Effects of the relative dynamics of ionospheric irregularities and GPS satellite on receiver tracking loop performance

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✓ Equatorial and low latitude ionosphere is associated with generation and evolution of post-sunset F region irregularities, triggered by R-T instability mechanism [Basu et al., 1978; Kelley et al., 1981; Bhattacharyya & Rastogi, 1985; Aarons, 1993], especially during equinoctial months of high solar activity period.

✓ Trans-ionospheric satellite signals encountered by an ionospheric irregularity structure, show fluctuation in various signal parameters such as amplitude, phase etc, commonly known as scintillation [Aarons, 1982; Aarons and Basu, 1994].

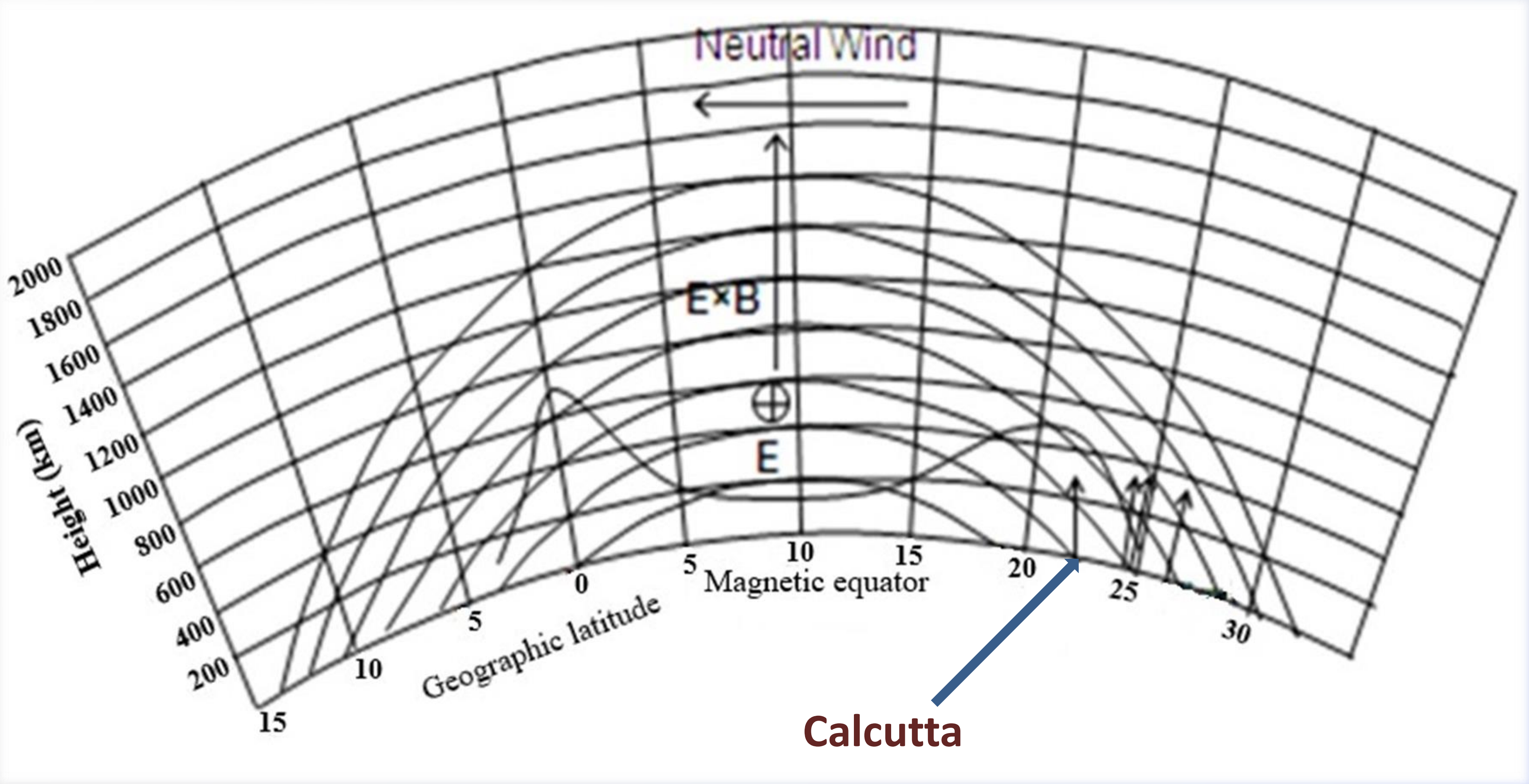
✓ Radio signals encountered by ionospheric irregularities can undergo fading, exceeding the tracking and locking bandwidths of commercial receivers sometimes lading to complete outage of the signal or loss-of-lock [Seo et al., 2009; Moraes et al., 2012; Jiao et al., 2015; Biswas et al., 2019].

✓ The relative motion between the GPS satellite vehicles and the drifting irregularities adds a further metric to this complex background dynamics which can also play an important role to enhance or decrease the impact of such signal outages, notably in terms of its duration.

✓ Despite the fact that signals intensity fading can be strongly associated with occurrence of intense scintillation, the latter has not been established as the sole cause of the former.

✓ Previous studies suggest that the relative velocity between the irregularity cloud and satellite can effect the apparent duration of signal fading [DasGupta et al., 2006].

