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

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- 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.

- These phenomena have the potential to cause serious damage to the technological infrastructure on which society relies

- GPS modernization program is focused on addition of a new navigation signal L5 (1176.45MHz) to the GPS constellation. The L5 is exclusively reserved for aviation navigation services and is designed with a protected spectrum, higher power, and greater bandwidth to support life-critical and high performance applications.

- For future aviation, GNSS will use dual-frequency civilian codes L1 and L5
- The frequency diversity mechanism at L1 and L5 frequencies may mitigate impact of ionospheric scintillations on GPS-based aviation – suggestion??

▶Overall robustness of this dual-frequency mechanism to ionospheric scintillations could be ascertained through a study of correlated scintillations. Understanding the correlation of signal fades across two frequencies is important to assess their collective mitigation effectiveness. **If signal fades at two frequencies are highly correlated, the actual aim of the frequency diversity scheme would be defeated *[Gherm et al., Proc. EuCAP,* 2006; *Das and Paul,* URSI-GA, 2014].**

Spatial Diversity

- Effects of an integrated GPS and GLONASS constellation on position accuracy were studied at different places over India during 1999-2001 [*Banerjee et al., J. Navigation*, 55, 3, 463-475, 2002].

- However the GLONASS constellation had degraded from 16 to 7 satellites only at that time, thereby making the observations dominantly GPS-only.

- In contrast the present scenario offers a full 'healthy' GLONASS constellation of 24 active satellites.

- A study on the effects of equatorial ionospheric scintillations on timing applications of GPS showed a degradation of the order of 60ns [*Banerjee et al., IEEE Trans. Instrmnt. And Measmnts.*, 56(5), 1596-1600, 2007].

- 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°.

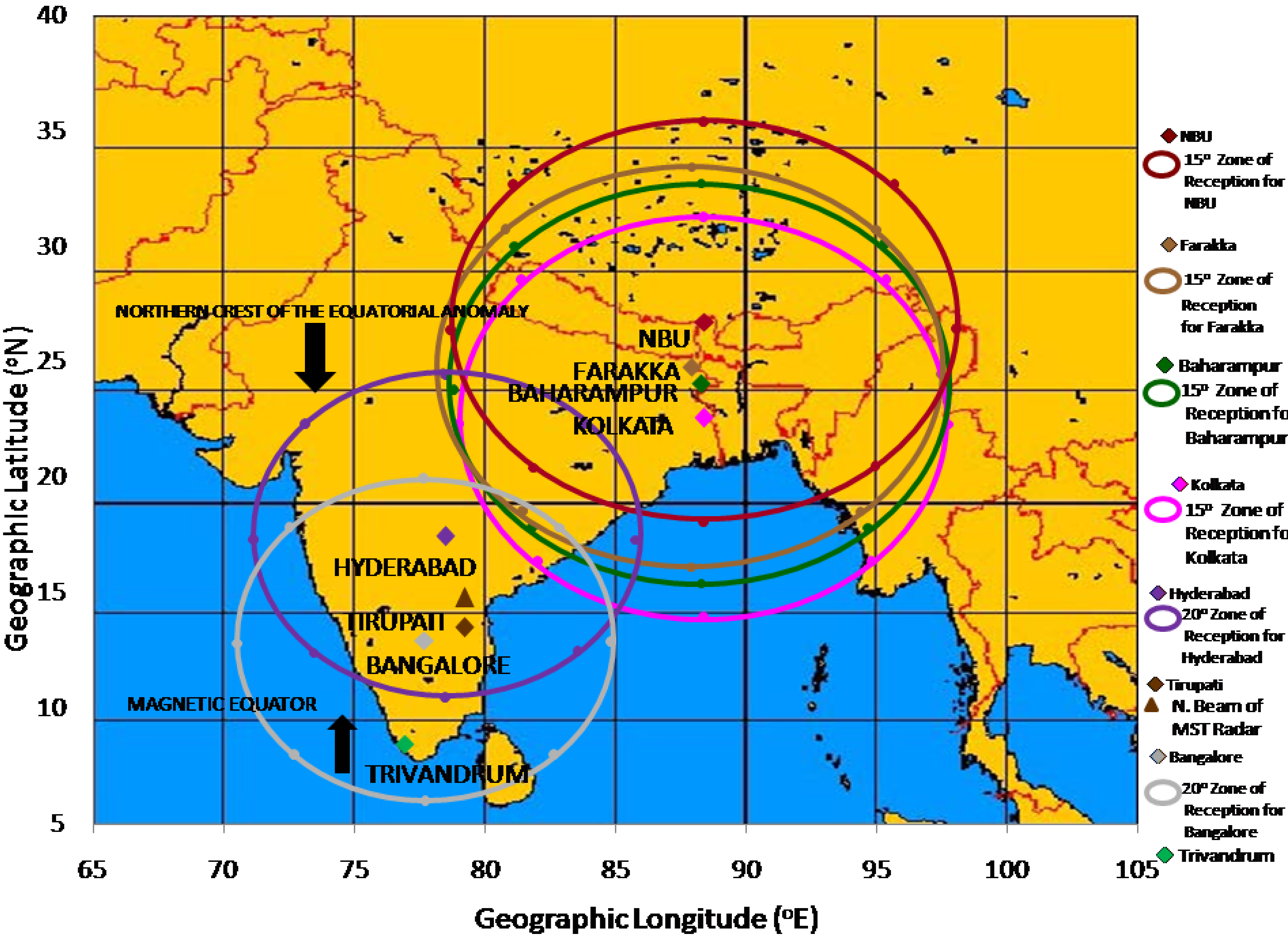
- As GPS-only constellation was not possible to address this issue, it will be very important to check the availability of increased number of ionospheric pierce points when multi-constellation receivers are operational at a station like Calcutta situated near the northern crest of the EIA [*Paul et al.*, *NAVIGATION*, 2005; *J. Atmos. Sol. Terr. Phys.*, 2011]

- Performance of an SDR GPS has been compared with a commercial GNSS ISM Rx [*Morton et al.*, URSI GA 2014]

Motivation

- 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 in the highly dynamic equatorial ionosphere.

- As future GNSS receivers will transmit three frequencies for civilian applications, namely, L1, L2, and L5 in case of GPS, G1, G2 and G5 by GLONASS and E1, E6 and E5a by GALILEO, this will provide more advanced three-frequency correction schemes for which knowledge of correlation of different frequency pairs (L1/L2, L1/L5, L2/L5) under scintillation conditions is desirable.



