

NavIC Multipath Signal Analysis for Soil Moisture Sensitivity in the Perspective of a Winter Wheat Crop

Vivek Chamoli*, Rishi Prakash, and Anurag Vidyarthi

Abstract—The retrieval of soil moisture in the presence of vegetation has received relatively less attention than bare land when observations are made with Global Navigation Satellite System (GNSS). In plane bare land, the reflected GNSS signal is affected by the land characteristics which is dielectric constant of soil. However, in vegetated land, the reflected signal is affected by dielectric constant of soil as well as the characteristics of vegetation which makes the retrieval of soil moisture a cumbersome task in the presence of vegetation. Monitoring soil moisture in vegetated land is important for soil health and its suitability for agriculture purposes. Therefore, the analysis of soil moisture in the presence of vegetation has been studied in this manuscript by utilising the Navigation with Indian Constellation (NavIC) which is a very new entry in GNSS domain by Indian Space Research Organization (ISRO). NavIC receiver setup was installed in a wheat agriculture land situated in Dehradun, India. The wheat crop was sown in the month of November, and it was harvested in the month of April. In situ measurement of soil moisture, crop height, humidity, soil temperature, and air temperature were made. Fixed frequency method and Lomb-Scargle Periodogram (LSP) method have been analysed to determine the sensitivity of soil moisture in the presence of vegetation. 15° to 30° elevation angle was utilised in the study. The sensitivity analysis was carried out by categorizing the crop based on crop height. Three crop categories have been considered which are 0 to 20 cm, 20 to 80 cm, and greater than 80 cm. The correlation coefficient in the first stage of crop growth using the fixed frequency method was 0.76, which decreased to 0.42 in second stage of crop growth and finally to 0.35 in the final stage of crop growth. The correlation coefficient using LSP method was -0.68 , -0.65 , and -0.50 for the first, second, and third stages of crop growth, respectively. It was observed that for lower crop height (< 20 cm), fixed frequency method is more useful than LSP method. However, for higher crop height (> 20 cm), LSP method is better suited.

1. INTRODUCTION

Global Navigation Satellite System (GNSS) is an Earth-orbiting satellite network that moves in different orbits around the earth and sends signals continuously to GNSS receivers. These signals contain location and time information through electromagnetic waves. GNSS signals are globally available, and their structures are generally known, apart from those signals used for the military purpose. These GNSS signals are also appropriate for remote sensing studied such as atmospheric, oceanographic, hydrological, and agricultural studies. Due to its unique capabilities, GNSS has gained popularity as a useful remote sensing tool. GNSS signals are precise, always available, capable of all-weather sensing, and capable of providing signals suitable for a wide range of land applications. Measurements of reflected GNSS signals from Earth's surface are used to determine geophysical parameters using GNSS-Reflectometry (GNSS-R) even though the current GNSS-R missions were built and visualized to monitor sea wave heights,

