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

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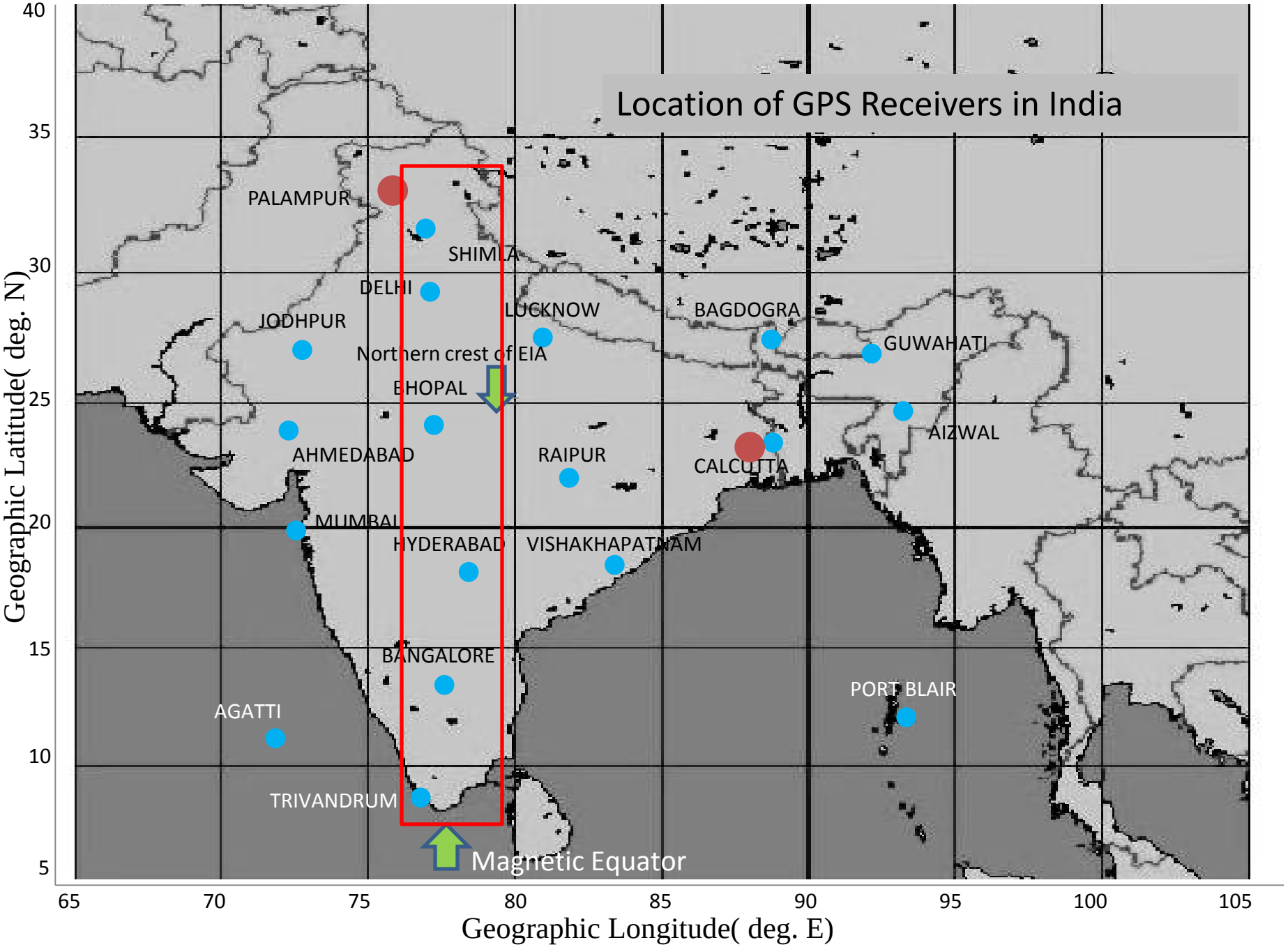
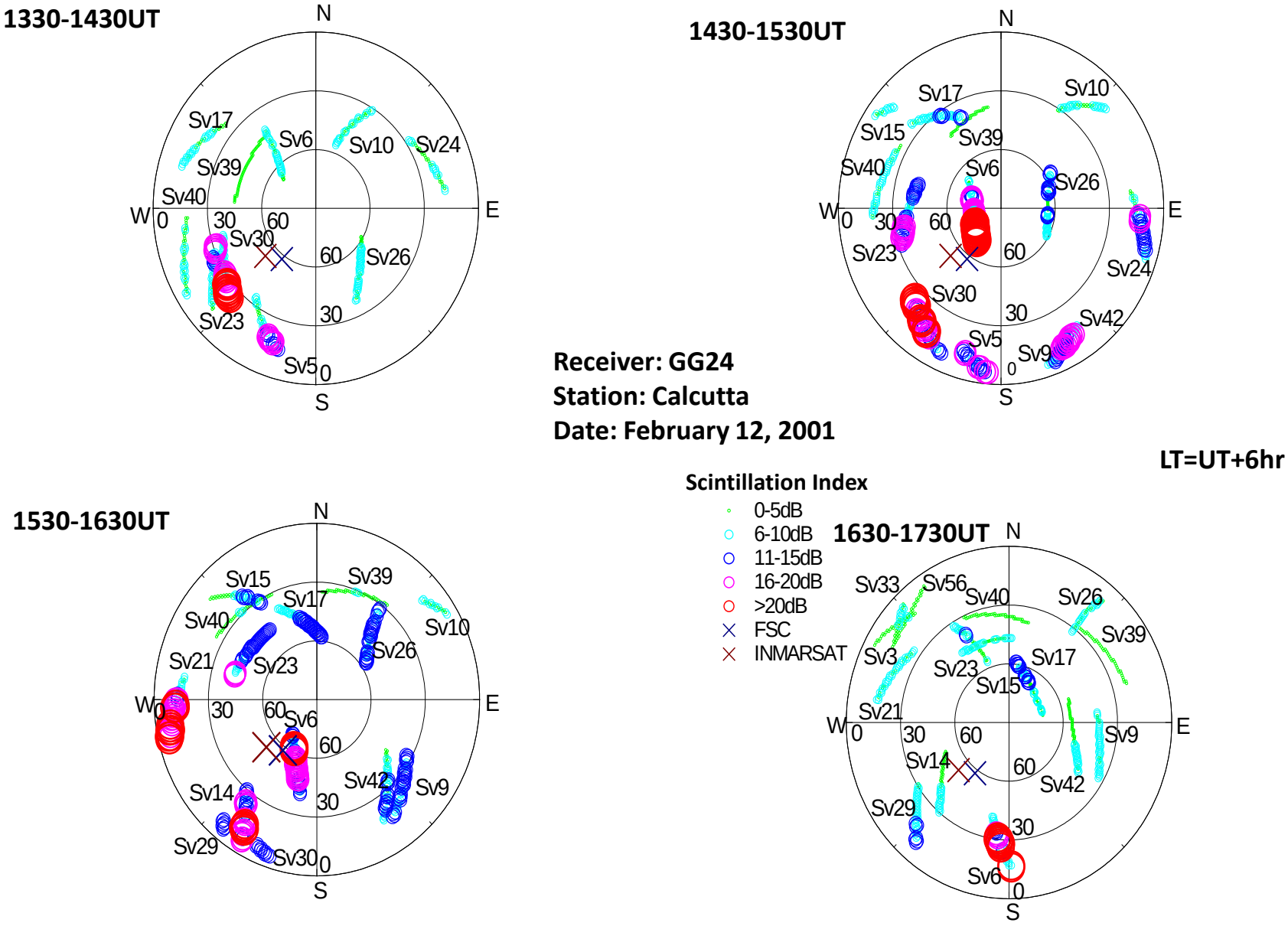
Introduction

- 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.

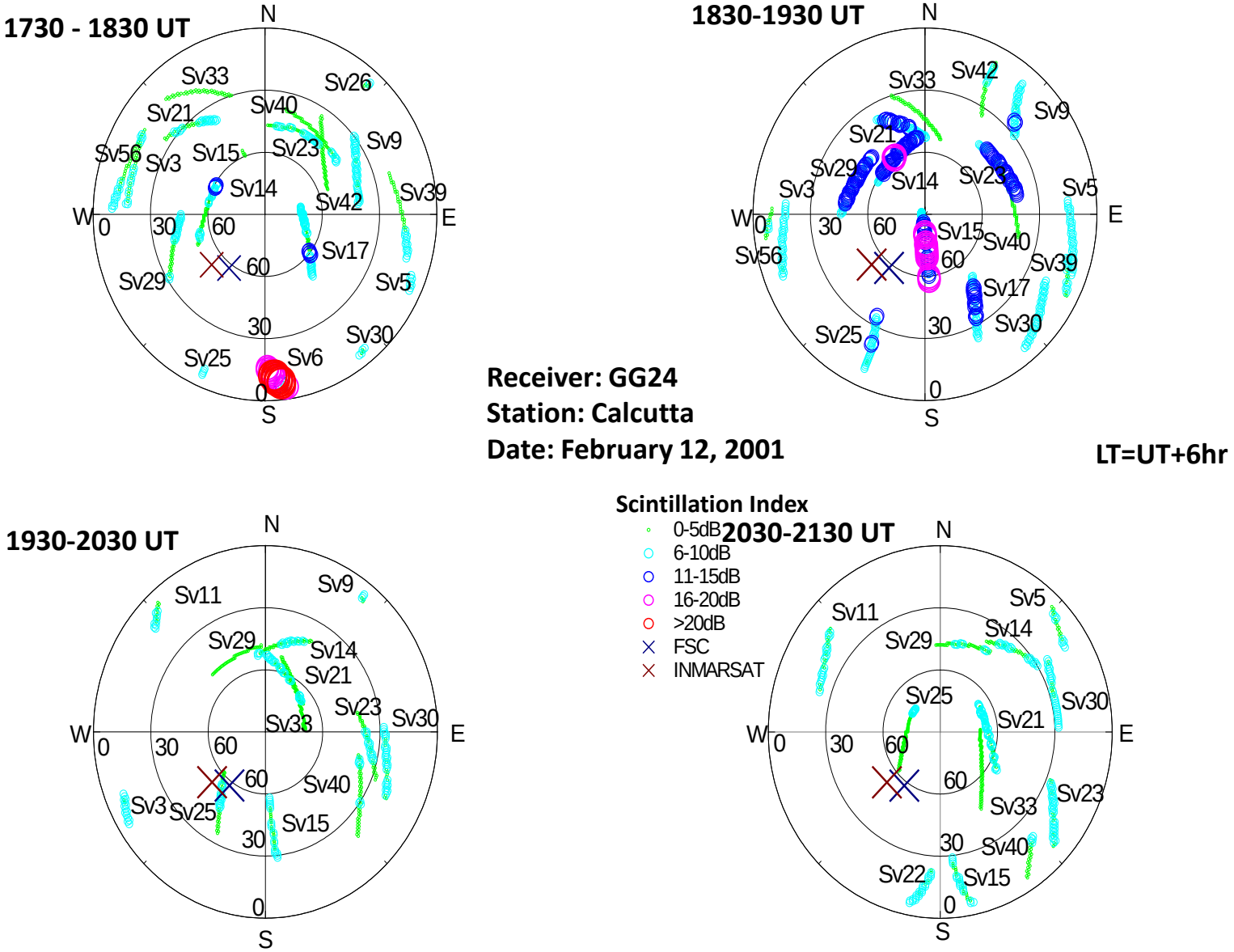

Location of GPS Receivers in India
PALAMPUR
SHIMLA
DELHI
JODHPUR
LUCKNOW
BAGDOGRA
GUWAHATI
Northern crest of EIA
BHOPAL
AIZWAL
AHMEDABAD
RAIPUR
CALCUTTA
MUMBAI
HYDERABAD
VISHAKHAPATNAM
BANGALORE
PORT BLAIR
AGATTI
TRIVANDRUM
Magnetic Equator
Geographic Latitude(deg. N)
Geographic Longitude(deg. E)
40
35
30
25
20
15
10
5
65
70
75
80
85
90
95
100
105

Station Geographic and Magnetic coordinates

Station	Geographic Latitude(deg. N)	Geographic Longitude(deg. E)	Magnetic Latitude(deg. N)
Trivandrum	**8.47**	**76.91**	**3.66**
Bangalore	**12.95**	**77.68**	**8.22**
Hyderabad	**17.44**	**78.47**	**12.84**
Bhopal	**23.28**	**77.34**	**19.20**
Delhi	**28.58**	**77.21**	**24.93**
Shimla	**31.09**	**77.07**	**27.65**
Agatti	**10.83**	**72.18**	**7.08**
Mumbai	**19.09**	**72.85**	**15.49**
Ahmedabad	**23.06**	**72.61**	**19.68**
Jodhpur	**26.26**	**73.05**	**23.00**
Aizwal	**23.83**	**92.62**	**18.32**
Guwahati	**26.12**	**91.59**	**20.94**
Port Blair	**11.67**	**92.72**	**4.94**
Calcutta	**22.58**	**88.38**	**17.23**
Bagdogra	**26.68**	**88.32**	**21.76**
Visakhapatnam	**17.72**	**83.22**	**12.44**
Raipur	**21.18**	**81.74**	**16.40**
Lucknow	**26.76**	**80.88**	**22.56**

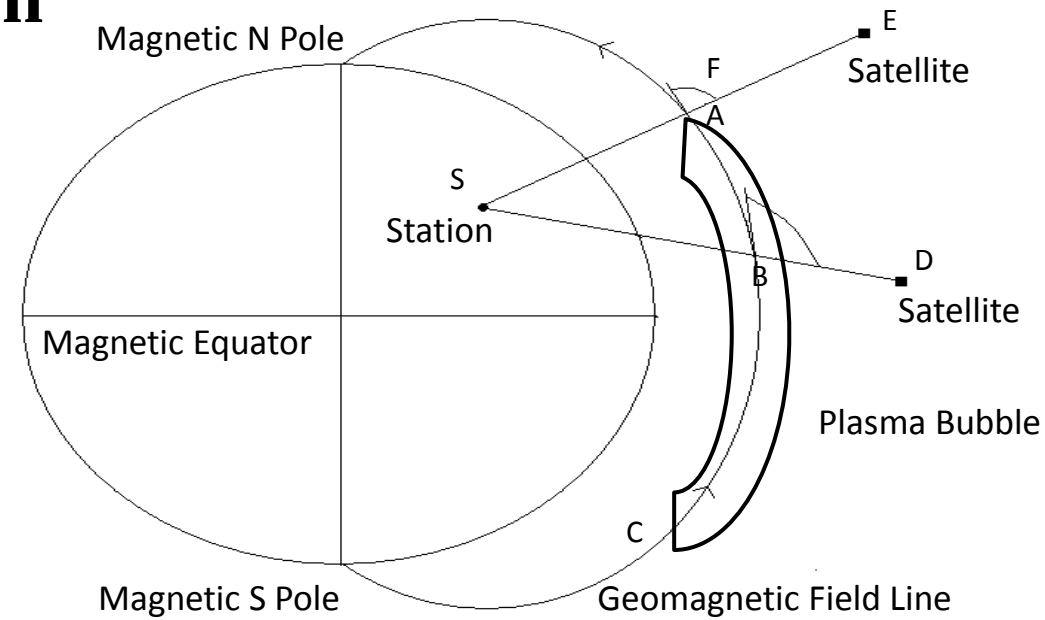


Elevation-Azimuth plots of GPS satellite tracks observed from Calcutta by GG24 during 1330-1730UT(1930-2330LT) on February 12, 2001.

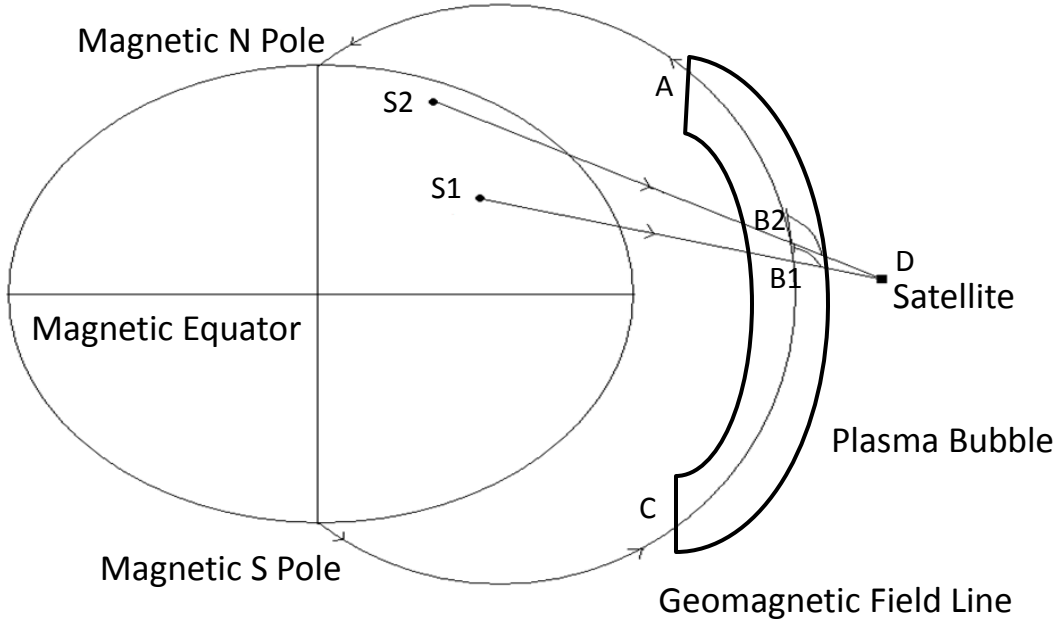


Elevation-Azimuth plots of GPS satellite tracks observed from Calcutta by GG24 during 1730-2130UT(2330-2730LT) on February 12, 2001.

