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

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Introduction

• It is well-established that intense low-latitude scintillations, particularly that observed from locations near the crests of the Equatorial Ionization Anomaly (EIA) have largely impaired the performance of GNSS.

• In this paper we present cases of intense scintillations observed from stations located poleward of the northern crest of the anomaly in the Indian longitude sector and examine the propagation conditions responsible.
Location of GPS Receivers in India

Northern crest of EIA

Geographic Longitude (deg. E)

Geographic Latitude (deg. N)
<table>
<thead>
<tr>
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<tr>
<td>Trivandrum</td>
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<td>12.44</td>
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<td>Lucknow</td>
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Elevation-Azimuth plots of GPS satellite tracks observed from Calcutta by GG24 during 1330-1730UT (1930-2330LT) on February 12, 2001.
Elevation-Azimuth plots of GPS satellite tracks observed from Calcutta by GG24 during 1730-2130UT(2330-2730LT) on February 12, 2001.
Propagation Geometry

a)

b) (Not to scale)
Station: Calcutta

[Latitude: 22.58°N, Longitude: 88.38°E (geographic); Magnetic Latitude: 17.23°N]

(a) Propagation angle map in terms of Subionospheric Latitude and Longitude for Calcutta

(b) Scintillation observed from Calcutta during 17:00-18:00 UT on September 9, 2004.

(c) Propagation angle map in terms of Magnetic Latitude and Subionospheric Longitude for Calcutta

QL S4 < 0.3 □ 0.3 ≤ S4 < 0.6 △ S4 ≥ 0.6

LT = UT + 05.83h
(a) Maximum propagation angle for the station vs. station Magnetic Latitude

\[ y = 1E-05x^5 - 0.001x^4 + 0.032x^3 - 0.427x^2 + 4.430x + 134.2 \]

(b) Magnetic Latitude of the center of the maximum propagation angle region vs. Magnetic Latitude of the station

\[ y = -3E-06x^6 + 0.000x^5 - 0.010x^4 + 0.192x^3 - 1.810x^2 + 9.299x - 21.30 \]

(c) Geographic Latitude of the center of the maximum propagation angle region vs. Geographic Latitude of the station

\[ y = -4E-06x^6 + 0.000x^5 - 0.021x^4 + 0.525x^3 - 6.812x^2 + 46.28x - 127.4 \]

(d) Geographic Longitude of the center of the maximum propagation angle region vs. Geographic Longitude of the station

\[ y = -2E-06x^6 + 0.000x^5 - 0.163x^4 + 17.95x^3 - 1109.x^2 + 365x - 49944 \]
• The zone of maximum propagation angle for any station in the northern magnetic hemisphere is located to the south of the station.

• The value of maximum propagation angle for a particular station depends on the magnetic latitude of the station, progressively increasing as one moves north from the magnetic equator. This is due to the fact that the magnetic field lines have minimum curvature over the magnetic equator, but the field lines gradually converge at higher latitudes and ultimately coalesce at the poles.
Station: Trivandrum
Period: August-October 2004

13UT-14UT 14UT-15UT 15UT-16UT 16UT-17UT

S4 < 0.3 □ 0.3 ≤ S4 < 0.6 △ S4 ≥ 0.6

Subionospheric Longitude(deg.E) △ Subionospheric Longitude(deg.E)

LT = UT + 05.17h
Station: Trivandrum
Period: August-October 2004

Subionospheric Longitude (deg. E) Subionospheric Latitude (deg. N)

○ S4 < 0.3 □ 0.3 ≤ S4 < 0.6 △ S4 ≥ 0.6

LT = UT + 05.17h
Maximum Propagation Angle : $146.69^\circ$

Zone: $0.06^\circ$ to $2.73^\circ$N and $73.38^\circ$ to $76.56^\circ$ E (geographic); $-5.35^\circ$ to $-2.10^\circ$N (magnetic)