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winds, and cyclones. By observing signal reflections from the Earth's surface, GNSS has demonstrated its effectiveness as an alternative observing method in previous years. L-band GNSS reflected signal was first identified as a potential Earth sensor for monitoring the ocean. Passive Reflectometric Interferometric System (PARIS), formerly known as GNSS-Reflectometry (GNSS-R), was one of the earliest recommendations to employ GPS reflected signals from the surface of the earth. GNSS remote sensing technology depends on GNSS constellation and does not require any additional satellite mission. GNSS-Interferometric Reflectometry (GNSS-IR) was first proposed in 2008 by Larson et al. [1]. The most of GNSS-based soil moisture estimation research has focused on bare soil. Further, these studies have been mostly done with GPS constellation [1–13]. To investigate the sensitivity of the GNSS multipath signal to soil moisture, researchers looked at the multipath amplitude, phase, and frequency. As a new navigation system, the susceptibility of the NavIC multipath signal to soil moisture must be investigated. Furthermore, very little research has been done to estimate soil moisture sensitivity in the presence of vegetation [14–16]. The reflected signal on plane bare land is affected by dielectric constant of soil. However, the reflected signal in vegetated terrain is affected by the soil dielectric constant as well as the vegetation parameters. As a result, it is important to assess the sensitivity of multipath signal amplitude for soil moisture in presence of vegetation. Chew et al. (2014) [14] developed a soil moisture estimation algorithm for the area around a geodetic antenna using GPS multipath signal. The algorithm presented a soil vegetation model that minimizes the influence of vegetation on soil moisture evaluation. Another paper by Chew and coauthors (2015) [15] uses an electro-dynamic forward model to simulate the changes in vegetation canopy using GPS SNR data. As a result of the vegetation model, when the weight of the canopy of vegetation reaches around 1.5 kg m^{-2} , and the sensitivity of soil moisture decreases. When the weight of vegetation is less than 1.5 kg m^{-2} , and soil moisture is known, multipath phase can be used to evaluate the moisture of vegetation. When the total weight of vegetation is unknown, normalised multipath amplitude has been used to measure it. Several assumptions have been taken to model the vegetation. Zhang et al. (2018) [16] measured the moisture of the soil and vegetation height by using the direct and reflecting signal from the surface of the soil around a field antenna. Rainfed wheat fields in the southwest of France used for the research of sensitivity of vegetation for estimating soil moisture. The signal to Noise ratio (SNR) prevailing time has been used to determine the vegetation height. The outcomes show that changes in soil moisture are more likely to vary the SNR dominant time period than changes in vegetation height.

Most of the researchers working in the domain of land parameter retrieval using GNSS work with GPS multipath signal. Very few work has been carried out to determine the land surface parameters using NavIC multipath signal. Further, the configuration of NavIC constellation is different from GPS constellation in several aspects. NavIC satellites are in Geo-synchronous and Geo-stationary orbit at the height of approximately 36,000 km, whereas GPS satellites utilise medium earth orbit and circle the earth at a height of approximately 20,200 km. The elevation angles available to study the land surface parameters is 5° to 30° in the case of GPS, whereas in the case of NavIC it is 15° to 30° . However, the polarization of transmitted signal for GPS as well as NavIC constellation is Right Hand Circular (RHCP) polarization. Different kinds of antenna configurations are used to transmit and receive the GPS and NavIC signals [17–19]. In the case of GNSS-IR, the elevation angle plays a very important role in the study of land surface parameters; therefore, the methodologies developed with GPS multipath signal cannot be directly applicable to NavIC multipath signal. Hence, there is a strong need to analyse the sensitivity of NavIC multipath signal for land surface parameters. This paper explores the sensitivity of NavIC multipath signal for soil moisture in the presence of vegetation at various stages of its growth.

2. EXPERIMENTAL SETUP FOR VEGETATED LAND

NavIC receiver installation flow diagram is shown in Fig. 1. It is composed of several components: a NavIC IGS receiver, a NavIC antenna, a DC power source, and a laptop.

IGS receiver stands for IRNSS+GPS+SBAS user receiver [20]. The IGS receiver receives data from NavIC, GPS Aided GEO Augmented Navigation (GAGAN), and GPS satellites at an interval of one second. Signals are received in two frequency bands: L5 and S1 for the NavIC satellites and L1 for GAGAN and GPS. Data are stored in excel format for each individual satellite. The columns of excel sheet provide pseudo range, Carrier to Noise (C/N_0) ratio, and other information corresponding

