Indian Journal of Radio & Space Physics
Vol. 46, March 2017, pp. 15-19

Ionospheric scintillation characteristics in IRNSS L5 and S-band signals

M R Sujimol* & K Shahana

Satcom Experiment and Operation Division, SAC, ISRO,
New Delhi 110 021, India

Received 24 April 2017; revised 18 September 2017; accepted 26 February 2018

Ionospheric scintillation is a common phenomenon observed over the low latitude Indian region. It occurs due to the rapid fluctuations in phase and amplitude of the signal and affects Global Navigation Satellite Systems (GNSS) very severely, especially in L-band. Severe scintillation leads to loss of lock at the receiver, which affects user position accuracy. Ionospheric scintillation mainly depends on solar cycle, user latitude, local time, season and elevation angle of the satellite. It also depends on the frequency of the transmitted signal. Usually, lower frequencies experience higher scintillation at ionosphere. In this paper, ionospheric amplitude scintillation effect on Indian Regional Navigation Satellite System (IRNSS) L5 and S-band frequencies is studied on the basis of computed S_4 index from Carrier to Noise (C/No) ratio measurements from IRNSS receivers installed at New Delhi and Ahmedabad. A comparison of L5 and S-band scintillation is done. A confirmation of scintillation phenomenon is also carried out using co-located GPS Septentrio (PolarRxS REO) receiver at frequency L1. It is, further, found that the scintillation occurrence is mostly in post sunset periods and may result in frequent loss of lock at L5 band during these periods.

Keywords: Ionospheric scintillation, Amplitude scintillation, S_4 index

1 Introduction

The ionosphere is a highly variable and complex physical system. It is produced by ionizing radiation from the sun. It is controlled by chemical interactions and transported by diffusion and neutral wind. Generally, the region between 250 and 400 km, known as the F-region of the ionosphere, contains the greatest concentration of free electrons. At times, the F-region of the ionosphere becomes disturbed, and small-scale irregularities develop. When sufficiently intense, these irregularities scatter radio waves and generate rapid fluctuations (or scintillation) in the amplitude and phase of radio signals. The impacts of scintillation are not mitigated by the same dual-frequency technique that is effective at mitigating the ionospheric delay. For these reasons, ionospheric scintillation is one of the most significant threats for Global Navigation Satellite Systems (GNSS) operating in the near equatorial and polar latitudes. Scintillation activity is most severe and frequent in and around the equatorial regions, particularly in the hours just after sunset.

1.1 Ionospheric scintillation

Ionospheric scintillation refers to the random variation in the phase and intensity of the received GNSS signals resulting from signal propagation though randomly structured and distributed irregularities in the earth's ionosphere. The phenomenon is observed primarily in the equatorial and high latitude region[1]. The highest level of activity is observed in the solar maximum periods. The signal intensity scintillation can cause deep signal fades and in extreme cases, the receiver is unable to acquire the scintillated signal. There are two types of ionospheric scintillations in Global Positioning System (GPS) measurements, viz., amplitude and phase scintillations. Amplitude scintillation refers to rapid fluctuation in signal intensity (or carrier to noise ratio, C/No) measured by a receiver, while phase scintillation refers to rapid fluctuation in the carrier-phase measurements[2,3]. Levels of amplitude and phase scintillations are commonly represented by the standard deviations of amplitude and phase, S_4 and $\sigma\varphi$, respectively, in a certain time period (typically 1 min). For the amplitude scintillation, rapid sampling of C/No is necessary, while rapid carrier-phase measurements are required for the phase scintillation. Furthermore, GPS receivers for phase scintillation measurements need to be equipped with a highly stable clock (oscillator), such as oven-controlled crystal oscillator (OCXO) to distinguish the phase fluctuations due to ionospheric scintillation and clock (oscillator) noise[2]. Both types of ionospheric scintillations are caused by plasma irregularities in the ionosphere. In the low-latitude regions, where the background electron density is high and plasma drift velocity is relatively slow, the amplitude scintillation is dominant. In this study, therefore, the amplitude scintillation is focused on.

1.2 Amplitude scintillation (S_4) index

Amplitude scintillation directly affects the carrier to noise ratio (C/No) of signals in a GPS receiver, as well as the noise levels in code and phase measurements[4]. It can be

*Corresponding author (E-mail: sujimol@sac.isro.gov.in)

sufficiently severe that the received GPS signal intensity from a given satellite drops below the receivers tracking threshold, causing loss of lock on that satellite, and hence, the need to re-acquire the GPS signal(s). This results in reduced accuracy navigation solutions and data loss.