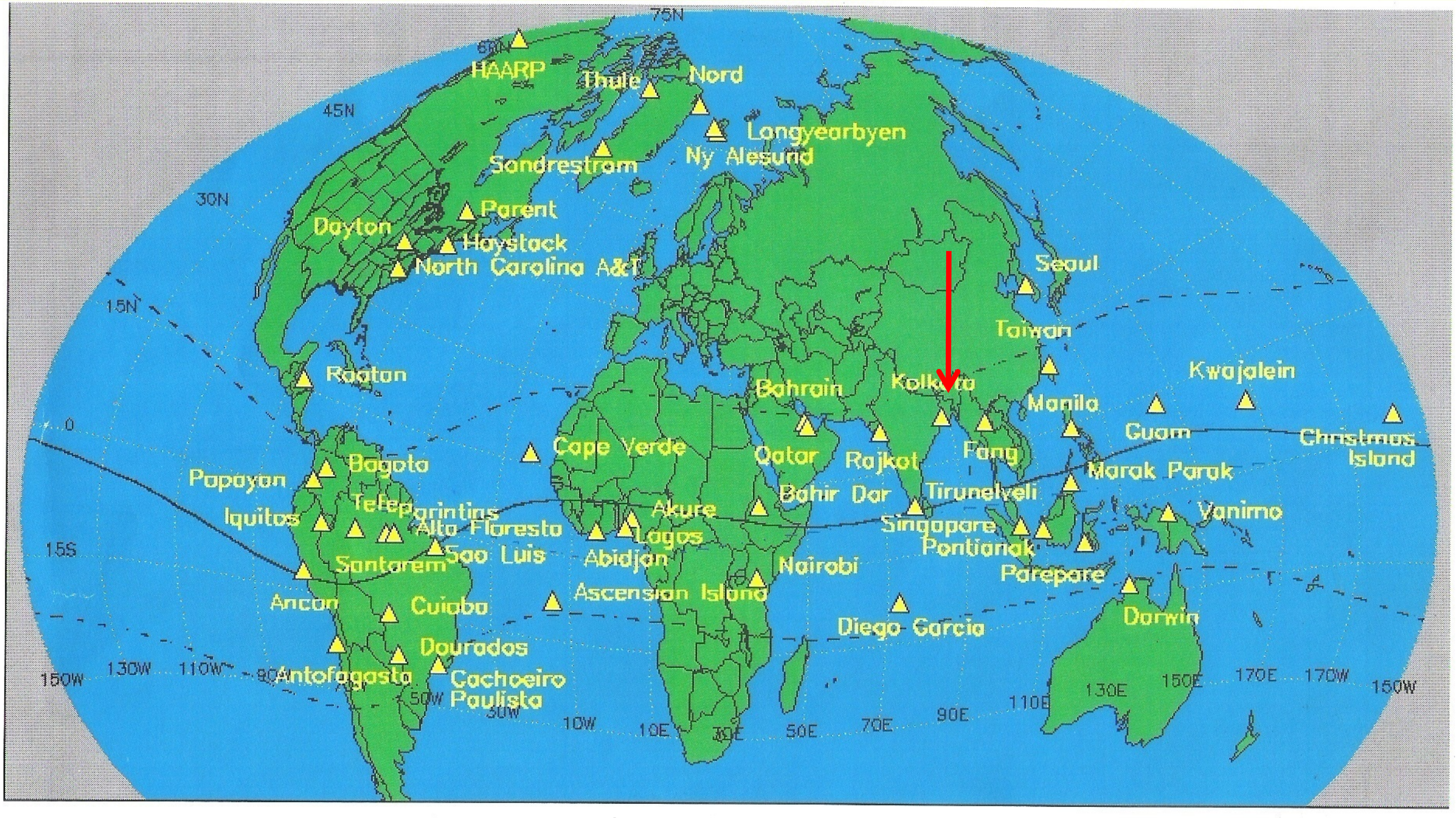
Geographic Latitude (°N)
Geographic Longitude (°E)
NORTHERN CREST OF THE EQUATORIAL ANOMALY
MAGNETIC EQUATOR
NBU
FARAKKA
BAHARAMPUR
KOLKATA
HYDERABAD
TIRUPATI
BANGALORE
TRIVANDRUM
NBU
15° Zone of Reception for NBU
Farakka
15° Zone of Reception for Farakka
Baharampur
15° Zone of Reception fo Baharampur
Kolkata
15° Zone of Reception fo Kolkata
Hyderabad
20° Zone of Reception for Hyderabad
Tirupati
N. Beam of MST Radar
Bangalore
20° Zone of Reception for Bangalore
Trivandrum

The Space Weather and Satellite Beacon group at the **Institute of Radio Physics and Electronics** and **S.K. Mitra Center for Research in Space Environment, University of Calcutta**, Calcutta (22.58°N 88.38°E geographic; 32°N magnetic dip) presently operates

- **GNU VHF (FLEETSATCOM, 250MHz) spaced-aerial measurements**

- Operates a **Proton Precession Magnetometer (PPM)** at the **Ionosphere Field Station (IFS) at Haringhata (22.94°N 88.52°E geographic; magnetic dip: 33.82°N)**, about 50km north-east of Calcutta at a place of relatively low radio-frequency interference.

SCINDA (SCIntillation Network Decision Aid) station of the US Air Force since November 2006 at the Institute of Radio Physics and Electronics, University of Calcutta, Calcutta



Global distribution of SCINDA stations

- **A multi-constellation, multi-frequency GNSS receiver is operational at the Institute of Radio Physics and Electronics, University of Calcutta, Calcutta (22.58°N 88.38°E geographic; magnetic dip: 32°N) since April 2013.**

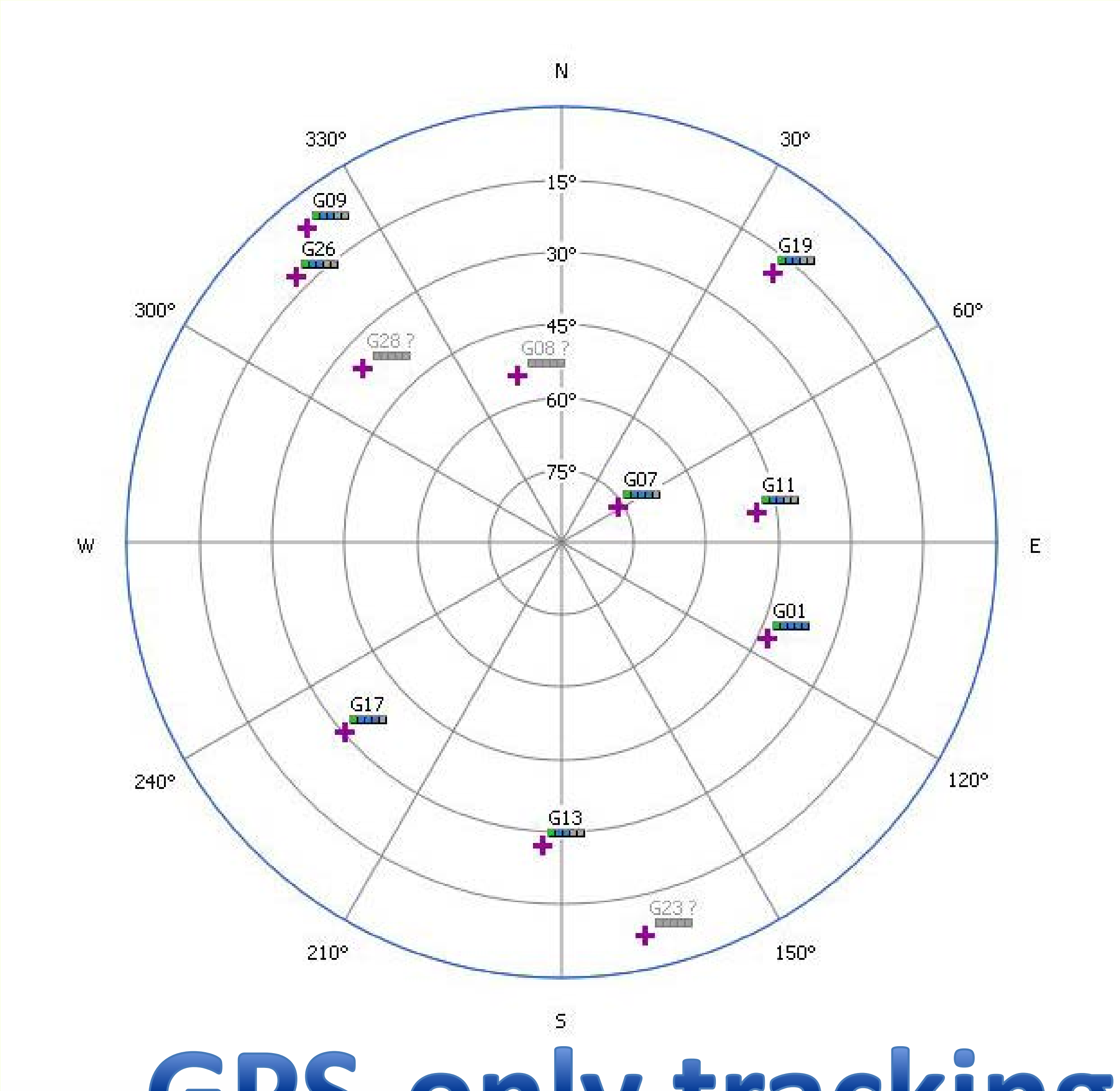
- **This receiver is capable of receiving signals from GPS, GLONASS, GALILEO and SBAS at L1 (1575.42MHz), L2 (1227.6MHz) and L5 (1176.45MHz) frequencies.**

