NavIC for Soil Moisture Retrieval over Agricultural Croplands: *A Potential Resource for Land Applications*

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Outline

- ❑ Importance of Soil Moisture and its various applications
- ❑ Methods of Soil Moisture measurements: Limitations & Opportunities
- ❑ Exploration of NavIC as Remote Sensing for land applications
- ❑ Basic Principles of GNSS-IR using NavIC
- ❑ Study Area and Data Used for Field Experiments
- ❑ Methodology
- ❑ Results and Discussions
- ❑ Conclusions & Future scope

Importance of Soil Moisture & Applications

Why soil moisture matters?

- ❑ **Monitor Drought**

- ❑ **Predict Floods**

- ❑ **Assist Crop Productivity**

- ❑ **Weather Forecasting**

- ❑ **Linking Water, Energy and Carbon Cycles**

Surface Soil moisture makes up only 0.05% of the Earth's fresh water resources but plays an important role in water, energy, and carbon cycle, in climatology and meteorology.

- **Hydrology and water management**
  - Wetland management
  - Flood forecasting
  - Hydrological modeling
- **Meteorology & Climate**
  - Climate models
  - Weather forecasting
  - Global/regional anomalies
- **Land cover and disturbances**
  - Agriculture (droughts/crop yield)
  - Vegetation growth
  - Occurrence of Fires
  - Landslides
- **Soils**
  - Carbon sequestration
  - Dust
  - Desertification
  - Salinity

In-situ measurement techniques

- **Direct measurements (Classical method)**
  - ❑Measure soil moisture directly
  - ❑Example:
    - ❑**Gravimetric measurement**
    - ❑**Volumetric measurement**

- ➢ Samples are collected from fields and are oven dried at 125°C for over 24-48 hours (depending on soil texture).
- ➢ Bulk density for each sampling point are derived from known volume sample ring and dry soil.

Percentage v/v Soil Moisture

$$= \frac{\text{(Wet wt. – Can wt.) – (Dry wt. – Can wt.)}}{\text{(Dry wt. – Can wt.)}} * BD * 100$$

In-situ measurement techniques

Indirect measurements

❑Measure another soil property and relate to soil moisture content

❑Examples:

- ❑TDR/FDR/Dielectric Methods
- ❑Neutron Probe (Cosmic Ray based)

<u>Utilization</u>

❑ **Validation of Satellite derived SM**

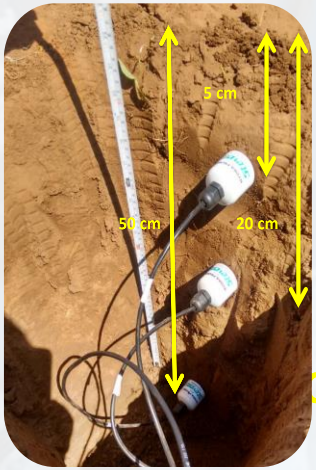
<u>Limitation</u>

❑ **<u>Time consuming and Expensive</u>**.

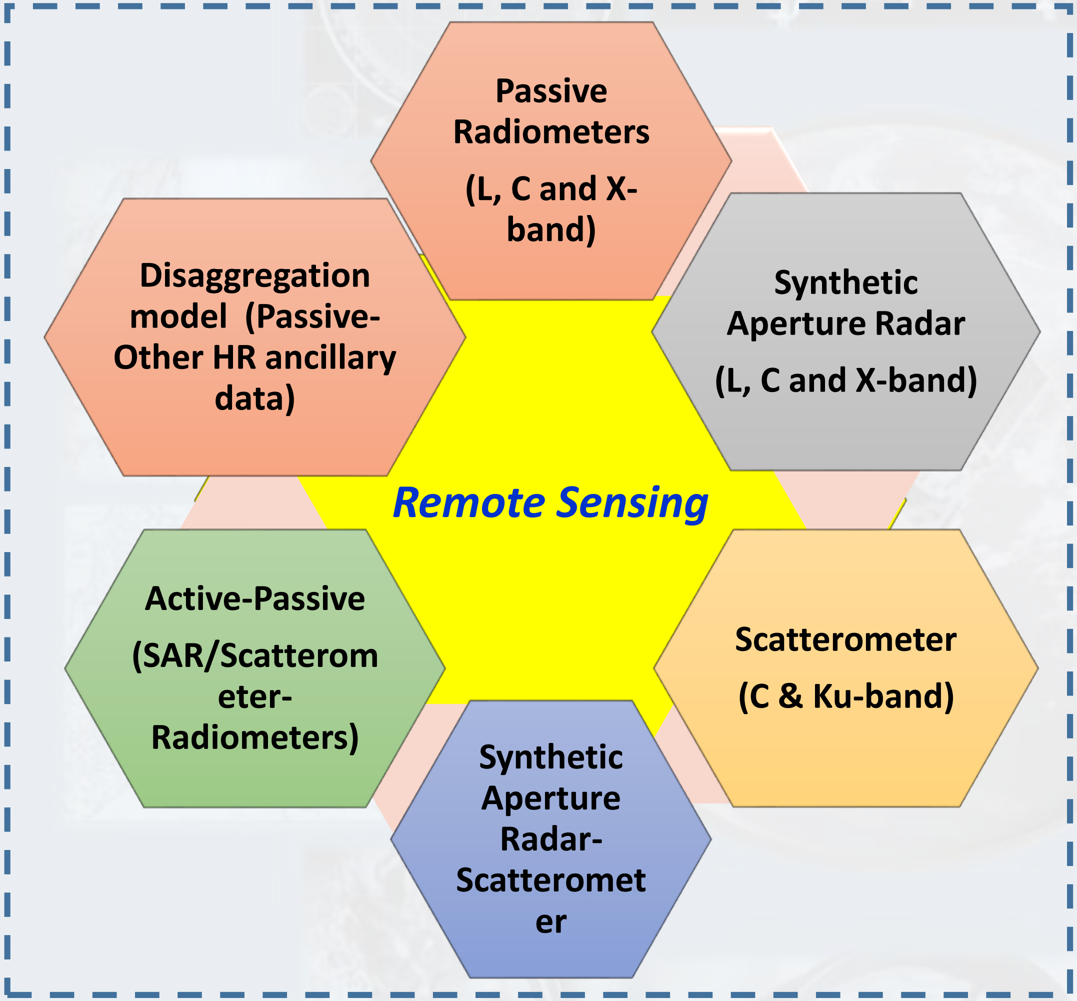
❑ **<u>Destructive</u>** methods.