Amplitude scintillation is quantified by the S_4 parameter, which is defined as the square root of the normalized variance of signal intensity over a given interval of time.[5-7]

$$S_4 = \sqrt{(\langle I^2 \rangle - \langle I^2 \rangle) / \langle I^2 \rangle} \quad \ldots (1)$$

where I is the signal intensity.

For a given C/No level in dB-Hz, the effect of ambient noise on S_4 index can be calculated and removed via Ambient noise factor:

Corrected S_4 index = S_4 – Ambient noise factor

$$\frac{\frac{100}{c/ng}\left(1+\frac{500}{19c/ng}\right)}{\text{effect of ambient noise}} \quad \ldots (2)$$

2 Data Sets and Statistical Results

Study of ionospheric amplitude scintillation is carried out for two stations Delhi and Ahmedabad using ACCORD Indian Regional Satellite Systems (IRNSS) receivers at L5 and S-bands for the equatorial months of March and September with a data sampling rate of 1 s interval. In the present analysis, 17 March and 14 September 2015 data is used for computing S_4 index form IRNSS 1A, 1B and 1C satellites from the C/No measurements. The algorithm for computing the S_4 index from C/No, ambient noise factor and corrected S_4 index is developed in Matlab (R2014a). The S_4 index is calculated for both L5 and S band. A confirmation of scintillation phenomenon is also done using co-located multi-frequency – multi-constellation Septentrio PolarRxS GPS receiver system at frequency L1. The S_4 index is calculated at frequency L1 using the data from this receiver for 17 March and 14 September 2015. The results are analyzed for the occurrence of amplitude scintillation.

3 Results and Discussion

Amplitude scintillation index (S_4) variation at Delhi Earth Station (DES), Delhi and Space Application Centre (SAC), Ahmedabad are studied in both L5 and S band. The S_4 index is derived from C/No measurements and the variation of C/No along with S_4 index are also plotted for comparison.

Figure 1 represents the amplitude scintillation index of L5 band at Delhi and Ahmedabad for the IRNSS 1A, 1B and