It provides at its output

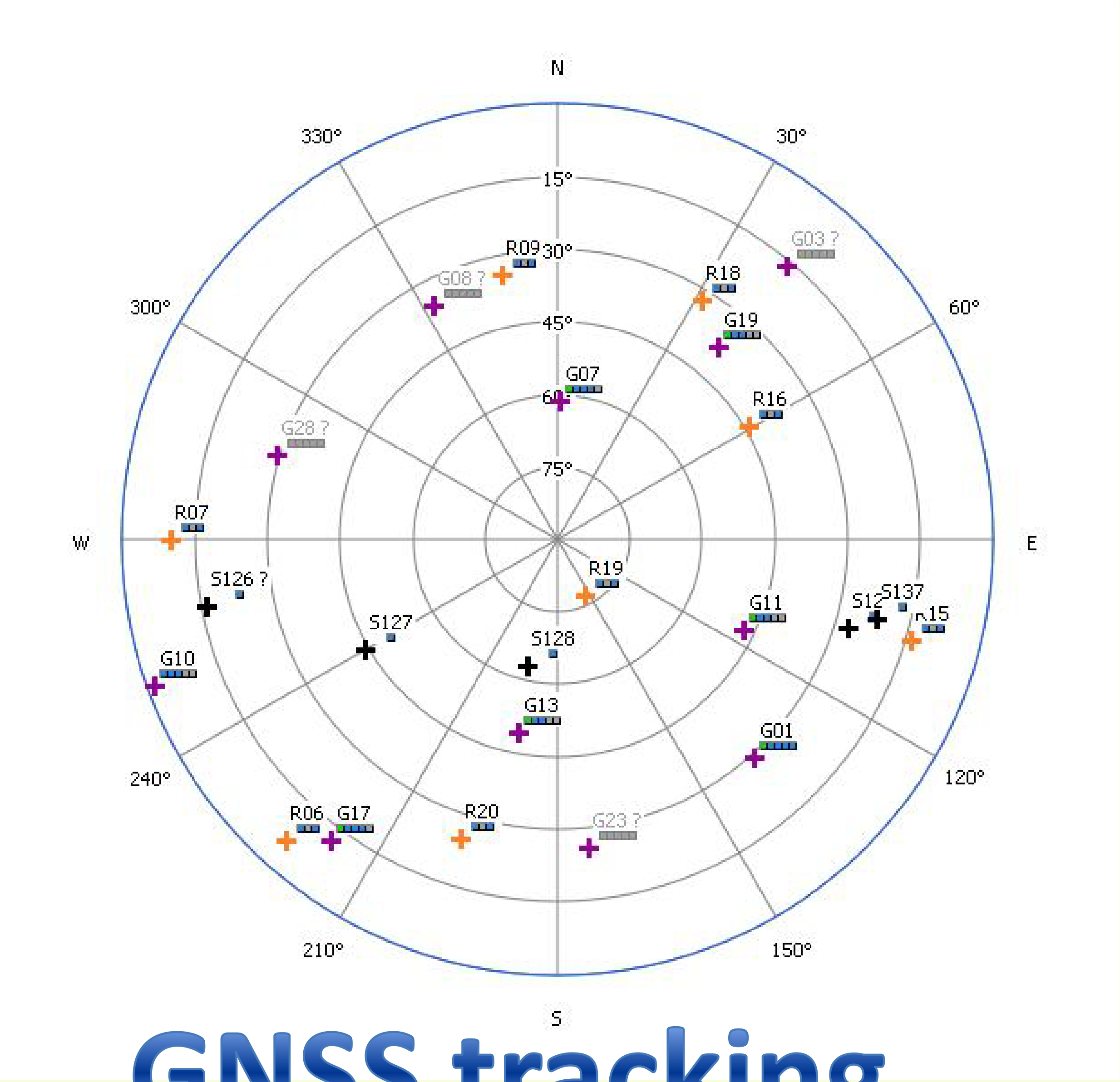
- **elevation**
- **azimuth**
- **time (UTC)**
- **carrier-to-noise ratios (CNO), and**
- **amplitude scintillation index S_4 at a sampling interval of 1minute.**

No. of nights of GPS scintillations observed from Calcutta with $S_4 \geq 0.6$ at elevation $\geq 15°$