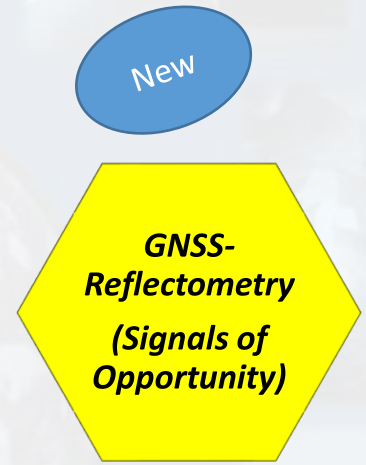
❑**<u>Point measurements</u>** in space and time of a temporal and spatial highly variable phenomenon.

❑Does not account for **<u>spatial and temporal variability of soil moisture</u>**.



Satellite based Soil Moisture Estimation Approach





- TDS-1
- CYGNSS
- FSCAT

How can utilize Ground based NavIC as potential resource?

Exploration of NavIC as Remote Sensing

- Can we utilize **<u>NavIC data as potential reference source</u>** to validate satellite soil moisture products?

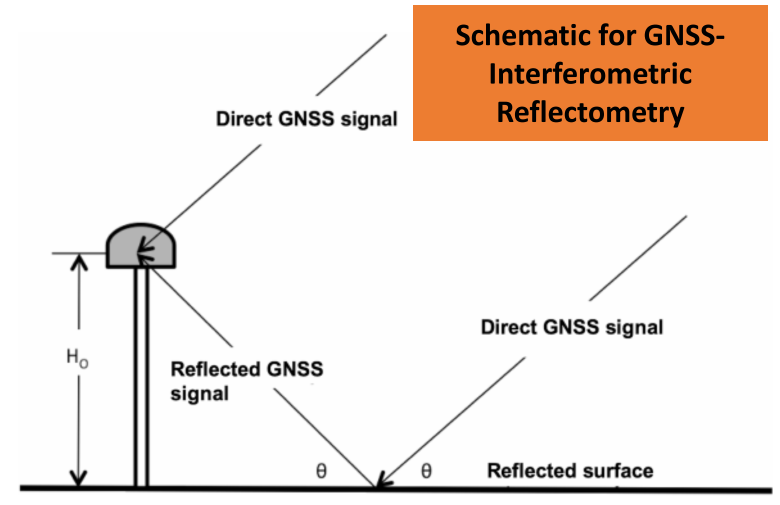
- Can we derive **<u>land parameters (Soil Moisture and crops)</u>** from NavIC Data?

- **<u>Sensitivity</u>** of NavIC observables towards land parameters?

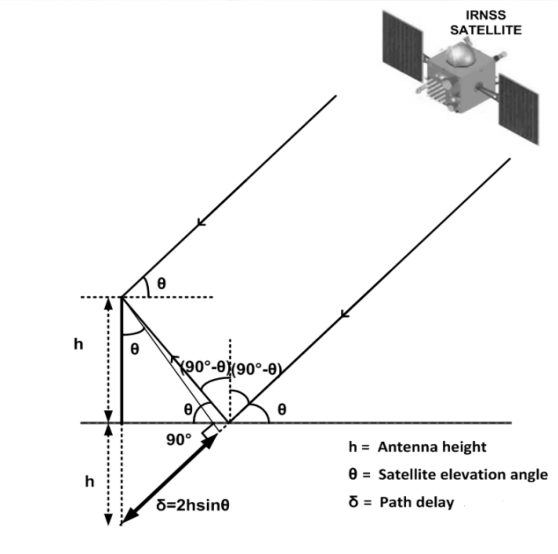
- **<u>Accuracy</u>** and **<u>quality</u>** of parameter retrievals?

