# On Use of Low Cost, Compact GNSS modules for Ionosphere Monitoring

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**Abstract**

High grade or special purpose Global Navigation Satellite System (GNSS) receivers are used for ionosphere monitoring and research. These special kinds of receivers may provide data up to 50 Hz rate. Dual frequency, compact, low cost GNSS receivers which provides raw data is now being used in Single Point or RTK precise point positioning. In this paper, an initiative is described to use these modules for GNSS-based monitoring of ionosphere activities. Here a comparative study between Leica GR50, a high-grade geodetic receiver and Ublox ZED-F9P, a low cost, dual frequency, compact receiver is carried out to explore the potential of such low-cost receivers for ionosphere probing. Studies are carried out on signal strength values in terms of C/N and Sindices. A fixed bias in signal strength values is observed between the data provided by the two receivers which is about 15 dB-Hz in L1 band and 8 dB-Hz in L2 band. Ublox F9P Sindices have limited resolution, but the variation signature follows that for the Leica GR50. The compact module showed the potential for being used as GNSS-based ionospheric monitors with Make and Model specific calibration and with the advantages of cost, size and power efficiency. A GNSS based Ionosphere monitoring Unit (GIMU) integrating small computer, Ublox F9P and wireless data communication module is also proposed for real time, concurrent ionosphere anomaly monitoring using a distributed network of such modules over a geographical region.

# On Use of Low Cost, Compact GNSS modules for Ionosphere Monitoring

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**Key Points:**

- Navigation satellite signals are used for ionosphere monitoring based on received signal strength and derived parameters from the basic measurement data.
- Survey-grade or special purpose navigation receivers as usually used for such purposes
- Low-cost, compact, GNSS receivers are now available with 5 Hz raw data output rate and have the potential for use in ionospheric research
- Similar signal strength and $S_4$ variation signatures are observed comparing a survey grade and a compact, low-cost receiver data.
- With necessary make and model-specific calibrations the compact modules may be used for ionospheric research.
- This may help in developing networked, concurrent GNSS-based ionospheric monitoring system distributed over a geographical area.

## Abstract

High grade or special purpose Global Navigation Satellite System (GNSS) receivers are used for ionosphere monitoring and research. These special kinds of receivers may provide data up to 50 Hz rate. Dual frequency, compact, low cost GNSS receivers which provides raw data is now being used in Single Point or RTK precise point positioning. In this paper, an initiative is described to use these modules for GNSS-based monitoring of ionosphere activities. Here a comparative study between Leica GR50, a high-grade geodetic receiver and Ublox ZED-F9P, a low cost, dual frequency, compact receiver is carried out to explore the potential of such low-cost receivers for ionosphere probing. Studies are carried out on signal strength values in terms of $C/N_0$ and $S_4$ indices. A fixed bias in signal strength values is observed between the data provided by the two receivers which is about 15 dB-Hz in L1 band and 8 dB-Hz in L2 band. Ublox F9P $S_4$ indices have limited resolution, but the variation signature follows that for the Leica GR50. The compact module showed the potential for being used as GNSS-based ionospheric monitors with Make and Model specific calibration and with the advantages of cost, size and power efficiency. A GNSS based Ionosphere monitoring Unit (GIMU) integrating small computer, Ublox F9P and wireless data communication module is also proposed for real time, concurrent ionosphere anomaly monitoring using a distributed network of such modules over a geographical region.