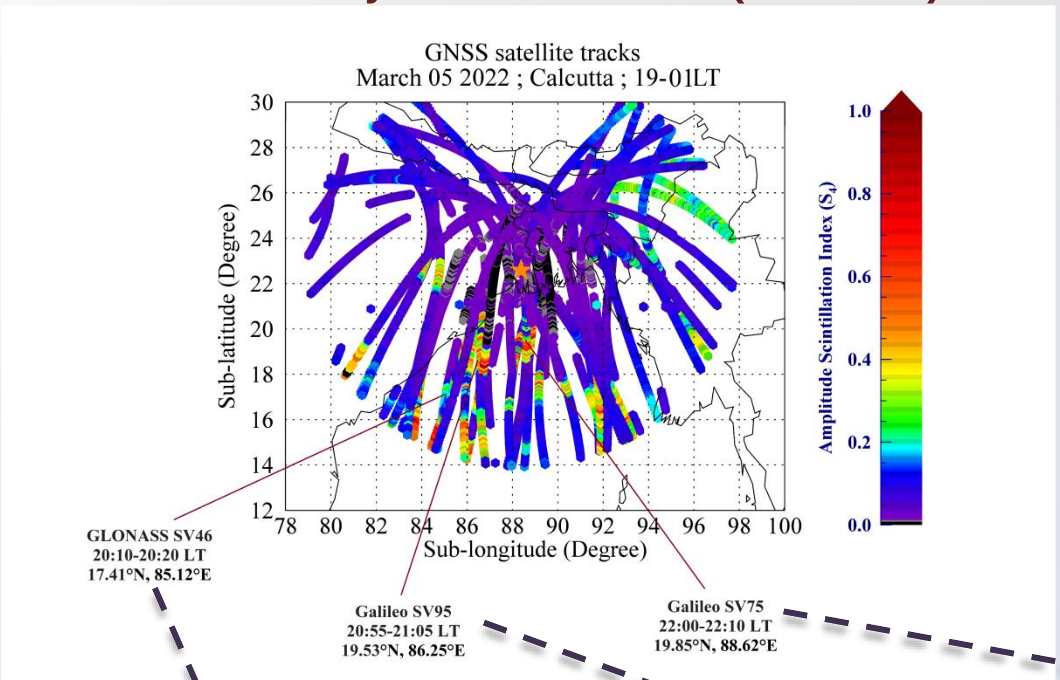
Location of the station



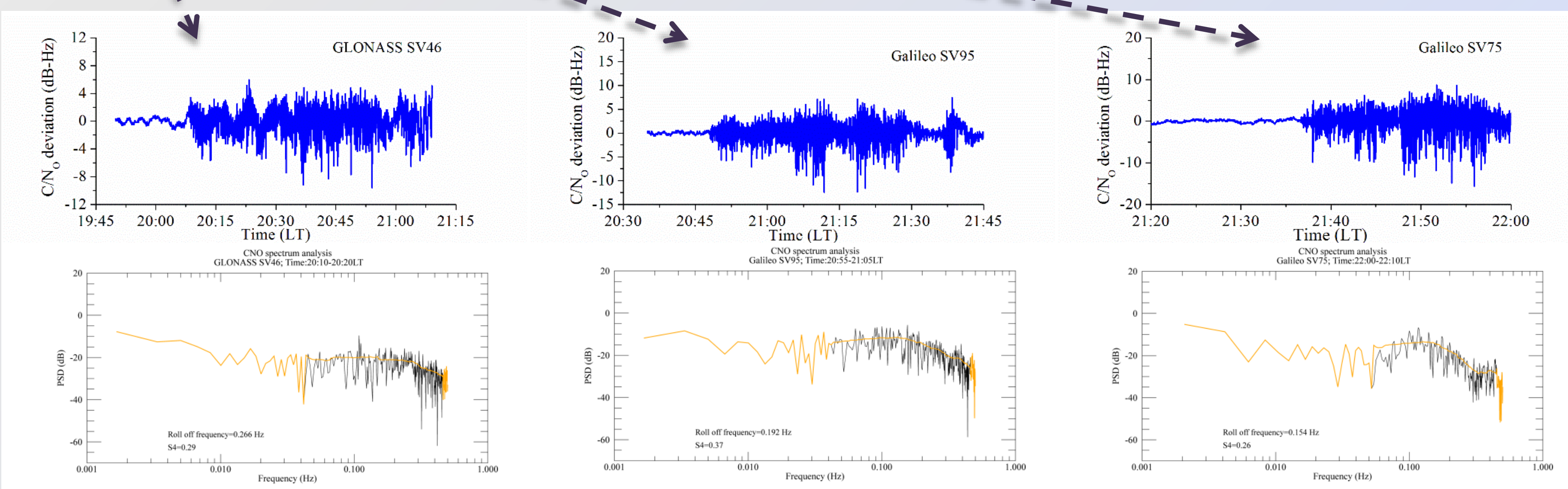
✓ The station **Calcutta (22.57° N, 88.37°E geographic; 18.54° dip latitude geomagnetic)** being located near the northern crest of EIA, some of the worst cases of signal perturbation caused by ionospheric irregularities are witnessed.

Irregularity dynamics observed at GNSS L1

A Case Study : March 05 2022 (GNSS L1)



- Figure shows **sub-ionospheric tracks** of 84 GNSS satellites, including GPS, GLONASS, Galileo, BeiDou, QZSS and SBAS, as observed from station **Calcutta** during **19-01LT** of March 05 2022.
- The sub-ionospheric satellite tracks are colour indexed in terms of amplitude scintillation index (S_4).
- PSD obtained for each scintillation patch, upholding the condition of weak scattering, (when S_4 was within 0.2-0.6).