- Can NavIC data directly be used in **<u>precision agriculture</u>** for soil moisture information?

Basic Principles of GNSS-IR using NavIC



Schematic for GNSS-Interferometric Reflectometry



Geometry of Multipath Reception

- Path difference causes interference at receiver.
- Multipath C/N_o is given as.

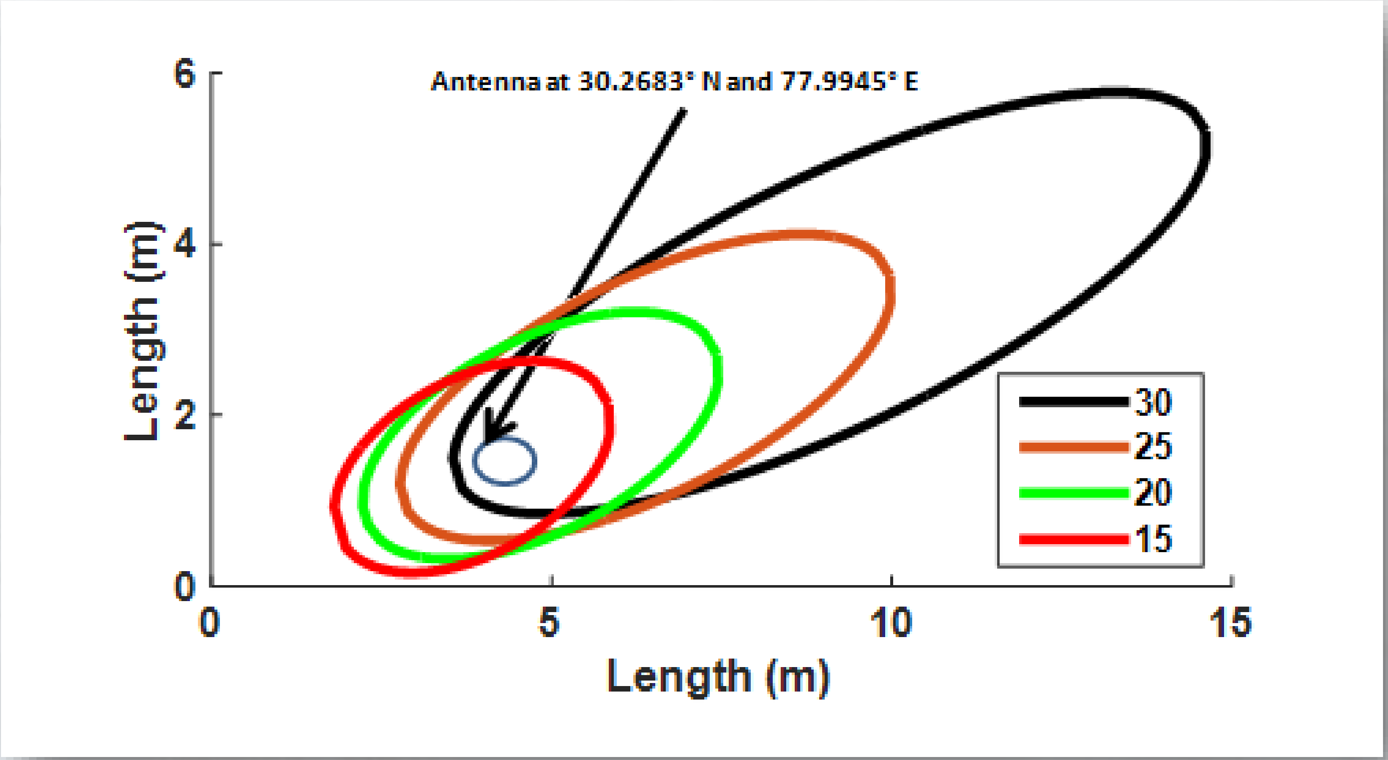
$$C/N_{\circ\, mpi} = A\cos\left(\frac{4\pi h}{\lambda}\sin\theta + \phi_{mpi}\right)$$

Where A is multipath Amplitude

ϕ_{mpi} **is the multipath phase**

Fresnel Zone for NavIC Multipath Signal

- Fresnel zone represent the area on the soil surface through with the reflected wave is received at the receiver.