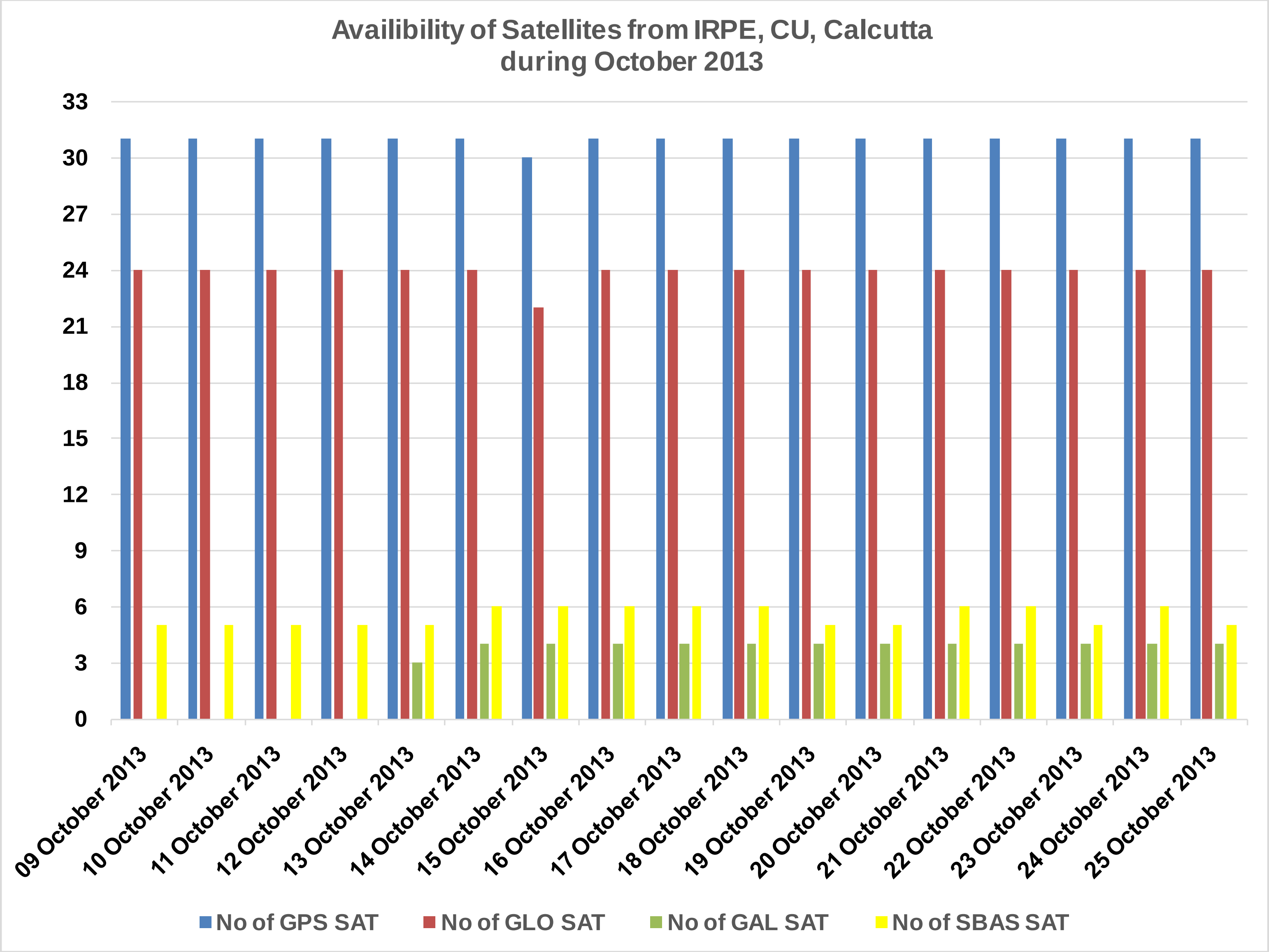
February – April 2011:	38
August – October 2011:	22
February – April 2012:	25
August – October 2012:	22
February – April 2013:	25
August – October 2013:	14
February-April 2014:	60!!
August – October 2014:	27



GPS-only tracking

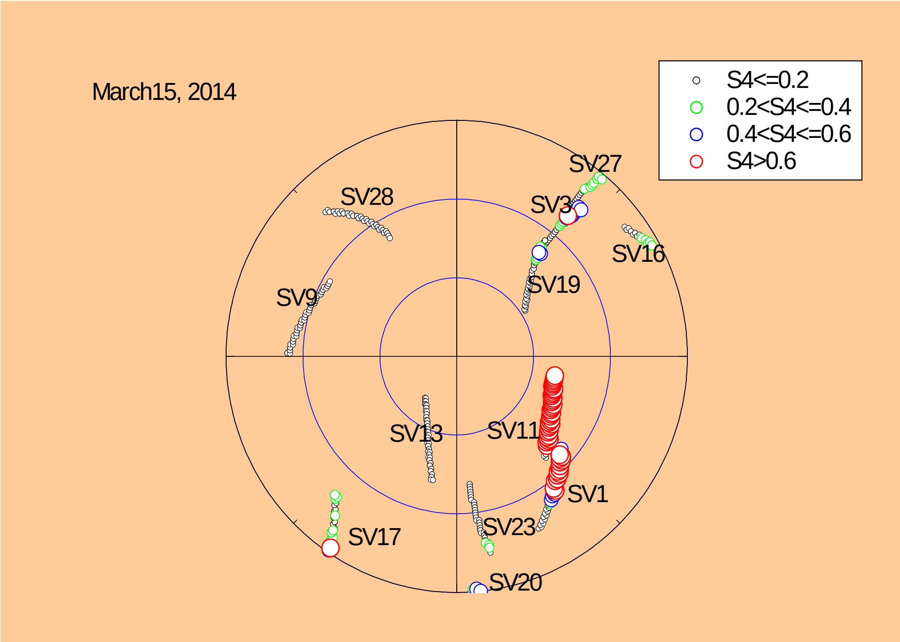


GNSS tracking

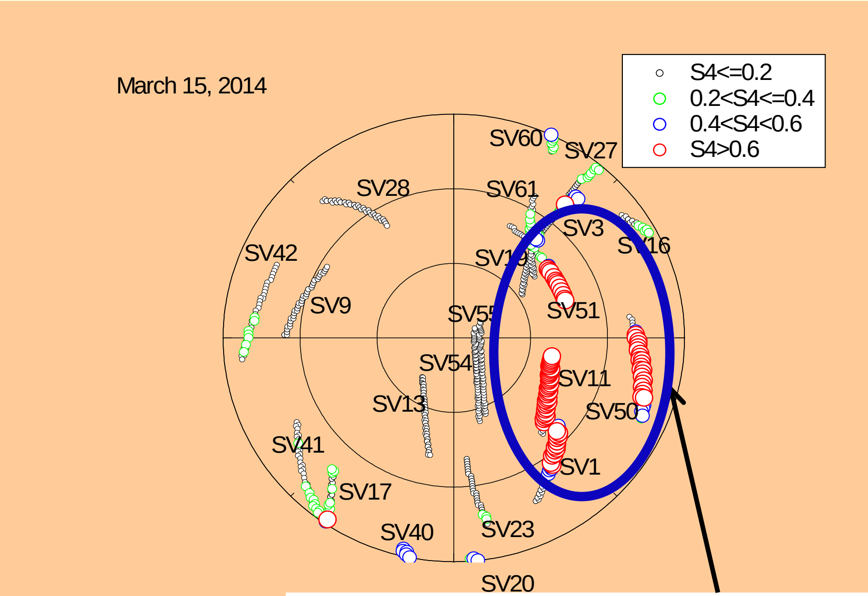


GPS – SV1-28, 31, 32 GLONASS – SV38-61 GALILEO – SV81, 82, 89, 90 SBAS – SV126-129, 137

March 15, 2014
13:00-14:00UT
Stn: Calcutta, India



GPS



Portion of the sky affected by intense scintillations

GPS + GLONASS +GALILEO

- **Availability of non-scintillating satellite links when SV links are affected by scintillations in certain section of the sky**
- **Possible identification of look angles with S4<0.4 at different hours**