Propagation Geometry



a)

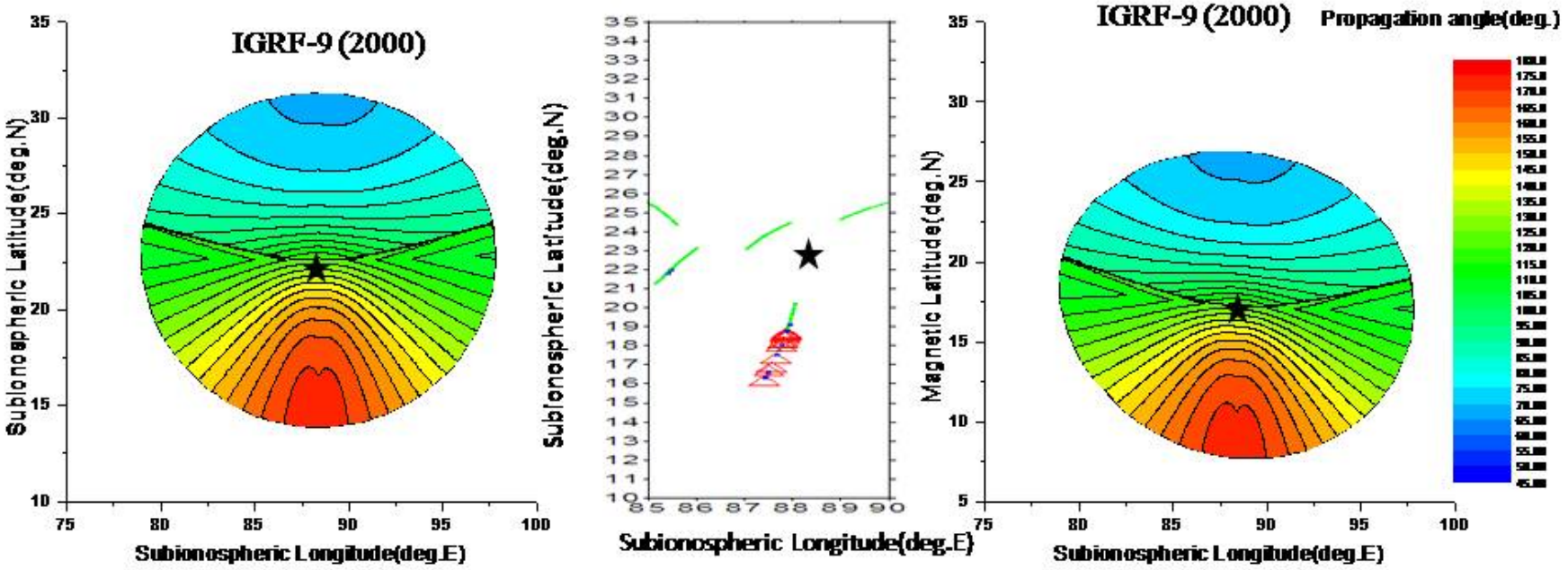


b)

(Not to scale)

Station: Calcutta

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



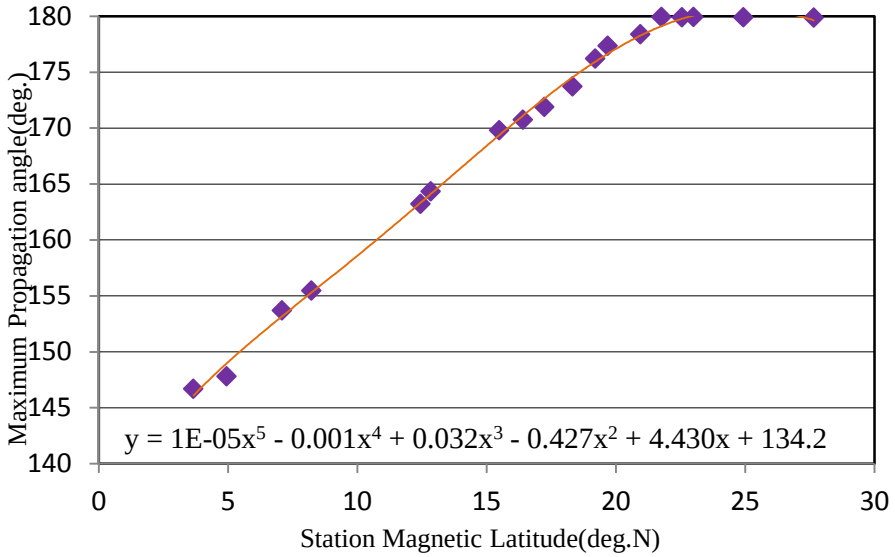
○ S4 < 0.3 □ 0.3 ≤ S4 < 0.6 Δ S4 ≥ 0.6 LT = UT + 05.83h

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

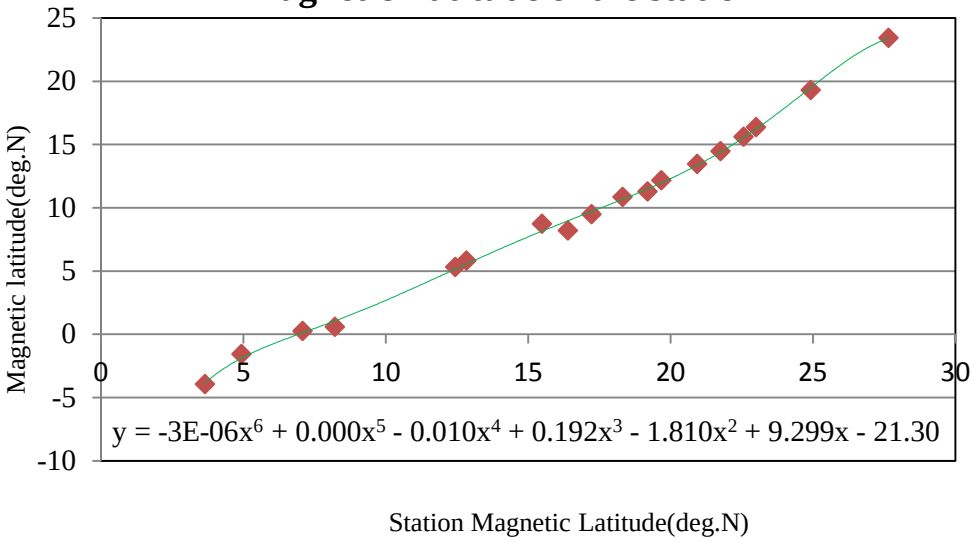
b)Scintillation observed from Calcutta during 17:00-18:00UT on September 9, 2004.

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

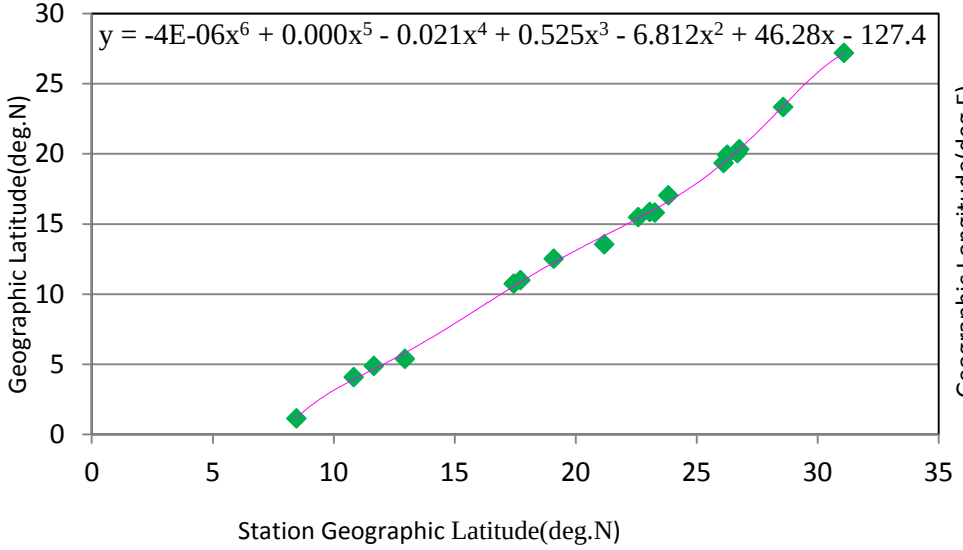
(a) Maximum propagation angle for the station vs. station Magnetic Latitude



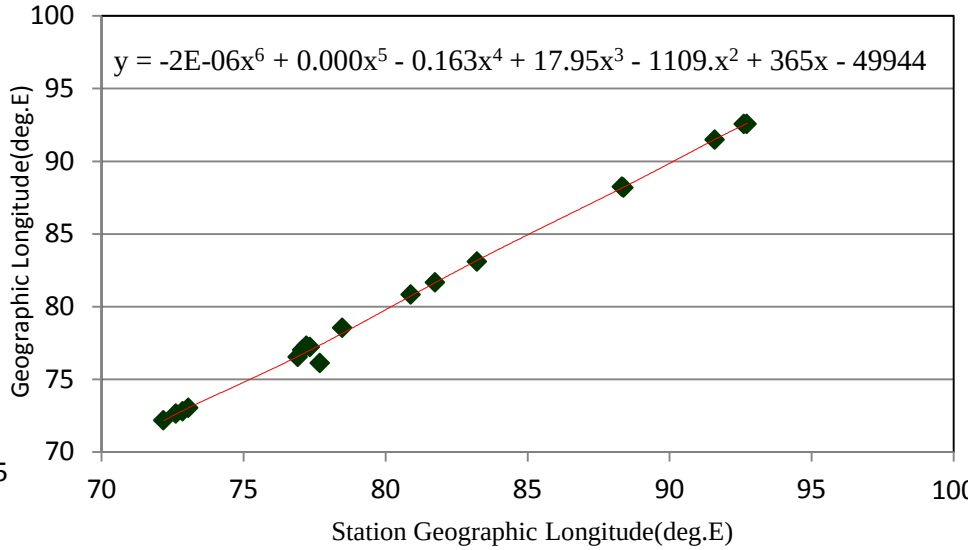
(b) Magnetic Latitude of the center of the maximum propagation angle region vs. Magnetic Latitude of the station



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



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

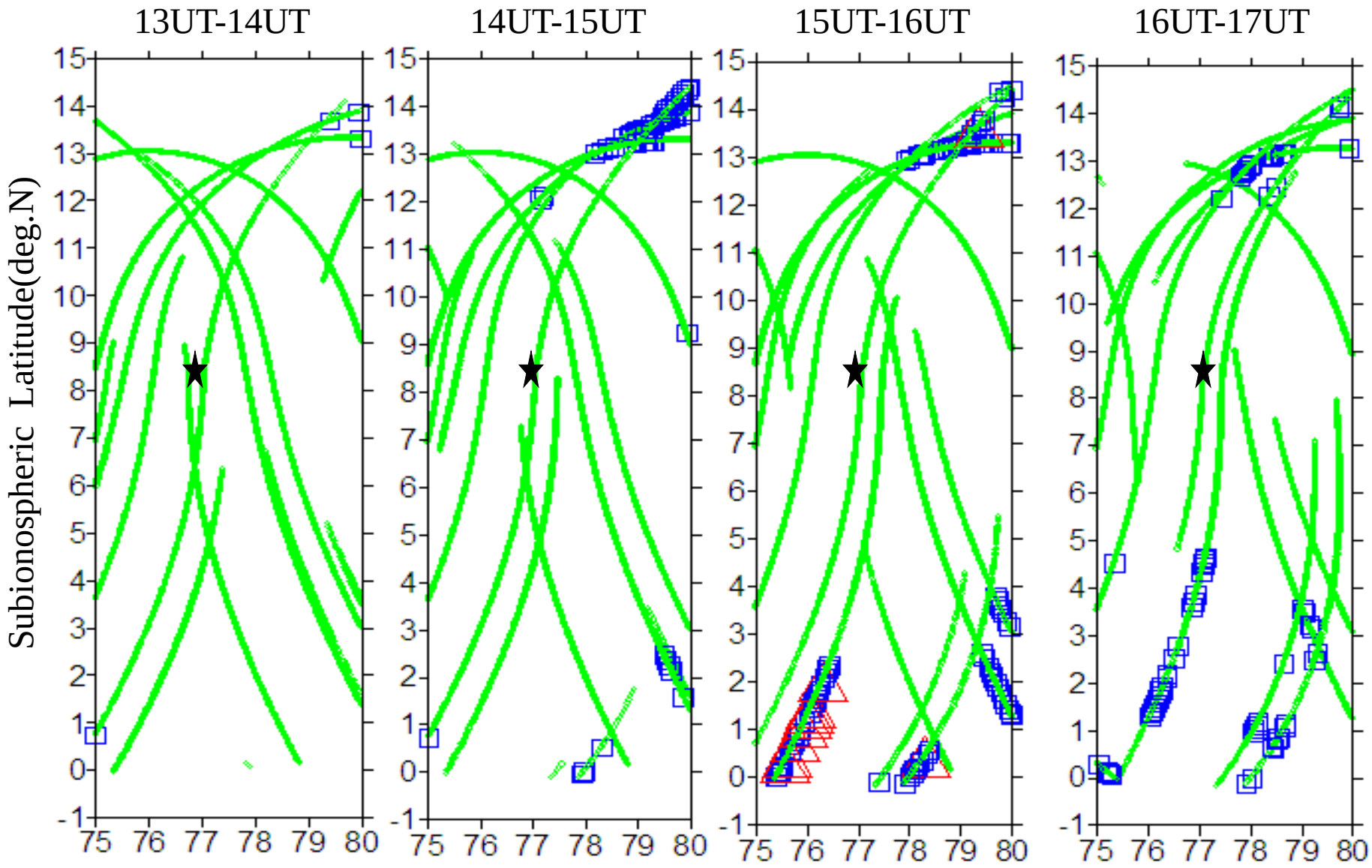


FROM PROPAGATION GEOMETRY…

- The zone of maximum propagation angle for any station in the northern magnetic hemisphere is located to the south of the station.