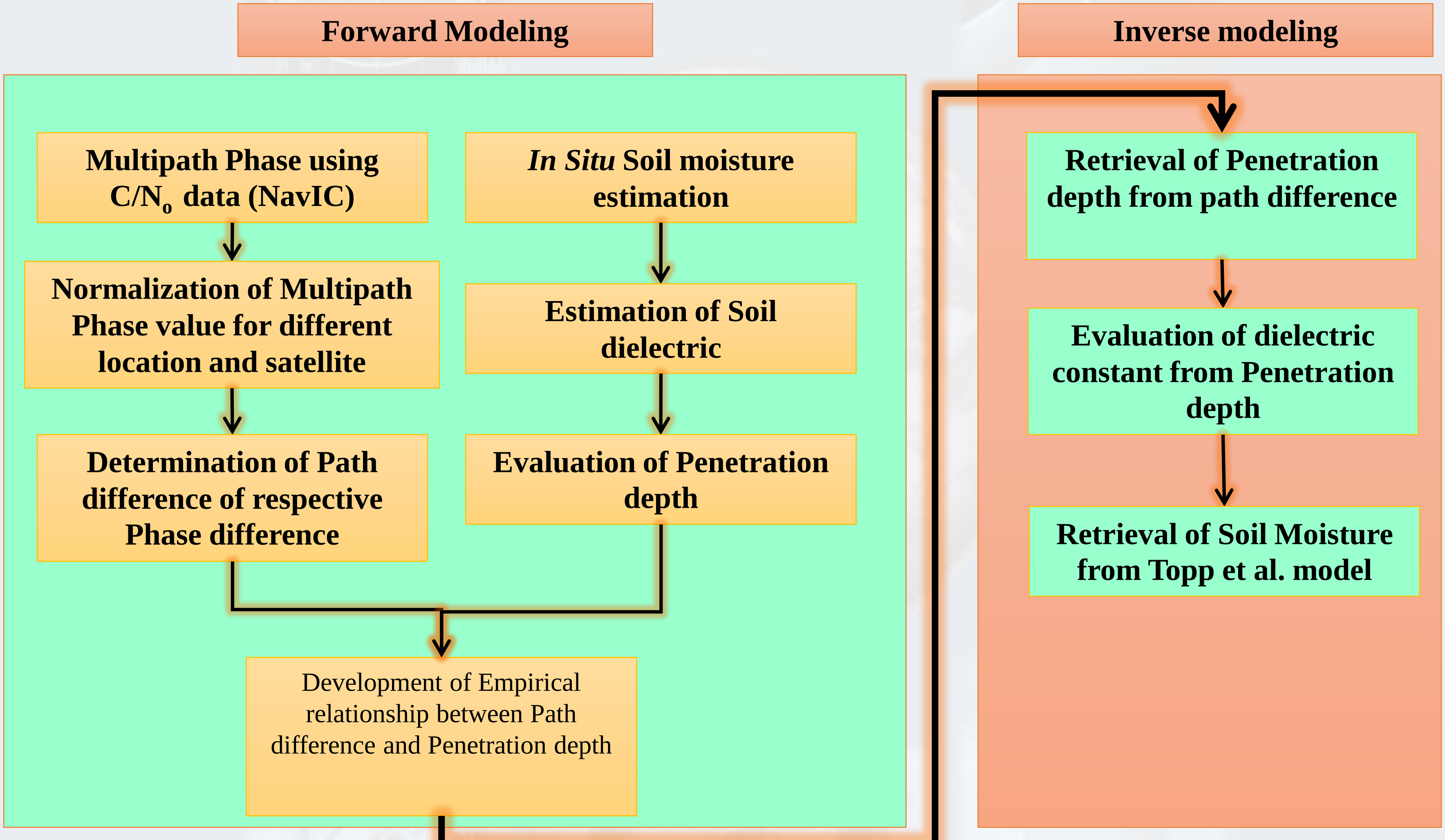
Study Area and Data Used for Field Experiments

- NavIC L5 band data utilized for Field experiments.
- Observations were carried out at Dehradun, Uttarakhand, India:

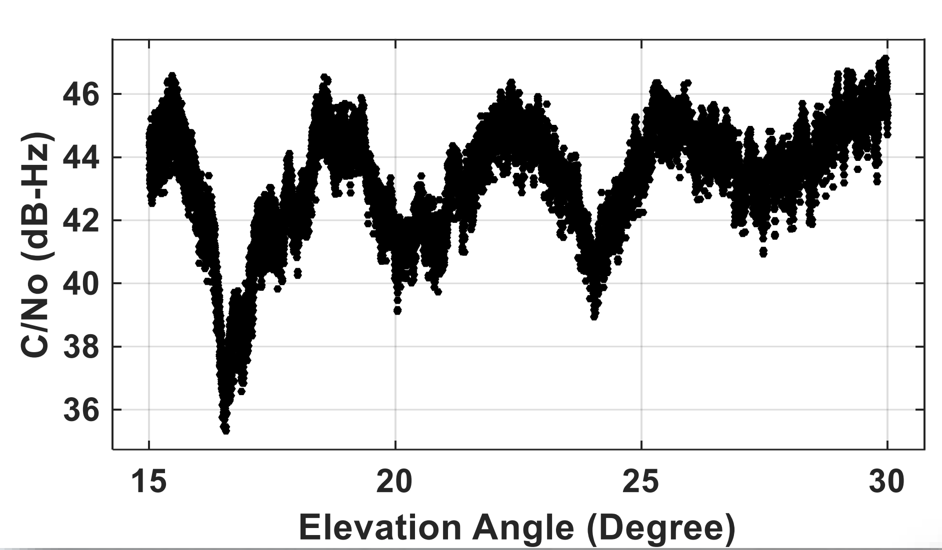
Field Photographs of NavIC Receiver deployment