## Plain Language Summary

Navigation satellites provided Position, Velocity and Timing (PVT) information to the users. The satellite signals are affected while passing through the ionosphere and therefore, GNSS also is used as a major tool for ionosphere studies. Survey grade or special purpose receivers are usually used for such studies those are costly and therefore is not affordable for all users. Because of advancement of digital integrated circuit technology, compact, low-cost GNSS receivers are available commercially primarily for positioning purposes. Some dual frequency compact receivers provide raw data output at a rate of 5Hz and therefore, have the potential for use in ionospheric monitoring and research. In this paper, results on the usability of such dual frequency, compact, low-cost GNSS receivers for ionospheric research has been presented. Comparative studies are made between survey grade and compact receivers for satellite signal strength values and derived ionosphere scintillation related parameters. It is found that the low-cost GNSS receivers have the potential to be used in ionosphere studies with make and model specific calibration. Multiple number of such receivers can be deployed over a geographical region for networked, concurrent monitoring and successful implementation of the idea may support the GNSS-based ionospheric research community.

## 1 Introduction

Ionosphere is a region of atmosphere approximately 45 to 965 km above the surface of the earth with a depth of several kilometers where electrons extracts out from the atoms as ultra-violate ray of sun illuminates on those atoms [Earth's Atmospheric layers, https://www.nasa.gov/mission_pages/sunearth/science/atmosphere-layers2.html, 2020]. It is a dispersive medium; radio waves passing through the medium are refracted and the amount of refraction is proportional to the number of electrons present in the particular region of the layer through which the signal passes, represented by Total Electron Content (TEC) of the medium. More specifically, the phase velocity and the group velocity of the electromagnetic waves passing through this dispersive layer differs. The density of the electrons over the region is not regular, it varies due to several reasons including solar radiation [Datta-Barua et al., 2003]. Electromagnetic signals from artificial satellites passing through the layer gets affected due to the variation of electron density in ionosphere and is a major concern in case of satellite-based applications like communication, remote sensing and navigation. These small-scale irregularities in electron density causes fluctuation in signal intensity; this phenomenon is called amplitude scintillation and it is measured by the S4 index, among many other parameters [Skone, 2000]. The consequence of amplitude scintillation is degradation of the signal strength the receiving end. Abrupt fluctuation in phase of the signal is called phase scintillation and may cause loss of lock and cycle slip in a satellite signal tracking receiver. So, this anomalous phenomenon is a big threat for satellite-based applications those are dependent on radio waves from satellites and the signal passes through the ionosphere. Researchers have carried out various types of work for monitoring and predicting such activity of the ionosphere region. Apart from typical navigation services, Global Navigation Satellite System (GNSS) signals are also used for Ionospheric study. Several studies on Ionosphere scintillation from different geographic regions has been carried out using GPS, GLONASS, Galileo and BeiDou constellations [Klobuchar, 1987; Doherty et al., 2000; Skone, 2000; Datta-Barua et al., 2003; Das Gupta et al., 2004; Ren et al., 2016;]. Recently, signals from the Indian regional navigation system, NavIC, transmitted from geostationary and geosynchronous orbits are also being used for these kinds of studies in the Indian region [Dan et al., 2018; Sharma et al., 2019]. Generally, special purpose or commercially available geodetic GNSS receivers capable of providing high data rate (~10 to 50 Hz) and multi-frequency (at least two frequencies) data are used for such studies. Cost of these types of receivers is around USD 20,000 or higher, that restricts the availability of such receivers for many users. Deployment of a network of multiple such receivers over a large geographical location for concurrent, long-term data recording is of interest but the method is constrained by cost, security of the electronics, size and power requirements at the field location. GNSS technology is passing through a notable change with the availability of low-cost, compact, multi-constellation, multi-frequency chipsets and receiver board modules. Extensive research on utility of such low-cost, compact GNSS receivers for positioning purposes have been done and reported over the globe [Takasu et al., 2009; Andrei, 2012; Manandhar, 2018; Mahato et al., 2019] and these modules became popular in many real-life applications [Omrani et al., 2013; Juras et al., 2016]. These receivers provide National Marine Electronic Association (NMEA) and raw data. Parameters of interest for GNSS-based ionospheric research may be extracted from the data provided by the compact receivers and therefore, ionospheric probing using such modules may be an interesting topic, that has not been much exploited. A study on TEC using Tersus BX305 compact receivers was done successfully, but these receivers are priced around USD 1,200 [Bramanto et al., 2018]. Software defined receivers were designed for space weather monitoring as reported by [O'Hanlon et al, 2011; Linty et al., 2011]. A prototype of low-cost receiver for monitoring ionosphere scintillation and associated parameters (S4, Carrier to Noise density ratio represented by $C/N_0$) was presented in [Curran et al., 2014]. An effort in use of compact, low-cost Multi-GNSS receiver (uBLox NEO-M8T, cost around USD 75) may be found in [Bose et al., 2019] where the $C/N_0$ value obtained from the compact receiver was compared with those from a Leica GR50 geodetic receiver. It was found that, the values differ by around 8 dB-Hz but have similar variation patterns. The $C/N_0$ values from the geodetic receiver shows more stable short-term variation w.r.t the values provided by the compact receiver. Some low cost GNSS receivers priced around USD 300 are now available in the market those can provide dual frequency raw data upto 5Hz rate.