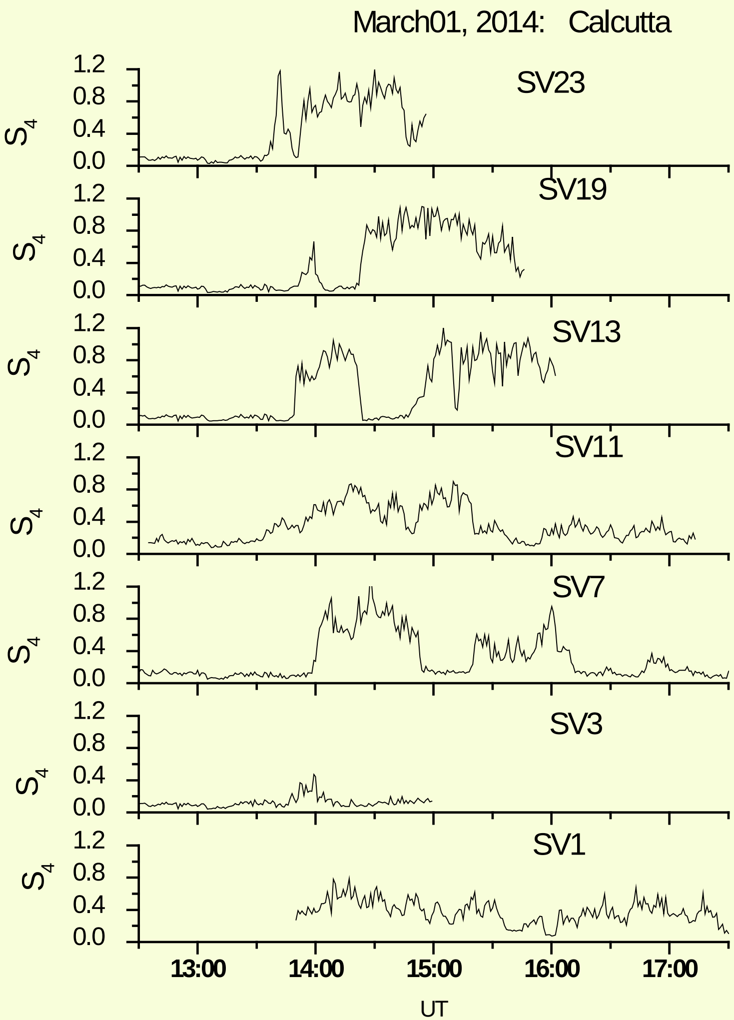
- **Significantly larger number of transionospheric satellite links were available in comparison to GPS-only scenario thereby providing scope for application of spatial diversity techniques to improve navigation position solutions under poor satellite-receiver geometry.**

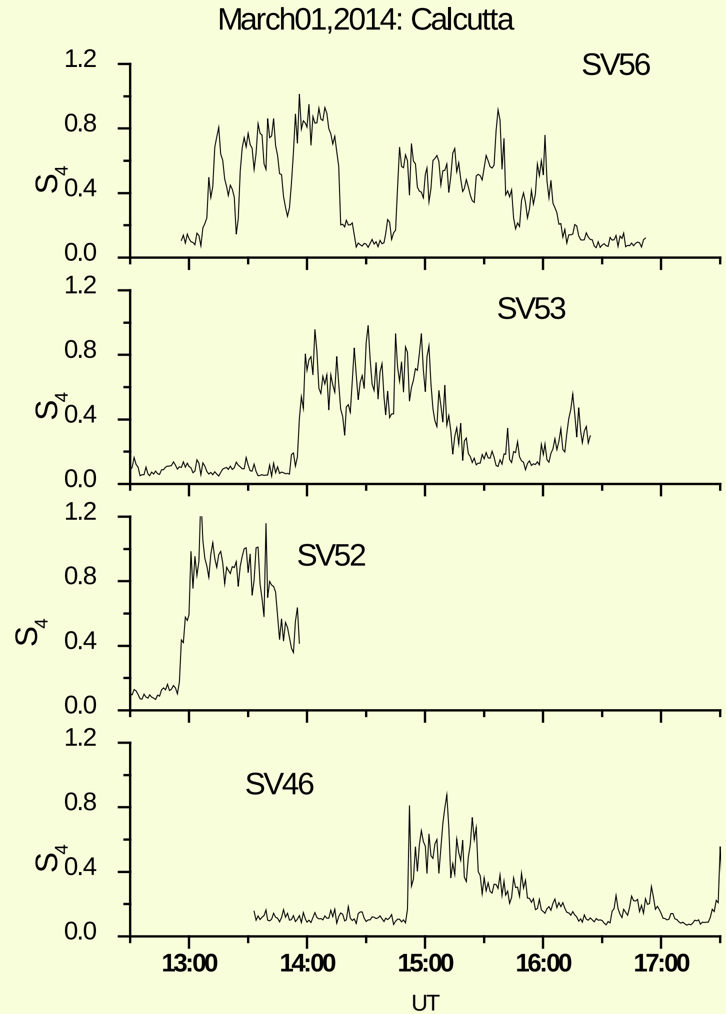
- **Access to larger number of satellite links above an elevation of 60° will be useful to reduce the effects of large range error rates for satellite-based navigation system arising out of sharp spatial gradients of ionization existing in the equatorial region.**

GPS

March 1, 2014 Calcutta

GLONASS



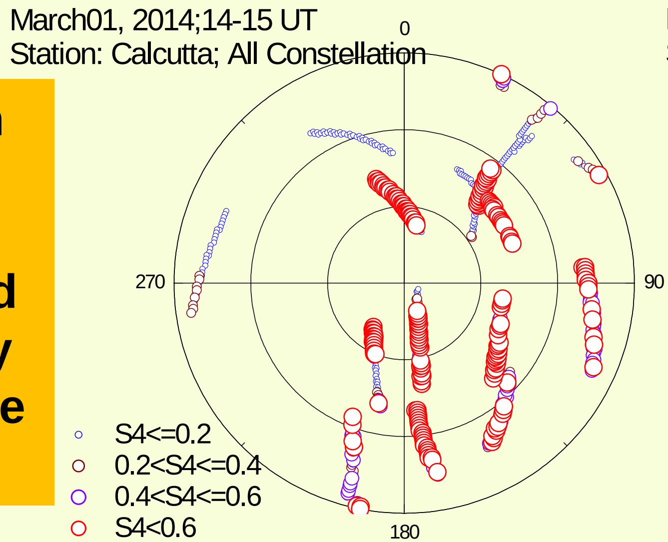


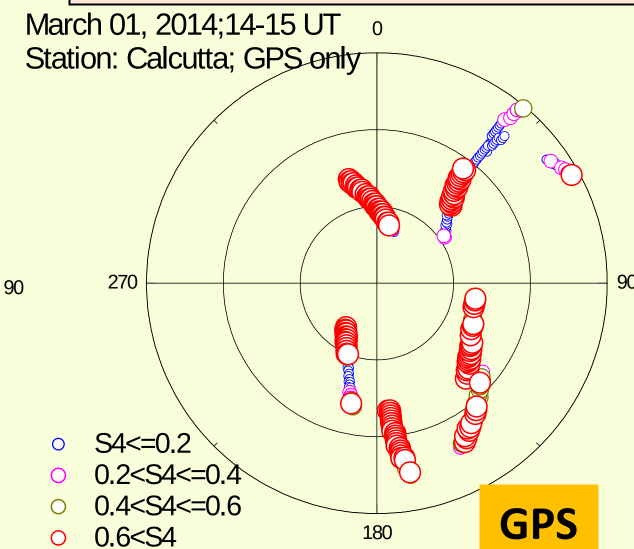
Estimation of scintillation-free SV look angles depending on satellite availability and temporal evolution of scintillation

March 1, 2014 Station: Calcutta

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

GPS + GLONASS +GALILEO





GPS

Increase in available Elevation by 32% and Azimuth by 43% in case of GNSS

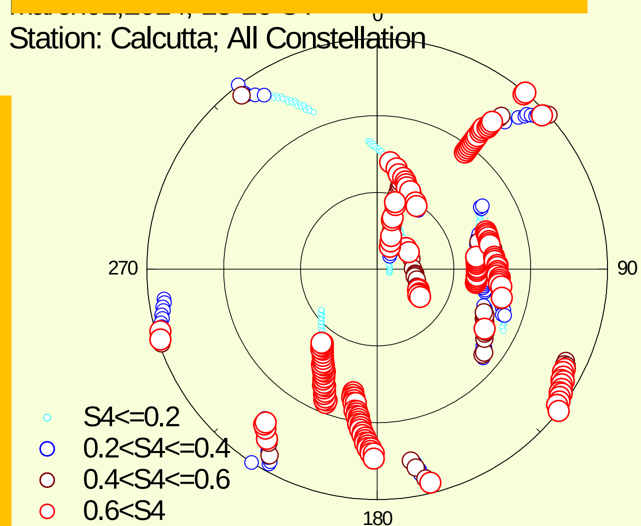
The 99 percentile values of elevation range of SVs unaffected by intense scintillations during 14-15 UT were found to be 30.45deg using multiconstellaton compared to 23 deg using GPS only.