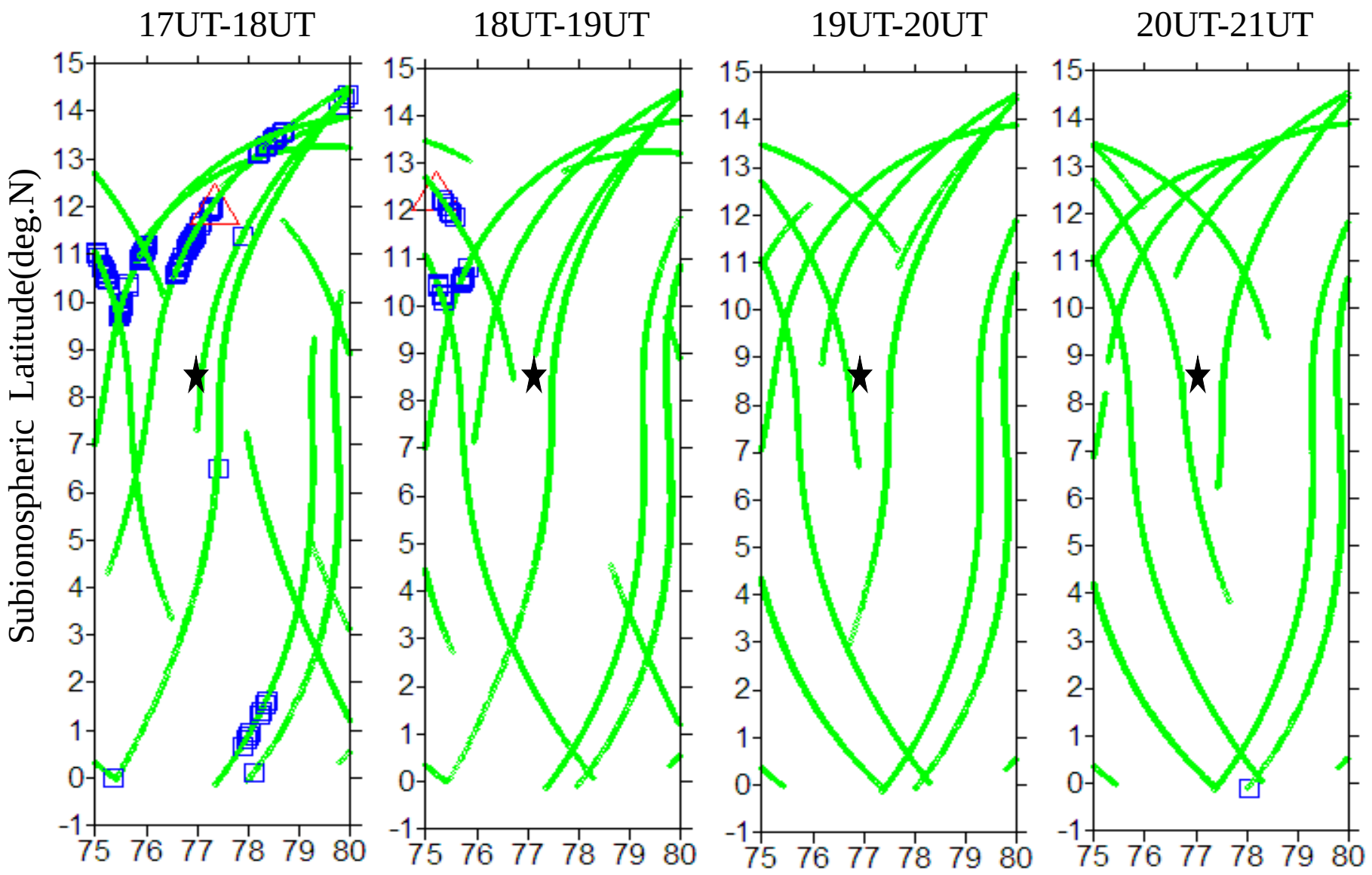
- The value of maximum propagation angle for a particular station depends on the magnetic latitude of the station, progressively increasing as one moves north from the magnetic equator. This is due to the fact that the magnetic field lines have minimum curvature over the magnetic equator, but the field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

Station: Trivandrum
Period: August-October 2004



○ S4 < 0.3 □ 0.3 ≤ S4 < 0.6 Δ S4 ≥ 0.6 Subionospheric Longitude(deg.E) LT = UT + 05.17h

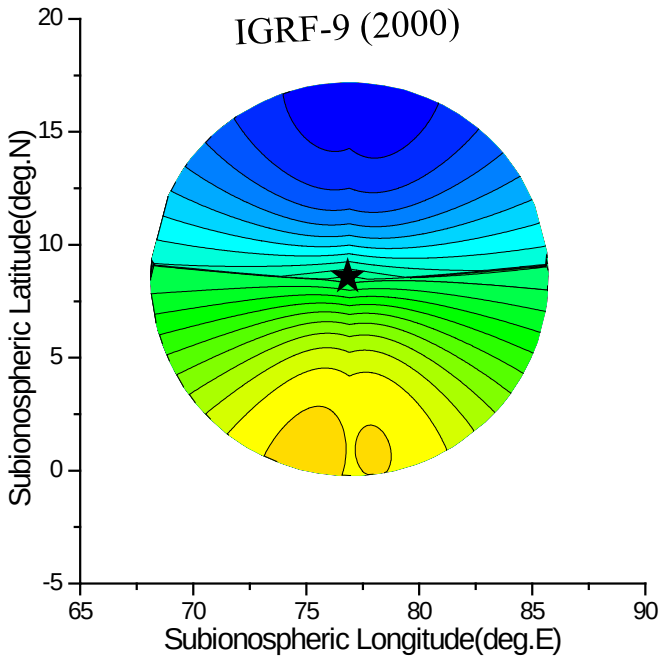
Station: Trivandrum
Period: August-October 2004



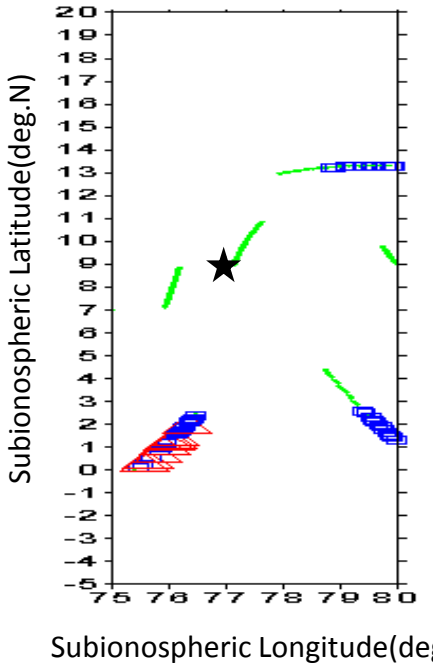
○ S4 < 0.3 □ 0.3 ≤ S4 < 0.6 Δ S4 ≥ 0.6 Subionospheric Longitude(deg.E) LT = UT + 05.17h

Station: Trivandrum

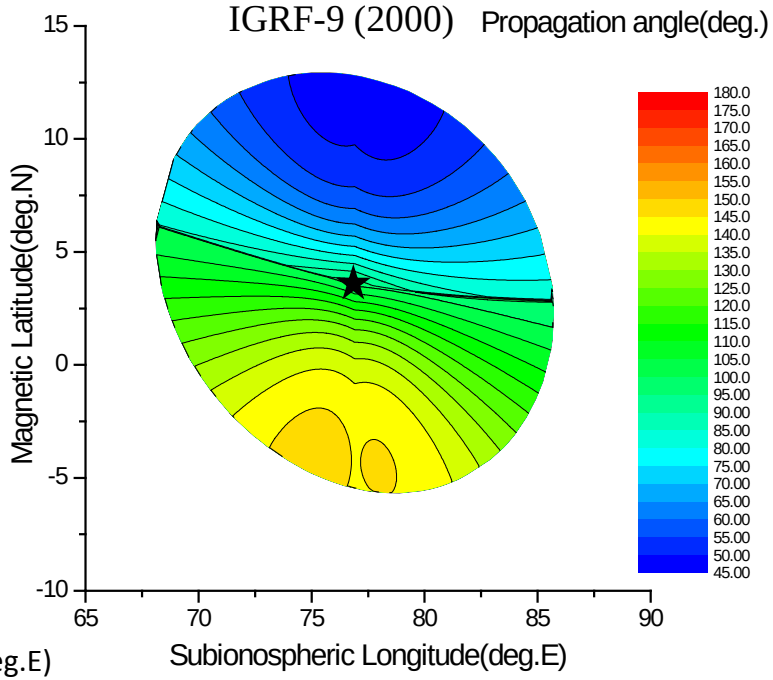
[Latitude:8.47°N, Longitude: 76.91° E (geographic) ;Magnetic Latitude:3.66°N]



(a)



(b)



(c)

Maximum Propagation Angle :146.69° ○ S4 < 0.3 □ 0.3 ≤ S4 < 0.6 Δ S4 ≥ 0.6 LT = UT + 05.17h

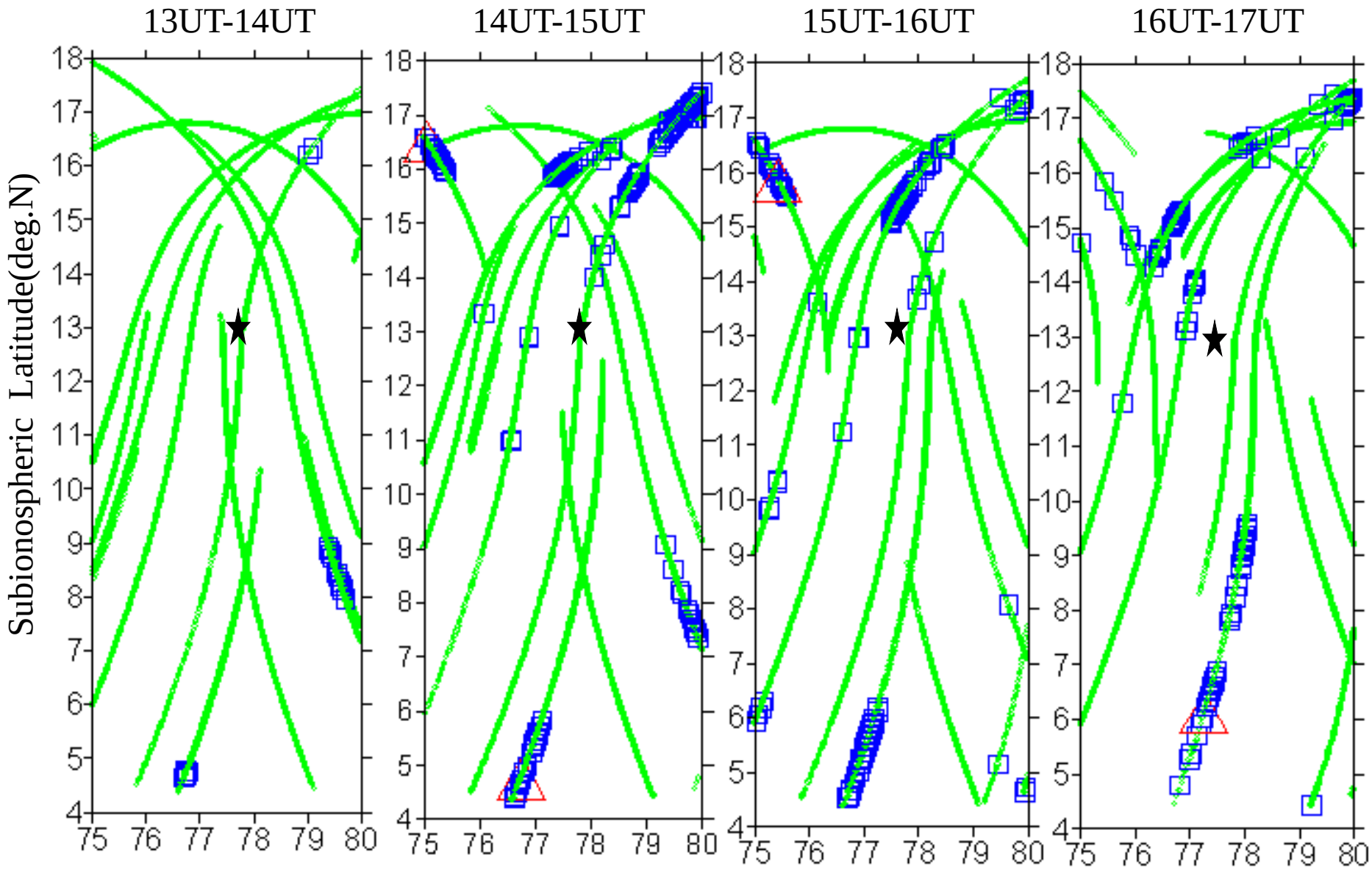
Zone: 0.06° to 2.73°N and 73.38° to 76.56° E (geographic) ;-5.35° to -2.10°N (magnetic)

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.

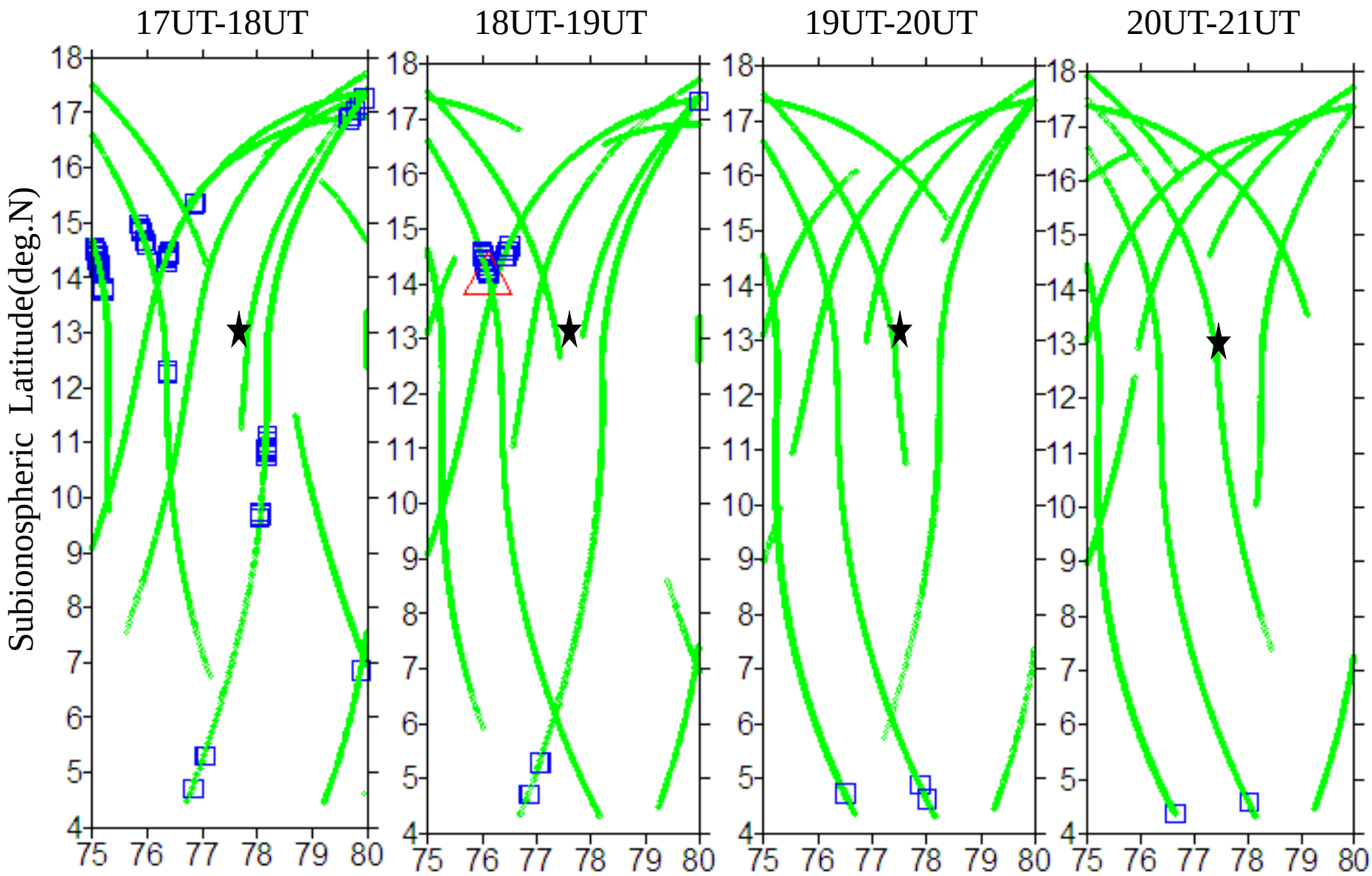
c) Propagation angle map in terms of Magnetic Latitude and Subionospheric Longitude for Trivandrum.