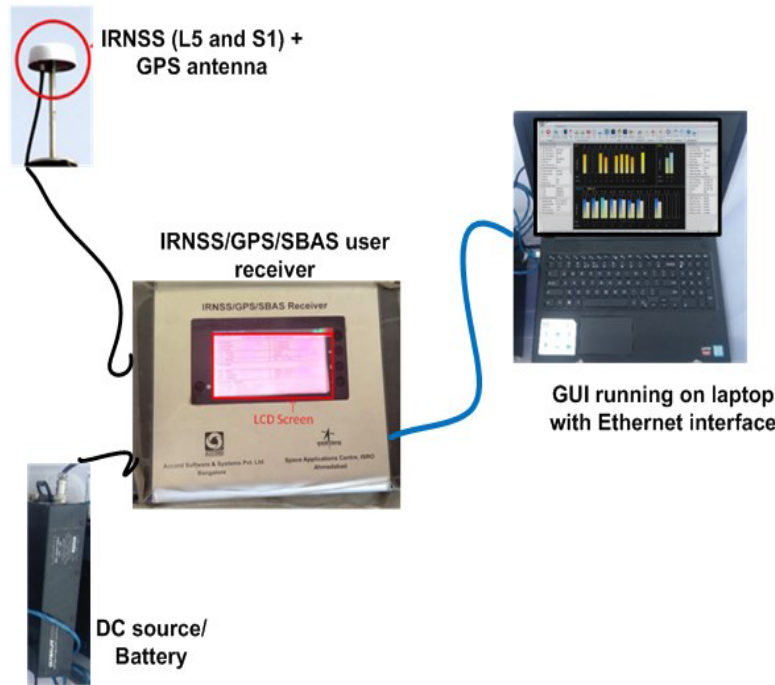


Figure 1. NavIC receiver's hardware setup.

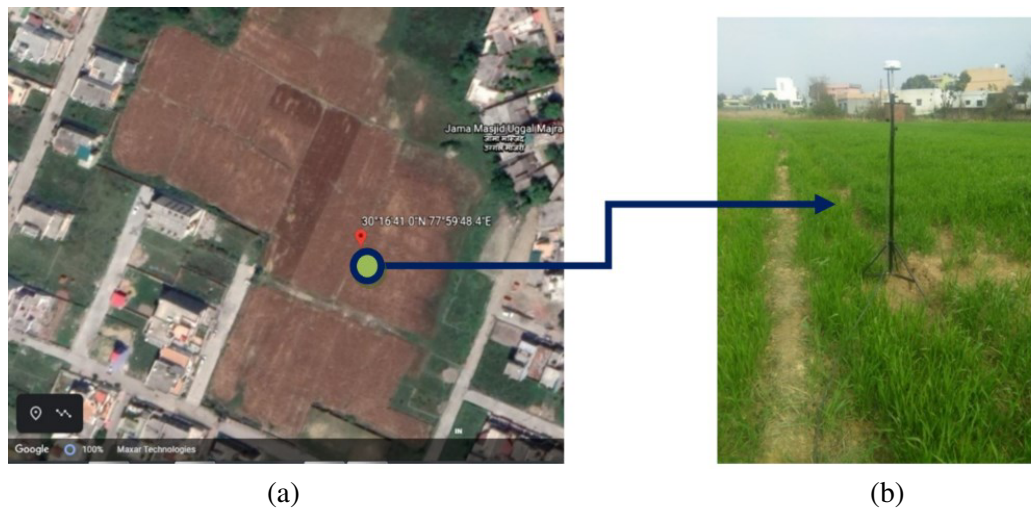


Figure 2. (a) Image of the experimental area from Google, (b) ground truth image of experimental area.

to elevation and azimuth angles. This study utilises variation in C/N_0 ratio with respect to elevation angle to determine the soil moisture sensitivity in the presence of vegetation. A spiral antenna which is circularly polarized has been used to receive the direct RHCP signal originating from NavIC satellites. The NavIC receiver setup was installed in an agriculture land containing wheat crop. The study area is situated in Dehradun, India, and the location of receiver antenna represented with Latitude and Longitude is $30^{\circ}.2780\text{N}$ and $77^{\circ}.99677\text{E}$, respectively. Figs. 2(a) and (b) show the Google earth image and ground truth image of study area. The study area image shown by Google earth was captured in the month of November. There was no crop in this month; therefore, bare soil can be observed in the study area image shown by Google earth. The image shown in Fig. 2(b) has been captured by the

authors in the month of February which shows the wheat crop along with the NavIC antenna on top of the stand. The height of NavIC antenna from the ground surface is 2 m. The average height of wheat crop shown in Fig. 2(b) is approximately 30 cm.

2.1. *In-Situ* Observation

In order to determine the sensitivity of soil moisture with the NavIC multipath C/N₀ ratio, in situ soil moisture measurements were carried out. Along with the soil moisture measurement, in situ measurement of soil temperature and crop height was also carried out.

