Indian Journal of Radio & Space Physics
Vol 48, September-December 2019, pp 64-71

Studies on variation of GNSS signal strengths from India

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Received 6 November 2017; Accepted 12 October 2018

Commercial Global Navigation Satellite System (GNSS) receivers provide the measure of received satellite signal strength in terms of Signal to Noise ratio (SNR) or Carrier to Noise ratio (C/N_0), through in many cases the terms are used interchangeably. The received signal strength affects the receiver performance, as this is one of the measures of usability of satellites for position solution purpose. GNSS signals pass through and are affected by atmosphere, therefore the signal strength values were also used for atmospheric research purposes. This paper presents the results of long-term studies on GPS, GLONASS and Galileo signal strengths and their variation patterns using data from a commercial multi-GNSS receiver operating from Burdwan situated in eastern India. It may be observed that generally signal strength values increase with increasing elevation angle of satellites, with decreasing fluctuations and the values saturate above certain elevation angle. The three constellations offer slightly different signal strengths and new generation Galileo and GLONASS satellites provide higher satellite signal strengths. The results would be useful in understanding the usability of GNSS signals for various purposes.

Keywords: *GNSS, GPS, GLONASS, Galileo, SNR, C/N_0*

1 Introduction

Currently multiple global and regional satellite based navigation systems are in operation, so signals from multiple systems are available for use simultaneously. A generic term-Global Navigation Satellite System (GNSS) has been coined to represent such systems together. Because of the typical geographical location, the multi-GNSS situation is important for India due to availability of large number of usable satellite signals. An important issue for multi-GNSS operation is the received signal strength and the signal strength variations. The Signal to Noise Ratio (SNR) or Carrier to Noise Ratio (C/N_0) values are quantitative measures of signal strength those are directly available from commercial GNSS receivers[1,2] and the terms are used interchangeably in many cases[3]. For a geodetic, static GNSS receiver the environment noise level remains nearly constant, so SNR corresponds to the received signal levels and may be used to study the satellite signal strengths[4]. Receiver's tracking and measuring ability depends on integration time, loop bandwidths, and receiver design tradeoffs such as noise figure, phase-locked loop or frequency-locked loops and is dependent on SNR or C/N_0 values[3]. Noise figure is a ratio of SNR_{in} to SNR_{out} through any RF component or system and a high SNR implies a low error ratio for digital modulation systems, so the minimum SNR sets the limit to receiver sensitivity[5,6]. Another important function of this parameter is to construct corrections for the carrier phase multipath error[2]. This paper presents the results of the studies on signal strengths and signal strength variations of different global navigations systems (GNSS) based on real-time data from Burdwan, situated in eastern part of India using a commercial survey-grade multi-GNSS receiver. We also have studied the SNR values of satellites from different navigation systems for the improving generations of satellites evolving over time. The paper starts with a brief theoretical discussion on SNR/ C/N_0 and then presents the results of the studies made over a long period of time. The study results would be useful for the users or system developers in understanding the signal strength values and their variation patterns while choosing any system or a combination for different applications.

2 SNR and CNO

Various types of available GNSS receivers in the market have different method for presenting the received signal strength of the GNSS satellites tracked. Some receiver shows the signal strength in

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terms of SNR or C/N_0 those are useful for the users, and for the GNSS receiver designers and testers[7].

SNR (generally expressed in dB) is defined as the ratio of the signal power and noise power within a given bandwidth whereas C/N_0 (expressed in dB-Hz) is the ratio of the carrier power and the noise power per unit bandwidth[8]. C/N_0 may be considered as a special case of SNR, as SNR must be referred to noise bandwidth, and C/N_0 is the amount of signal (amplitude) integrated over one second; C/N_0 is the SNR over a 1Hz bandwidth[3].

SNR is expressed in terms of the ratio

$$SNR(dB) = S - N \quad ...(1)$$

Where S is the signal power in units of dBm or dBW and N is the noise power in a given band width in units of dBm or dBW

$C/N_{0,}$ on the other hand, refers to the ratio of the carrier power and noise power per unit bandwidth. We can express C/N_0 as follows:

$$\frac{C}{N_0}(dB - Hz) = C - (N - BW) = C - N_0 = SNR + BW \quad ...(2)$$

Where C is the carrier power in dBm or dBW, N is the noise power in dBm or dBW, N_0 is the noise power density in dBm-Hz or dBW-Hz, BW is the bandwidth of observation[6,8]. The C/N_0 value provides an indication of signal quality that is independent of the algorithms used by the receiver. But the SNR is useful when evaluating the performance of the acquisition and tracking stages in a receiver. The SNR is an indication of the level of noise present in the measurement, whereas C/N_0 alone fails to provide the information[2]. With this preliminary idea, the signal strength values are studied for the GNSS systems.