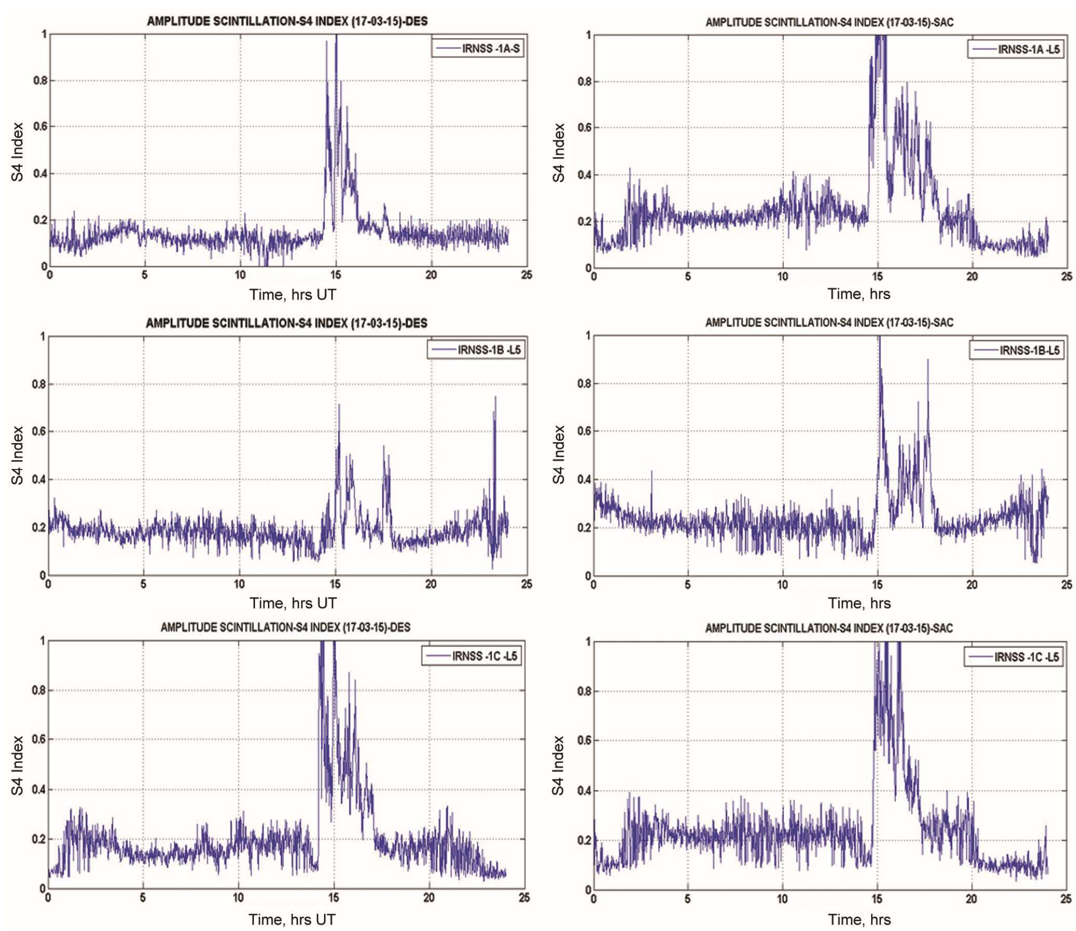

Fig. 1 — S_4 index at L5 band on 17 March 2015 at Delhi and Ahmedabad

1C. It can be observed that there is severe ionospheric scintillation at L5 band of radio signals from all three IRNSS satellites, post sunset period. The S_4 index of L5 band at this period is found to be greater than or equal to 0.4. Strong scintillation is generally considered to occur when S_4 is greater than ~0.6 and is associated with strong scattering of the signal in the ionosphere. Below this is weak scintillation. An S_4 level below 0.3 is unlikely to have a significant impact on GPS. Figure 2 shows the ambient noise factor of L1, L5 and S-band calculated for a particular case on the same date. The ambient noise factor is very negligible, of the order of 10^{-3}.

The same analysis is carried out in the S-band. The impact of ionospheric scintillation in S-band of radio signals can be noted from Fig. 3, which shows variations in S_4 index for IRNSS 1A, 1B, and 1C on 17 March 2015. Here, S_4 index is