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a) Propagation angle map in terms of Subionospheric Latitude and Longitude for Trivandrum.
b) Scintillation observed from Trivandrum during 15:00-16:00UT on September 15, 2004.
c) Propagation angle map in terms of Magnetic Latitude and Subionospheric Longitude for Trivandrum.
Station: Bangalore
[Latitude: 12.95°N, Longitude: 77.68° E (geographic); Magnetic Latitude: 8.22°N]

Maximum Propagation Angle: 155.46°

Zone: 4.48° to 6.25°N and 75.73° to 76.50° E (geographic); -0.32° to 1.48° N (magnetic)

a) Propagation angle map in terms of Subionospheric Latitude and Longitude for Bangalore.
b) Propagation angle map in terms of Magnetic Latitude and Subionospheric Longitude for Bangalore.
Station: Hyderabad
Period: August-October 2004

LT = UT + 05.17h

Subionospheric Latitude(deg.N) Subionospheric Longitude(deg.E)

○ S4 < 0.3 □ 0.3 ≤ S4 < 0.6 △ S4 ≥ 0.6 Subionospheric Longitude(deg.E) LT = UT + 05.17h
Station: Hyderabad
Period: August-October 2004

LT = UT + 05.17h

Subionospheric Latitude (deg. N)
Subionospheric Longitude (deg. E)

○ S4 < 0.3  □ 0.3 ≤ S4 < 0.6  △ S4 ≥ 0.6  Subionospheric Longitude (deg. E)  LT = UT + 05.17h
Station: Hyderabad
[ Latitude:17.44°N, Longitude: 78.47° E (geographic) ;Magnetic Latitude:12.84°N]

Maximum Propagation Angle : 164.34°

Zone:  8.80° to 12.69°N and 76.47° to 80.61° E (geographic) ; 3.71° to 7.92°N (magnetic)

(a) Propagation angle map in terms of Subionospheric Latitude and Longitude for Hyderabad.

(b) Scintillation observed from Hyderabad during 17:00-18:00UT on September 3, 2004.

(c) Propagation angle map in terms of Magnetic Latitude and Subionospheric Longitude for Hyderabad.

LT = UT + 05.17h
Station: Bhopal
Period: August-October 2004

Subionospheric Latitude(deg. N)
Subionospheric Longitude(deg. E)

○ S4 < 0.3 □ 0.3 ≤ S4 < 0.6 △ S4 ≥ 0.6

Subionospheric Longitude(deg. E)  LT = UT + 05.17h
Maximum Propagation Angle : 176.21°

Zone: 14.84° to 16.98°N and 76.06° to 76.52°E (geographic); 10.42 to 12.66°N (magnetic)

a) Propagation angle map in terms of Subionospheric Latitude and Longitude for Bhopal.

b) Scintillation observed from Bhopal during 17:00-18:00UT on October 28, 2004.

c) Propagation angle map in terms of Magnetic Latitude and Subionospheric Longitude for Bhopal.
Station: Delhi
Period: August-October 2004

Subionospheric Latitude (deg. N)
Subionospheric Longitude (deg. E)

○ $S4 < 0.3$  □ $0.3 \leq S4 < 0.6$  △ $S4 \geq 0.6$

Subionospheric Longitude (deg. E)  \[ LT = UT + 05.17h \]
Station: Delhi
Period: August-October 2004

Subionospheric Latitude (deg.N)
Subionospheric Longitude (deg.E)  LT = UT + 05.17h

17UT-18UT  18UT-19UT  19UT-20UT  20UT-21UT

○ $S4 < 0.3$  □ $0.3 \leq S4 < 0.6$  △ $S4 \geq 0.6$
Station: Delhi

Latitude: 28.58°N, Longitude: 77.21°E (geographic); Magnetic Latitude: 24.93°N

Maximum Propagation Angle: 179.88°

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.