3 Experimental Setup

Multi-GNSS data was recorded from GNSS Laboratory Burdwan (GLB), The University of Burdwan, India (Lat 23.2545°N, Lon 087.8468°E) using a JAVAD DELTA G3T multi-GNSS Receiver. The receiver can provide data in Receiver Independent Exchange Format (RINEX) and National Marine Electronics Association (NMEA) 0183 (version 4.1) format at 1 Hz rate. Information about each visible satellite-PRN #, elevation, azimuth and corresponding signal strength (SNR) was extracted from the raw NMEA data and were studied to observe the signal strength values and the variations.

To select a suitable multi-GNSS receiver for the study, we first compared three types of receivers- a GoeS-1M (a GPS-GLONASS OEM receiver) with a generic GPS-GLONASS antenna, a Javad DELTA G3T with GrAnt G3T antenna and an IRNSS-GPS-SBAS (IGS) receiver (developed by ISRO) with vendor supplied proprietary antenna as shown in Table1. Comparing the SNR values from the receivers, the DELTA G3T receiver is chosen for two reasons- the DELTA G3T receiver can track and use GPS, GLONASS, Galileo signals, and it provides higher signal strength values in comparison to the other two receivers; data collected from this receiver over a long period of time is used here.

Although the RINEX data (v.2.10) represent "*the original signal strength values given by the receiver for L1 and L2 tracking*"[6], we have chosen NMEA data from the receiver for our analysis for easy data extraction and availability of NMEA data from the receivers. We compared the SNR values obtained from the JAVAD receiver in RINEX and NMEA formats as presented in Table 2. It may be seen that, the SNR values obtained from the NMEA data are matching

Table 1 — Comparison of Signal strength values(SNR) obtained from different GNSS receivers on 04 April, 2017

Time (IST)	Navigation system	signal strength(SNR) values obtained from		
		GEOS-1M	DELTA G3T	IGS
05:32:06	GPS PRN NO. #23	37	49	48
	GPS PRN NO. #3	39	55	50
	GPS PRN NO. #9	28	38	40
05:38:07	GPS PRN NO. #22	37	47	46
	GPS PRN NO. #08	30	47	40
	GPS PRN NO. #26	40	53	47
05:43:04	GPS PRN NO. #03	39	55	50
	GPS PRN NO. #07	32	42	41
	GPS PRN NO. #27	35	52	44

Table2 — Signal strength (SNR) value obtained from NMEA and RINEX data using JAVAD DELTA G3T GNSS receiver on 13 February, 2017

Time (IST) (hh:mm:ss)	Navigation system	signal strength(SNR) value obtained from	
		NMEA data	RINEX data
12:42:12	GPS PRN #28	47	46.75
	GLONASS PRN #87	41	41
	Galileo PRN #11	46	46
13:08:54	GPS PRN#8	51	50.50
	GLONASS PRN #65	38	36
	Galileo PRN #22	48	48
13:09:05	GPS PRN #07	53	52.25
	GLONASS PRN #86	53	53
	Galileo PRN #30	41	40.25

well with those obtained from the RINEX files and therefore NMEA data is used in this manuscript.

4 Observations

4.1 On Multi GNSS signal strengths comparison

Variation of signal strengths for simultaneous GNSS data obtained for different satellite navigation systems (GPS, GLONASS and Galileo) was observed using Multi-GNSS data for19 September 2014 (MJD 56919) from GLB, India. An asociated constraint for such study is the simulataneous availability of satellites from all the three constellations for comparison, those have large elevation angle variation from horizon to the zenith. During the observation time, Galileo was in its initial stage and only few Galileo statellites were available for use. Observing GNSS data over muliple days, such condition was fulfilled for 19 September, 2014 where at least one satellite from each of the constellations was simultaneously present with visibility from the horizon to near zenith. The satellites (PRN #5 of GPS, PRN #66 for GLONASS and PRN #19 for Galileo) were selected for the study. Elevation angle for each of the satellites and corresponding signal strength in terms of SNR (dB*Hz) were collected from the Javad DELTA receiver and variation of SNR values with increasing elevation angle are shown in Fig. 1. It may be observed that above 15^{o} elevation angle, signal strengths exceeds 40 dB*Hz, GLONASS satellite's signal strengths were higher than those for GPS or Galileo satellites, and Galileo signal were witnessed to be more stable than the other two constellations. The figure points towards the difference in signal strengths and signal strength variation patterns for different GNSS systems, and this primary observation encouraged us to study the aspect in more details considering each of the constellation individullay; results of the studies are presented in subsequent sections.