Station: Bangalore
Period: August-October 2004



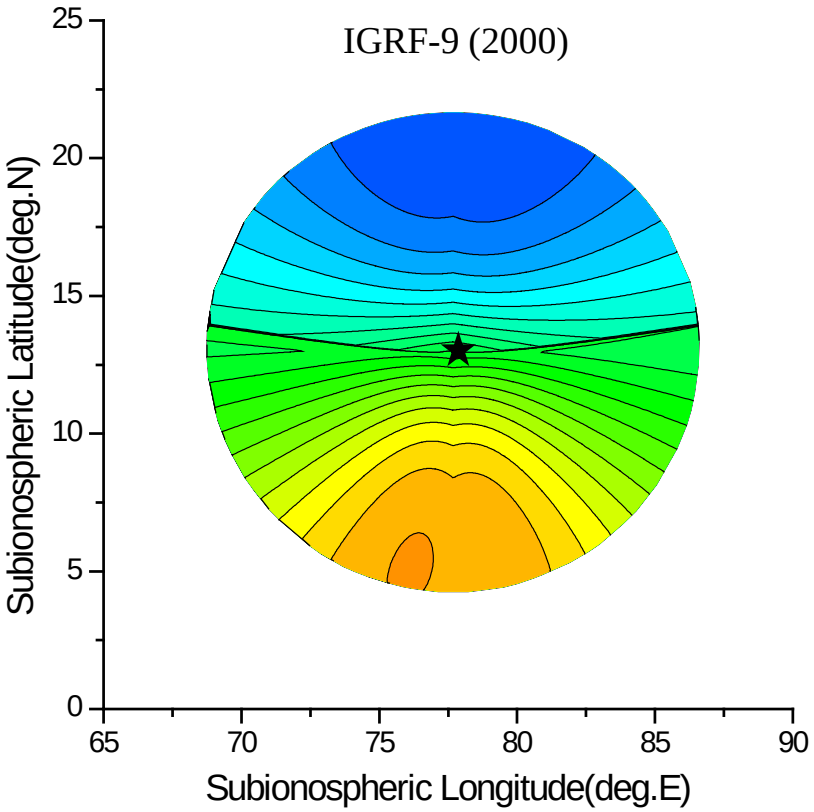
○ S4 < 0.3 □ 0.3 ≤ S4 < 0.6 Δ S4 ≥ 0.6 Subionospheric Longitude(deg.E) LT = UT + 05.17h

Station: Bangalore
Period: August-October 2004

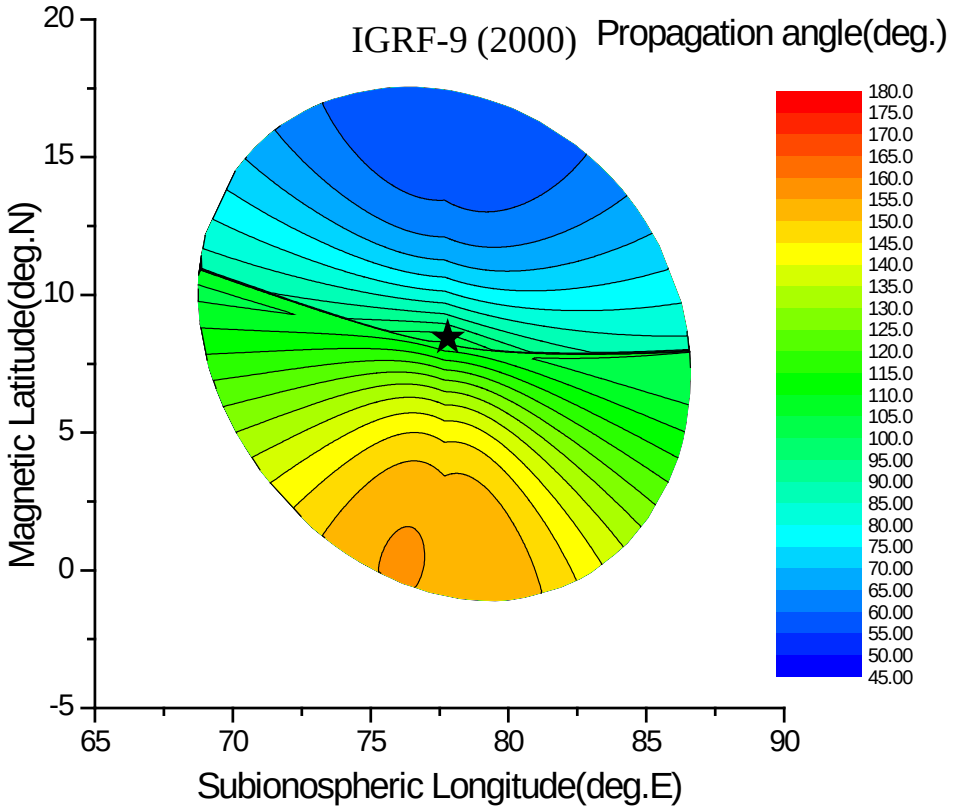


Station: Bangalore

[Latitude:12.95°N, Longitude: 77.68° E (geographic) ;Magnetic Latitude:8.22°N]



(a)



(b)

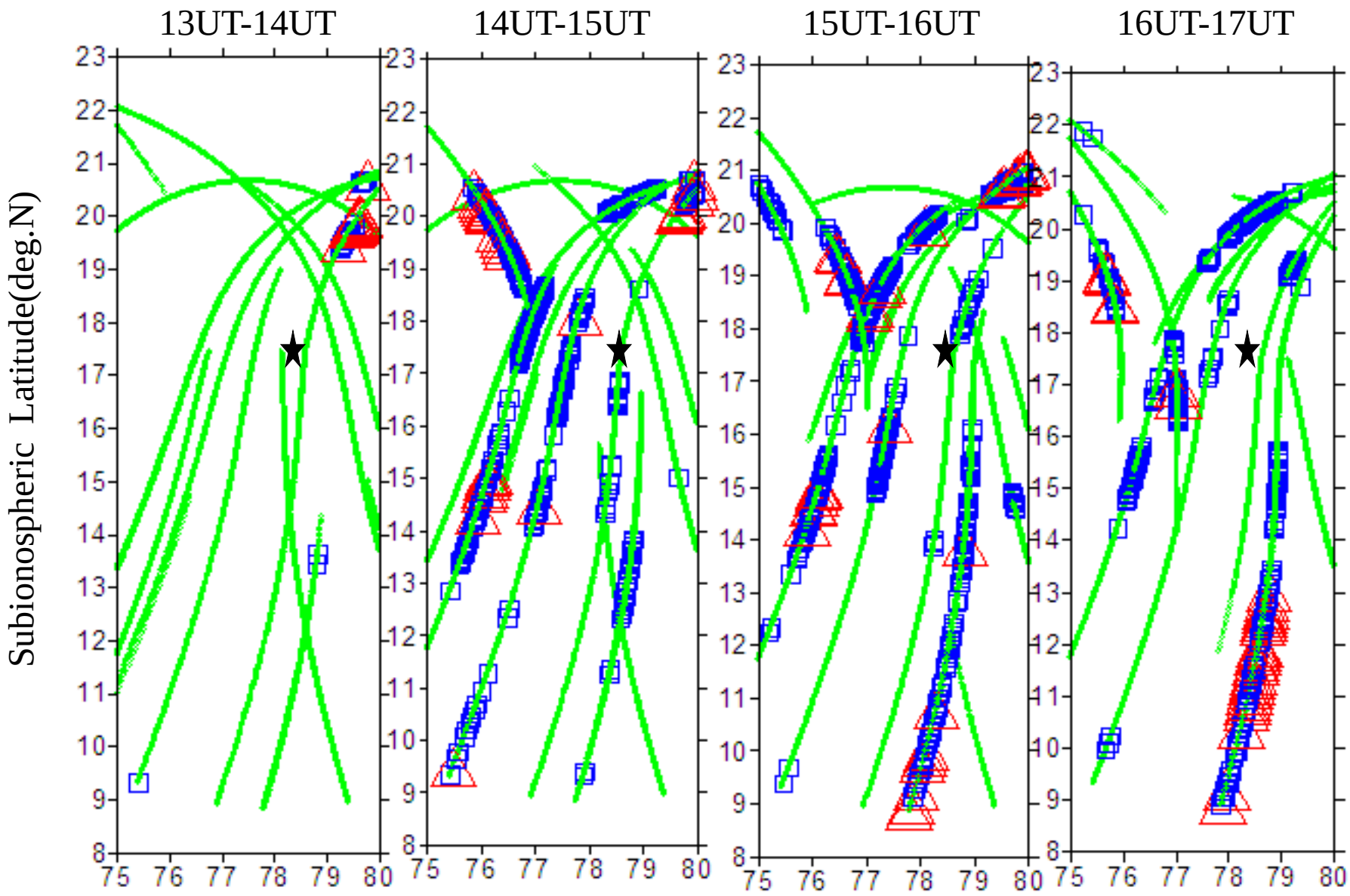
Maximum Propagation Angle :155.46°

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.

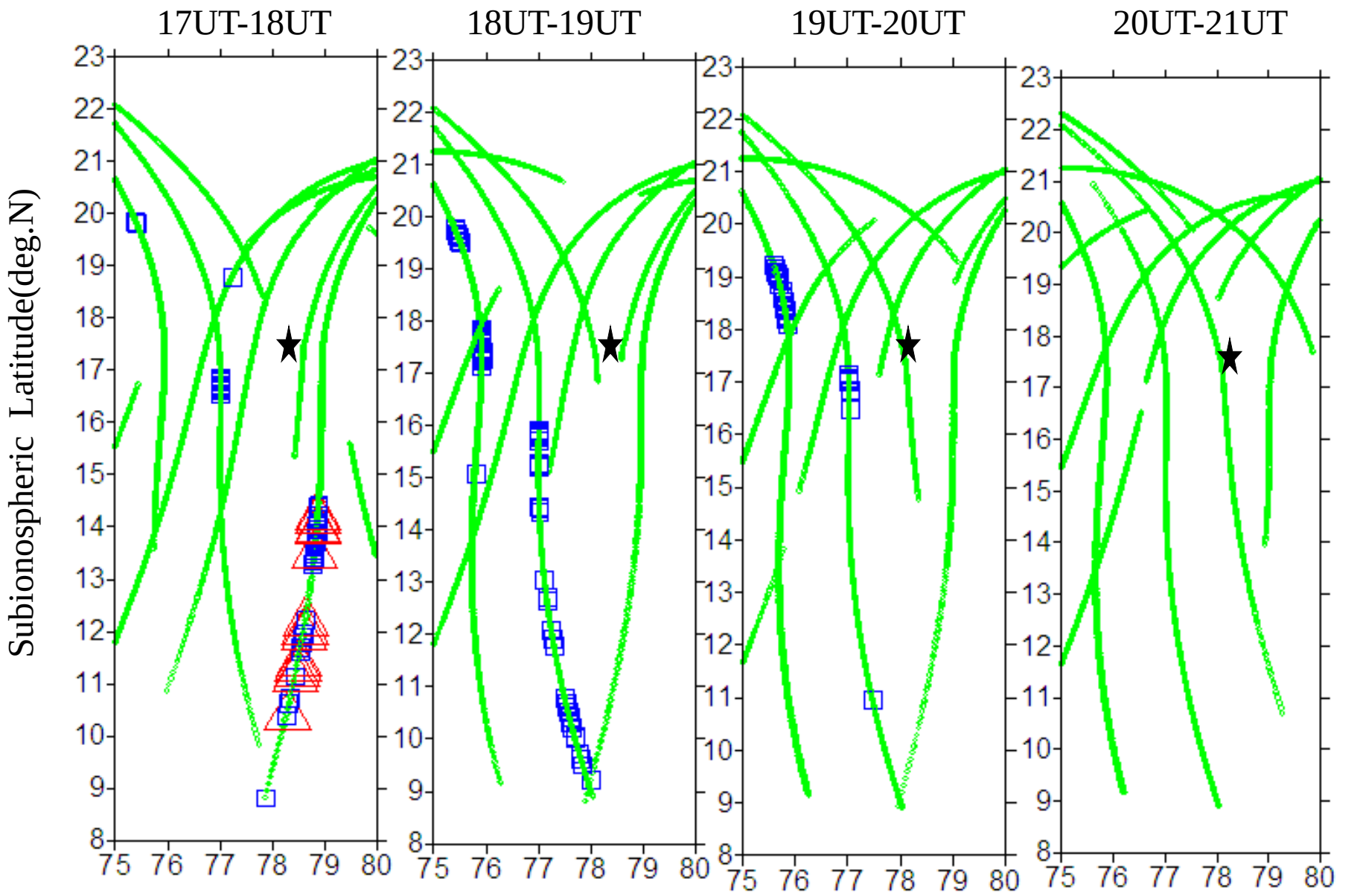
b) Propagation angle map in terms of Magnetic Latitude and Subionospheric Longitude for Bangalore.

Station: Hyderabad
Period: August-October 2004



○ S4 < 0.3 □ 0.3 ≤ S4 < 0.6 Δ S4 ≥ 0.6 Subionospheric Longitude(deg.E) LT = UT + 05.17h

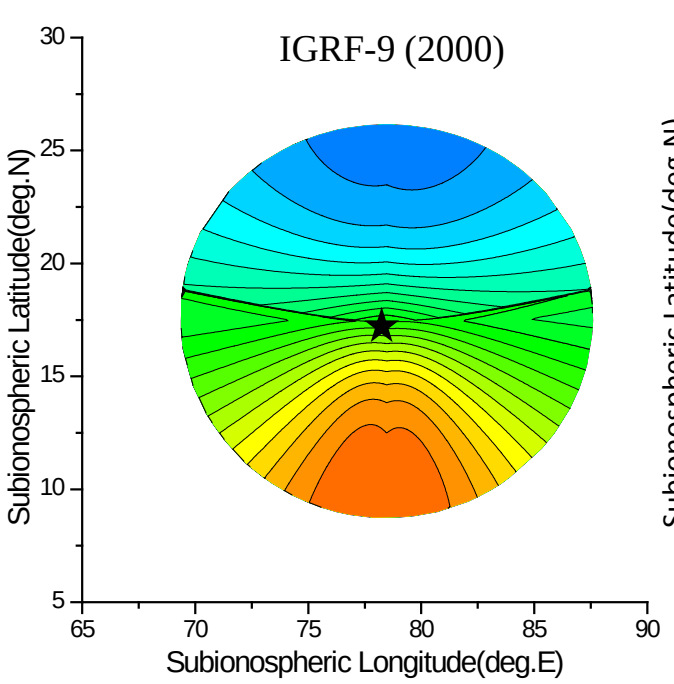
Station: Hyderabad
Period: August-October 2004



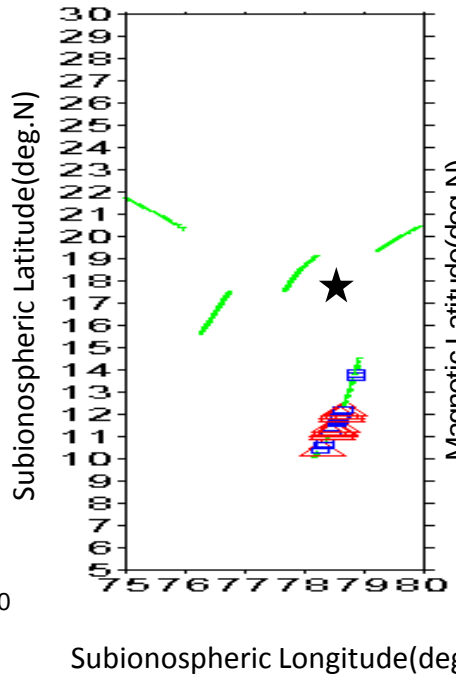
○ S4 < 0.3 □ 0.3 ≤ S4 < 0.6 Δ S4 ≥ 0.6 Subionospheric Longitude(deg.E) LT = UT + 05.17h

Station: Hyderabad

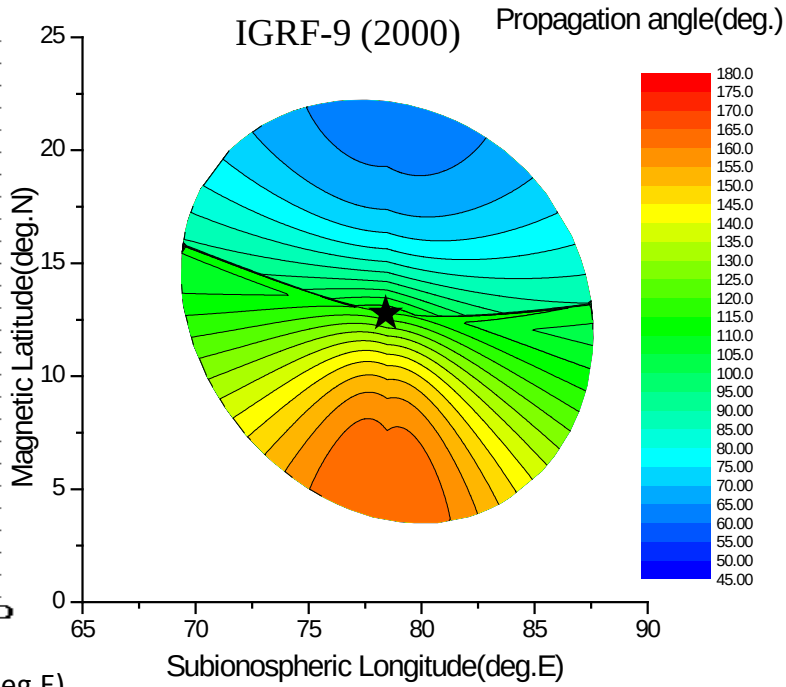
[Latitude:17.44°N, Longitude: 78.47° E (geographic) ;Magnetic Latitude:12.84°N]



(a)



(b)



(c)

Maximum Propagation Angle : 164.34°

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

LT = UT + 05.17h

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

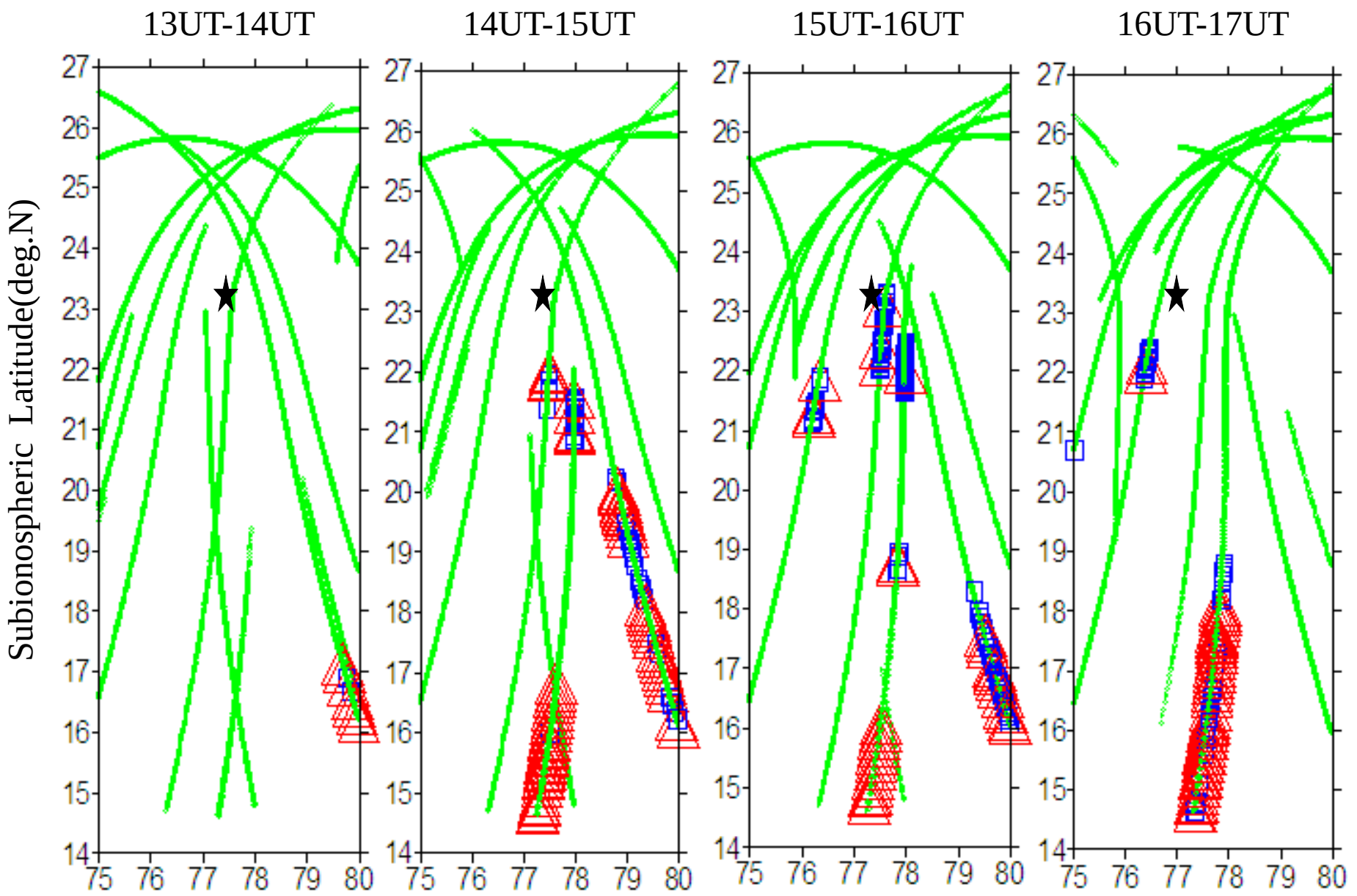
a)Propagation angle map in terms of Subionospheric Latitude and Longitude for Hyderabad.