Irregularity dynamics observed at GNSS L1

- Roll-off frequency is translated into Fresnel frequency (f).
- **Transverse and zonal drift velocity** is obtained using

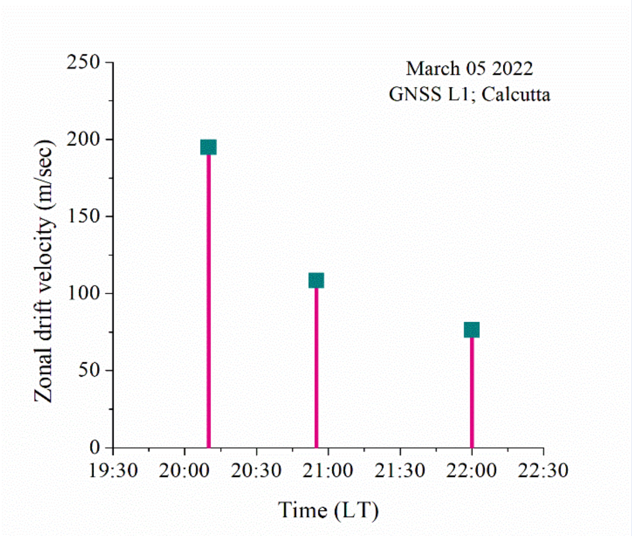
$$V_{drift-trans} = f \times \sqrt{2}D_F = f \times \sqrt{2\lambda z}$$

$$V_{drift-zonal} = \frac{V_{drift-trans}}{\cos\chi}$$

[Bhattacharyya and Rastogi, 1985; Basu et al., 1986 ; Ros et al., 2000]

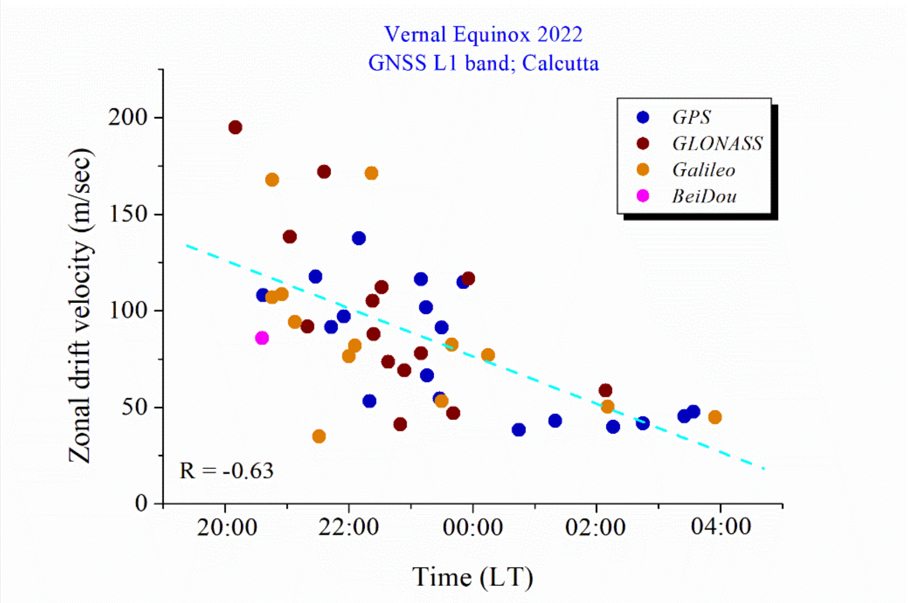
Where, z = IPP height; λ = radio wavelength; χ= ionospheric zenith angle,

- The east-west zonal drift velocity was measured to be **195m/s**, **108m/s** and **76m/s** at around **20:10LT**, **20:55LT** and **22:00LT** respectively.



[LT = Local time for Calcutta = UTC+ 06:00 Hr]

Statistical study: Vernal equinox 2022 (GNSS L1)



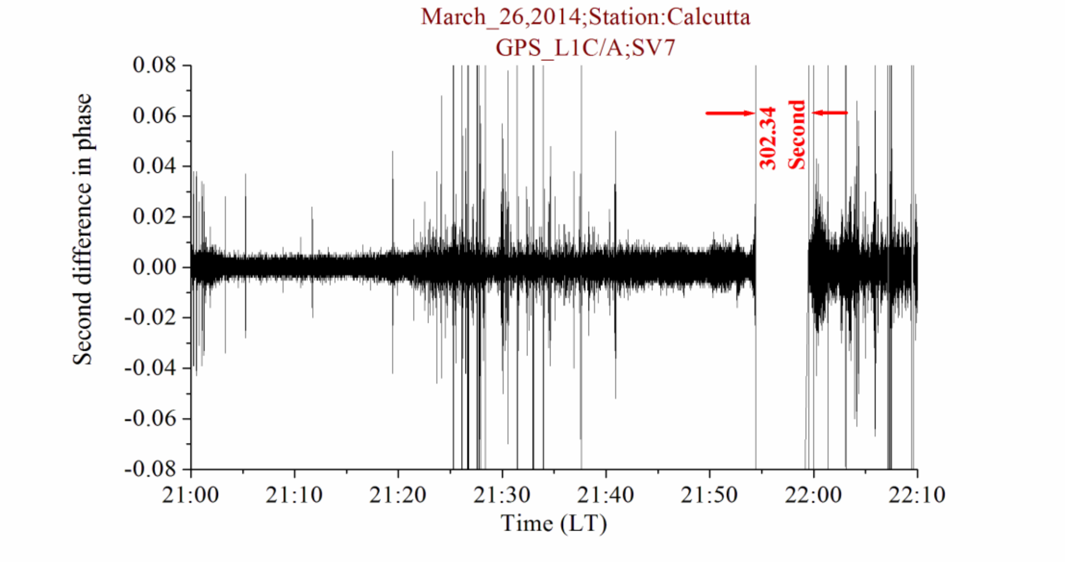
- Maximum zonal drift velocity obtained is **~195m/s** at around **20:10LT**.
- **During 20-28 LT** (20 – 04LT), the zonal drift velocity varied between **~200 m/sec to 45 m/sec.**
- A **descending trend** exists between east-west zonal drift velocity and local time, with a **correlation coefficient -0.63**.