For comparison of GNSS signal strengths, SNR of satellites from each of the individual systems are studied first. For simplicity and comprehensive analysis, satellite elevation angles are subdivided into range bins of 5^{o} each, from horizon to the zenith. All SNR values for the satelltes lying within a range bin of 5^{o} are collected together, analysed and the results are presented against the higher range boundary (i.e., values for the elevation angle range bin of 30 – 35^{o} are shown against 35^{o}).

4.2 GPS signal strength and variations

Data of several days for of different generation GPS satellites having visibility (elevation angles) from near the horizon to zenith are selected. Average and standard deviation of the SNR values for L1 C/A signal (1575.42 MHz) for these satellites lying within an elevation angle range bin of 5^{o} are calculated and the results are presented in Fig. 2 and Table 3. In Fig. 2, the average values are shown against the upper elevation range boundary, the standard deviations are shown as error bars on the average values.

[▪] denotes the maximum achieved elevation of a satellite

It may be observed from the Table 3 and Fig. 2 that, around 20^{o} elevation angle, GPS signal strength reaches 40 db*Hz; the strengths increase, become

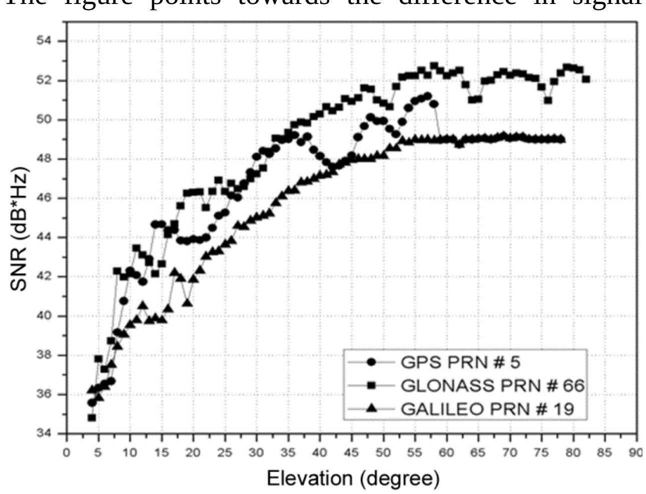

Fig. 1 — Variation of SNR values with increasing elevation angles for GPS, GLONASS and Galileo satellites on 19 September 2014 using JAVAD DELTA G3T receiver

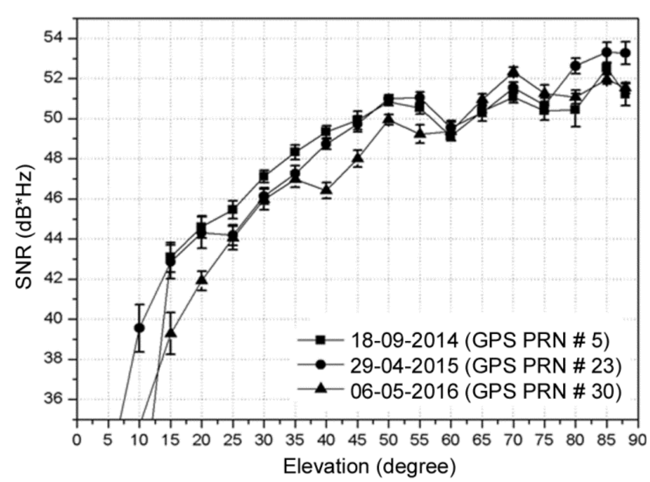

Fig. 2 — Variation of average and standard deviation of SNR values of GPS-L1 signal for different GPS satellite generations. PRN #5 (Block IIR-M), PRN #23 (Block IIR), PRN #30 (Block IIF)

Table 3 — Variation of average and standard deviation of signal strength (SNR) of GPS L1 C/A signals; Receiver: Javad DELTA G3T; data duration around 3.45 hrs