Therefore, potential of such dual-frequency, multi-constellation modules may be exploited for ionospheric probing. This may be done by studying $C/N_0$ values for different satellites or from the derived parameters such as S4 index, the normalized standard deviation in signal intensity over a certain period, that may be calculated using $C/N_0$ values from formula given below [Chakraborty et al, 2017].

$$S_4 = \sqrt{\left[\frac{< S_i^2 > - < S_i >^2}{< S_i >^2}\right]} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.(1)$$

Where $S_i = 10^{0.1 \times C/N0}$

In this paper, an effort has been made to explore the capabilities of low-cost, compact dual-frequency GNSS receivers for ionospheric probing based on the $C/N_0$ and $S_4$ values. A comparative study on signal strength and $S_4$ indices obtained from both types of receivers have been presented that indicates the potential of using such modules for the purpose, specifically in case of networked operation over a large geographical region. A method is adopted for carrying out this study is Section 2. Section 3 describes the results and discussions and finally the conclusions are presented in Section 4.

## 2 Methodology

A Leica choke ring (AR 25) antenna is mounted on the rooftop of The University of Burdwan, India (23.2545°N, 87.8547°E, -8.85m). RF signal from the antenna is fed to a 1: 4 active GNSS signal splitter as shown in Figure 1. Two ports of the splitter is connected with two types of GNSS receivers- one is a compact, low-cost, multi-constellation, dual frequency (L1 and L2), Ublox ZED-F9P (cost~ USD 300) and the another is a Leica GR50, a multi-frequency, geodetic receiver (cost ~23,500 USD). GPS L1 Signals are tracked by both the receivers are C/A coded but the L2 signals tracked by the F9P and Leica GR50 are L2C (L) coded and L2C (M) coded respectively. The antenna LNA is powered up by the bias voltage supplied from Leica receiver through 'DC through' port of the splitter. Both the receivers are operated in GPS-only mode. Raw data from the F9P is recorded at 5Hz rate using the vendor supplied proprietary software (*UCentre version 19.12*) and then is converted into RINEX by RTKLib 2.4.3 b33 [RINEX 3.03 ftp://igs.org/pub/data/format/rinex303_update1.pdf, 2020; RTKLIB: An Open Source Program Package for GNSS Positioning http://www.rtklib.com/, 2020]. RINEX data obtained from the GR50 geodetic receiver at 5Hz rate is stored in the internal memory of the receiver. It is observed that GPS satellites, GPS PRN #6 (G6) and GPS PRN #12 (G12) were visible on the sky for a long time during the data recording period, and data for these two satellite signals are taken into consideration for this study. RINEX data file provides pseudo ranges and signal strengths for each frequency for each of the tracked satellite. The signal strength are directly obtained from the RINEX data files and the S4 indices are calculated using equation (1). It is to be noted that the S4 index is calculated over a span of 60 sec @5Hz (for 300 epochs) in this paper. The results are discussed in the next section.