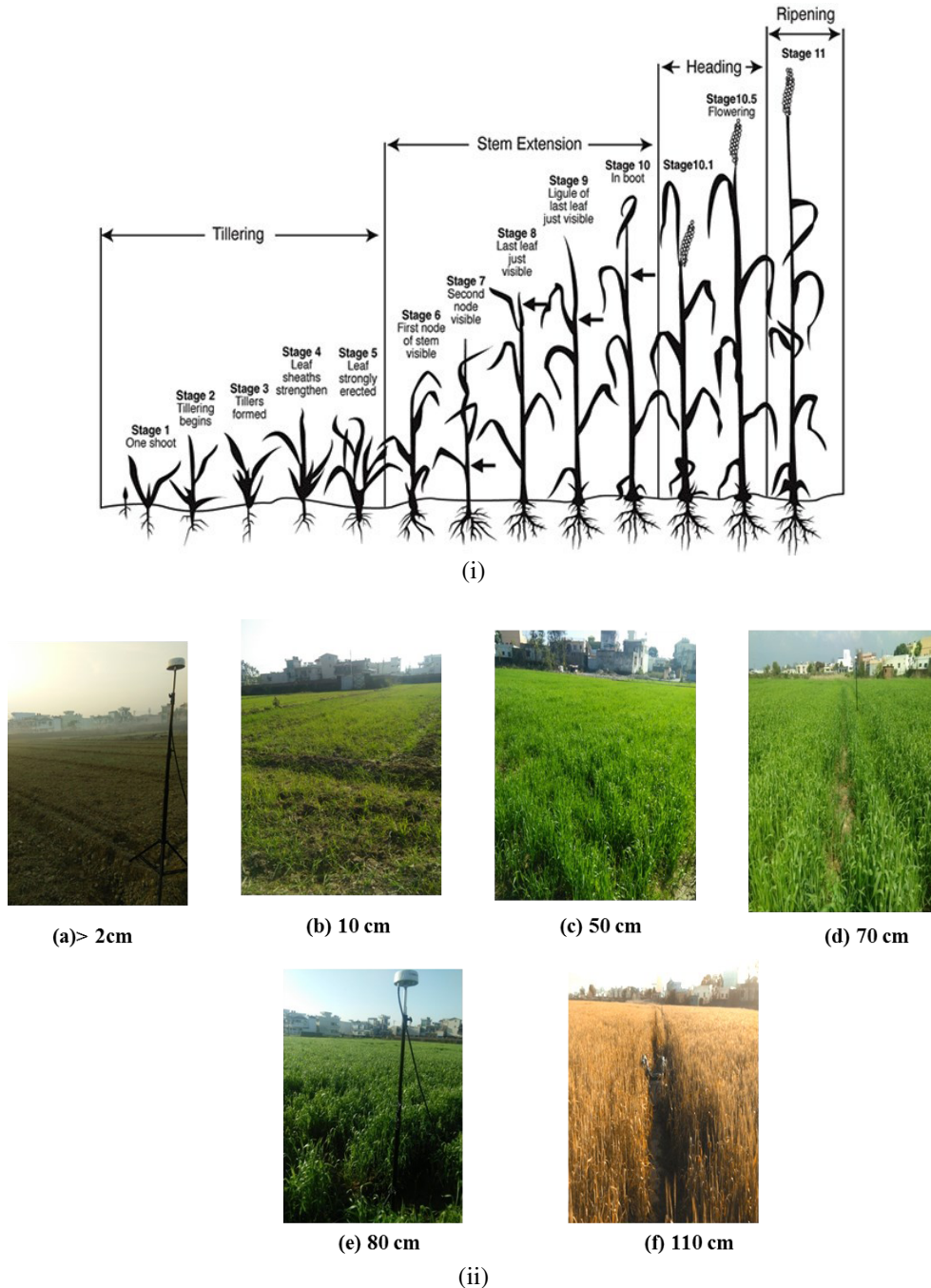


Figure 3. Wheat crop development stages (a) sketch depiction, (b) ground truth photos.