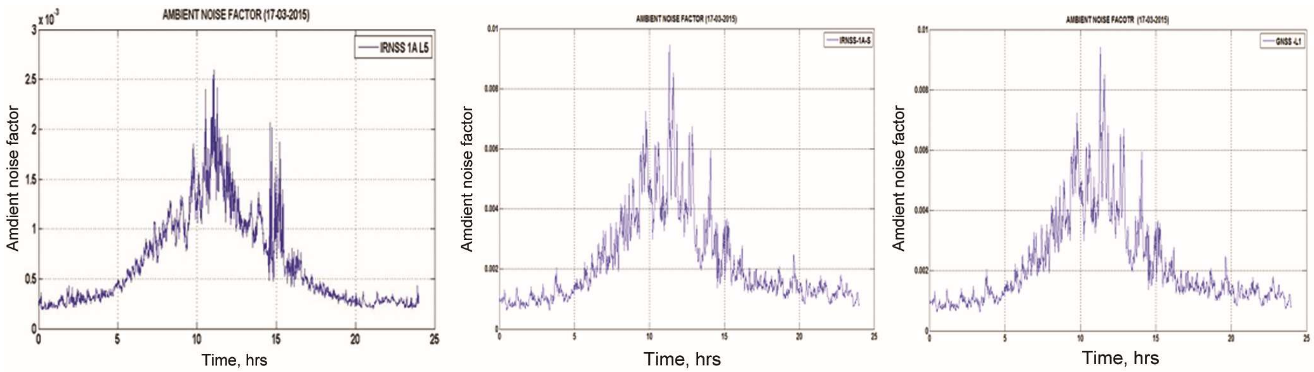

Fig. 2 — Ambient noise factor on 17 March 2015

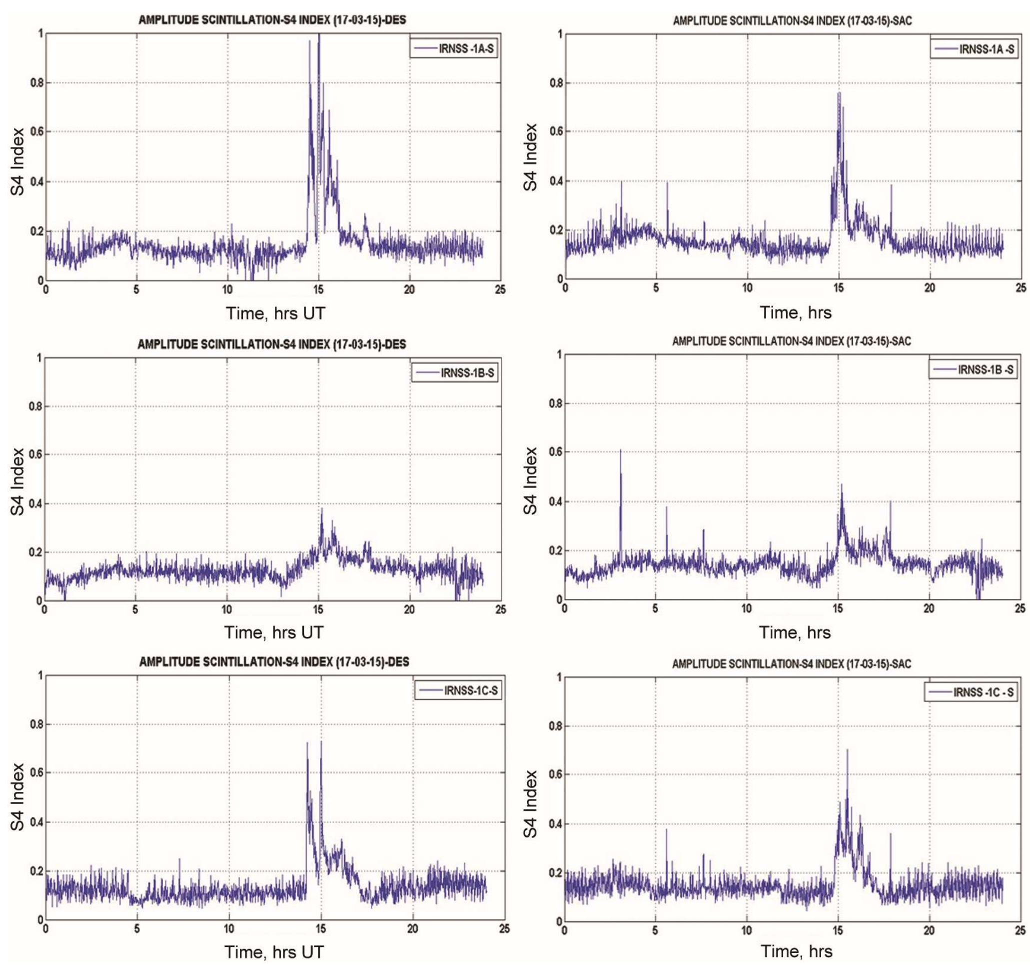

Fig. 3 — S_4 index at S band on 17 March 2015 at Delhi and Ahmedabad

very less compared to L5 band. A peak in the radio scintillation, albeit of lesser magnitude, can easily be noted around 1500 hrs UT (2030 hrs IST). The September data (14 September 2015) is also analyzed for S_4 index at L5 and S band using the IRNSS 1A, 1B, 1C and 1D data from Delhi. The results are plotted in Fig. 4. The scintillation event is much weaker in Delhi in this month.

Figure 5 illustrates the amplitude scintillation in L1 band of radio signal recorded by the Septenentrio PolaRxS receiver, which is a multi-constellation GNSS receiver. The