Relative motion between satellite and irregularity

➢ **Loss-of-lock** : Under adverse conditions of ionosphere,

Rapid phase fluctuation increases the PLL tracking error, leading to possibility of cycle slip. Loss of phase lock occurs when the tracking error exceeds the pull-in range of the discriminator [Humphreys et al., 2005, 2010].

Transionospheric satellite signal power fades below the dynamical range of the receiver, causing the DLL to lose track of the signal completely [Seo et al., 2009; Guo et al., 2020].



[**Biswas et al., *Space Weather*, 2019**]

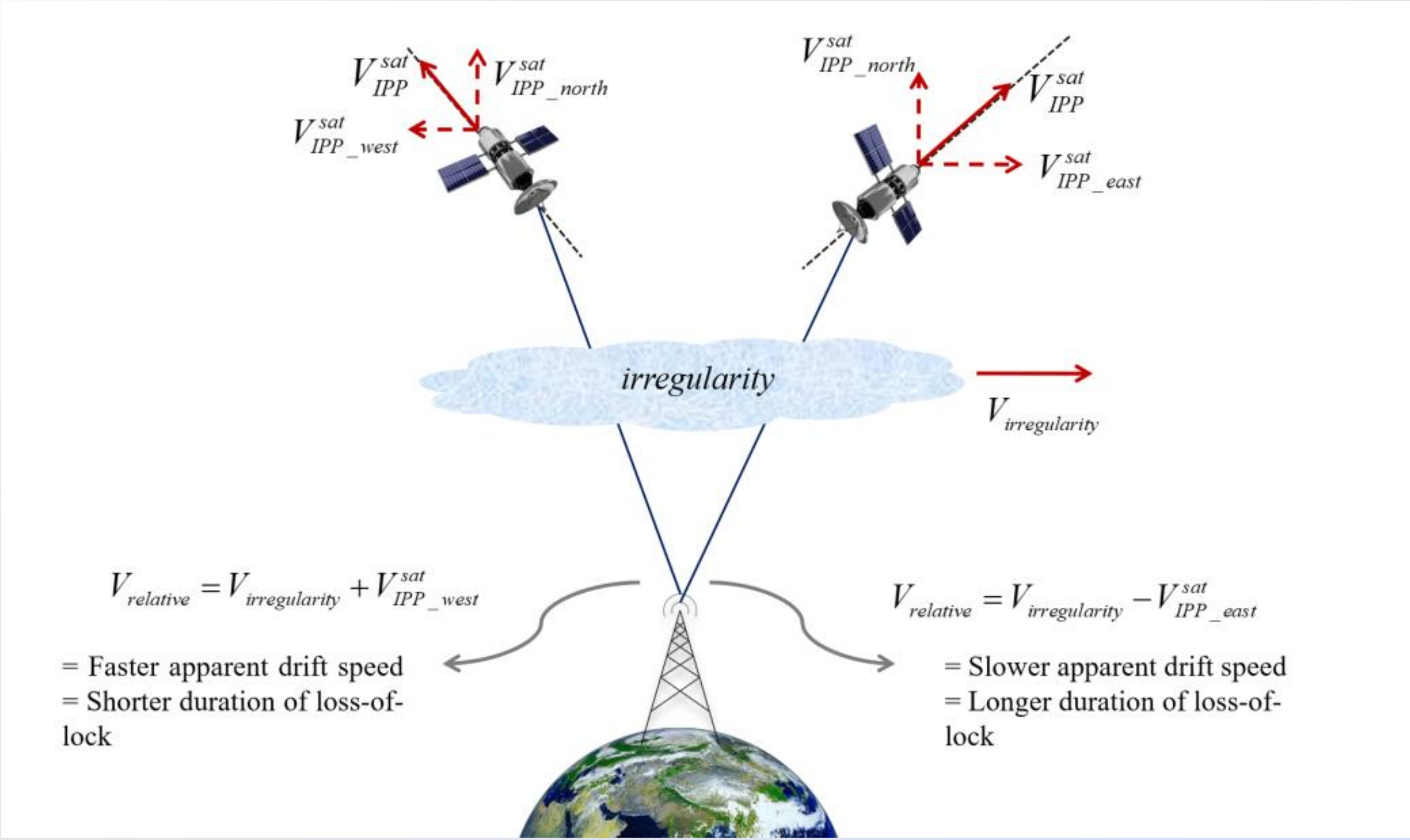
▪ A loss-of-lock for 302.34 sec was observed on March 26, 2014 at GPS SV7.