2.1.1. Soil Moisture Measurement

It is crucial to evaluate the amount of water or moisture in a particular mass of soil because it influences microbial activity, nutrients movement, and plant growth. An oven dried sample group or soil sample is used to quantify soil moisture content using the gravimetric method, which involves weighing the sample, drying it in the oven until there is no more mass loss, and then reweighing it. Microwave oven based method has been utilised to determine the in situ soil moisture [21]. The maximum and minimum values for soil moisture were 5.32% and 23.87%, respectively.

2.1.2. Temperature and Humidity Measurement

Soil temperature was measured with temperature probe, and data about atmospheric temperature and humidity was obtained from <https://weather.com>. The maximum soil temperature was 28 degrees Celsius, and the minimum was 12.7 degrees Celsius. The maximum and minimum values for atmospheric temperature were 32 and 14 degrees Celsius, respectively. The maximum humidity value was 74.5, and the lowest was 32.

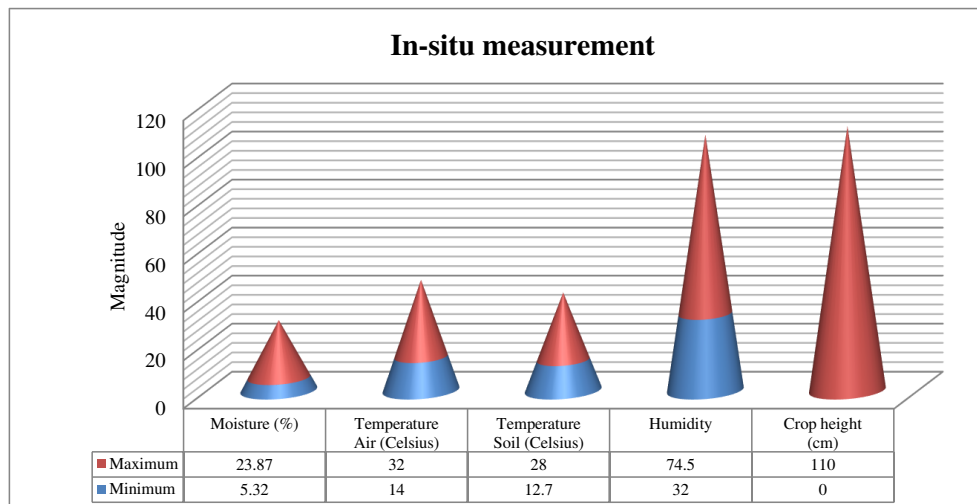


Figure 4. In-situ parameters with their maximum and minimum values.

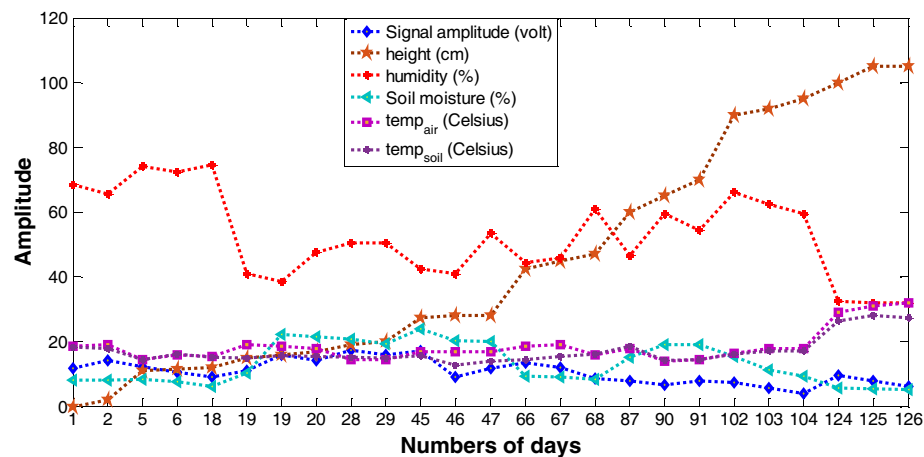


Figure 5. In situ measurement (Soil moisture, crop height, soil temperature, air temperature, humidity) and NavIC signal amplitude (at 15° to 30°).