- **The in situ soil moisture was collected three times a day and reported soil moisture value is average of 20 samples.**

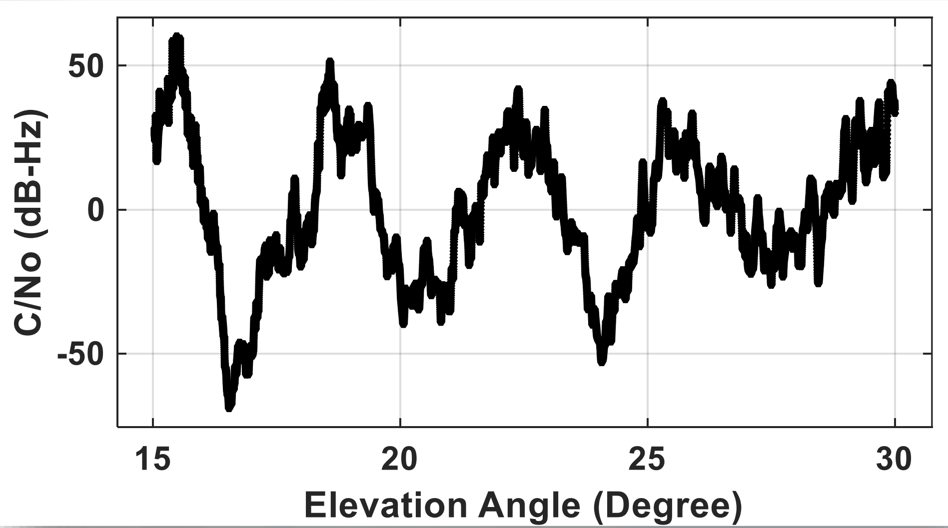
Methodology



Multipath Signal from NavIC Satellite

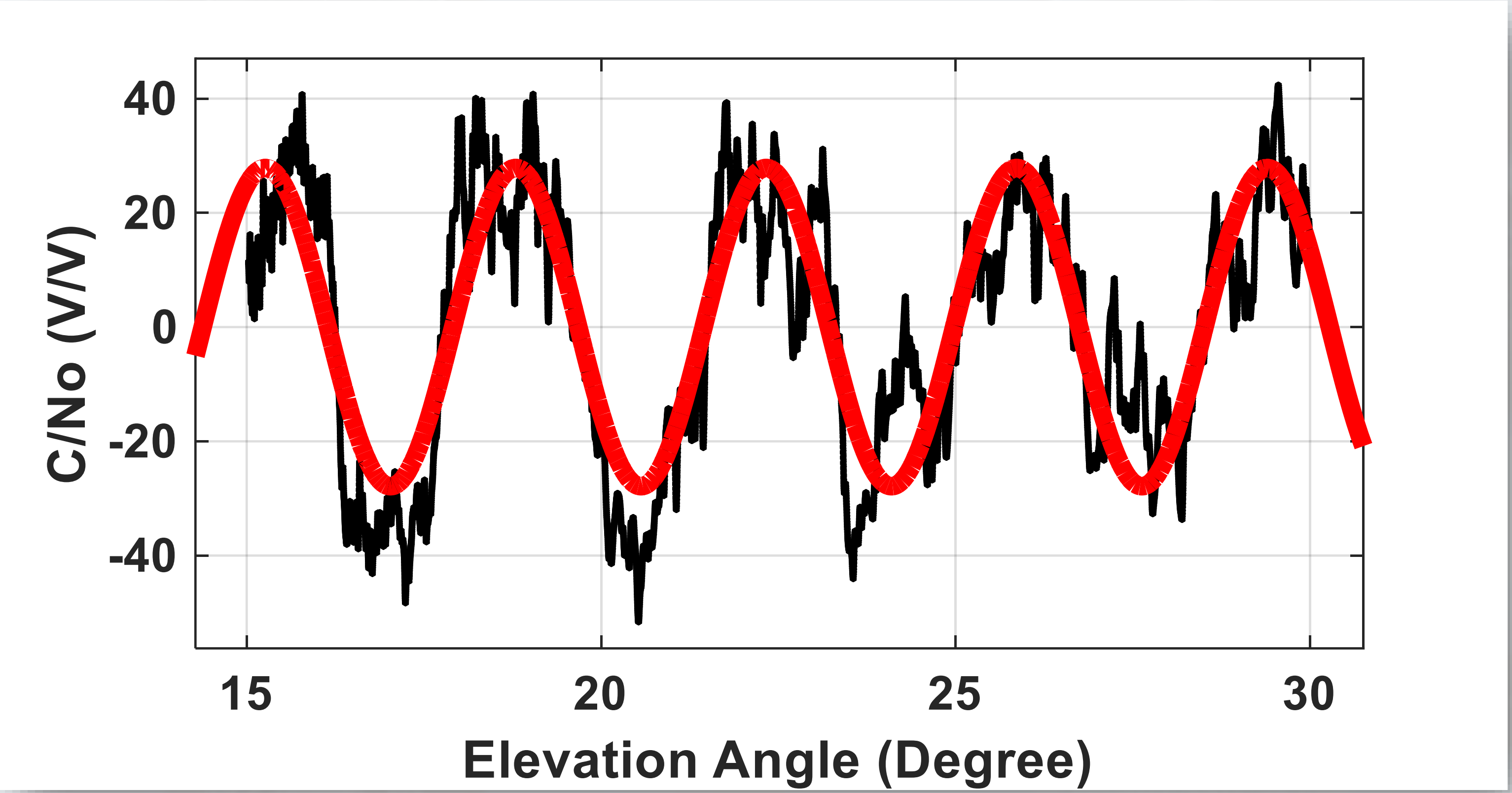


Raw multipath signal



Detrended and noise removed signal

Multipath Signal from NavIC Satellite



Fitted sinusoidal signal

Methodology: Normalization of Phase