✓ Eastward velocity component of the satellite at the IPP may vary between zero to more than 100 m/sec, where the total velocity varies from ~0 – 250 m/sec. However, 65% of the eastward satellite velocity at IPP falls within 0-70 m/sec [Kintner et al., 2001].

✓ When the eastward velocity of the moving satellite, at ionospheric pierce point (IPP) matches the eastward velocity of a bubble (100-150m/sec) [Fejer et al., 1985], the fading rate becomes slow, giving rise to degradation in the tracking-loop performance [Kintner et al., 2001; 2004].

✓ This in turn gives rise to cycle slips and loss-of-lock of a signal [DasGupta et al., 2006; Kintner et al., 2001; 2004]

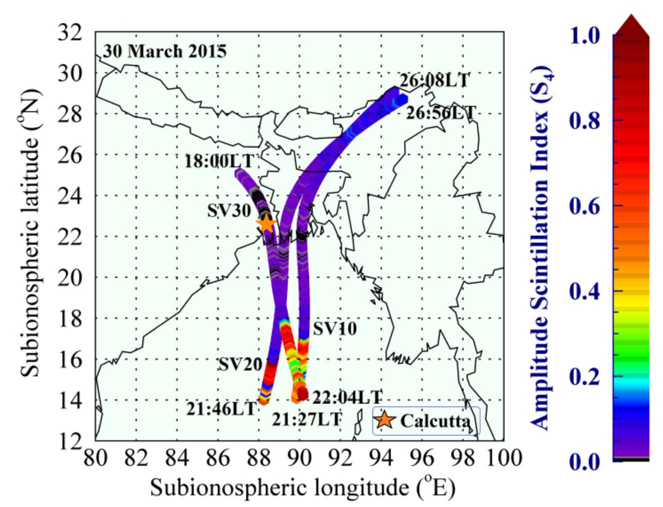
Relative motion between satellite and irregularity



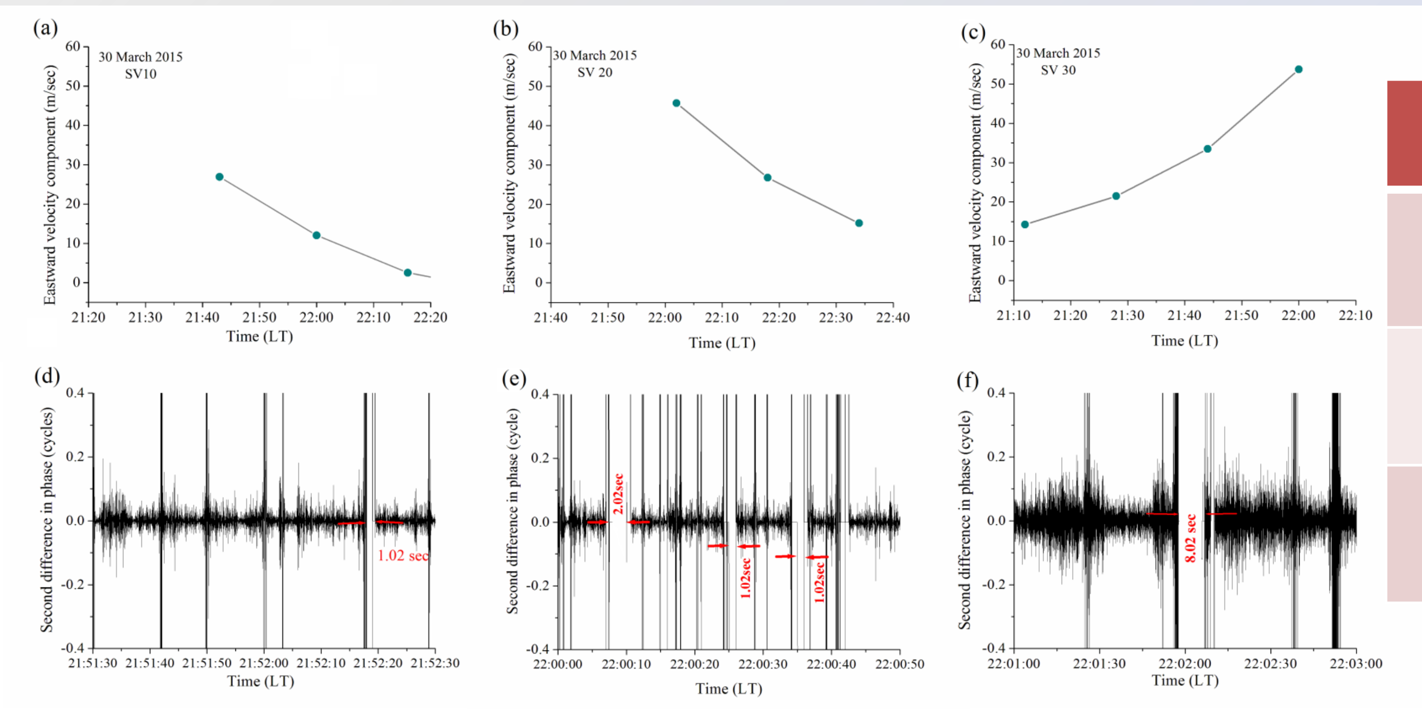
- Moving satellites (GPS) can have a dominant component of the velocity in the east-west direction.
- The relative speed of ground scintillation pattern may be slower or faster.
- This in turn gives rise to longer or shorter duration of loss-of-lock.