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

LT = UT + 05.17h
Station: Shimla
Period: August-October 2004

LT = UT + 05.17h

Subionospheric Latitude (deg.N) Subionospheric Longitude (deg.E) LT = UT + 05.17h

- S4 < 0.3
- 0.3 ≤ S4 < 0.6
- S4 ≥ 0.6
Station: Shimla
Period: August-October 2004

Subionospheric Latitude (deg. N)
Subionospheric Longitude (deg. E)

○ S4 < 0.3 □ 0.3 ≤ S4 < 0.6 △ S4 ≥ 0.6

LT = UT + 05.17h
Station: Shimla
[Latitude: 31.09°N, Longitude: 77.07°E (geographic); Magnetic Latitude: 27.65°N]

Maximum Propagation Angle: 179.85°

Zone: 26.34° to 28.02°N and 76.34°-77.68°E (geographic); 22.48° to 24.35°N (magnetic)

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

LT = UT + 05.17h

Zone: 26.34° to 28.02°N and 76.34°-77.68°E (geographic); 22.48° to 24.35°N (magnetic)
• For stations with magnetic latitude within 25°N, enhanced scintillations due to field-aligned propagation occur when the irregularities causing L-band scintillations are in decaying phase, in the region of maximum propagation angle corresponding to the station as long as it lies within the equatorial irregularity belt (±20° magnetic latitude).

• For Bangalore and Agatti the zone of the maximum propagation angle is about the magnetic equator where ambient ionization is low, the irregularities being field-aligned and the field has minimum curvature at the magnetic equator, the ray path traverses shorter path length through irregularities in this zone and they could not be viewed ‘end-on’. Hence no enhanced scintillation owing to field alignment were observed from these stations.

• For Shimla with magnetic latitude greater than 25°N, 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.
Time: 13-14UT  
18.1-19.1LT

Time: 14-15UT  
19.1-20.1LT

Time: 15-16UT  
20.1-21.1LT

Time: 16-17UT  
21.1-22.1LT

Subionospheric Longitude (deg. E)

Subionospheric Latitude (deg. N)

Station: PALAMPUR

Date: April 02, 2014

SSN: 86
Station: DELHI
Date: April 10, 2013
SSN: 94

Subionospheric Longitude (deg. E)
Subionospheric Latitude (deg. N)

Time: 13-14UT
18.2-19.2LT

Time: 14-15UT
19.2-20.2LT

Time: 15-16UT
20.2-21.2LT

Time: 16-17UT
21.2-22.2LT
Station: DELHI
Date: April 10, 2013
SSN: 94

Subionospheric Longitude (deg. E)

Subionospheric Latitude (deg. N)

Time: 17-18UT
22.2-23.2LT

Time: 18-19UT
23.2-00.2LT

Time: 19-20UT
00.2-01.2LT

Time: 20-21UT
01.2-02.2LT
Conclusions

• GPS scintillations observed from stations located poleward of the equatorial ionization anomaly in the Indian longitude sector, i.e. outside the irregularity belt, observe intense scintillations only when the satellite ray-path is aligned along the geomagnetic field line i.e. when the satellite views the bubble ‘end-on’ and the region of maximum propagation angle for that particular station overlaps with the equatorial irregularity belt.

• The algorithm developed in the paper can identify the outage zones for reference stations in the Indian SBAS located within and outside the equatorial irregularity belt. This information will be useful for SBAS users.
Acknowledgements

• The authors are grateful to International Association of Geomagnetism and Aeronomy (IAGA) for providing the IGRF coefficients.
• The authors acknowledge the help of Mr. Utsav Bhowmik in developing the algorithm.

Thank you!
Station: DELHI
Date: September 09, 2004
SSN: 42

Subionospheric Latitude (deg.N) vs. Subionospheric Longitude (deg. E)

Time: 13-14UT
18.2-19.2LT

Time: 14-15UT
19.2-20.2LT

Time: 15-16UT
20.2-21.2LT

Time: 16-17UT
21.2-22.2LT