2.1.3. Crop Measurement

The soil moisture study is carried out in the presence of vegetation; therefore, wheat crop field has been selected to determine the sensitivity of soil moisture for NavIC multipath signal at various stages of crop growth. The wheat crop was sown in the winter in the month of November 2018, and it was harvested in the month of April 2019. Wheat growing cycle can be split into four stages: tillering, stem extension, heading, and ripening as shown in Fig. 3(i). Fig. 3(ii) shows the ground truth images of wheat cropland at various stages of crop growth starting from showing days to the harvesting days.

In the winter, the average height of wheat plants was less than 20 cm, but it swiftly expanded in the spring, reaching 50 cm in March 2019 and 110 cm in April 2019. From planting until harvest, the surface roughness of the soil was considered stable. Wheat plants were planted at random in the research area. Fig. 4 shows the in-situ parameters with their maximum and minimum values. Fig. 5 shows the magnitude of all in-situ parameters along with the NavIC multipath amplitude for the 15° to 30° elevation angle.

3. ANALYSIS OF NAVIC MULTIPATH SIGNAL FOR SENSITIVITY OF SOIL MOISTURE IN ELEVATION ANGLES VARYING FROM 15° TO 30°

Analysis of NavIC multipath signal for the sensitivity of soil moisture in elevation angles varying from 15° to 30° has been done according to [22]. Two different methods are studied to determine the sensitivity of multipath amplitude for soil moisture. The first one is fixed frequency method, and other one is Lomb Scargle Periodogram method. In the case of fixed frequency method, the frequency of NavIC multipath signal is considered as constant in evaluation of NavIC multipath amplitude. The determination of this constant or fixed frequency is based on the antenna height above the soil surface. However, in the case of Lomb Scargle Periodogram method, the power of signal has been evaluated to correlate it with soil moisture. Following sections discuss these methods in detail.

3.1. Fixed Frequency Approach

Theoretical observations suggest that, if the height of the antenna is fixed, the multipath frequency will also be fixed. The formation of the multipath interference pattern is because the phase difference is created due to extra path traveled by the reflected wave. This path difference and corresponding phase difference change with the change in the elevation angle and create interference pattern which is sinusoidal in nature. The frequency of this sinusoidal interference pattern can be evaluated as [23–25]

$$f = \frac{4\pi h}{\lambda} \quad (1)$$

where h is the height of the antenna from soil surface, and λ is the wavelength of the NavIC signal.

In this study, antenna has been kept at the height of 2 m above the soil surface. Therefore, the multipath interference signal will be 98.55 Hz as the wavelength of the NavIC signal is 25.50 cm. Now, for the evaluation of multipath amplitude for NavIC multipath signal, which has been done with the least square estimation, the frequency is kept fixed at 98.55 Hz. This is the reason that this approach is called a fixed frequency approach. The coefficient of correlation between soil moisture and NavIC multipath amplitude of the signal at various stages of wheat crop height between 15° and 30° at a fixed frequency of 98.55 Hz is shown in Fig. 6.

The correlation coefficient is 0.76 when the wheat crop height is small (crop height less than 20 cm), and crop leaf density is low, showing that the correlation is strongly positive. In the second stage of wheat crop (crop height 20–80 cm) the correlation coefficient was 0.42. The correlation coefficient was 0.35 in the final phases when the wheat crop height was high (crop height greater than 80 cm). The value of correlation coefficient decreases with the increase in crop height. The increase in crop height provides more scattering to incident NavIC signal which may be the main reason for the decrease in correlation coefficient as the major amount of signal after scattering will move in another direction than the direction of the receiver. Further, with the increase in the height of crop other parameters of crop also increase, and the volume scattering occurs due to which the interaction of NavIC signal with soil surface will be less. The effect will also decrease the correlation of the multipath amplitude with soil

