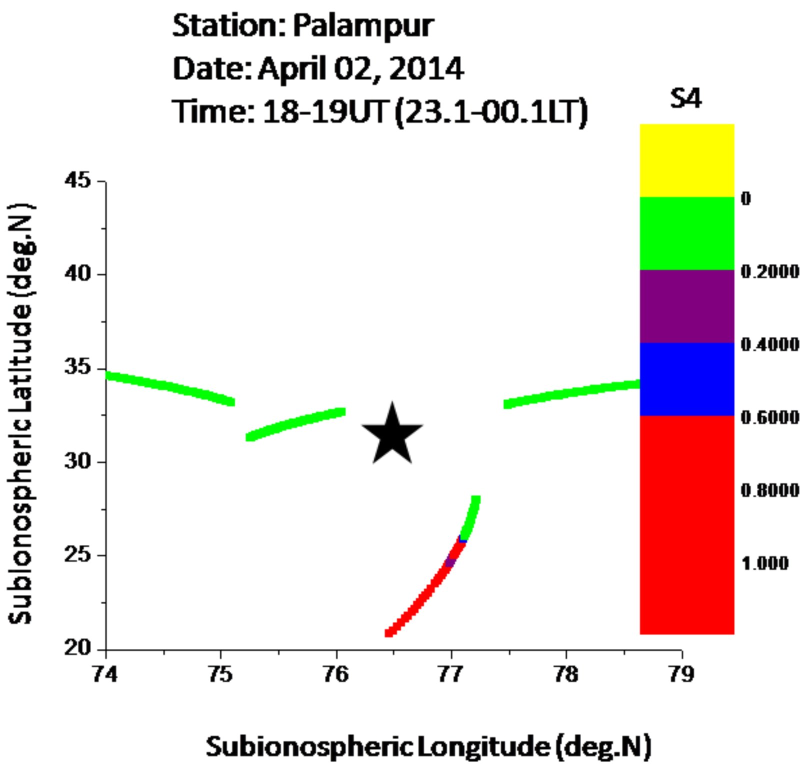


Figure 1. Occurrence of scintillations on April 02, 2014 during 18-19UT (23.1-00.1LT) observed from Palampur.

Since Palampur is located outside the equatorial irregularity belt, it is unlikely to observe intense scintillations from Palampur, that too in the midnight hours, when the irregularities responsible for L-band scintillations have decayed. This prompted an examination of the propagation geometry involved. Figure 2 shows the propagation angle map for Palampur with IGRF-10. To avoid multipath effects, the propagation angle map is for zone of reception above 20^o elevation angle.