- The multipath C/N_o in case of GNSS forms a sinusoidal pattern due to interference of direct and reflected signal which can be represented by equation:

$$C/N_o = A\cos\left(\frac{4\pi h}{\lambda}\sin\theta + \phi\right) \qquad (1)$$

- Shift in multipath phase was observed at different location.

- To make location independent, normalization of multipath phase was purposed.

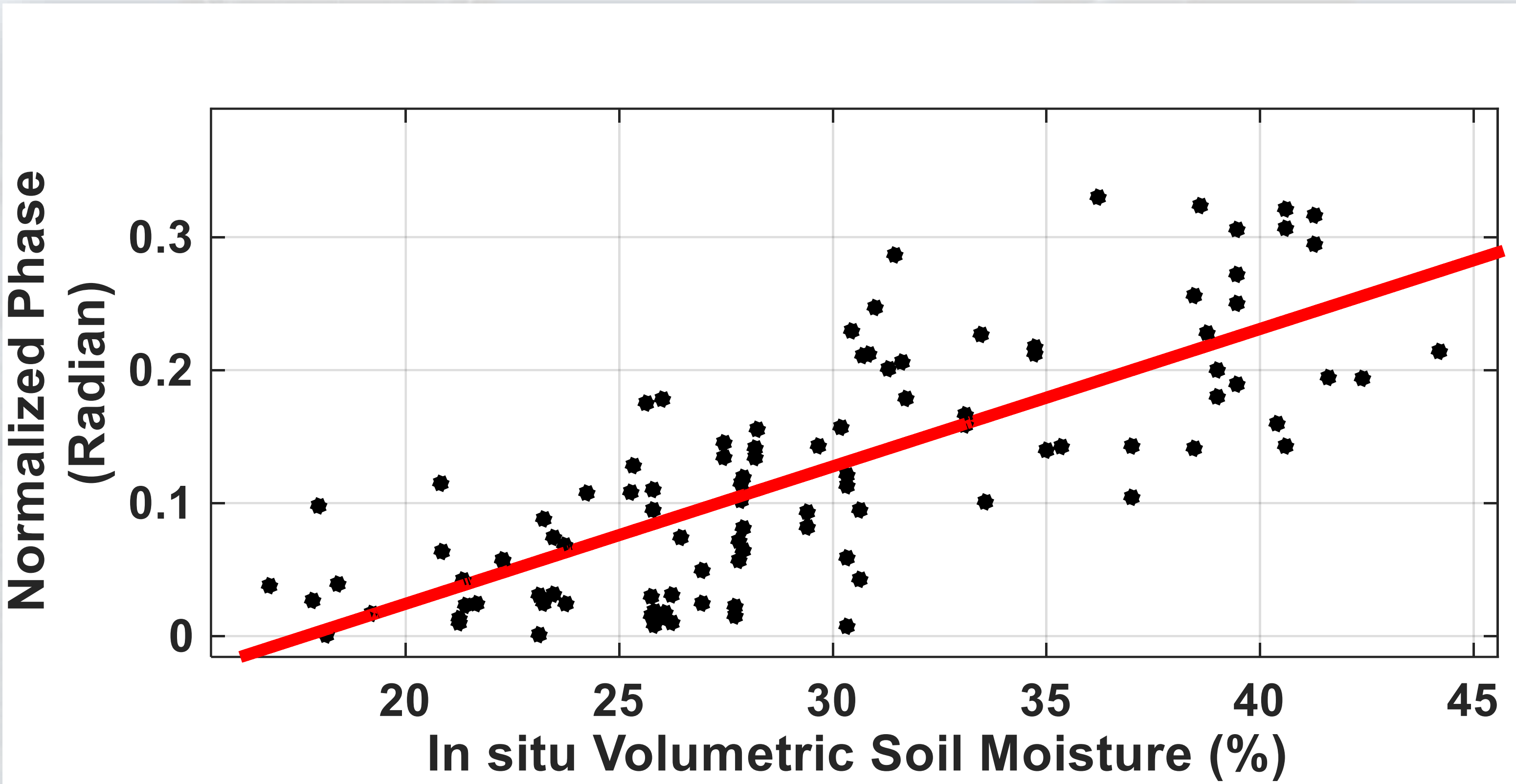
$$\Delta\phi_n = \phi - \phi_{\min} \qquad (2)$$

Where,

$\phi_{\min}$ minimum value of estimated phase for a particular coordinate or satellite.