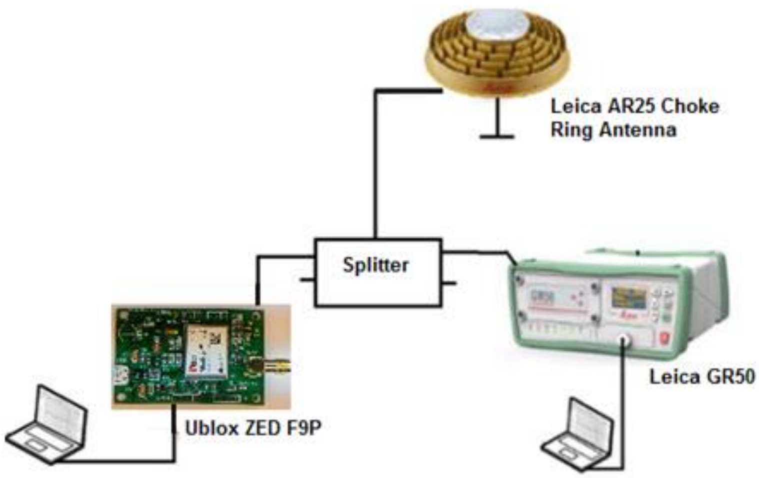
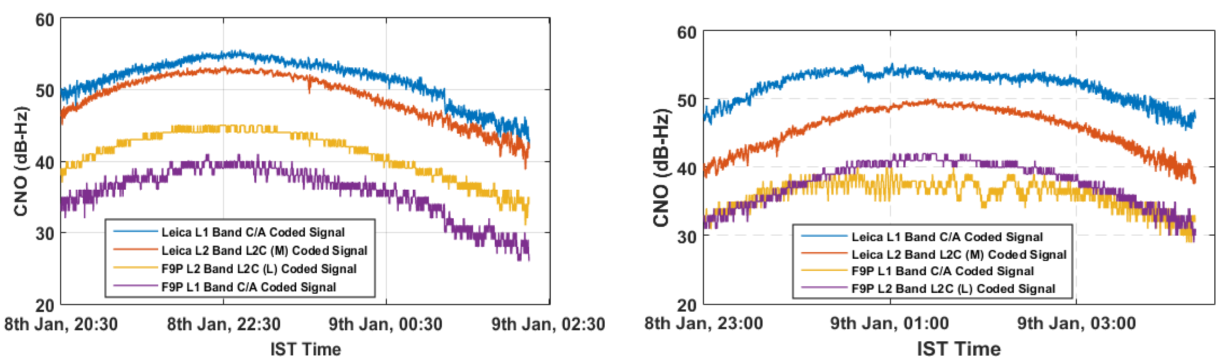



**Figure 1.** Experimental setup for the comparative study of Ublox ZED F9P and Leica GR50 Receivers for GNSS-based atmospheric research

## 3 Results and discussions

Signal strength ($C/N_0$) values for G6 and G12 in L1 and L2 frequency bands are plotted against local time as shown in Figure 2. From these Figures, the following observations can be made:




(a) (b)

**Figure 2.** Variation of signal strength in L1 and L2 band with local time obtained from U-blox F9P and Leica GR50 receiver for (a) GPS PRN #6, (b)GPS PRN#12