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.

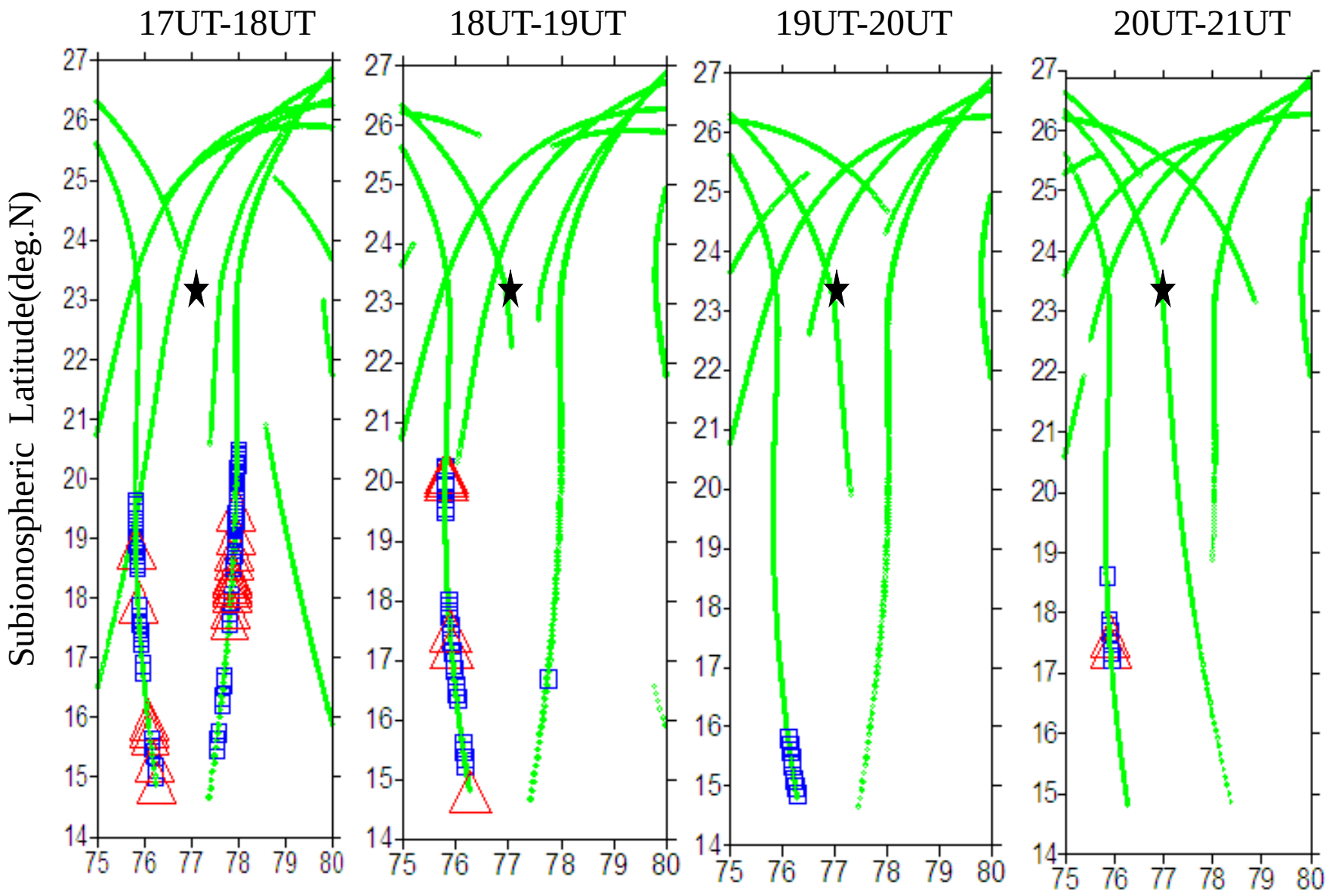
Station: Bhopal

Period: August-October 2004



○ S4 < 0.3 □ 0.3 ≤ S4 < 0.6 Δ S4 ≥ 0.6 Subionospheric Longitude(deg.E) LT = UT + 05.17h

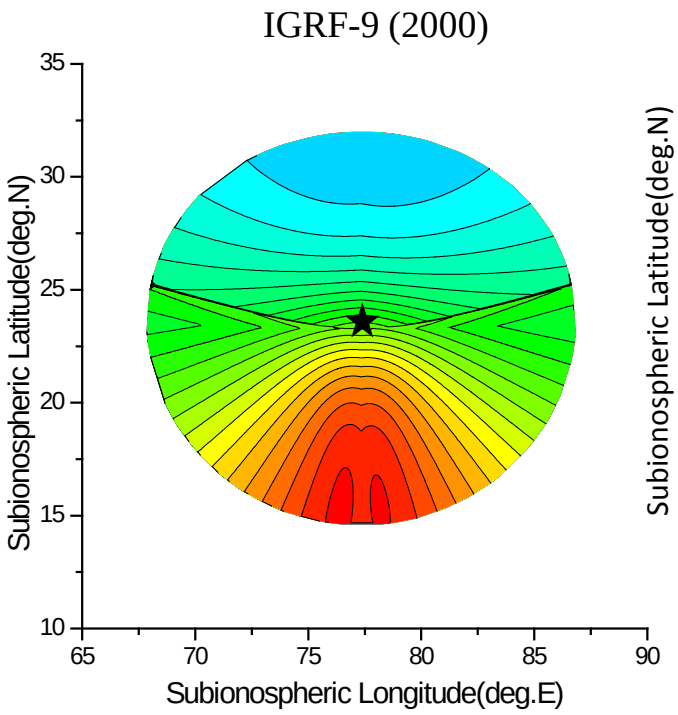
Station: Bhopal
Period: August-October 2004



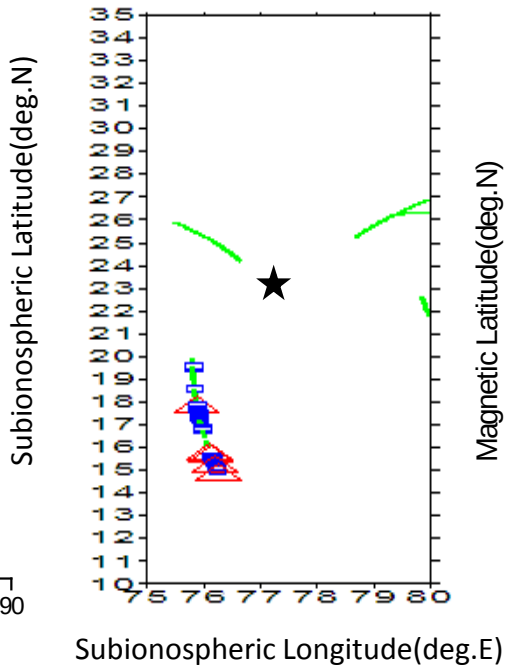
○ S4 < 0.3 □ 0.3 ≤ S4 < 0.6 Δ S4 ≥ 0.6 Subionospheric Longitude(deg.E) LT = UT + 05.17h

Station: Bhopal

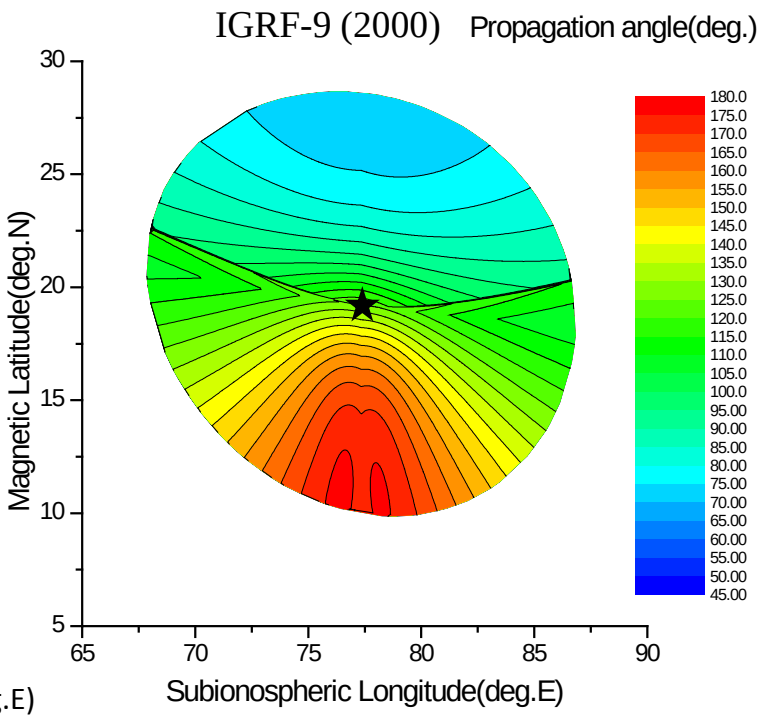
[Latitude:23.28°N, Longitude: 77.34° E (geographic) ;Magnetic Latitude:19.20°N]



(a)



(b)



(c)

Maximum Propagation Angle :176.21° ○ S4 < 0.3 □ 0.3 ≤ S4 < 0.6 Δ S4 ≥ 0.6 LT = UT + 05.17h

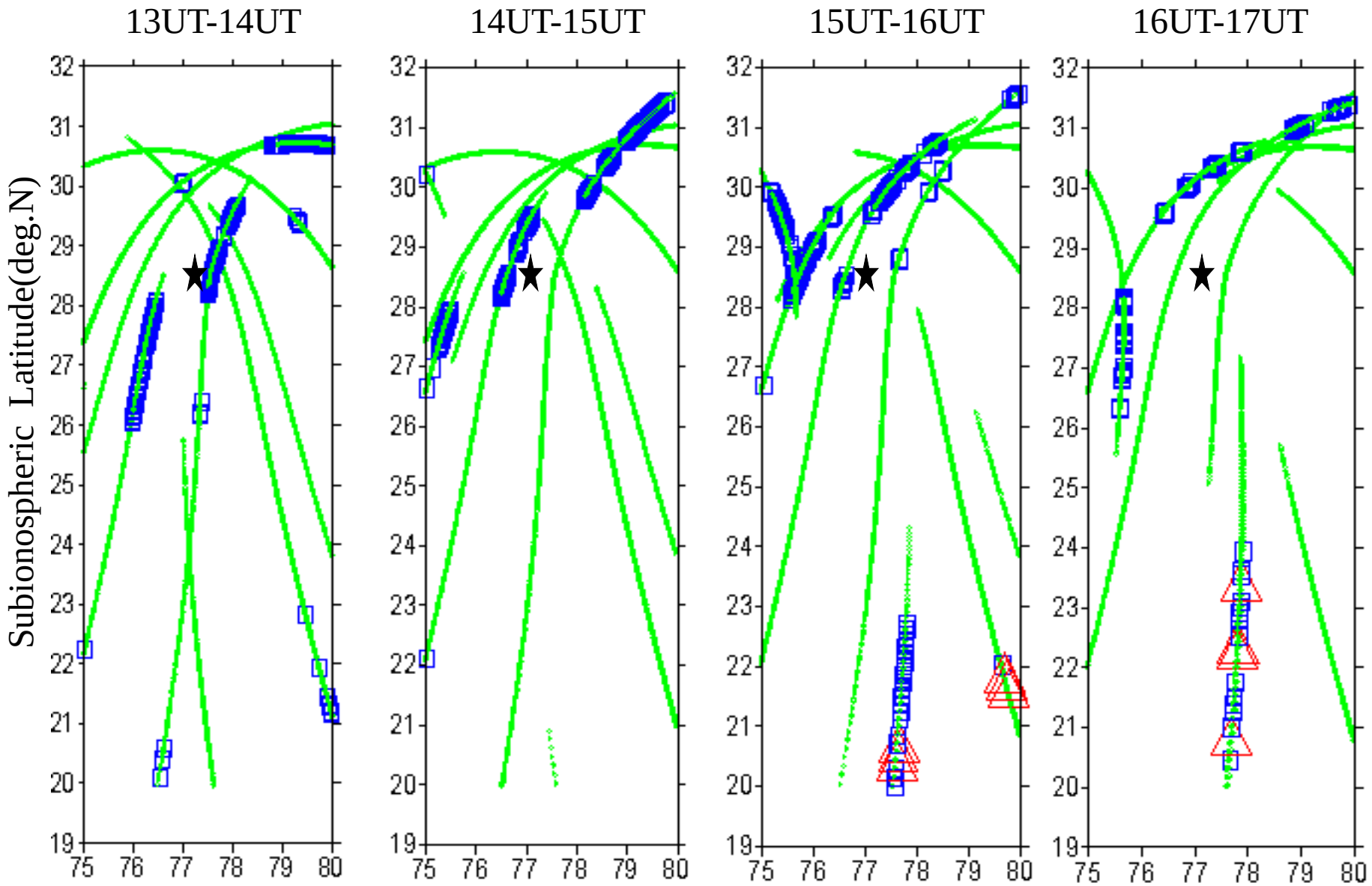
Zone: 14.84° to 16.98°N and 76.06° to 76.52°E (geographic) ; 10.42 to 12.66°N (magnetic)

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.