ϕ estimated multipath phase of that day.

Relationship between Normalized Phase and Volumetric Moisture Content of Soil



- The correlation coefficient value observed between Normalized Phase and VMC of soil is 0.71

Development of Empirical Relationship

- Path delay which is required to develop relationship with penetration depth can be evaluated with this phase difference using equation:

$$\Delta l_n = \frac{\lambda}{2\pi}\Delta\phi_n \quad (3)$$

- Penetration depth can be evaluated with the in situ soil dielectric property from equation:

$$P_d = \frac{\lambda\sqrt{\varepsilon'}}{2\pi\varepsilon''} \quad (4)$$

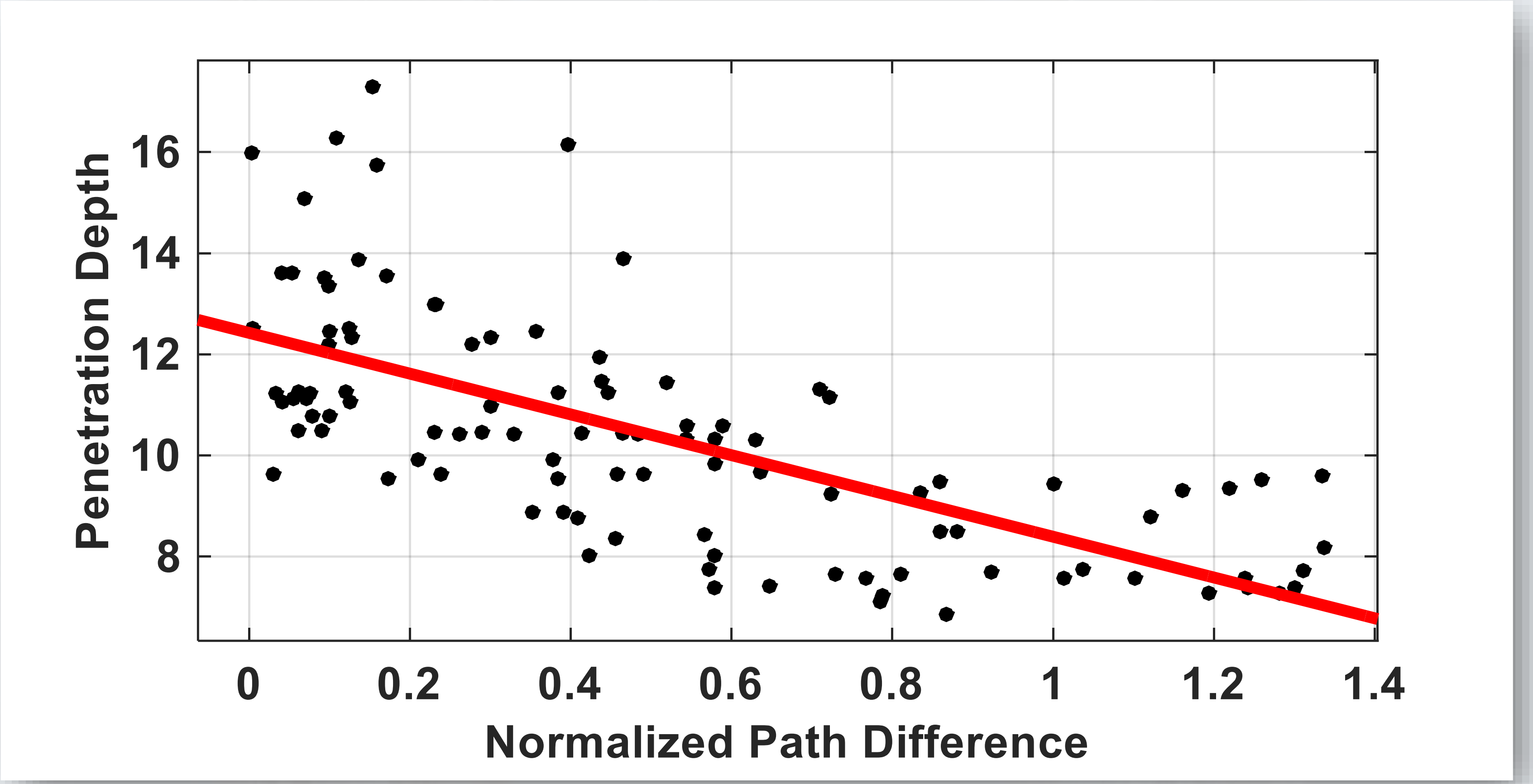
- An empirical relationship has been drawn between the normalized path difference and penetration depth is given below.

$$P_d = a \times \Delta l + b \quad (5)$$

where,

$a = -4.5$ $\qquad$ $b = 12.69$

Relationship Between Normalized Path Difference and Penetration Depth



- The correlation coefficient value observed between Normalized Path difference and penetration depth is 0.71

Calculation of Volumetric Moisture Content Using Developed Empirical Equation

- The developed empirical relationship (i.e., equation 6) between path delay and penetration depth can provide the value of penetration depth for the given path delay.