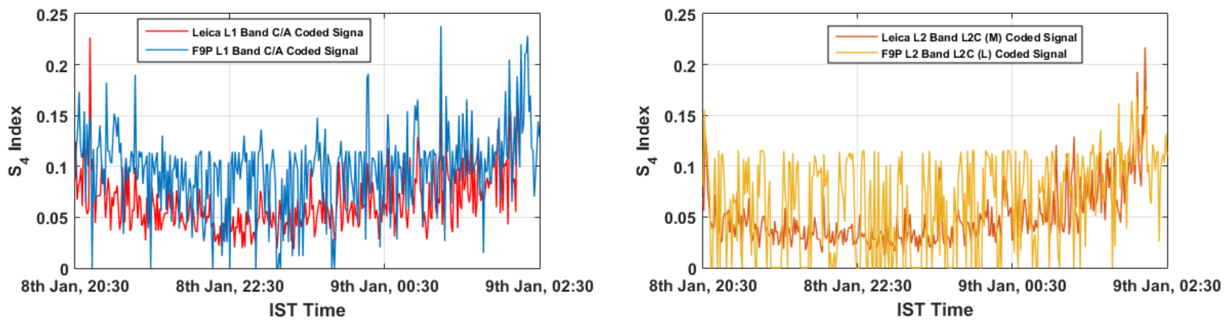
(i) Difference between GR50 GPS L1 signal strength and Ublox GPS F9P L1 signal strength ($C/N_0$) is about 15 dB-Hz and for L2 the signal strength is about 8 dB-Hz. In case of the Ublox F9P receiver, the signal strength ($C/N_0$) values have less resolution in comparison to the .GR50 values.

(ii) Very similar variation pattern is observed in $C/N_0$ values obtained from both the receivers.

(iii) For G12, L1 and L2 signal strength values of Ublox F9P are overlapping in some cases, but the difference between the values obtained from the two receivers remains similar as described in (i) above.

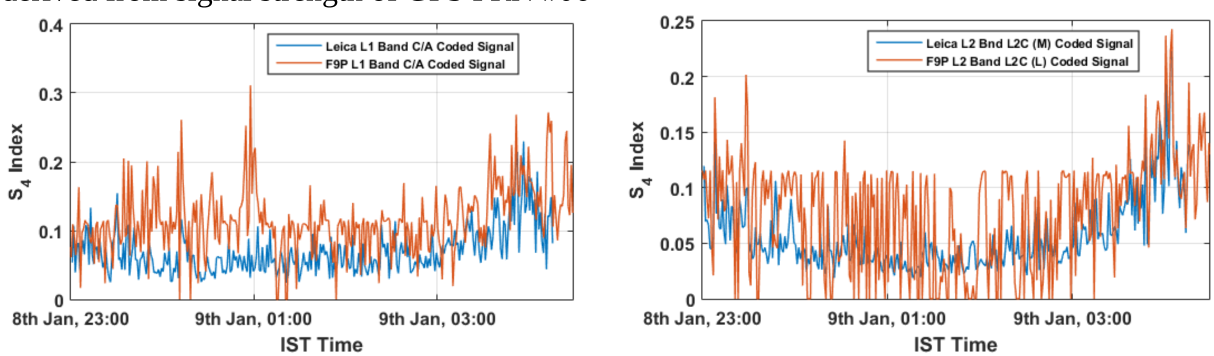
Similarity of signal strength variation and the fixed difference between the signal strength values in a frequency band for the two types of receivers suggest that, with proper calibration such compact modules may be used for ionospheric monitoring purposes. However, make and model specific calibration is needed for the purpose.

$S_4$ indices for G6 and G1) are plotted against the local time and are shown in Figure 3 and 4 respectively. From these figures it is observed that




(a) (b)

**Figure 3.** $S_4$ index comparison between Leica and Ublox in (a) L1 band and (b) L2 band, derived from signal strength of GPS PRN #06




(a) (b)

**Figure 4.** $S_4$ index comparison between Leica and Ublox in (a) L1 band and (b) L2 band, derived from signal strength of GPS PRN #12

(i) $S_4$ calculated from Leica GR50 has lesser instantaneous variation in comparison to those calculated from data using Ublox F9P receiver, but the values obtained from both the receivers follow similar variation pattern.

(ii) For G6, Leica S4 values ranges from 0.025 to 0.25 for both L1 (C/A) and l2 (L2C[M]) bands. For F9P, the highest value of S4 is 0.25 in L1 (C/A) band and 0.20 in L2 (L2C[L]) band. The zero values of S4 is case of F9P are attributed to the inferior resolution of $C/N_0$ values.