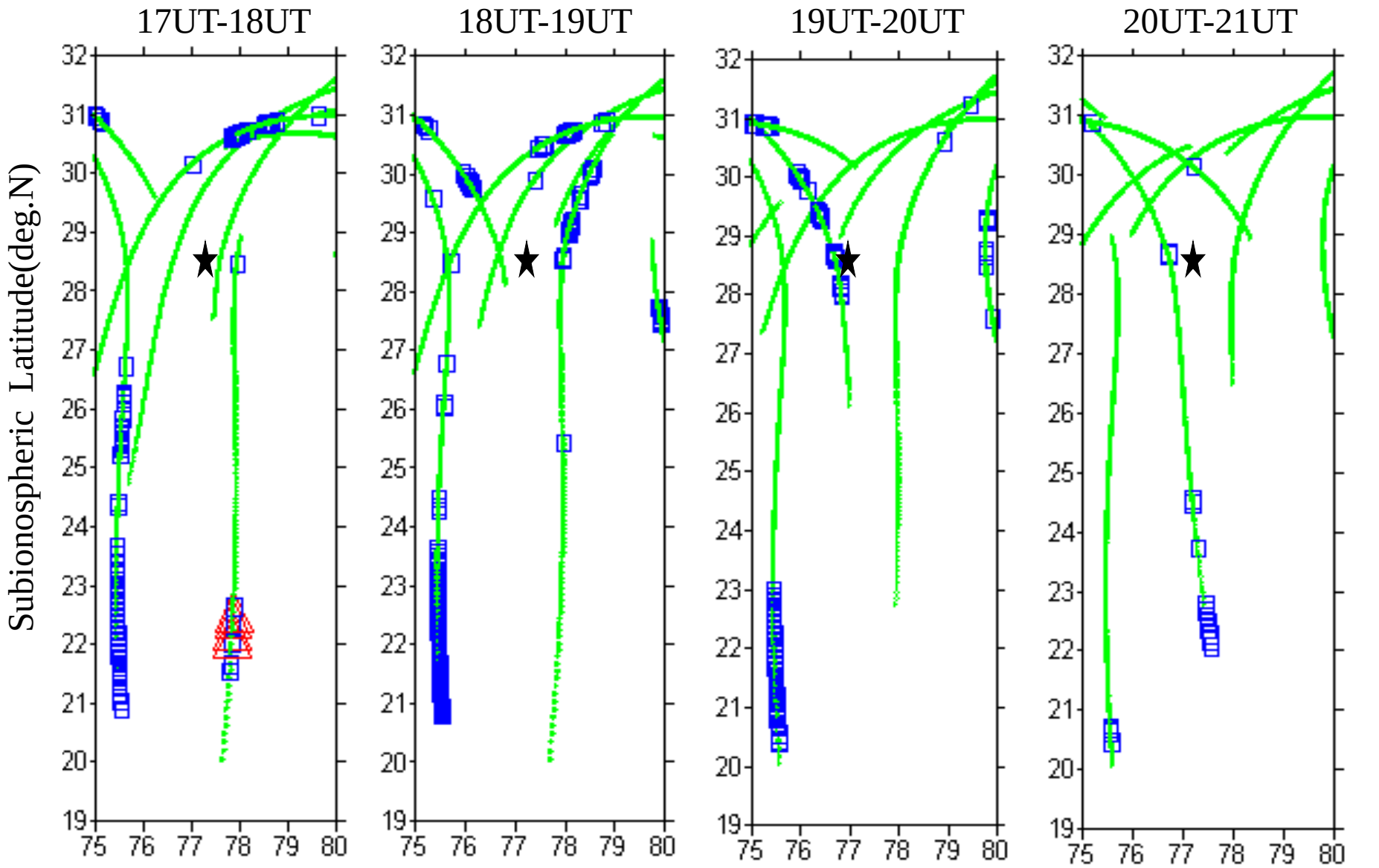
c) Propagation angle map in terms of Magnetic Latitude and Subionospheric Longitude for Bhopal.

Station: Delhi
Period: August-October 2004



○ S4 < 0.3 □ 0.3 ≤ S4 < 0.6 Δ S4 ≥ 0.6 Subionospheric Longitude(deg.E) LT = UT + 05.17h

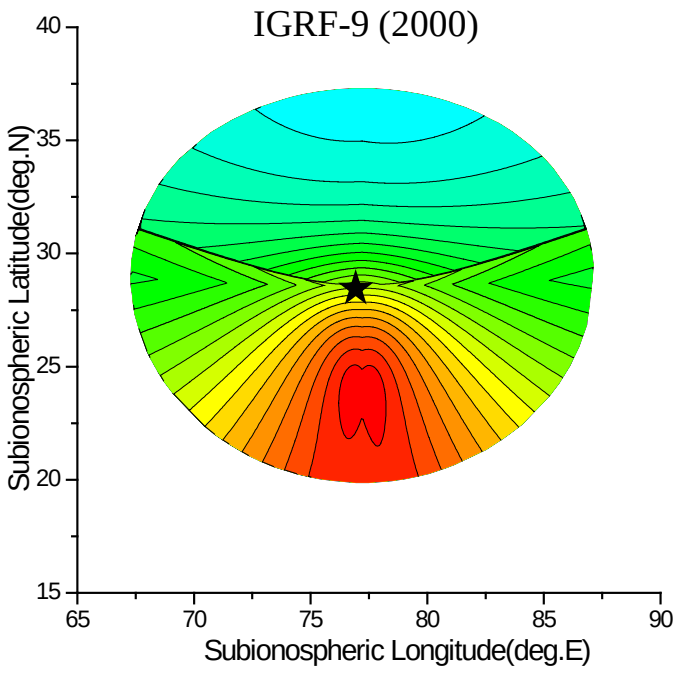
Station: Delhi
Period: August-October 2004

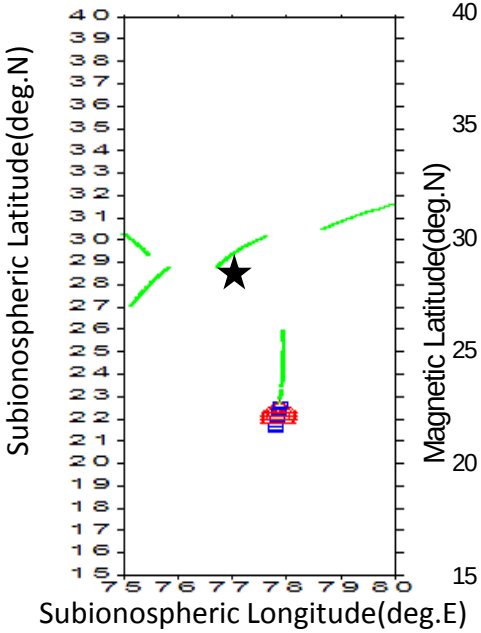


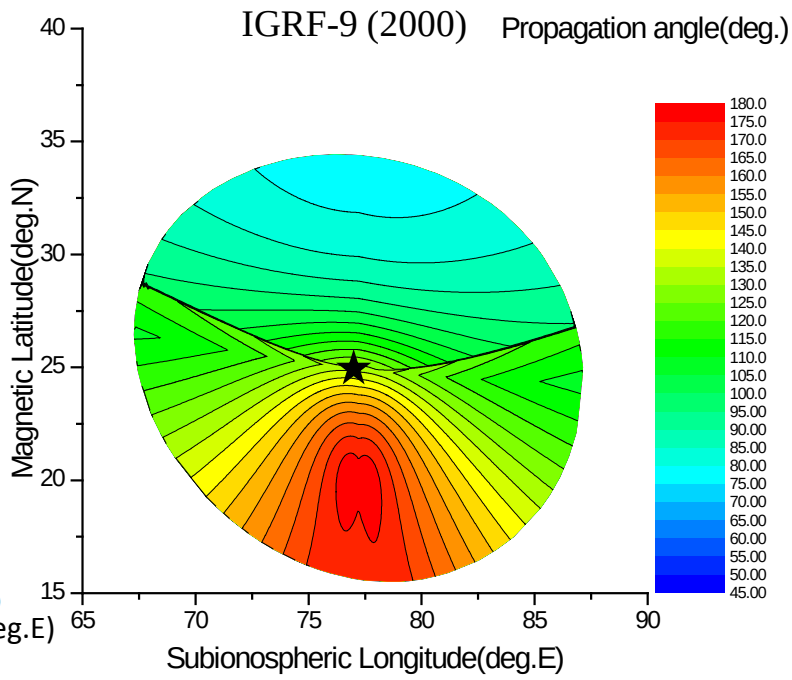
○ S4 < 0.3 □ 0.3 ≤ S4 < 0.6 Δ S4 ≥ 0.6 Subionospheric Longitude(deg.E) LT = UT + 05.17h

Station: Delhi

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







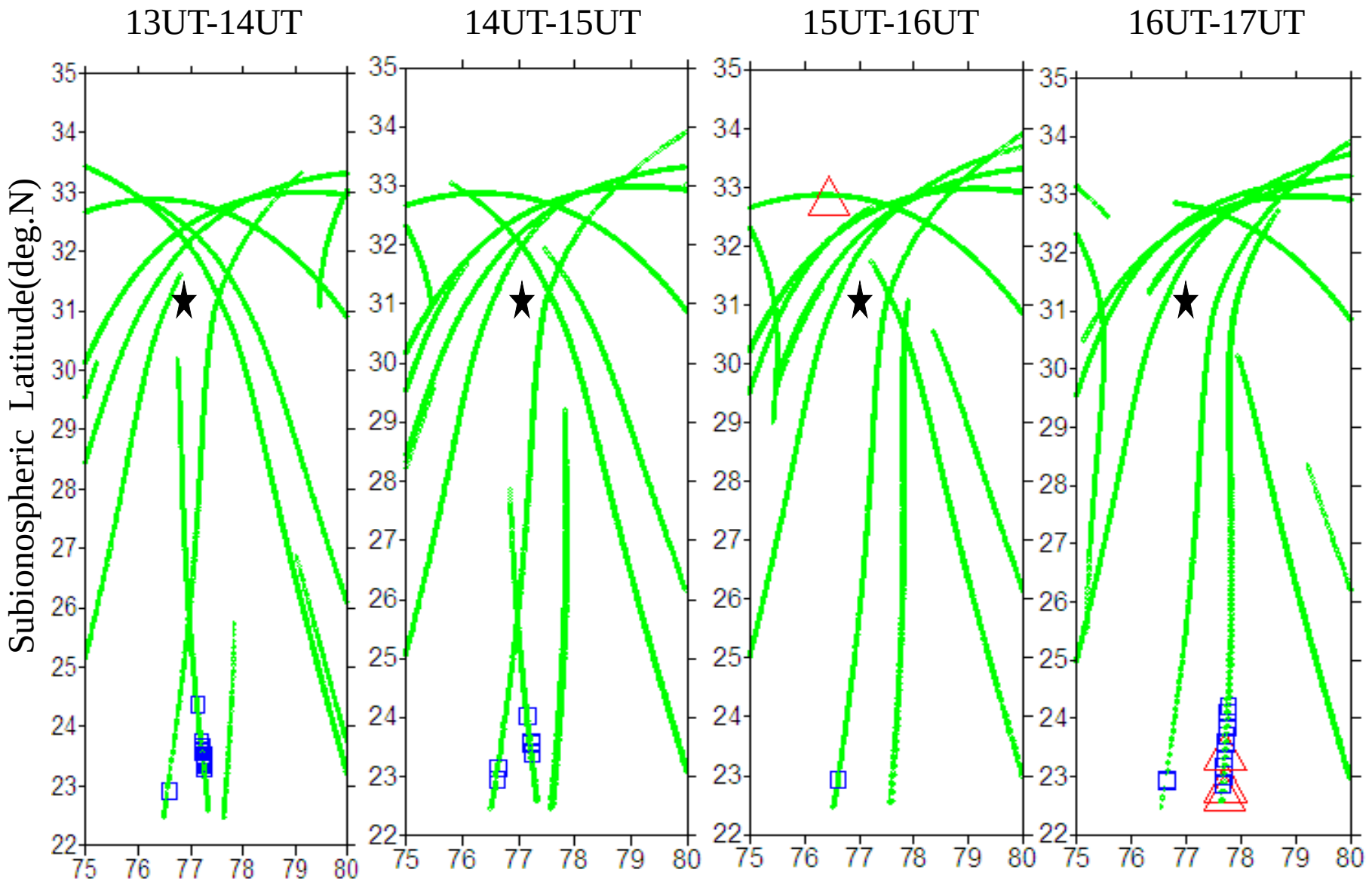
(a) (b) (c)

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)

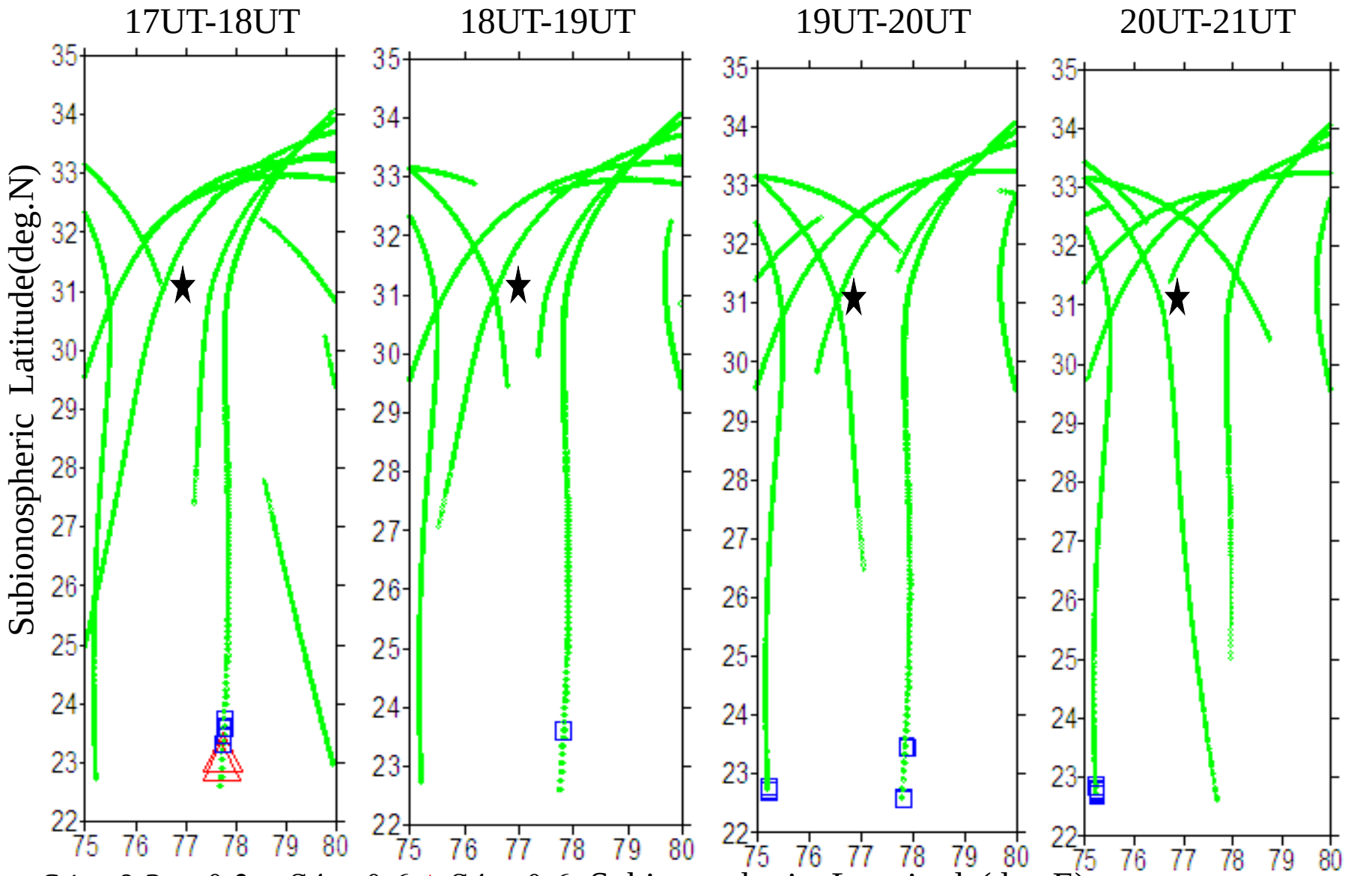
a)Propagation angle map in terms of Subionospheric Latitude and Longitude for Delhi.
b)Scintillation observed from Delhi during 17:00-18:00UT on September 11, 2004.
c)Propagation angle map in terms of Magnetic Latitude and Subionospheric Longitude for Delhi.