Elevation (Degree)	10 March 2014 (PRN#16)IIR-M	07 May 2015 (PRN#23)IIR	27 April 2016 (PRN#30)IIF
	Average (Std deviation) (dB*Hz)	Average (Std deviation) (dB*Hz)	Average (Std deviation) (dB*Hz)
5	37.2 (2.8)	32.1 (3.9)	33.1 (2.7)
10	39.6 (1.8)	39.41 (2.7)	35.1 (2.4)
15	42.3 (1.3)	43.2 (1.7)	39.5 (2.1)
20	42.9 (1.1)	44.4 (1.4)	42.0 (1.1)
25	45.2 (1.0)	44.1 (1.1)	44.0 (1.1)
30	47.0 (0.7)	46.1 (0.8)	45.9 (1.0)
35	47.4 (0.6)	47.2 (0.9)	47.2 (0.7)
40	49.5 (0.7)	48.5 (0.6)	46.6 (0.9)
45	49.0 (0.8)	49.6 (0.9)	48.2 (0.9)
50	50.3 (1.1)	51.0 (0.4)	50.2 (0.5)
55	51.5 (0.8)	51.0 (0.6)	49.3 (0.9)
60	51.5 (0.6)	49.5 (0.7)	49.7 (0.9)
65	50.7 (0.8)	50.1 (0.8)	51.3 (0.6)
70	52.3 (0.5)	50.9 (0.5)	52.8 (0.4)
75	51.4 (1.0)	50.5 (0.7)	51.4 (1.0)
80	50.4 (0.6)	52.3 (0.7)	51.3 (0.7)
85	51.4 (0.5)	53.2 (0.7)	52.1 (0.5)
90	50.9 (0.1) [87^0]	53.1 (1.1) [86^0]	51.82 (0.5) [89^0]

Table 4 — Variation of average and standard deviation of signal strength (SNR) of GLONASS L1 C/A signals

Elevation (Degree)	10 March 2014 (PRN#69) GLONASS M	07 May 2015 (PRN#90) GLONASS M	21 July 2016 (PRN#73) GLONASS K
	Average (Std deviation) (dB*Hz)	Average (Std deviation) (dB*Hz)	Average (Std deviation) (dB*Hz)
5	38.7 (2.3)	37.7 (1.4)	36.0 (2.2)
10	42.3 (1.5)	39.3 (1.9)	40.3 (2.0)
15	46.0 (1.1)	40.7 (1.3)	43.0 (1.4)
20	46.1 (1.1)	43.7 (1.2)	50.6 (2.5)
25	47.4 (0.8)	44.8 (0.9)	45.6 (0.7)
30	48.3 (0.6)	45.7 (0.6)	47.2 (0.7)
35	48.8 (0.8)	46.9 (0.5)	48.3 (0.7)
40	50.4 (0.5)	47.9 (0.5)	49.3 (0.5)
45	51.1 (0.5)	48.3 (0.5)	50.0 (0.6)
50	51.7 (0.5)	49.0 (0.3)	50.6 (0.5)
55	52.0 (0.2)	49.1 (0.3)	50.9 (0.5)
60	52.0 (0.2)	49.5 (0.5)	51.4 (0.5)
65	52.1 (0.3)	49.7 (0.5)	51.9 (0.3)
70	52.2 (0.4)	49.8 (0.4)	52.0 (0.1)
75	52.1 (0.3)	49.9 (0.3)	52.3 (0.5)
80	52.2 (0.4)	50.0 (0.1)	52.7 (0.5)
85	52.1 (0.4) [85^0]	50.0(0.1) [84^0]	52.9(0.3) [81^0]

more stable with increasing elevation angle and the values saturate around 50^o elevation angle. Similar work may be found in S Hetet (2000)[2] and Shikhar Deep *et al*., (2018)[9], where the GPS signals are only studied. Similar fluctuations of SNR values above 50^o elevation has been shown in Shikhar Deep *et al*., (2018)[9]. Fluctuations in average and standard deviations values may be observed at higher elevation angles after the saturation. From the observation location, usable GPS satellites may be found till near-zenith position and all GPS satellite generations exhibit comparable signal strength values and variation patterns.