(iii) For G12, Leica $S_4$ ranges from 0.025 to 0.25 for both L1 (C/A) and L2 (L2C [M]) bands. For F9P, the highest value of S4 is 0.25 in L1 (C/A) band and 0.20 in L2 (L2C [L]) bands. Zero S4 values may also be witnessed here.

Similarity in the calculated $S_4$ values obtained using two types of receivers and similarity in the variation patterns suggests that, with necessary software-based filtering, the compact modules are usable for ionospheric monitoring purposes.

Based on the observations presented and the work presented in [Bose et al., 2019], it is seen that, the compact, low-cost GNSS modules have the potential for being used as ionospheric monitoring purpose with proper make and model specific calibration. It is noted that the $C/N_0$ values obtained from the National Marine Electronic Association (NMEA) data is same as obtained from the corresponding RINEX data. Therefore, A low-cost, compact, GNSS-based Ionosphere Monitoring Module (GIMU) is proposed here which consists of a compact, low-cost receiver (e,g., Ublox Zed F9P receiver capable of producing data @5 Hz) with an antenna, a Raspberry Pi (RPi) as the controller and data logger (with optional display), a GSM/ GPRS/ 4G dongle for internet connectivity and a power bank with solar panel support as shown in Figure 6. The RPi receives and processes data that can be stored in the on-board memory in case of stand-alone application or the data may be sent to a central server for networked data collection. The total cost of this GIMU would be around USD 400. NMEA data obtained from the GNSS module contains $C/N_0$ value for each satellite and $S_4$ index could be derived from the $C/N_0$ values [NMEA data, https://www.gpsinformation.org/dale/nmea.htm]. Using the GIMU, real time $C/N_0$ and $S_4$ values may be stored in the unit or may be transmitted from the GIMU using a Cellular Mobile dongle to a central server as shown in Figure 5.

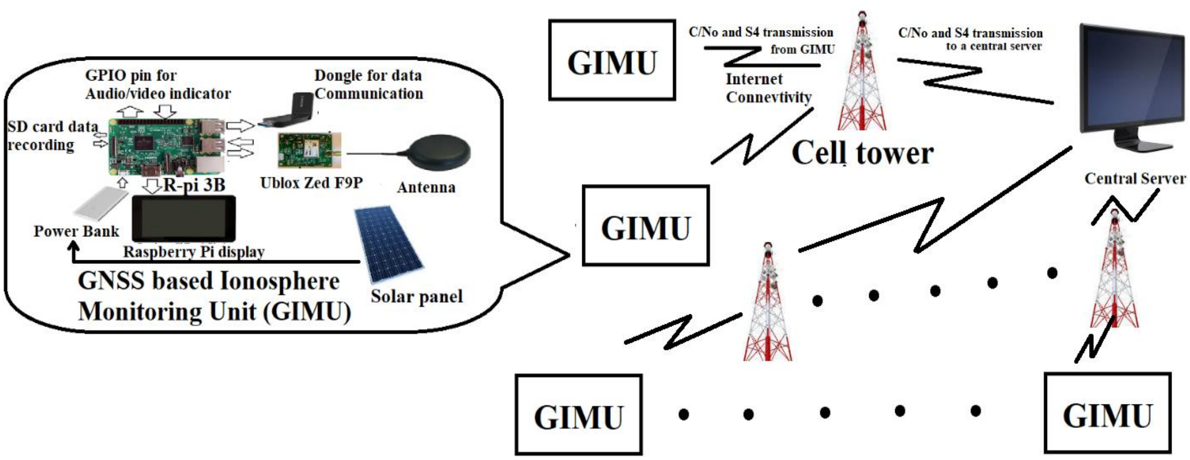



**Figure 5.** Proposed ionosphere data monitoring network using low cost GNSS receiver interfaced with Raspberry Pi and Cellular Mobile Dongle