Station: Shimla
Period: August-October 2004



○ S4 < 0.3 □ 0.3 ≤ S4 < 0.6 Δ S4 ≥ 0.6 Subionospheric Longitude(deg.E) LT = UT + 05.17h

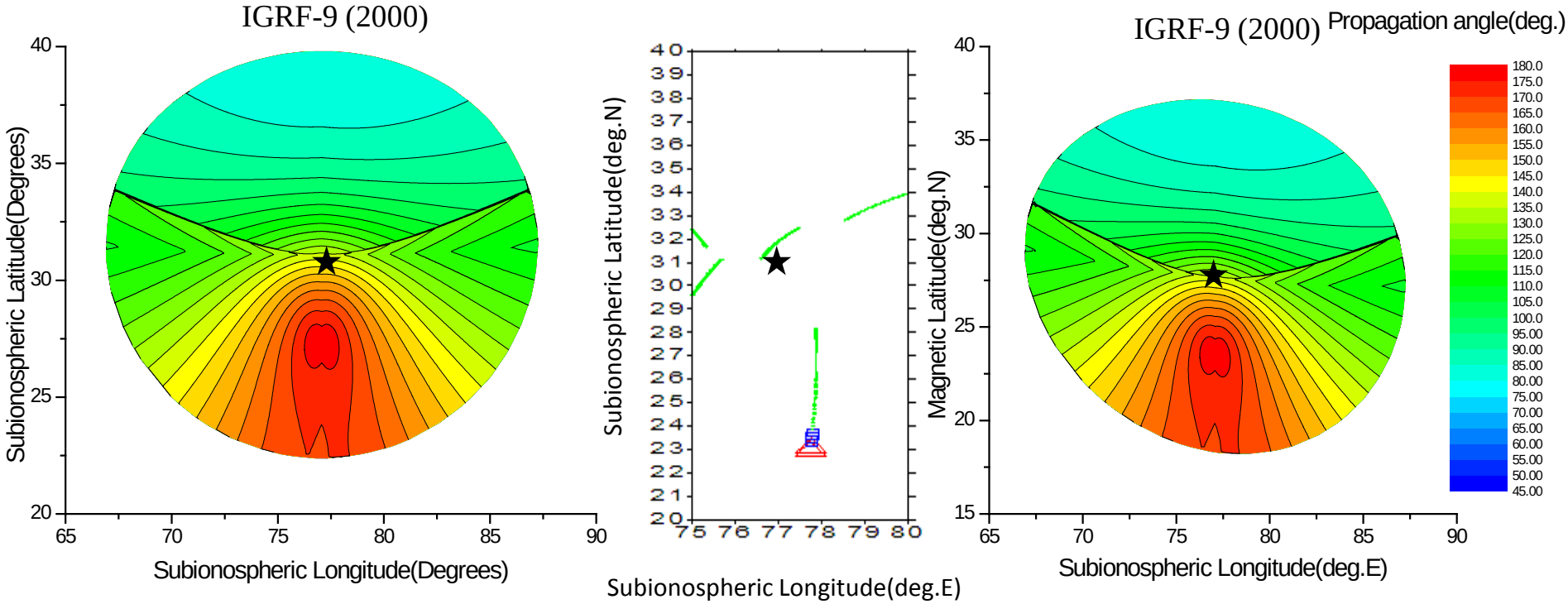
Station: Shimla
Period: August-October 2004



○ S4 < 0.3 □ 0.3 ≤ S4 < 0.6 Δ S4 ≥ 0.6 Subionospheric Longitude(deg.E) LT = UT + 05.17h

Station: Shimla

[Latitude:31.09°N, Longitude: 77.07° E (geographic) ;Magnetic Latitude:27.65°N]



(a) (b) (c)

Maximum Propagation Angle : 179.85° ○ S4 < 0.3 □ 0.3 ≤ S4 < 0.6 Δ S4 ≥ 0.6 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)

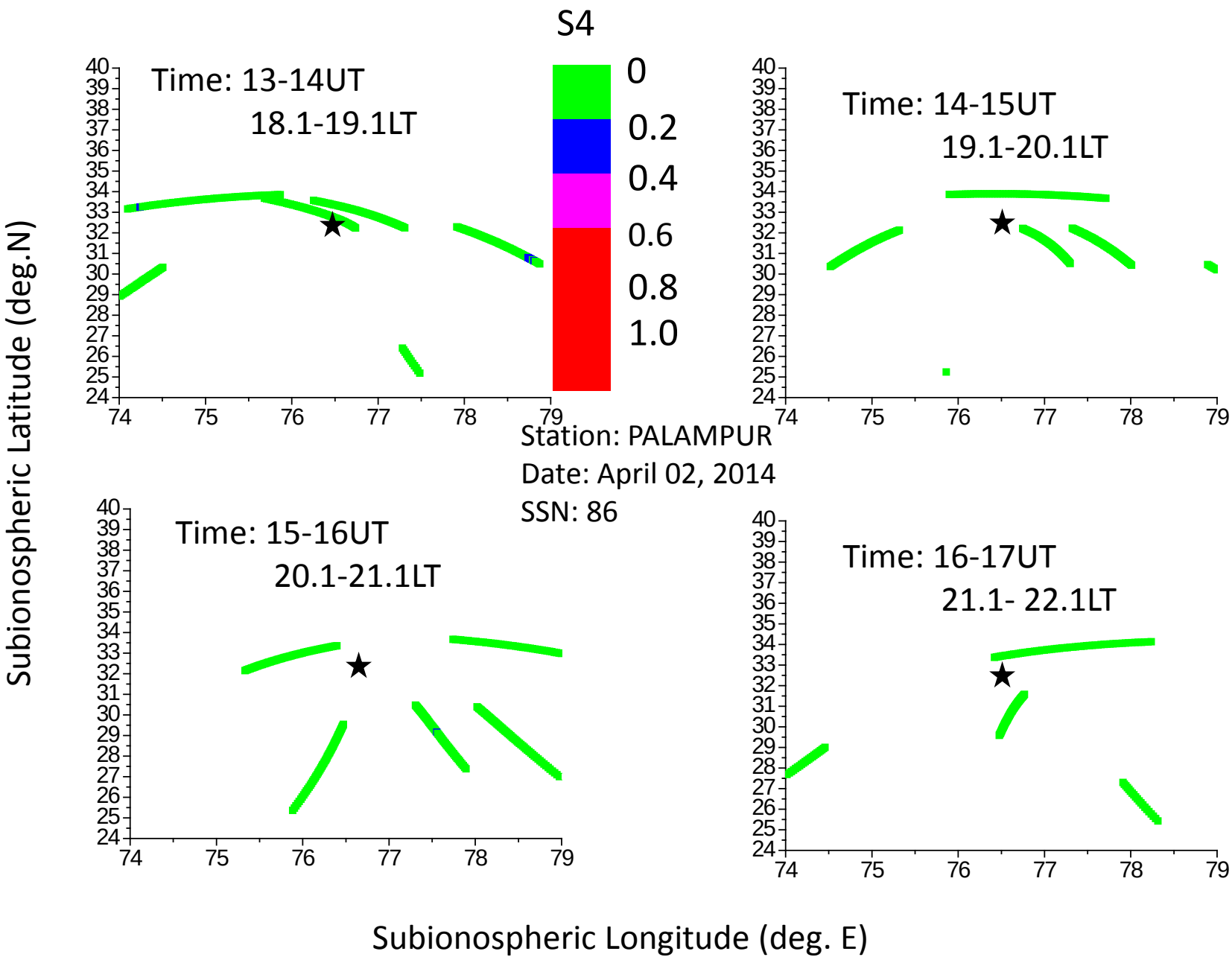
a)Propagation angle map in terms of Subionospheric Latitude and Longitude for Shimla.
b)Scintillation observed from Shimla during 17:00-18:00UT on September 11, 2004.
c)Propagation angle map in terms of Magnetic Latitude and Subionospheric Longitude for Shimla.

FROM SCINTILLATION DATA ANAYSIS AND COMPARISON WITH THEORETICAL PROPAGATION ANGLE MAPS….

- For stations with magnetic latitude within 25^{o}N, enhanced scintillations due to field-aligned propagation occur when the irregularities causing L-band scintillaltions 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^{o} 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^{o}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.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0.6
0.8
1.0
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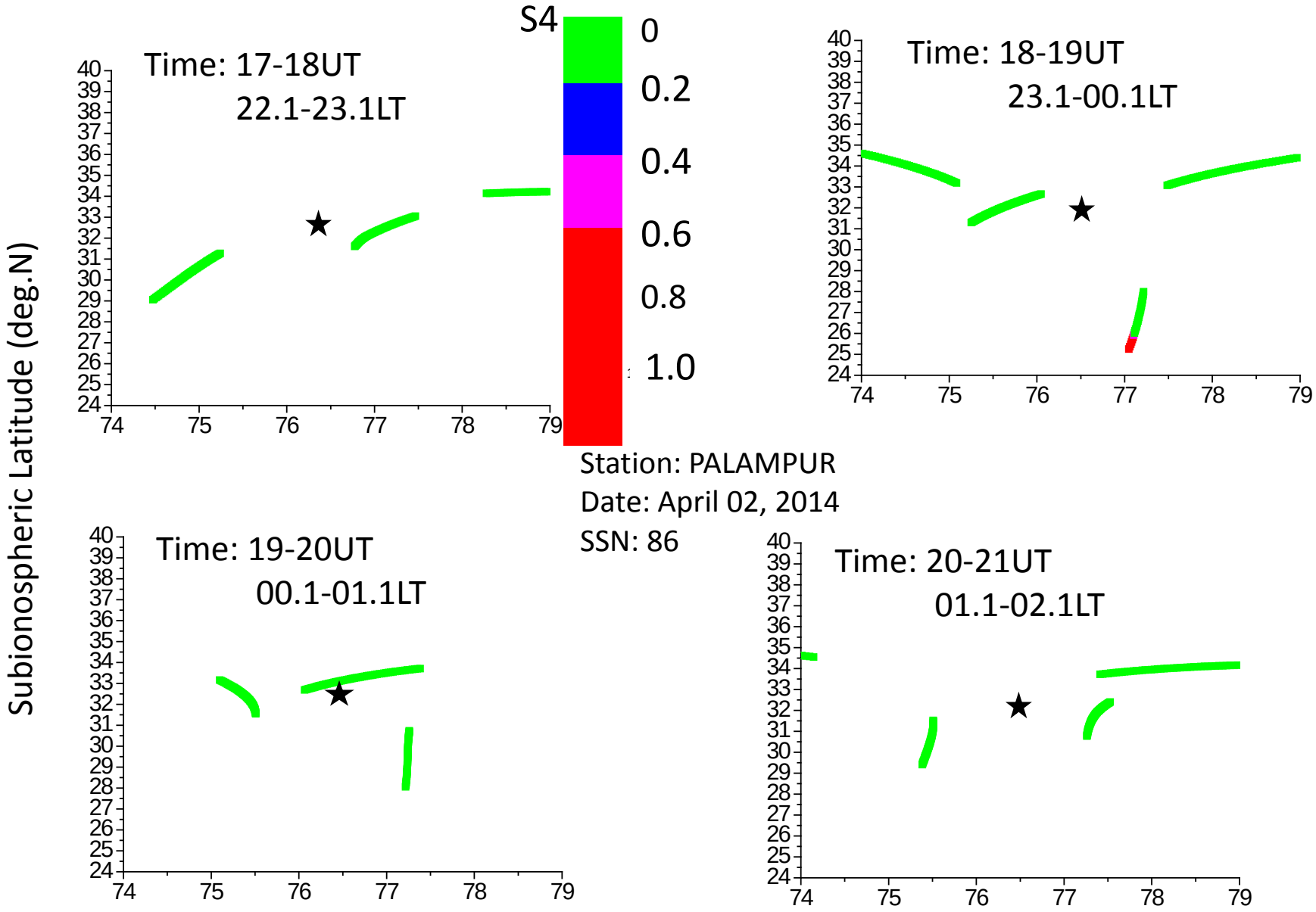
18.1-19.1LT
Time: 14-15UT
19.1-20.1LT
Time: 15-16UT
20.1-21.1LT
Time: 16-17UT
21.1- 22.1LT
Station: PALAMPUR
Date: April 02, 2014
SSN: 86
Subionospheric Latitude (deg.N)
Subionospheric Longitude (deg. E)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Time: 19-20UT
00.1-01.1LT
Time: 20-21UT
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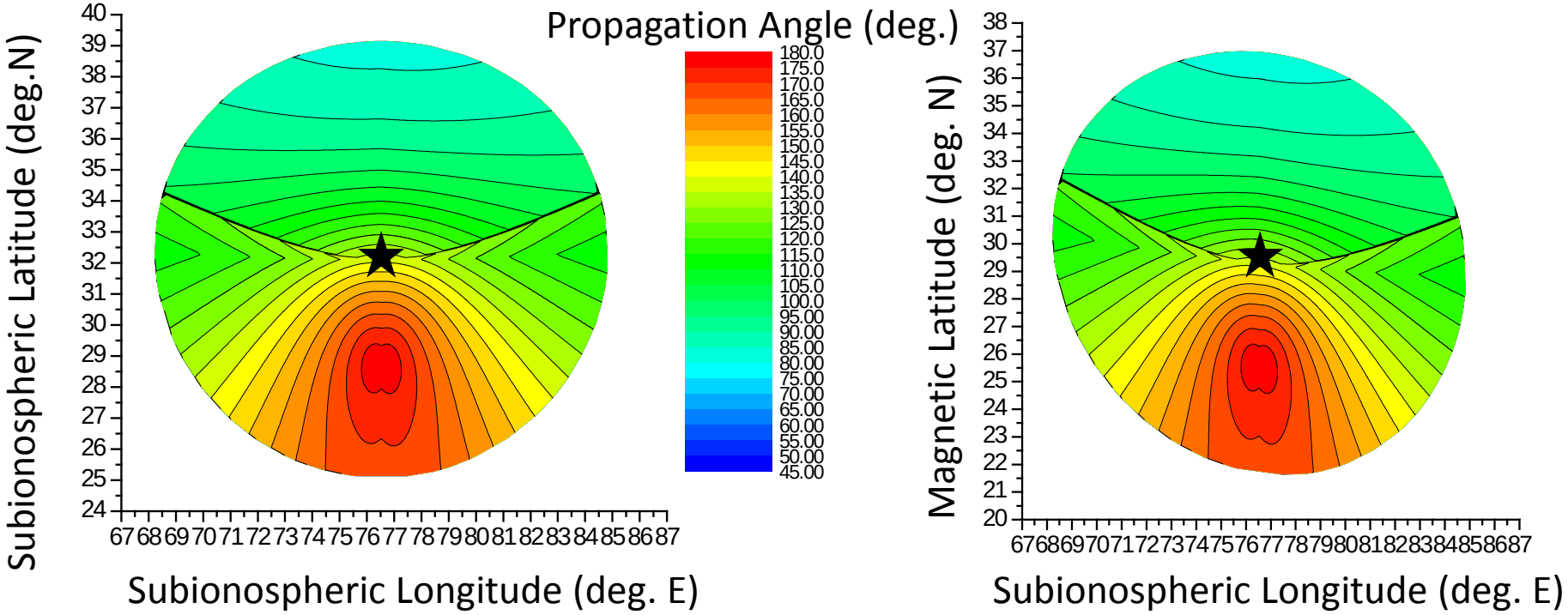
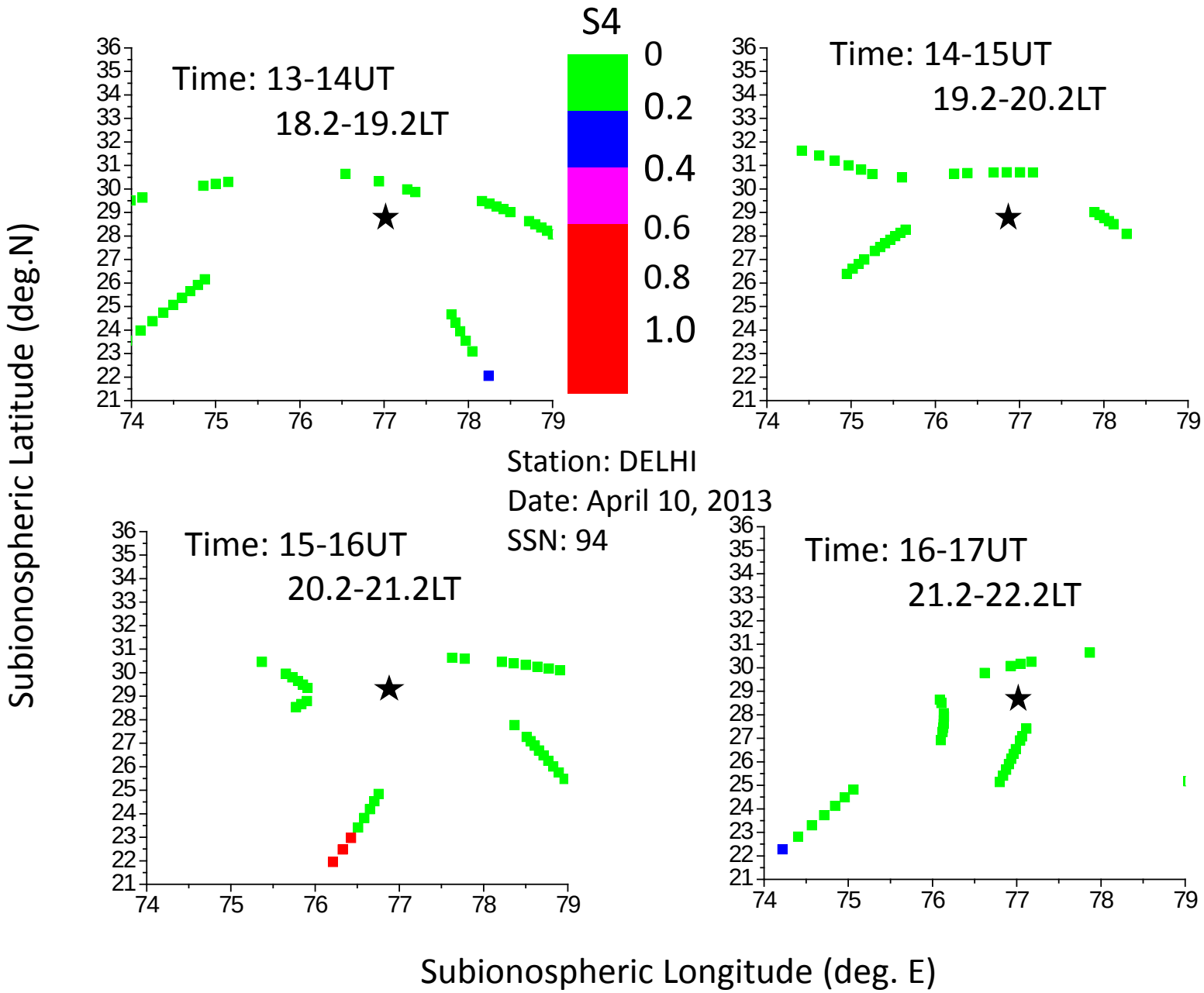
Station: PALAMPUR
Date: April 02, 2014
SSN: 86
Subionospheric Latitude (deg.N)
Subionospheric Longitude (deg. E)