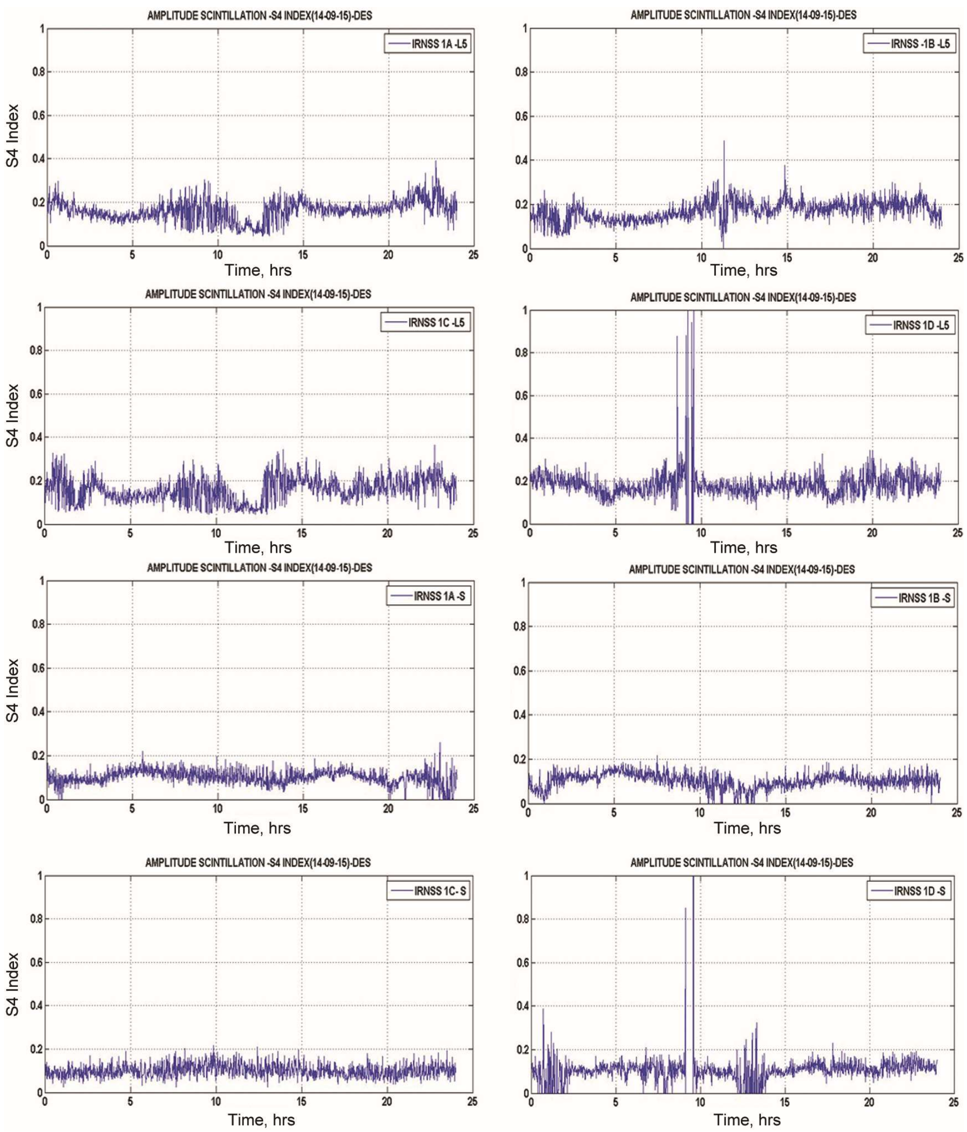

Fig. 4 — S_4 index at S band on 14 September 2015 at Delhi

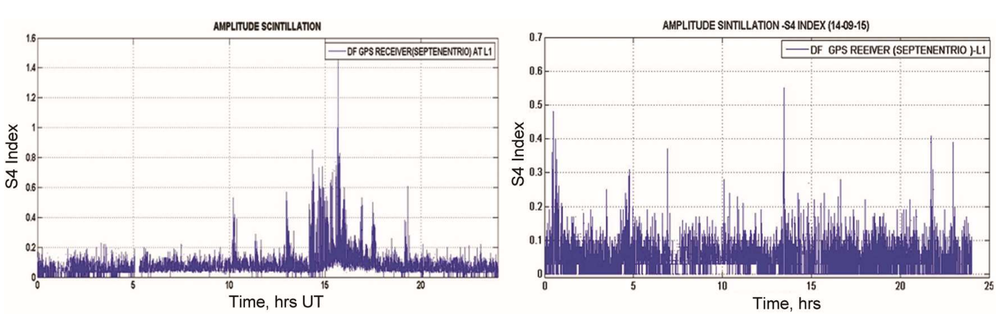

Fig. 5 — S_4 index from Septenentrio- dual frequency receiver at L1 band at Delhi