Concurrent, Networked monitoring of ionosphere is possible over a large disturbed geographical region using multiple such GIMUs those can also provide precise location of the monitoring point. An alternative option may be recording (or online transmission) of raw GNSS data from the compact modules, that can be post-processed to obtain pseudorange and carrier phase measurement values for calculation of other derived ionospheric parameters. An individual GIMU in stand-alone operation may be used as an instantaneous ionospheric anomaly monitor that can generate audio/ visual alert in case of out-of-threshold values pre-decided by the user. The advantages of such a compact GIMU are low cost, small size, low-power requirement and therefore, multiple number of such GIMU can be deployed over a geographical region for continuous real time ionosphere monitoring.

## 4 Concluding remarks and future scope of work

In this manuscript, the potential of compact GNSS low-cost modules for ionospheric monitoring has been presented. It is seen that, such modules can be used for the purpose with a limited capability but having the advantages of cost, size and power requirement. Make and model specific calibration for the parameters of interest is an important issue for the purpose. After proper calibration, such modules can be used in standalone mode or in a networked manner for concurrent monitoring of ionospheric parameters from multiple points scattered over a geographical region. A GNSS based Ionosphere monitoring Unit (GIMU) using such low-cost GNSS modules is proposed for real time ionosphere monitoring purpose. Future work would contain study of similar modules from other manufacturers, use of commercial, compact antennas and studies on signals from other constellations. In case of India, an interesting option may be the use of recently available NavIC enabled compact modules those would use signals from satellites placed in geostationary and/ or geosynchronous orbits that have much lower variation in IPP from any observation location. The work may be extended in S Band with the availability of S-Band enabled compact NavIC receivers. Further work would also include derivation of other associated ionospheric monitoring parameters from the raw data provided by such receivers.

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## References

Andrei, C.O., 2012, June. Cost-effective precise positioning using carrier phase navigation-grade receiver. In *2012 International Conference on Localization and GNSS* (pp. 1-6). IEEE.

Bose, A., Santra, A., Mahato S. & Dan, S., 2019. Low Cost, Compact GNSS Modules for Atmospheric Probing. *20th International Beacon Satellite Symposium*, University of Warmia and Mazury, Olsztyn, Poland, pp. 146, https://drive.google.com/file/d/1f7Lp1HTcYg3mro9n0MuFhr-AdReqd-j3/view.

Bramanto, B., Gumilar, I., Sidiq, T.P., Kuntjoro, W., Tampubolon & D.A., 2018, May. Sensing of the atmospheric variation using Low Cost GNSS Receiver. In *IOP Conference Series: Earth and Environmental Science* (Vol. 149, No. 1, p. 012073). IOP Publishing. DOI:10.1088/1755-1315/149/1/012073.

Chakraborty, S.K., Chatterjee, S. & Jana, D., 2017. A study on multifrequency scintillations near the EIA crest of the Indian zone. *Advances in Space Research*, 60(8), pp.1670-1687.

Curran, J.T., Bavaro, M. and Fortuny, J., 2014, April. An open-loop vector receiver architecture for GNSS-based scintillation monitoring. In *Proceedings of the European Navigation Conference (ENC-GNSS)*, Rotterdam, The Netherlands (pp. 7-14).

Dan, S., Santra, A & Bose., A. 2018. Preliminary Observation of IRNSS/ NavIC Signals for Atmospheric Studies. *National Conference on Materials, Devices and Circuits for Communication Technology (MDCCT)*, Burdwan, INDIA, June, pp. 53-56.

Das Gupta, A., Ray, S., Paul, A., Banerjee, P. & Bose, A., 2004. Errors in position-fixing by GPS in an environment of strong equatorial scintillations in the Indian zone. *Radio Science*, 39(1), pp.1-8. DOI: 10.1029/2002RS002822.