Station: PALAMPUR

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Time: 15-16UT
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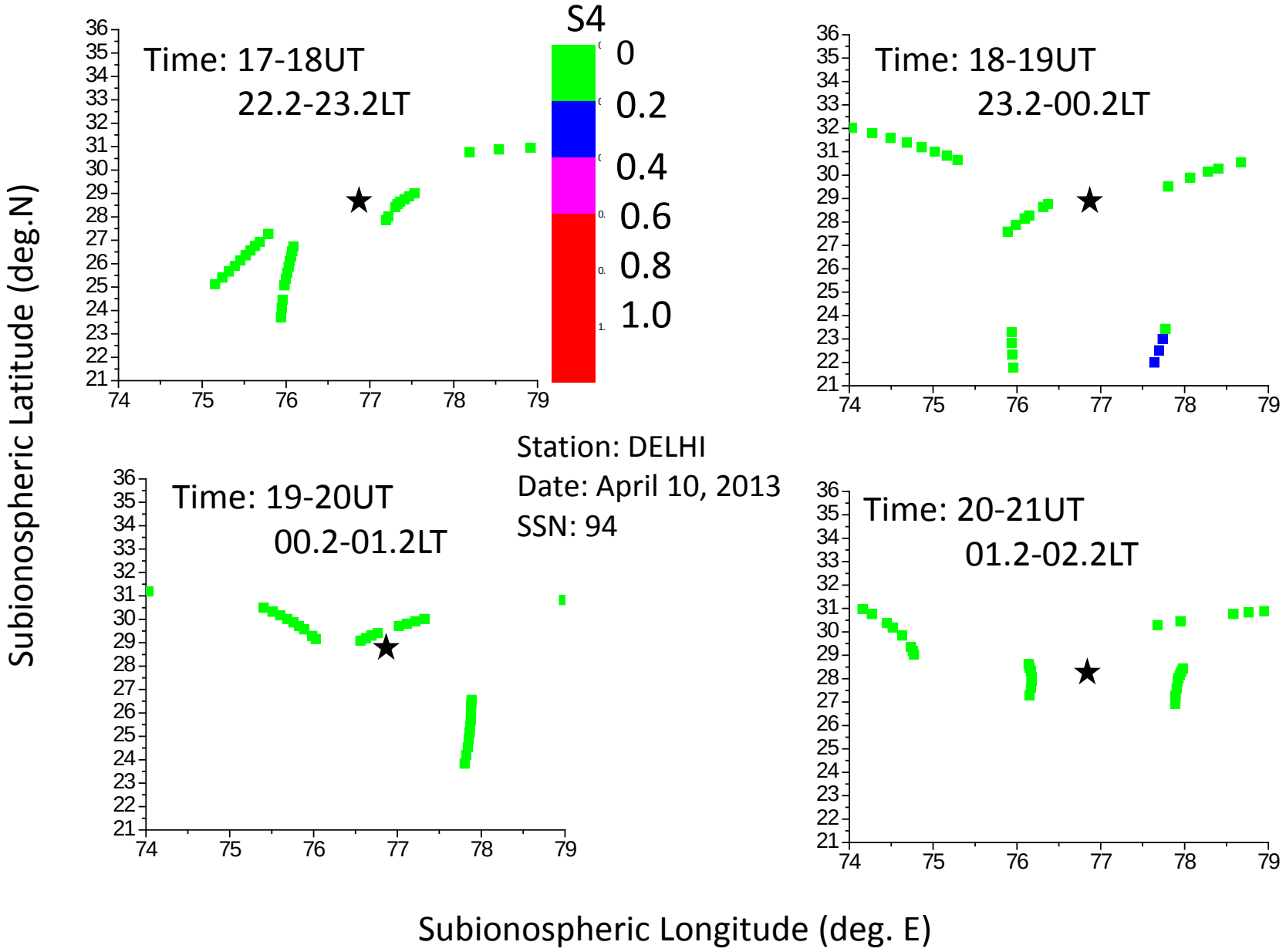
Station: DELHI
Date: April 10, 2013
SSN: 94
Subionospheric Latitude (deg.N)
Subionospheric Longitude (deg. E)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Station: DELHI
Date: April 10, 2013
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Time: 19-20UT
00.2-01.2LT
Time: 20-21UT
01.2-02.2LT
Subionospheric Latitude (deg.N)
Subionospheric Longitude (deg. E)

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.

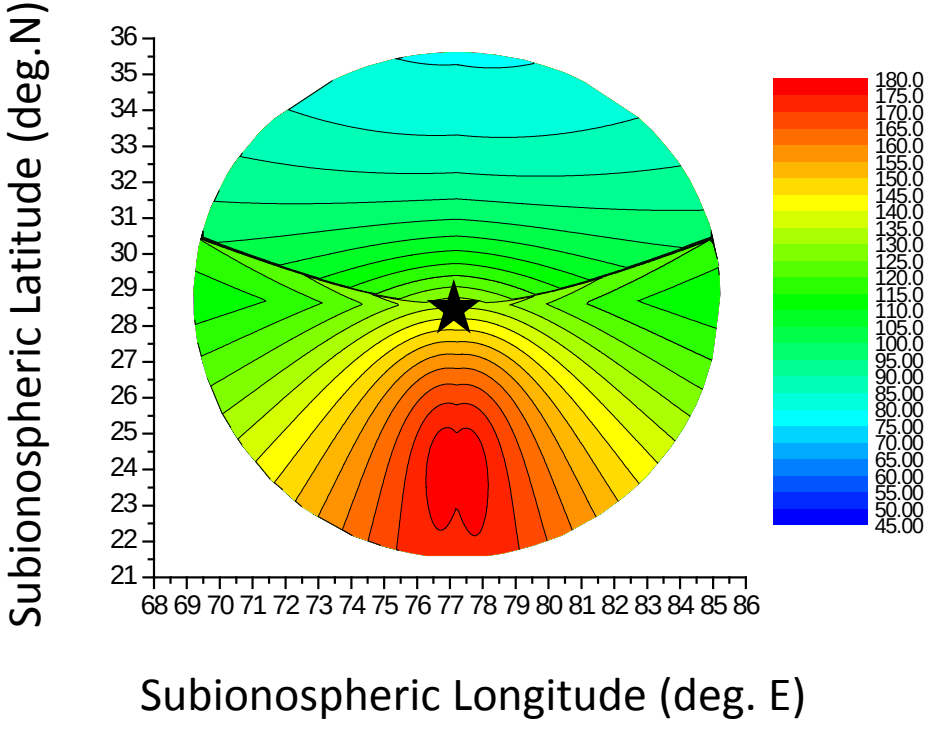
Acknowledgements

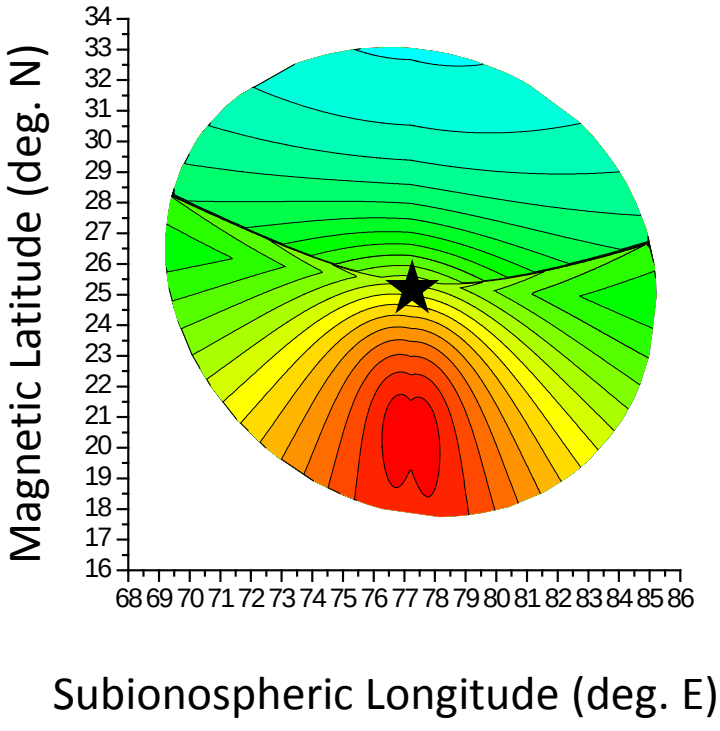
- The authors are grateful to International Association of Geomagnetism and Aeronomy (IAGA) for providing the IGRF coeffecients.
- The authors acknowledge the help of Mr. Utsav Bhowmik in developing the algorithm.

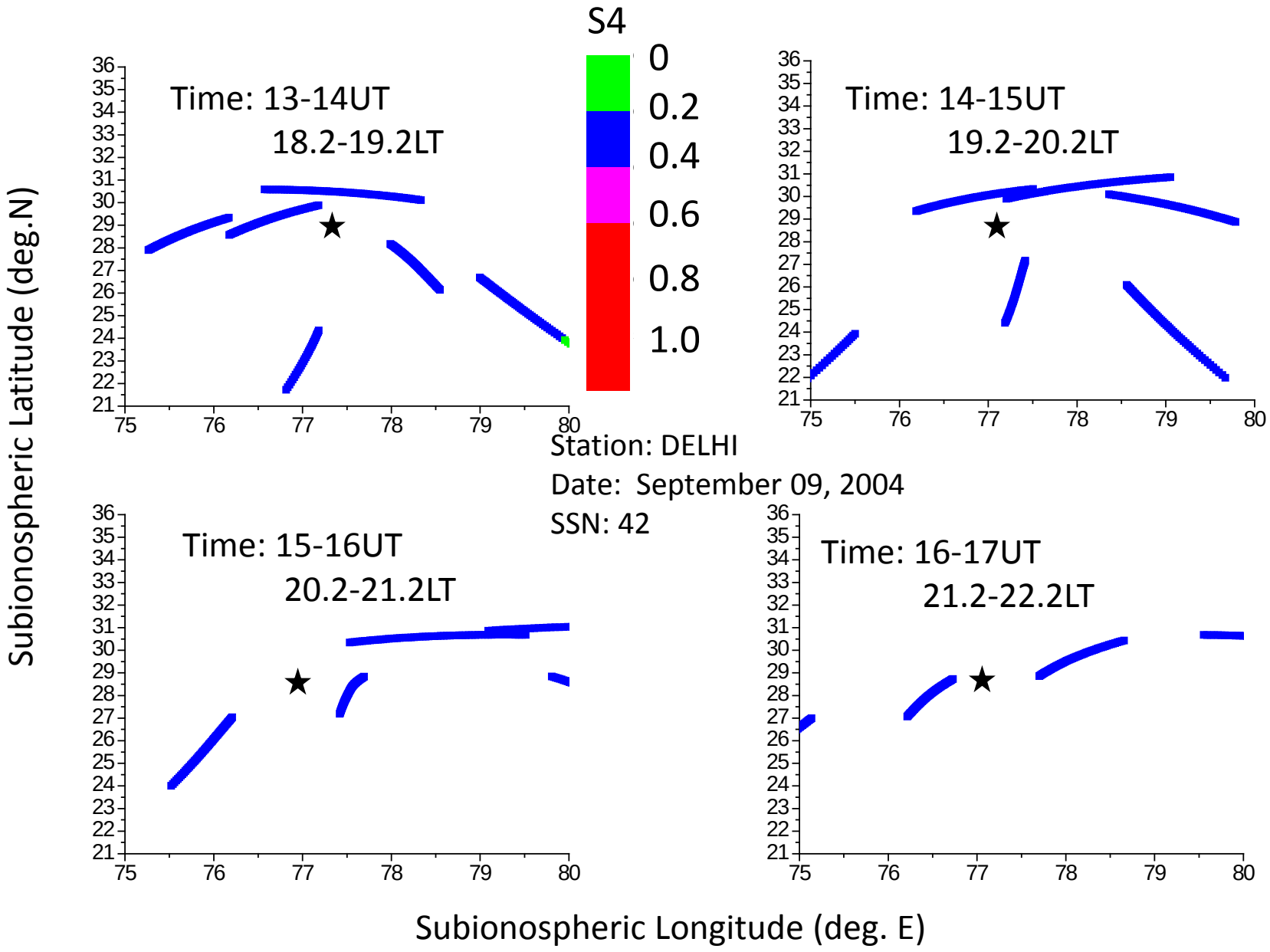
Thank you!

Station: DELHI

Propagation Angle (deg.)



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Time: 14-15UT
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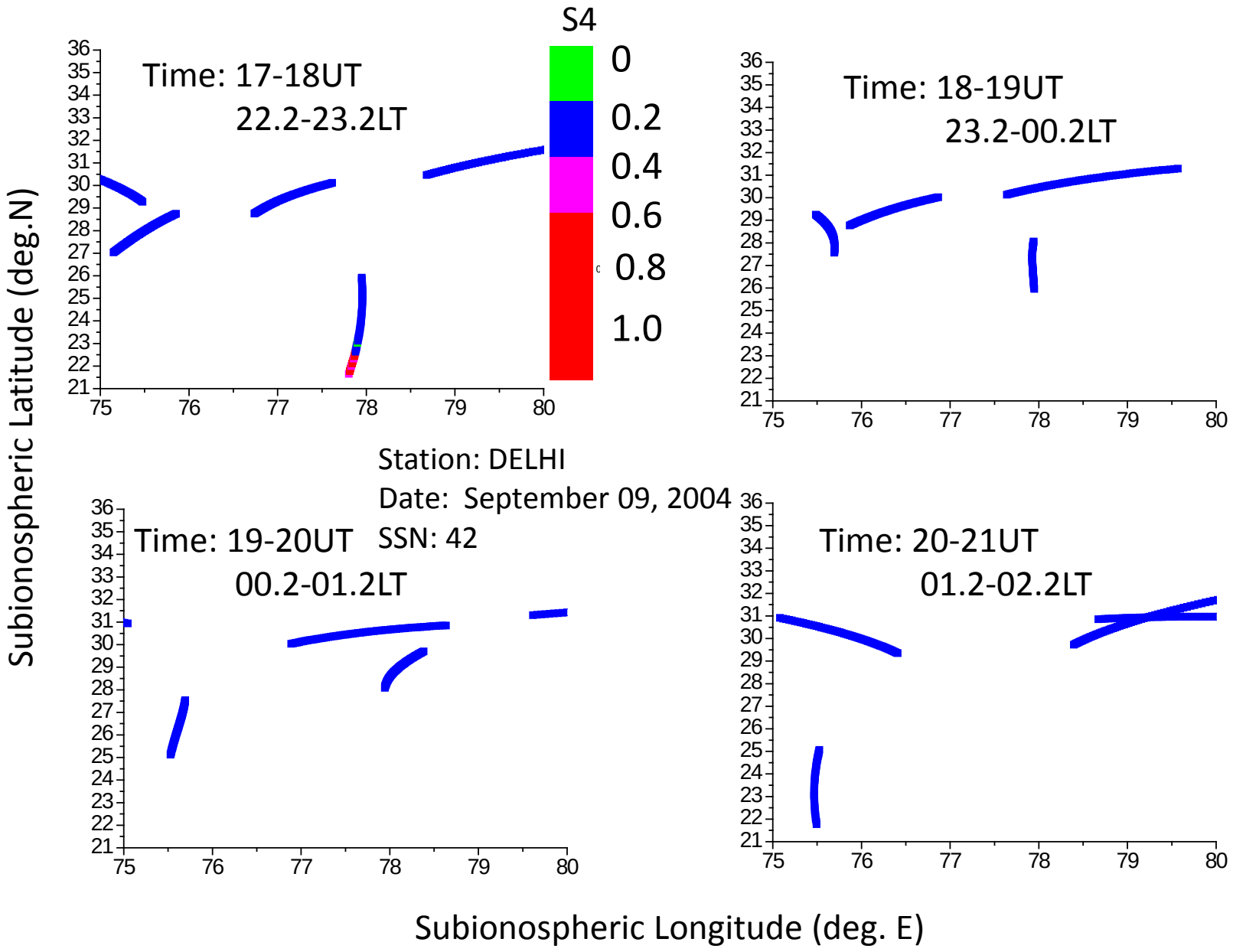
Time: 15-16UT
20.2-21.2LT
Time: 16-17UT
21.2-22.2LT
Station: DELHI
Date: September 09, 2004
SSN: 42
Subionospheric Latitude (deg.N)
Subionospheric Longitude (deg. E)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Time: 18-19UT
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Time: 19-20UT
00.2-01.2LT
Time: 20-21UT
01.2-02.2LT
Station: DELHI
Date: September 09, 2004
SSN: 42
Subionospheric Latitude (deg.N)
Subionospheric Longitude (deg. E)