4.3 GLONASS signal strength and variations

Similar effort was carried out using GLONASS L1 C/A signals (1592.9525 MHz to 1610.485 MHz) for different days and the results are presented in Fig. 3 and Table 4. In Fig. 3, values are shown against higher boundary of elevation angle range bin and the standard deviations are shown on the average values. Here also, the signal strength values increase with elevation angle. SNR values higher than 40 dB*Hz may be obtained for elevation angles exceeding 20^o, becomes stable above 30^o and saturates around 60^o-70^o with a nominal SNR around 48 dB*Hz[10]. Variation in signal strength values for different GLONASS satellite-generations may be noticed. It is seen from Fig. 3 that for PRN #84, an M-class satellite launched in 2007[11], the signal strength is much lower than that for the same class of satellite launched in 2010 (PRN#89, Class M) or that for K-Class satellite (PRN#73). Table 4 also reveals that the GLONASS-M satellites launched in 2010 onwards have similar signal strengths and from GLB, maximum obtained elevation angles of trackable GLONASS satellites are slightly lower than the GPS satellites.

In Figs 3 & 4, we wanted to represent the general variation of GLONASS signal strengths with changing elevation angles. Therefore, intentionally, data sets for varying PRN Ids and dates scattered over a long period and for different GLONASS generations are selected.

[▪] denotes the maximum achieved elevation of a satellite

4.4 Galileo signal strength and variations

Here we have used Galileo E1 (1575.42 MHz) signals from different Galileo generations (In Orbit Validation (IOV) and Full Operational Capability

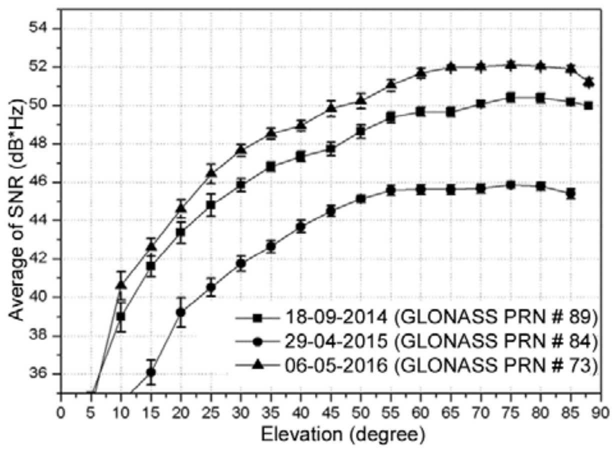

Fig. 3 — Variation of average and standard deviation of signal strength of L1 C/A signal of different GLONASS satellite generations; PRN #89 and PRN #84 (GLONASS M); PRN #73 (GLONASS K)

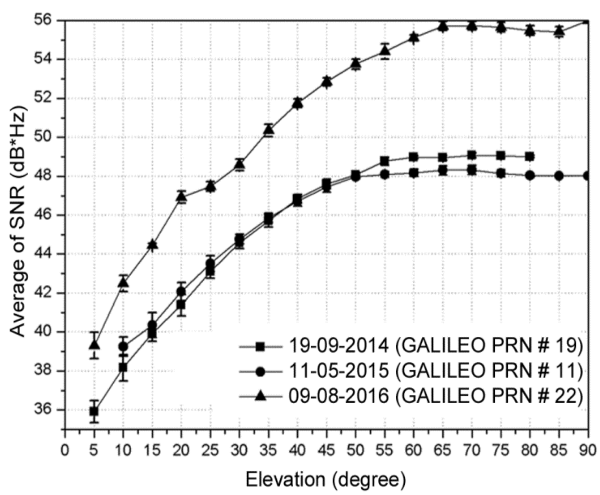

Fig. 4 — Variation of average and standard deviation of signal strengths of E1 C/A signal of different Galileo satellite generations. Galileo PRN #11, PRN#19 (IOV), PRN #22 (FOC)

(FOC)) satellites for analysis and comparison. Similar analysis as presented in the preceding sections has been made for Galileo signals and the results are presented in Fig. 4 and Table 5. It may be seen that Galileo FOC satellites provide SNR values better than 40 dB* Hz above 10^o elevation angle, signal strengths increase smoothly till 60^o elevation angle and saturates around a nominal value of 55 dB*Hz. Galileo signals are found to be more stable than the GPS or GLONASSS signals. From the observation location situated in the eastern part of India, Galileo satellite's visibility is restricted up to the maximum elevation angles those are lower than the other two constellations. It is also observed that the Galileo Full Operation Capability (FOC) satellites have much higher signal strengths in comparison to the In-Orbit Validation (IOV) satellites.