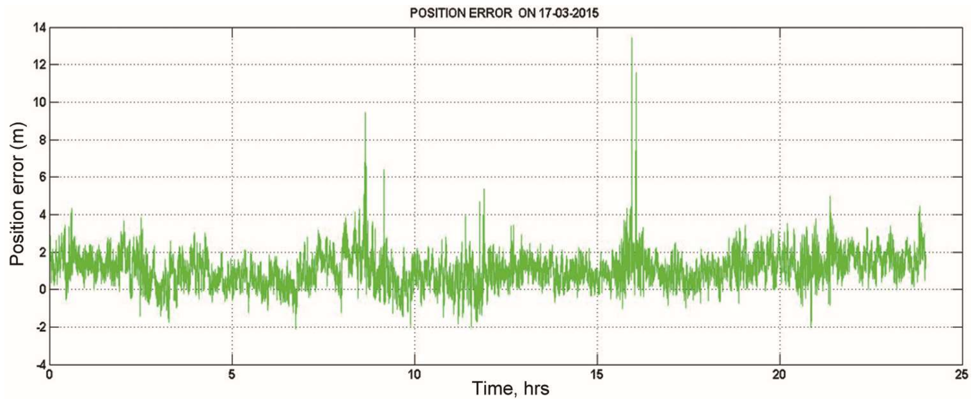

Fig. 6 — Position error measured in the hybrid mode on 17 March 2015

S_4 index from this receiver in the band L1 is plotted for 17 March 2015 and 14 September 2015. Appreciable amplitude scintillations in L1 signals during 1400 – 1800 hrs UT can be clearly noted on 17 March 2015 as the case in IRNSS L5 and S. The S_4 index of L1 band during this period is found to be greater, the magnitude of the scintillation in L1 signal, however, is less compared to the L5 signal as recorded by the IRNSS receiver. On 14 September, the scintillation is weak as it observed from the IRNSS L5 and S band.

Figure 6 shows the position error measured on 17 March 2015 using hybrid mode (IRNSS L5+S and GPS L1). The position accuracy has shown an increase in value (> 12 m) when the S_4 index of 0.8 is observed on the same day in the L5 band. This is due the loss of lock of the signal of few satellites in the L5 and S band, which in turn reduces the position accuracy.

4 Conclusions

Ionospheric scintillation effect on IRNSS at L5 and S-band has been studied at New Delhi and Ahmedabad. It is observed that severity of amplitude scintillation at L5 band is more than at S band. It is, further, found that the scintillation occurrence is mostly in post-sunset periods and may result in frequent loss of lock at L5 and S band during these periods. Further, phase scintillation can also be studied as the new ACCORD receiver has carrier phase measurements also. It is a fact that the GNSS and IRNSS signals are affected by space weather impact, including solar radio emission and solar wind, mainly due to its effect on the equatorial geomagnetic field. Thus, the individual space weather elements may be derived from their signatures on the navigation signals of IRNSS and GNSS, the latter being tracked by the GAGAN system and variations and correlations may be efficiently studied.

Acknowledgement

The authors sincerely thank the Director SAC for providing opportunity to carry out this study. They would also like to acknowledge the support and guidance provided by Deputy Directors, SNAA and SNPA. The authors would also like to thank Dr Rajkumar Chaudhary, SPL, VSSC for providing support. Thanks are also due to Shri A P Shukla, Shri Ashish Shukla, Shri S Sunda and Shri Rajat Acharya for giving necessary guidance. Finally, the authors would like to thank the staff at Delhi Earth Station (DES) for the encouragement throughout the study.

References

1 Olwendo O J, Baki P, Cilliers P J, Doherty P & Radicella S, *J Atmos Sol-Terr Phys (UK)*, 138 (2016) 9-22.

2 Skone S, Lachapelle G, *et al.*, Investigating the impact of ionospheric scintillation using a GPS software receiver, *Paper presented at ION GNSS Conference*, Long Beach CA, 13-16 Sept 2005.

3 Kintner P M, Ledvina B M & De Paula E R, *Space Weath (USA),* 5 S09003.

4 *Effect of ionospheric scintillation on GNSS – A White paper*, SBAS Working group, November 2010

5 *Guidance matrial on scintillation measurements*, (International Civil Aviation Organisation, Place), October 2013.

6 GAfoori F & Skone S, *GPS scintillation modeling and receiver design strategies for low latitude regions*, ION GNSS Conference, 2014.

7 Priyadarshi S, *Surv Geophys (Netherlands)*, 36 (2015) 295–324.