Effects on signal tracking of the receiver

A Case Study : March 30 2015



- 3 GPS satellite tracks (**SV10, 20 and 30**) as observed from Calcutta.
- The tracks are color coded in terms of amplitude scintillation index (S_4) that depicts mild (S_4< 0.2), moderate (S_4: 0.2-0.4) and intense (S_4> 0.6) scintillation.
- Signature of scintillation is observed on all 3, within a subionospheric longitude of ~ 88°E- 90°E, all during 21:27-22:04 LT.



Satellite	Loss-of-lock	Velocity
SV10	1.02 sec	18.5 m/sec
SV20	2.02 sec	47 m/sec
SV30	8.02 sec	55 m/sec

Effects on signal tracking of the receiver

- **Negative value** of velocity means the east-west component was **westward**.

- correlation between eastward velocity component and duration of loss-of-lock is investigated.

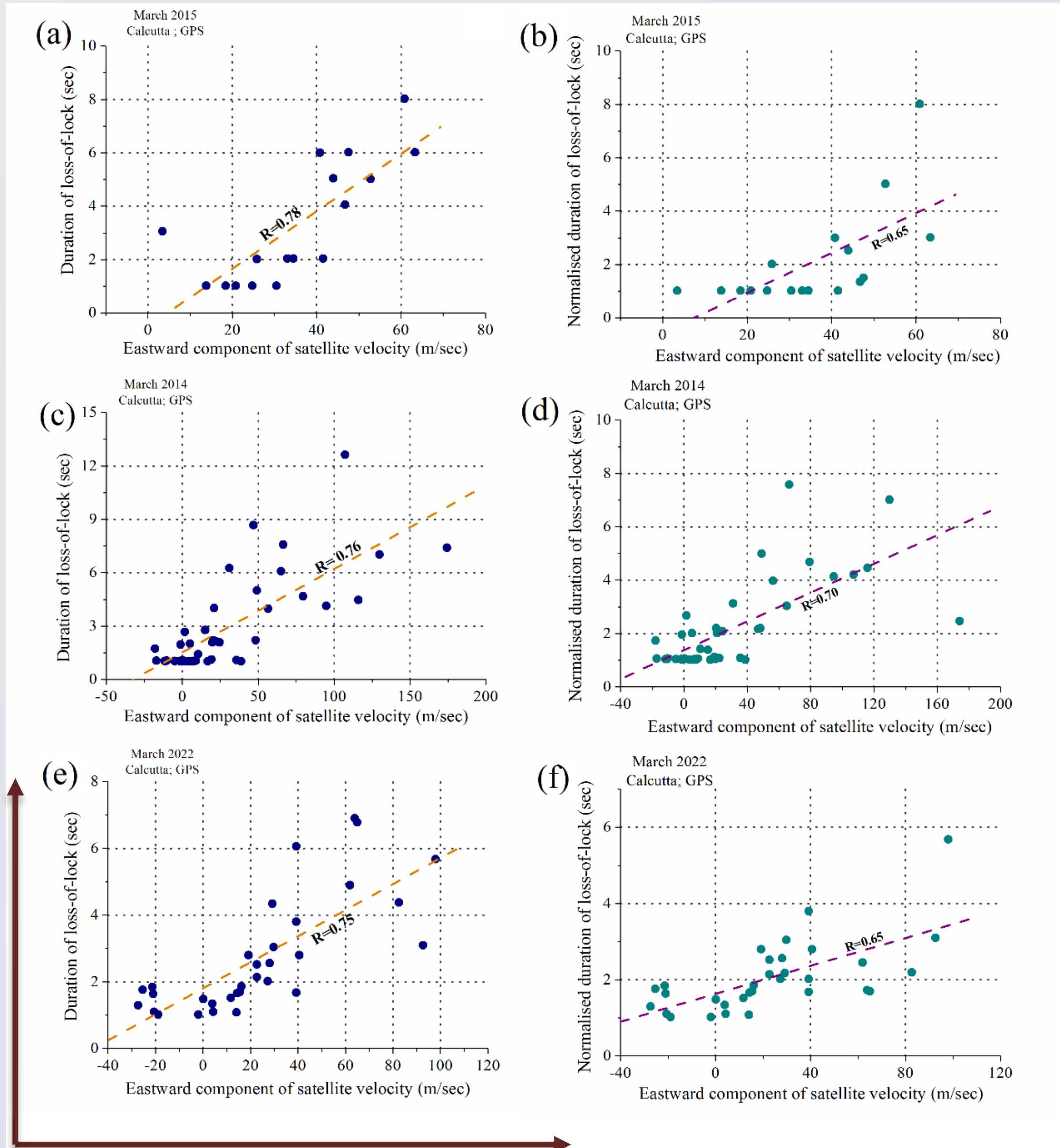
- *Normalised Duration = N/D*

where, D = Total duration/min
N = Total no. of cases/min

March 2015 – 78% / 65%
F10.7 – 113.03 SFU

March 2014 – 76% / 70%
F10.7 – 134.07 SFU

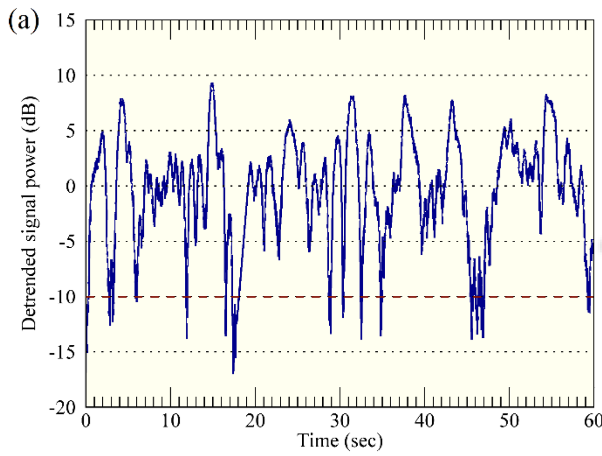
March 2022 – 75% / 65 %
F10.7 – 104.95 SFU