Datta-Barua, S., Doherty, P.H., Delay, S.H., Dehel, T. & Klobuchar, J.A., 2003, September. Ionospheric scintillation effects on single and dual frequency GPS positioning. In *Proceedings of ION GPS/GNSS* (pp. 336-346). Portland, Oreg: Inst. of Navigation.

Doherty, P.H., Delay, S.H., Valladares, C.E. & Klobuchar, J.A., 2003. Ionospheric scintillation effects on GPS in the equatorial and auroral regions. *Navigation*, 50(4), pp.235-245.

Earth's Atmospheric layers, https://www.nasa.gov/mission_pages/sunearth/science/atmosphere-layers2.html, accessed on 26/01/2020.

Juras, P. & Slavik, R., 2016. Usage of Raspberry Pi for temperature and relative humidity measurements and comparison with HAM simulation. In *Applied Mechanics and Materials* (Vol. 824, pp. 552-559). Trans Tech Publications Ltd.

Klobuchar, J.A., 1987. Ionospheric time-delay algorithm for single-frequency GPS users. IEEE *Transactions on aerospace and electronic systems*, (3), pp.325-331. DOI: 10.1109/TAES.1987.310829.

Linty, N., Correia, E., Hunstad, I. & Kudaka, A.S., 2018. Installation and Configuration of an Ionospheric Scintillation Monitoring Station Based on GNSS SDR Receivers In Brazil. *Revista Mackenzie De Engenharia E Computação*, 18(1).

Mahato, S., Santra, A., Dan, S., Rakshit, P., Banerjee, P. & Bose, A., 2019, March. Preliminary Results on the Performance of Cost-effective GNSS Receivers for RTK. In *2019 URSI Asia-Pacific Radio Science Conference (AP-RASC)* (pp. 1-4). IEEE.

Manadhar, D., 2018. Low-Cost High-Accuracy GNSS Receiver. *Training on GNSS–Course* (T141-30).

NMEA data, https://www.gpsinformation.org/dale/nmea.htm, accessed on 25/01/2020

O'Hanlon, B.W., Psiaki, M.L., Powell, S., Bhatti, J.A., Humphreys, T.E., Crowley, G. & Bust, G.S., 2011. CASES: A smart, compact GPS software receiver for space weather monitoring. In *Radionavigation Laboratory Conference Proceedings*.

Omrani, A., Shiekhdavoodi, M.J. & Shomeili, M., 2013. Determine Sugarcane harvester field efficiency using global positioning system (GPS) data. *Elixir International Journal*, *56*, pp.13260-63.

Ren, X., Zhang, X., Xie, W., Zhang, K., Yuan, Y. & Li, X., 2016. Global ionospheric modelling using multi-GNSS: BeiDou, Galileo, GLONASS and GPS. *Scientific reports*, 6, p.33499. DOI : 10.1038/srep33499.

RINEX 3.03, ftp://igs.org/pub/data/format/rinex303_update1.pdf, accessed on 10/01/2020.

RTKLIB: An Open Source Program Package for GNSS Positioning, http://www.rtklib.com/ accessed on 10/01/2020.

Sharma, A.K., Gurav, O.B., Bose, A., Gaikwad, H.P., Chavan, G.A., Santra, A., Kamble, S.S. & Vhatkar, R.S., 2019. Potential of IRNSS/NavIC L5 signals for ionospheric studies. *Advances in Space Research*, 63(10), pp.3131-3138. DOI: 10.1016/j.asr.2019.01.029.

Skone, S., 2000. Impact of ionospheric scintillation on SBAS performance. *Proceeding of ION GPS 2000*, Institute of Navigation, Salt Lake City, UT, USA, September.

Takasu, T. & Yasuda, A., 2009, November. Development of the low-cost RTK-GPS receiver with an open source program package RTKLIB. In *International symposium on GPS/GNSS* (pp. 4-6). International Convention Center Jeju Korea.