Table 5 — Variation of average and standard deviation of signal strength (SNR) of L1 C/A signal of Galileo satellites

Elevation (Degree)	01 December, 2014 (PRN#11); IOV	17 February, 2015 (PRN#19); IOV	09 August, 2016 (PRN#22); FOC
	Average (Std deviation) (dB*Hz)	Average (Std deviation) (dB*Hz)	Average (Std deviation) (dB*Hz)
5	32.9 (5.7)	18.9 (2.3)	39.3 (1.3)
10	40.0 (0.8)	34.3 (4.7)	42.5 (0.8)
15	42.1 (1.4)	38.6 (0.9)	44.5 (1.2)
20	44.2 (0.8)	41.3 (1.2)	46.9 (0.6)
25	44.7 (0.7)	42.8 (0.8)	47.5 (0.5)
30	45.5 (0.5)	44.1 (0.7)	48.6 (0.6)
35	46.5 (0.5)	45.5 (0.7)	50.3 (0.6)
40	47.3 (0.5)	46.6 (0.6)	51.8 (0.5)
45	48.0 (0.4)	47.5 (0.5)	52.9 (0.4)
50	48.5 (0.5)	48.3 (0.6)	53.8 (0.5)
55	49.0 (0.0)	48.9 (0.4)	54.4 (0.8)
60	49.1 (0.3)	49.0 (0.2)	55.1 (0.3)
65	49.5 (0.5)	49.0 (0.1)	55.7 (0.5)
70	49.6 (0.5)	49.1 (0.3)	55.7 (0.4)
75	49.2 (0.4)	49.0 (0.2)	55.7 (0.5)
80	49 (0.0) [80^0]	49.0 (0.2) [79^0]	55.5 (0.5)
85	NA	NA	55.4 (0.5)
90	NA	NA	56.0(0.2) [89^0]

[▪] denotes the maximum achieved elevation of a satellite

4.5 Comparison of GNSS (GPS, GLONASS and Galileo) signals strengths

Now, we compared the signals of all the three systems for 28 May 2015 simultaneously. Signals obtained from Javad DELTA receiver for PRN #7 (GPS-IIR), PRN #80 (GLONASS-M) and PRN #12 (Galileo- IOV) are compared and the results are shown in Figs 5 & 6 and in Table 6. From these figures, our initial observations on signal strength and variation patterns for the three constellations are endorsed.

It may be seen that up to the elevation angle of around 50^o, stability and strengths of the signals from the three constellations are comparable, but exceeding that, Galileo signals are more stable and GPS signal show slightly higher fluctuations compared to the other two constellations.

4.5.1 Comparison of GNSS signals strengths using IGS station data

To compare and validate the results obtained from GLB, data from the nearby IGS stations as shown in Table 7 are used[12]. Out of these four stations, only

DGAR provides navigation information (.nav files) for all the three constellations and the other three stations in India provide GPS-only data. Therefore, LCK, India data is used to study GPS signal strength variations and data for DGAR, lying close to the Indian region is used to analyse the signal strengths for all the three constellations. It is to be noted that, for the IGS stations, data is obtained in 30 sec intervals, while for observations made from GLB, data rate of 1 Hz is used.

For LCK, the RINEX files (.obs and .nav) were used in RTKLib[13] to extract elevation and SNR values of the GPS satellites. In case of DGAR, elevation and signal strength data for GPS satellites are obtained using same method, elevation angle values for GLONASS and Galileo satellites during the observation period are found out using System Tool Kit (STK) from AGI[14].