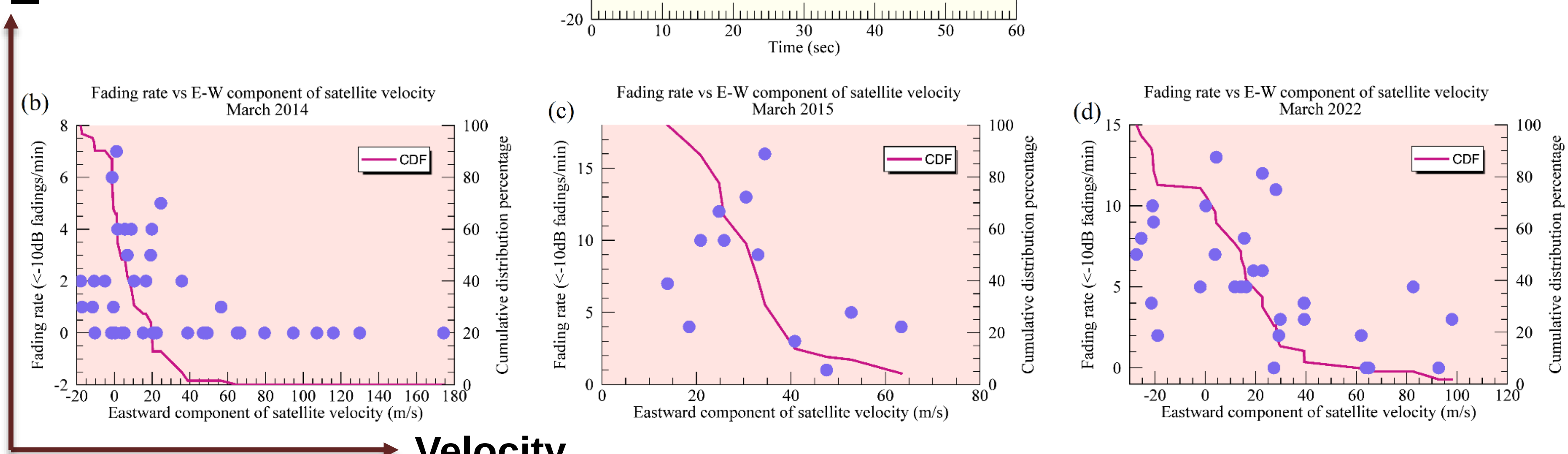
Loss-of-lock

Eastward component of satellite velocity

Effects on signal tracking of the receiver

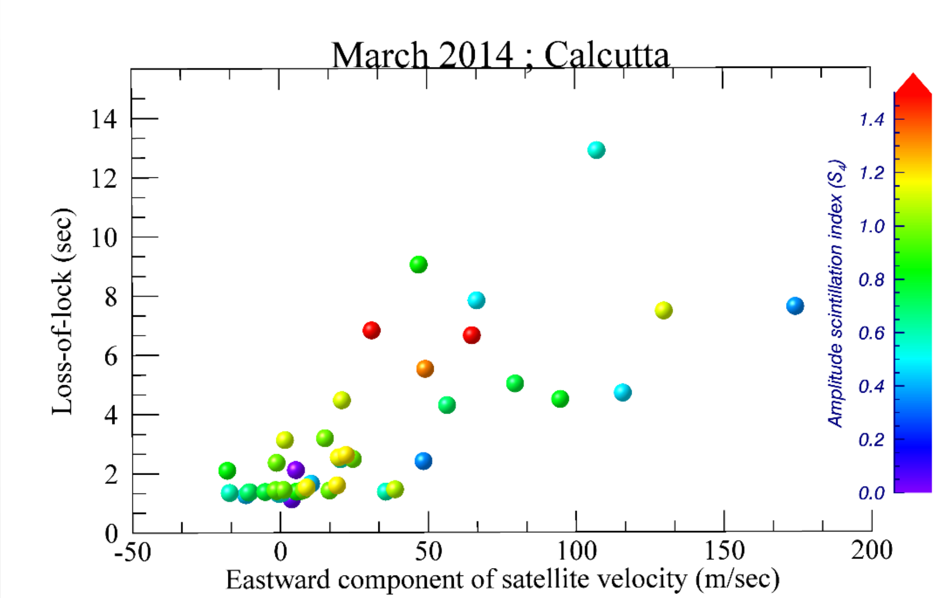


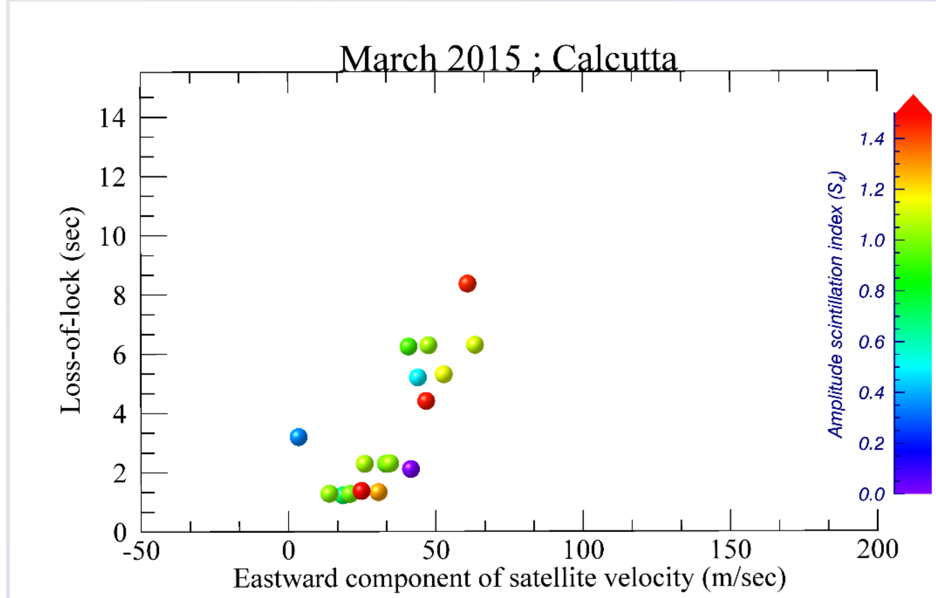
- **Signal fading rate :** Number of fading per min with depth <-10 dB

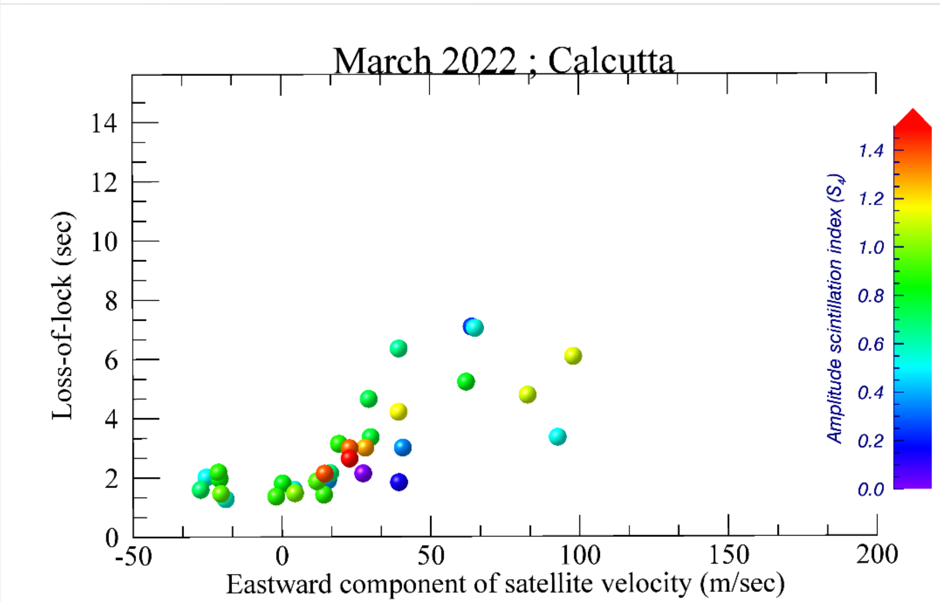


- **Fading rate** is comparatively **higher for velocity < 40m/sec.**
- Line shows **cumulative distribution percentage (CDF)** for the statistics. Median value of CDF, corresponds to satellite velocity of 16.69m/sec, 31.76m/sec and 19.14m/sec respectively during March 2014,March 2015 and March 2022.
- Fading rate varies inversely with eastward component of satellite velocity.

Effects on signal tracking of the receiver







- Previous study by Biswas et al. (2019) during March 2014, from Calcutta, reports that majority of loss-of-lock cases were observed for S_4>0.6 at GPS L1.

- Figure shows the **combined effect of S_4 and satellite velocity at IPP to cause loss-of-lock** at transionospheric signals.

- Longer duration of loss-of-lock are sometimes associated with moderate values S_4, instead of being evidently correlated with intense amplitude scintillation.

Summary and Conclusion

- Effects of scintillation on transionospheric satellite signal can critically compromise the performance of ground-based receivers. Such effects are noted to be most severe at equatorial and low-latitude stations.

- Motion of the GPS satellites can be crucial while studying signal perturbations due to irregularities generated in the ionosphere.

- Zonal drift velocity measured at GNSS L1, from a low-latitude station Calcutta, during vernal equinox of 2022, was found to vary between 200 – 45 m/sec.

- The eastward velocity component may resonate with the drifting speed of irregularity in the ionosphere. This gives rise to cycle slips in the receiver recorded phase which may lead to loss-of-lock in case of stronger signal perturbation.

- Observations made under different solar activity period, led to find significant correlation (75-78%) between duration of signal loss-of-lock and eastward component of satellite velocity.

- Rate of signal fading is found to inversely vary with eastward component of satellite velocity, having majority values for velocity <40 m/sec.

- Even for moderate S_4 (S_4: 0.4-0.6), if the eastward velocity component is high, loss of lock will be longer compared to cases with intense S_4 and lower eastward velocity. Although S_4 is taken to be a crucial parameter for signal perturbation, satellite velocity at IPP also plays important role in causing signal outage.

References

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THANK YOU