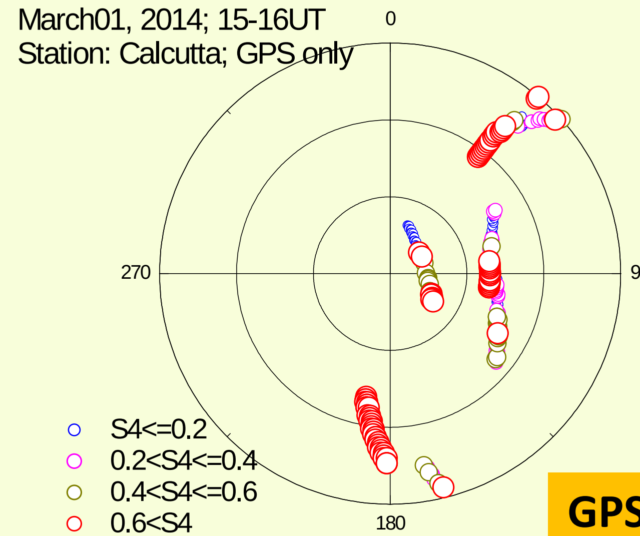
The 99 percentile values of azimuth range of SVs unaffected by intense scintillations during 14-15 UT were found to be 10 deg using multiconstellaton compared to 7 deg using GPS only.

March 1, 2014 Station: Calcutta

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

GPS + GLONASS +GALILEO





GPS

Increase in available Elevation by 105% and Azimuth by 5% in case of GNSS

The 99 percentile values of elevation range of SVs unaffected by intense scintillations (S_4>0.6) during 15-16 UT were found to be 29.38 deg using multiconstellaton compared to 14.3 deg using GPS only.

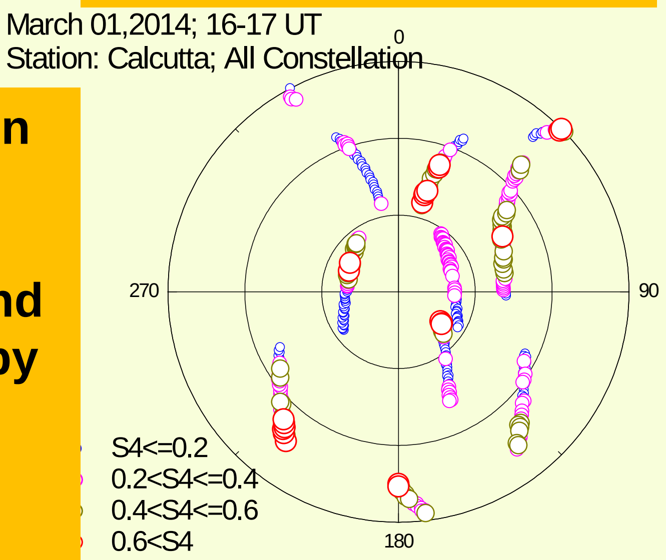
The 99 percentile values of azimuth range of SVs unaffected by intense scintillations (S_4>0.6) during 15-16 UT were found to be 26 deg using multiconstellaton compared to 24.68 deg using GPS only.

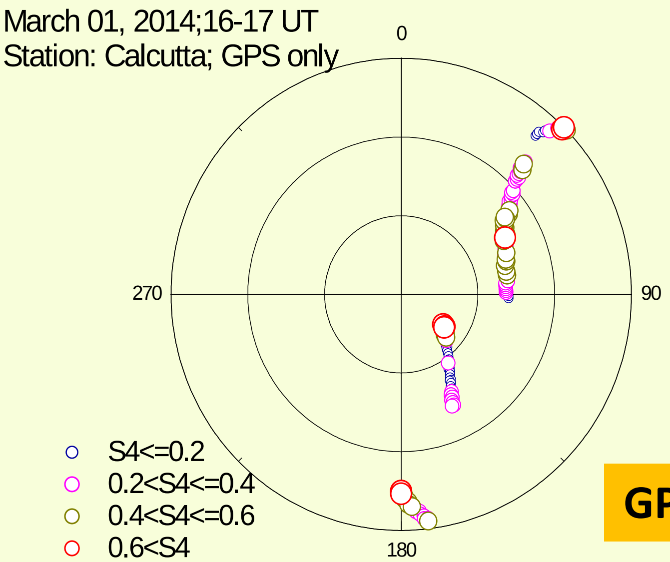
March 1, 2014 Station: Calcutta

16:00-17:00UT (22:00-23:00LT)

GPS + GLONASS +GALILEO

Increase in available Elevation by 14% and Azimuth by 116% in case of GNSS





GPS

The 99 percentile values of elevation range of SVs unaffected by intense scintillations during 16-17 UT were found to be 32.62 deg using multiconstellaton compared to 28.62 deg using GPS only.

The 99 percentile values of azimuth range of SVs unaffected by intense scintillations during 16-17 UT were found to be 22.38 deg using multiconstellaton compared to 10.38 deg using GPS only.

- **Presently analyzing huge volumes of GNSS data spread over two equinoxes of 2014 to identify scintillation-free or mildly affected look angles at different local times**

- **May provide diagnostics for spatial redistribution of communication and navigation links during periods of scintillations**

Conclusions

- Identification of scintillation-free SV look angles is important to design and plan communication and navigation traffic allocation during scintillation occurrence

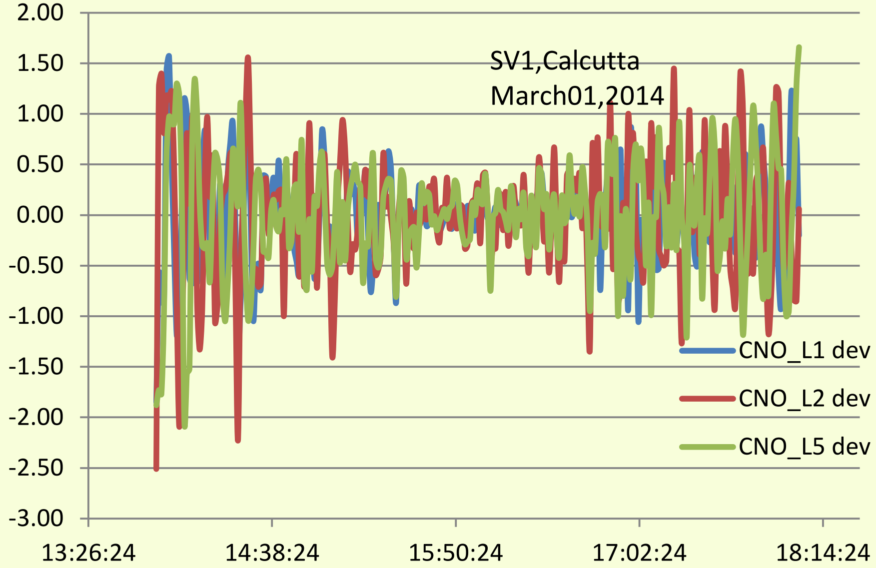
- Scintillation occurrence follows a temporal variation from early evening to midnight period