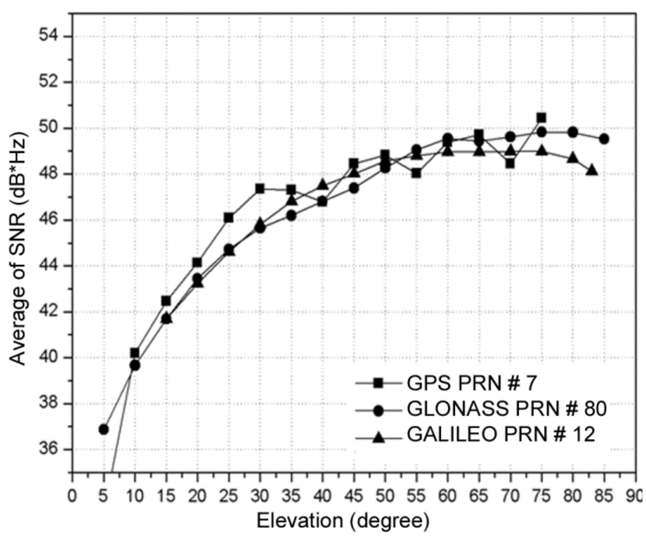

Fig. 5 — Comparison of average signal strength variation on 28 May, 2015

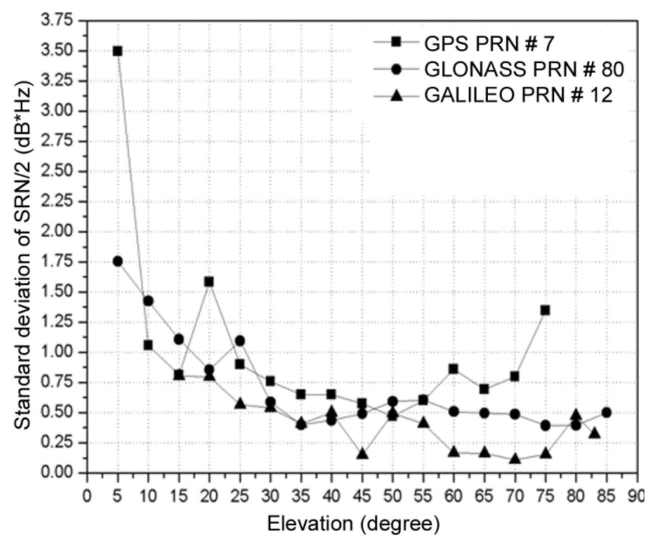

Fig. 6 — Comparison of standard deviation of signal strength variation on 28 May, 2015

Table 6 — Comparison of average and standard deviation of signal strength of GNSS signals for 20 June 2016 (Receiver used: Javad DELTA G3T)

Elevation (Degree)	Average signal Strength (dB*Hz)			Standard Deviation of signal Strength (dB*Hz)		
	GPS-IIF PRN #30	GLONASS PRN #78	Galileo-FOC PRN #24	GPS-IIF PRN #30	GLONASS PRN #78	Galileo-FOC PRN #24
5	34.0	32.4	NA	NA	1.4	NA
10	38.1	37.1	40.5	3.2	2.1	1.1
15	41.2	39.7	42.8	0.9	1.0	1.9
20	43.3	40.8	46.3	1.4	0.9	1.0
25	45.3	40.9	47.2	1.1	0.8	0.9
30	45.6	41.3	47.8	0.6	0.7	0.7
35	46.4	42.0	48.6	0.9	0.8	0.7
40	47.4	42.7	50.0	0.5	0.5	0.8
45	48.2	43.4	50.9	0.9	0.6	0.7
50	49.7	43.7	51.7	0.5	0.6	0.4
55	49.8	43.9	52.1	0.4	0.5	0.3
60	49.0	44.5	52.3	0.6	0.5	0.5
65	50.3	44.9	52.8	0.7	0.3	0.4
70	50.5	44.9	53.0	0.5	0.2	0.0
75	49.9	45.0	53.1	0.7	0.2	0.3
80	51.2	44.9	53.1	0.7	0.3	0.4
85	51.9	45.0	53.4	0.5	0.2	0.5
90	51.0	32.4	NA	0.8	1.5	NA

Table 7 — Nearby IGS stations and descriptions

IGS Station and Code	Location	Receiver use	Comment
Lucknow, India LCK400IND (LCK)	26.9121° N 80.9556° E	LEICA GRX1200+GNSS	
Hyderabad, India HYDE00IND (HYDE)	17.4172° N 78.5508° E	LEICA GRX1200GGPRO	Ephemeris data (.nav file) for GLONASS and Galileo satellites not available
Bangalore, India IISC00IND (IISC)	13.0211° N 77.5703° E	SEPT POLARX5	
Diego Garcia, USA DGAR00GBR (DGAR)	-7.2696° N 72.3702° E	JAVAD TRE-3DELTA	Ephemeris data for all three constellations available