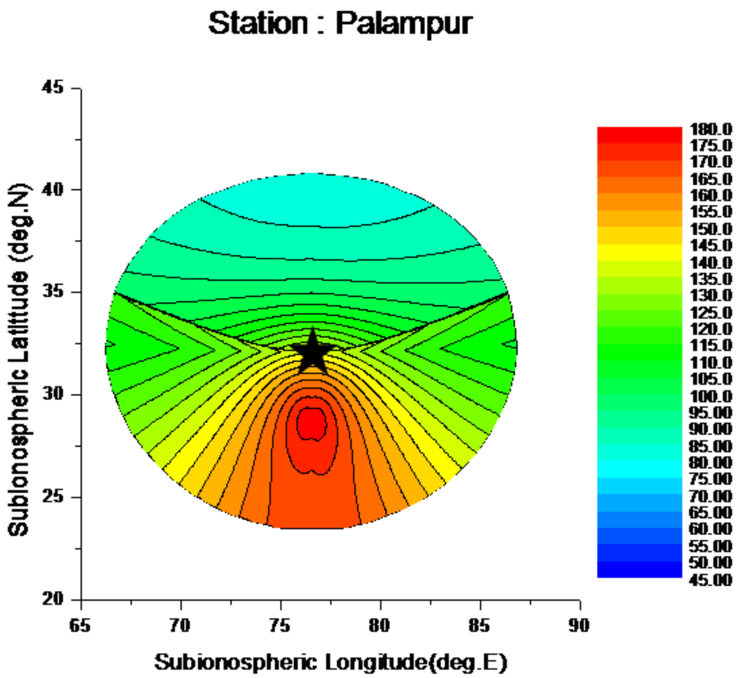
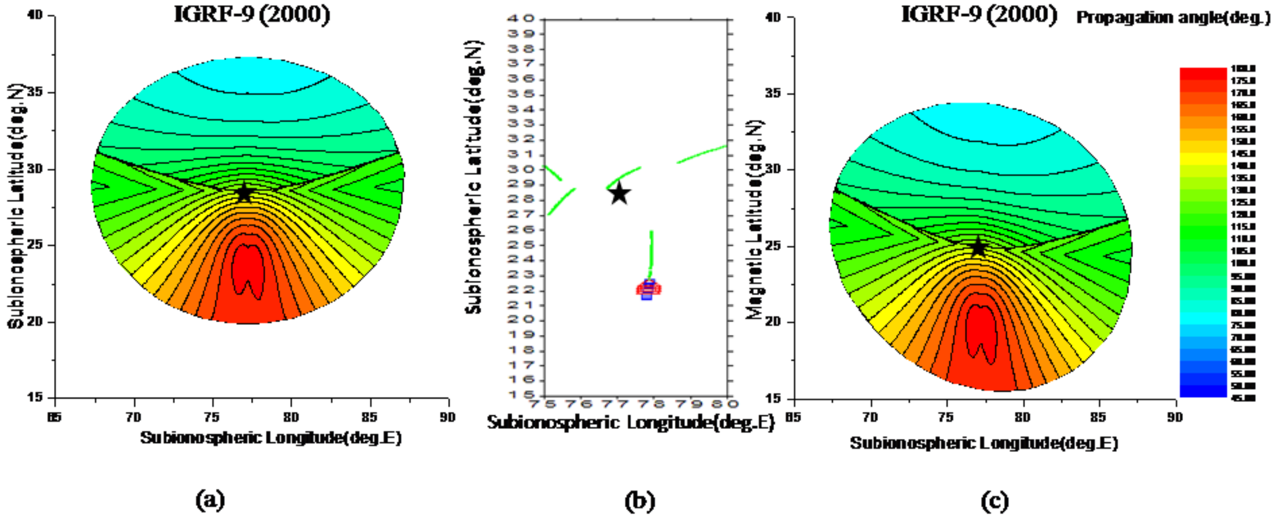


Figure 2. Propagation angle map for Palampur with IGRF-2010 coeffecients

The maximum propagation angle observed from Palampur is 179.77^{o}. It is observed that the scintillation patch observed on the night of April 02, 2014, shown in Figure 1, coincided with the region of maximum propagation angle indicated by the red eye in the contour. This implies that the GPS satellite link passing through this region will view the equatorial plasma-bubble 'end-on' that is traverse a longer path length through the field tube. Thus even with reduced irregularity intensity, the satellite link with maximum propagation angle will experience enhanced scintillation activity because traversing a longer path length implies greater phase deviation. During the other hours, no satellite links were present in the region of maximum propagation angle.

Similar cases of propagation geometry induced scintillations have been observed from Delhi and Shimla. Figure 3 shows scintillation occurrence during 17-18UT (22.1-23.1LT) on September 11, 2004 observed from Delhi.

Station: Delhi
[Latitude:28.58°N, Longitude: 77.21° E (geographic) ;Magnetic Latitude:24.93°N]



Maximum Propagation Angle : 179.88° ○ S4 < 0.3 □ 0.3 ≤ S4 < 0.6 Δ S4 ≥ 0.6 LT = UT + 05.17h

Zone: 21.66° to 24.98°N and 76.46°-78.17°E (geographic) ; 17.46° to 21.11°N (magnetic)

a)Propagation angle map in terms of Subionospheric Latitude and Longitude for Delhi.
b)Scintillation observed from Delhi during 17:00-18:00UT on September 11, 2004.
c)Propagation angle map in terms of Magnetic Latitude and Subionospheric Longitude for Delhi.

Figure 3. Occurrence of scintillations with S4>0.6 indicated with red triangle in (b) coincide with the red eyes of the contours in (a) and (c).

4. CONCLUSIONS

The intense scintillation activity observed from stations located beyond the crest of the equatorial anomaly, arise mainly out of propagation geometry. Even with weak irregularities present in the equatorial region, GPS satellite links traversing through the equatorial plasma bubbles in a field-aligned path can cause intense scintillations at locations beyond the anomaly crest where scintillation is least expected.

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