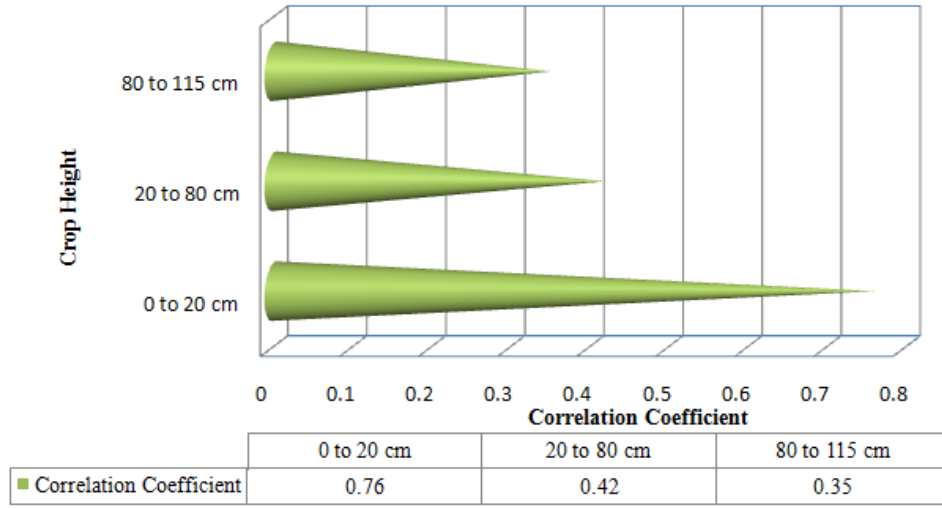


Figure 6. Correlation coefficient between NavIC multipath signal amplitude and soil moisture.

moisture. Therefore, the advisable height of crop for which multipath amplitude is sensitive to soil moisture is less than 80 cm.

3.2. Lomb-Scargle Periodogram (LSP)

LSP is a process that makes it possible to accurately measure a Fourier-like estimator of sampling power spectrum using such inconsistent sampled data and to evaluate the oscillation period intuitively [26–28]. Here is a short description of the formalism of the LSP given the set of S measurements of sample at measured time (v_g) and observation times d_g (where $g = 1, 2, 3, \dots, S$), and the Lomb-Scargle normalized periodogram (LSnP) at frequency f is defined as

$$\text{LSnP} = \frac{1}{2\sigma^2} \left\{ \frac{\left(\sum_g (v_g - v_m) \cos \omega (d_g - D) \right)^2}{\cos \omega (d_g - D)^2} + \frac{\left(\sum_g (v_g - v_m) \sin \omega (d_g - D) \right)^2}{\sin \omega (d_g - D)^2} \right\} \quad (2)$$

where v_m and σ^2 are the mean and variance of the measurements, respectively and $\omega = 2\pi f$. v_m is given as

$$v_m = \frac{1}{S} \sum_g v_g \quad (3)$$

$$\sigma^2 = \frac{1}{S-1} \sum_g (v_g - v_m)^2 \quad (4)$$

and the offset time D is defined by the

$$\tan 2\omega D = \frac{\sum_g \sin 2\omega d}{\sum_g \cos 2\omega d} \quad (5)$$

During the observation, the LSP power spectrum of the NavIC multipath signal on minimum and maximum soil moisture is shown in Fig. 7. Fig. 8 demonstrates the correlation coefficient of soil moisture

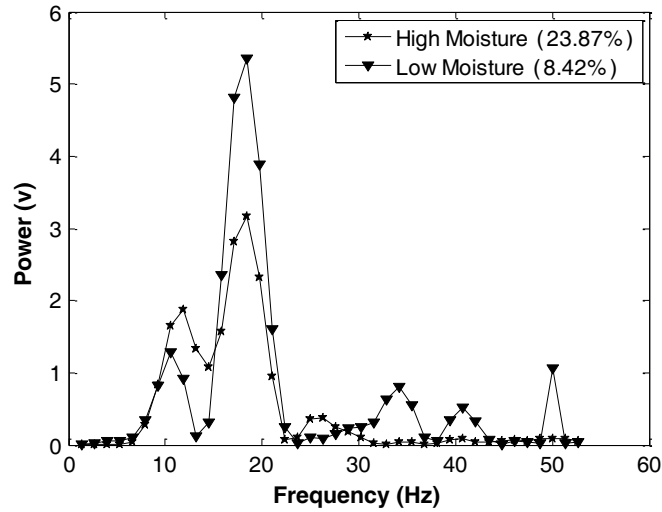


Figure 7. LSP of NavIC multipath signal on date 03/December/2018 at 8.42% moisture and on date 14 January 2019 at 23.87% moisture.