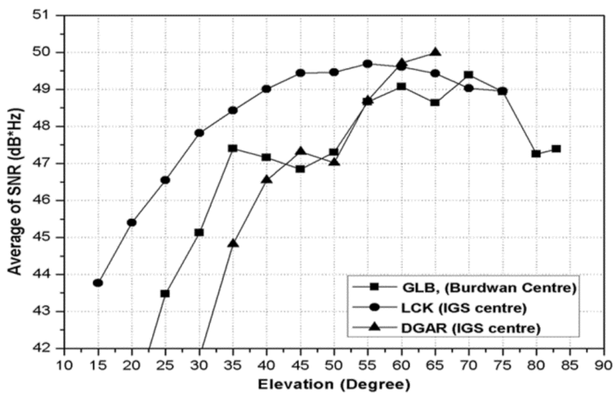

Fig. 7 — Comparison of GPS signal strength variation for the same GPS satellite (PRN #16) from different locations on 20 June, 2018

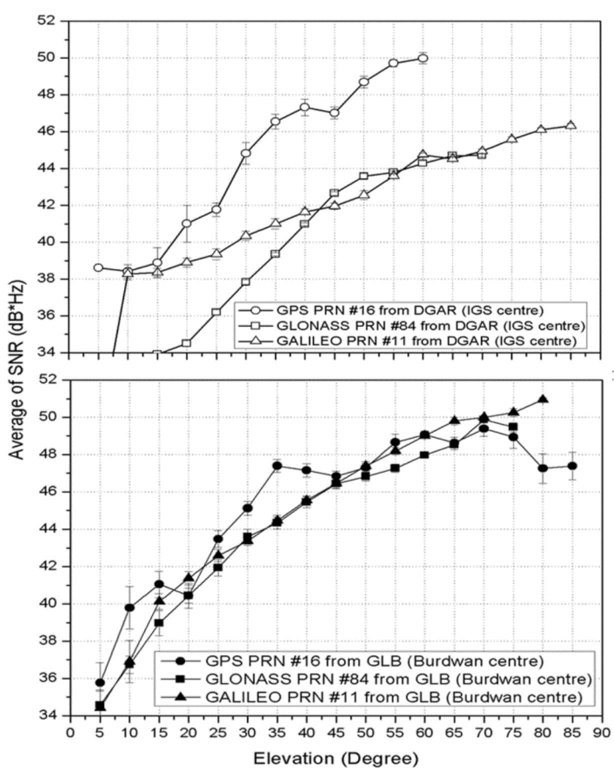

Fig. 8 — Comparison of average and standard deviations of GNSS signal strength for DGAR (top) and GLB, Burdwan for same PRN son 19 June 2018

Comparison of GPS signal strength variations for GLB (Burdwan, Receiver: Javad DELTAG3T), LCK and DGAR are shown in Fig. 7. It may be noted that, data for DGAR supports the observation of higher fluctuations in GPS signal. LCK data also shows smaller fluctuations in GPS signal, but the data rate of LCK IGS data is not regular, therefore, number of samples within each elevation angle range bin varies widely for the case, which may have suppressed some of the information within an elevation angle range bin.

Now, GPS, GLONASS and Galileo signal strengths for IGS Station DGAR and GLB, Burdwan are compared for the same PRNs for the same observation day as shown in Fig. 8. In the figures, the standard deviations are shown as error bars on the average values plotted against the higher value elevation angle range bin. Figure 8 again supports the primary observation of relatively higher variation in GPS satellite signal strengths in comparison to the other two constellations.

5 Conclusion

The results presented here would be useful to understand the signal strengths and its variation patterns for currently operational GNSS systems using long term data. All GNSS signals studied here have no significant attenuation effects since all the SNR value fluctuations are always within 3dB from peak to peak. From the observations, stability of Galileo signals, enhanced signal powers for new generation Galileo and GLONASS satellites, and the fluctuation of signal strengths of GPS satellites from higher elevation angles may be noted. GNSS signal strength values are often used for atmospheric research purposes, and these results may be useful for the concerned research community. The results may also be useful for GNSS system and application developers. With operation of Beidou and NavIC, similar studies may be taken up for all available constellations together in future. The study specifically may be useful for the Asia-Oceania region, where signals from all GNSS systems are now available for concurrent use.

Acknowledgement

The authors acknowledge Defence Research and Development Organization (DRDO), Government of India for financial support (Project Code: ERIP/ ER/ DG-MSS/ 990516601/ M/ 01/ 1658) for carrying out the studies. The authors also acknowledge the free use of *RTK Lib*, and *STK licence* from AGI.

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