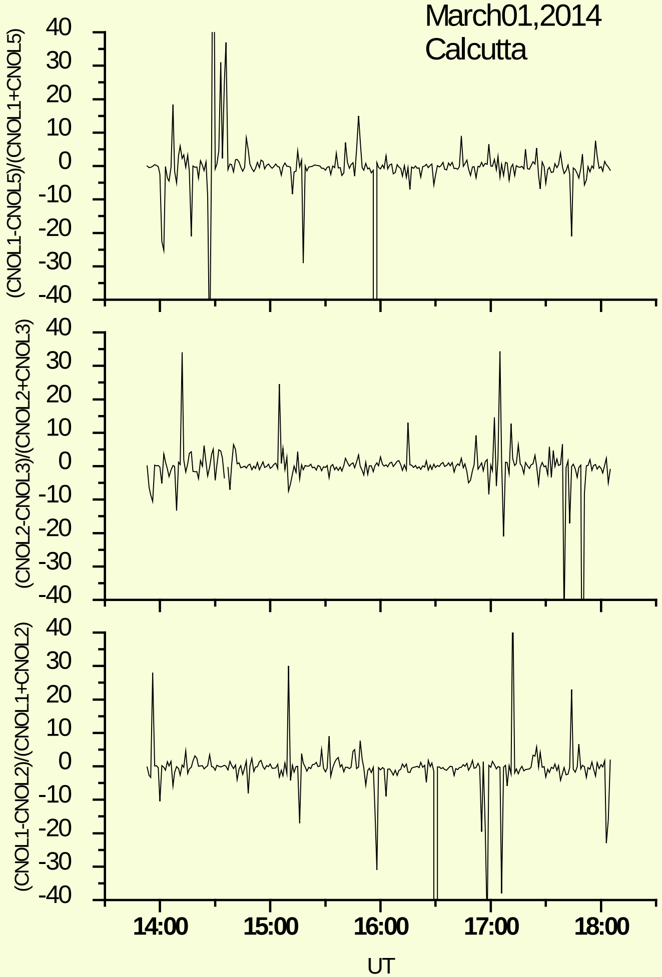
- Orbital geometry of different GNSS dictate availability of SV links at different times of a day at different look angles

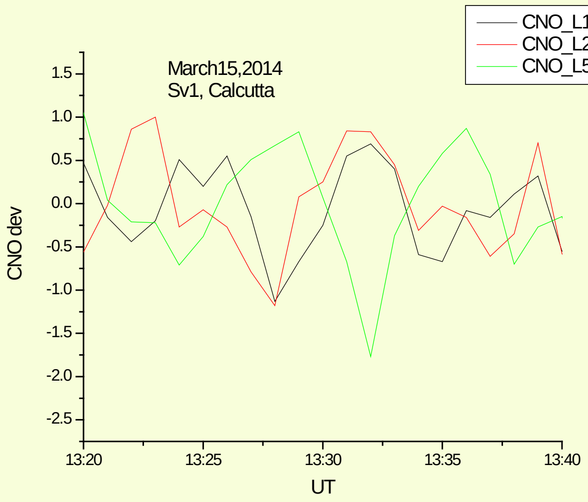
- Finally obtained result is a combination of both factors

- Efforts are being made to tabulate SV links free of scintillation or with mild scintillation every hour based on which a strategy could be developed following analysis of a sizable volume of data

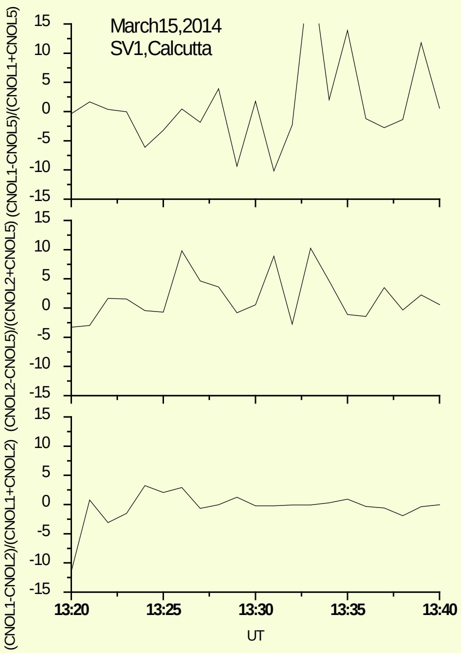
Thank You


SV1,Calcutta
March01,2014
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
-3.00
13:26:24
14:38:24
15:50:24
17:02:24
18:14:24
CNO_L1 dev
CNO_L2 dev
CNO_L5 dev

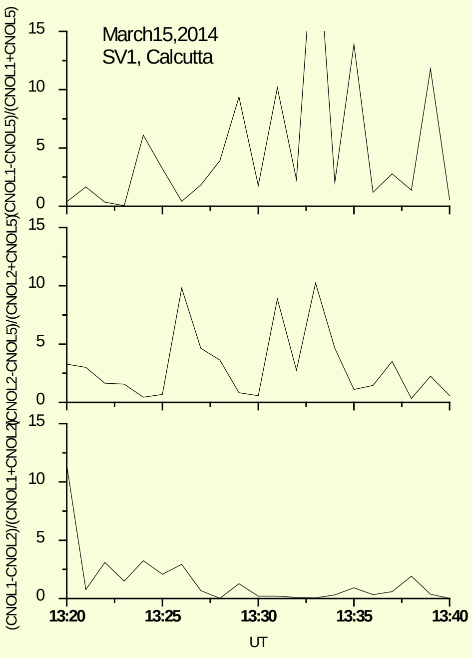

March01,2014
Calcutta
(CNOL1-CNOL5)/(CNOL1+CNOL5)
(CNOL2-CNOL3)/(CNOL2+CNOL3)
(CNOL1-CNOL2)/(CNOL1+CNOL2)
40
30
20
10
0
-10
-20
-30
-40
14:00
15:00
16:00
17:00
18:00
UT



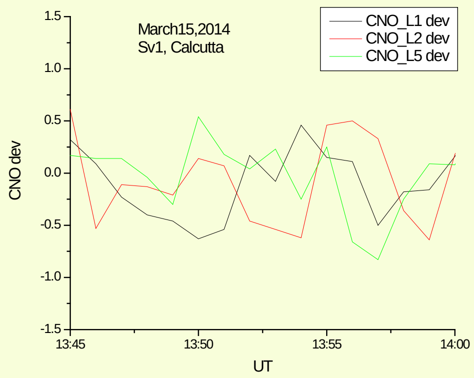
March15,2014
Sv1, Calcutta
CNO_L1 dev
CNO_L2 dev
CNO_L5 dev
CNO dev
UT
13:20
13:25
13:30
13:35
13:40