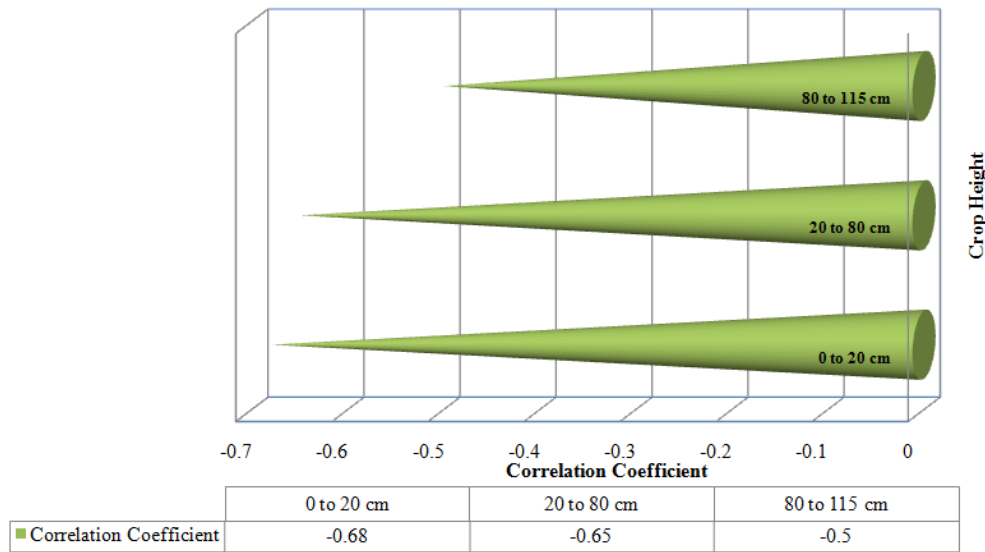


Figure 8. Correlation coefficient between NavIC multipath signal LSP power and soil moisture.

with NavIC multipath signal LSP power at various phases of wheat crop height in 15° to 30° elevation angles.

In the initial stage of crop growth (crop height less than 20 cm), the correlation coefficient was -0.68 . The correlation was -0.65 in the second stage of the wheat crop (crop height 20–80 cm). The correlation coefficient was -0.50 in the last stages of the wheat crop (crop height greater than 80 cm), when the crop height was high. Overall (through the entire wheat crop growth cycle), a negative correlation value of -0.59 was observed between soil moisture and the NavIC multipath signal LSP power. LSP power show a negative correlation with soil moisture, i.e., the increase in soil moisture decreases the LSP power. Further, with the increase in crop height the correlation coefficient decreases which can be observed from Fig. 8. However, if we compare the correlation coefficient of LSP power with soil moisture and multipath amplitude with soil moisture in crop height group 20 to 80 cm and 80 to 115 cm, LSP approach provides the better correlation. Therefore, it may be concluded that fixed frequency approach

is better for lower vegetation height, i.e., less than 20 cm, and as for higher vegetation height, i.e., greater than 20 cm LSP approach is better. Similar results have also been observed by Wu et al. [29] in case of GPS.

4. CONCLUSION

The sensitivity of NavIC multipath signal in lower elevation angles (i.e., 15° to 30°) for soil moisture in the presence of vegetation at various stages of crop growth has been analysed. Fixed frequency approach and Lomb-Scargle Periodogram (LSP) approach have been explored to determine the sensitivity of multipath amplitude and LSP power towards soil moisture. Wheat crop has been considered, and the analysis from sowing stage to the harvesting stage has been carried out. It has been observed that for lower crop height (less than 20 cm) fixed frequency approach provides the correlation coefficient of 0.76 whereas LSP approach provides the correlation coefficient of -0.68 . Though both the approaches provide high correlation with soil moisture for lower crop height condition, it can be concluded that fixed frequency approach is better than LSP approach in low crop height condition. The correlation coefficient in the second and final stages of crop growth for LSP approach is -0.65 and -0.50 , respectively, which is better than the fixed frequency approach. Therefore, for crop height greater than 20 cm, LSP approach can be better utilised with respect to fixed frequency approach for studying soil moisture in the presence of vegetation.

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