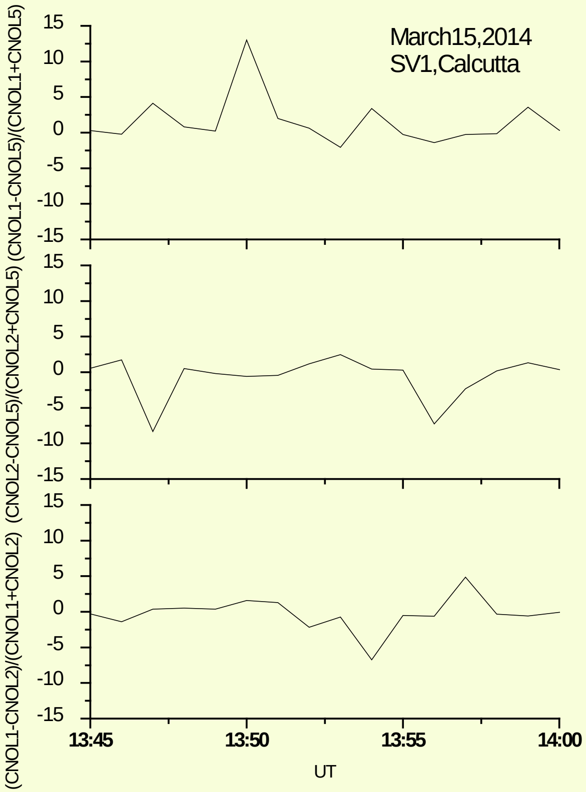
March15,2014
SV1,Calcutta
(CNOL1-CNOL5)/(CNOL1+CNOL5)
(CNOL2-CNOL5)/(CNOL2+CNOL5)
(CNOL1-CNOL2)/(CNOL1+CNOL2)
UT
13:20
13:25
13:30
13:35
13:40



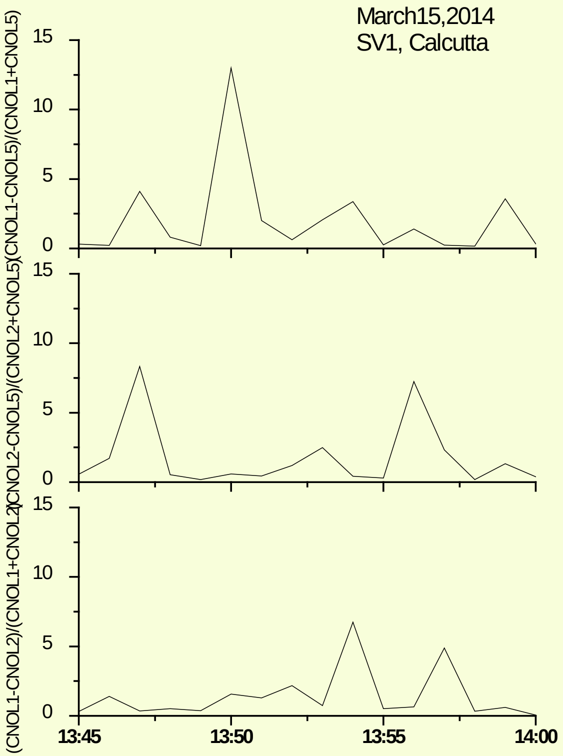
March15,2014
SV1, Calcutta
(CNOL1-CNOL5)/(CNOL1+CNOL5)
(CNOL2-CNOL5)/(CNOL2+CNOL5)
(CNOL1-CNOL2)/(CNOL1+CNOL2)
UT
13:20
13:25
13:30
13:35
13:40



March15,2014
Sv1, Calcutta
CNO_L1 dev
CNO_L2 dev
CNO_L5 dev
CNO dev
UT

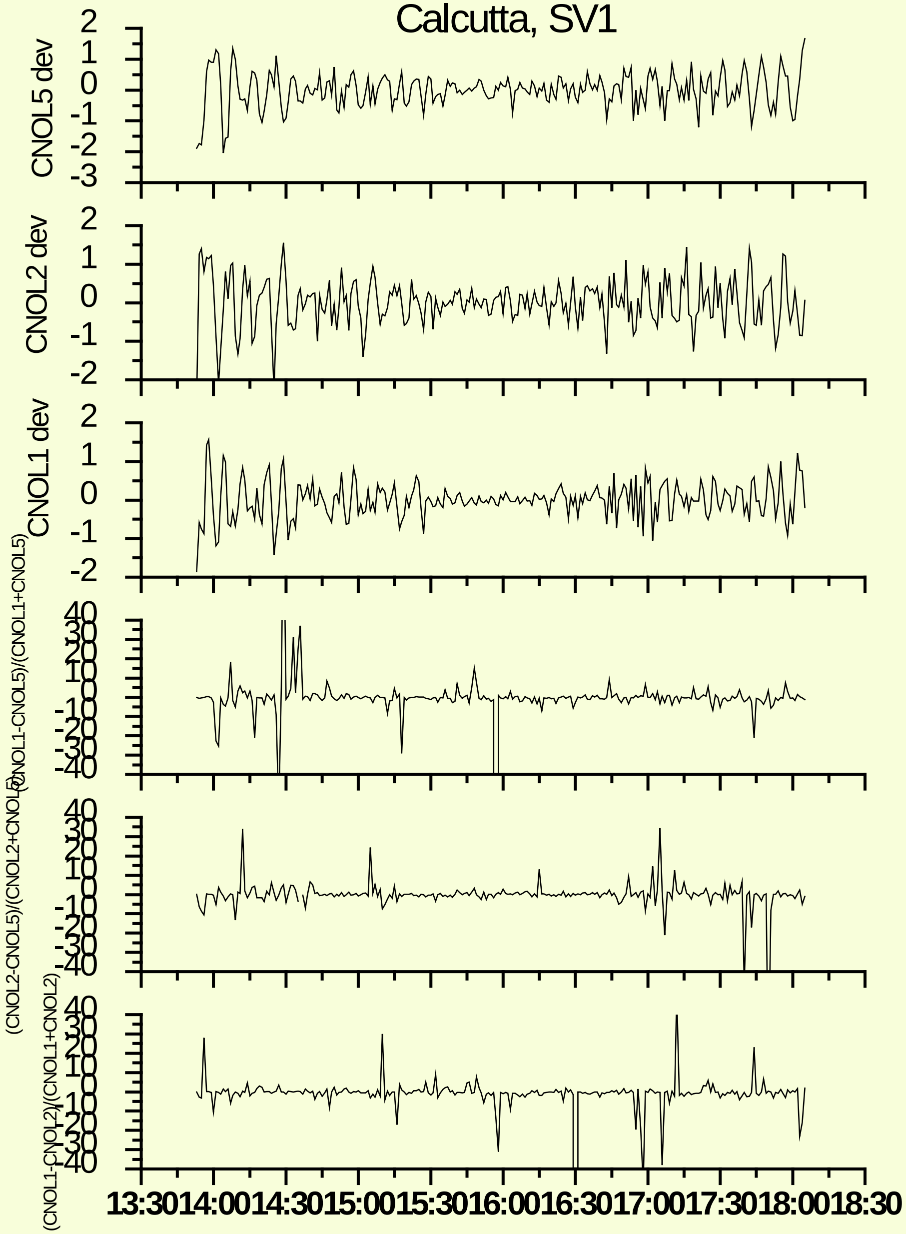


March15,2014
SV1,Calcutta
(CNOL1-CNOL5)/(CNOL1+CNOL5)
(CNOL2-CNOL5)/(CNOL2+CNOL5)
(CNOL1-CNOL2)/(CNOL1+CNOL2)
UT



March15,2014
SV1, Calcutta
(CNOL1-CNOL5)/(CNOL1+CNOL5)
(CNOL2-CNOL5)/(CNOL2+CNOL5)
(CNOL1-CNOL2)/(CNOL1+CNOL2)
UT

March01,2014
Calcutta, SV1



Calcutta (USRP)

Evening of 14 February 2015 (Day 045)

Last Updated: 13 Mar 21:37Z

300km Sunset over Calcutta: 13:15Z (19:08 Local) 300km Sunrise: 00:43Z (06:37 Local)