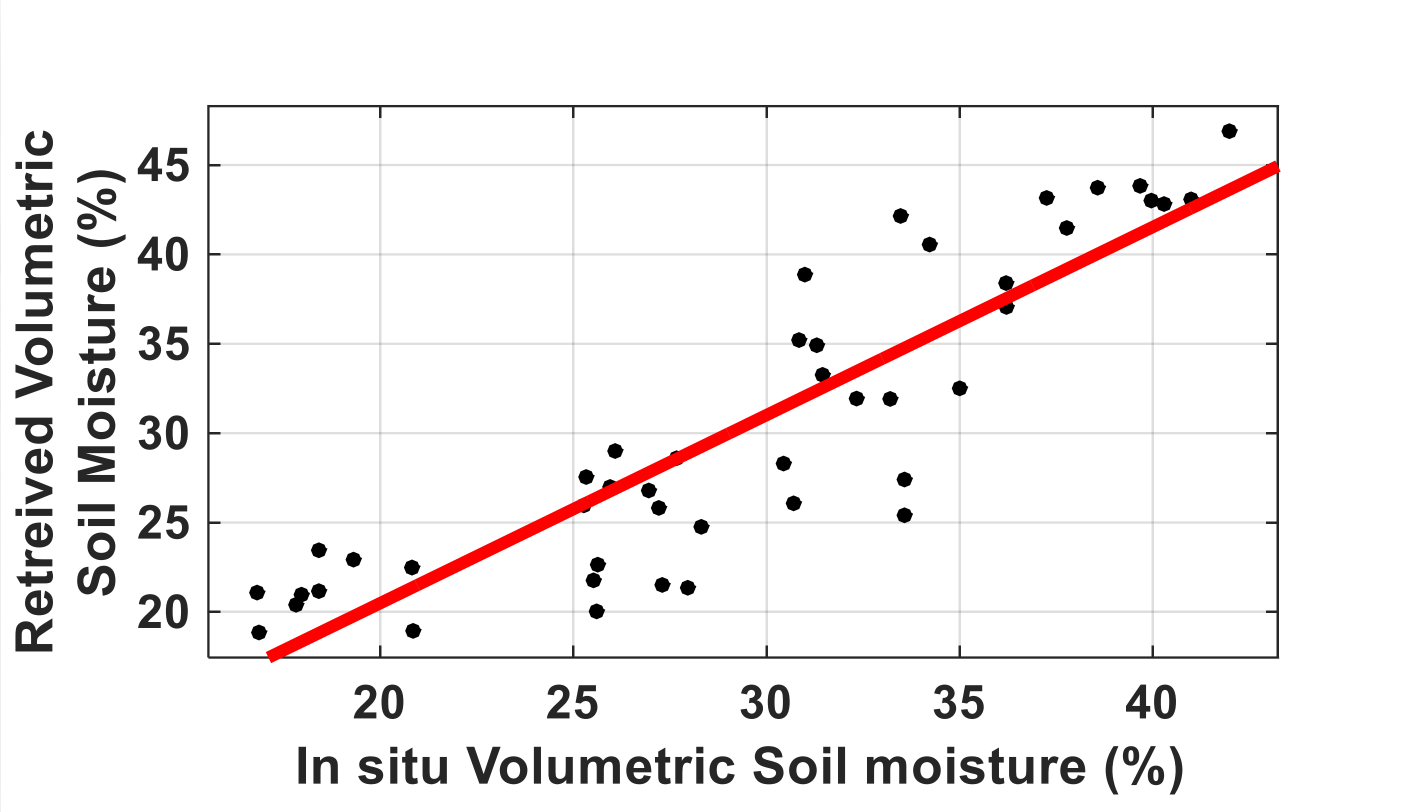
- Once the value of penetration depth is estimated using developed empirical model, the value of dielectric permittivity can be computed using optimization techniques.

- Further equation 4 and 5 can be utilized to determine dielectric values in accordance to the inverse modeling approach.

- **Finally, the value of volumetric moisture content of soil can be calculated using another form of the equation from Topp *et al.***

$$VMC = -5.3\times10^{-2} + 2.29\times10^{-2}\varepsilon' - 5.5\times10^{-4}(\varepsilon')^{2} - 4.3\times10^{-6}(\varepsilon')^{3}$$

Validation of Developed Inversion Model



Correlation Coefficient = 0.902 Bias = 0.97%

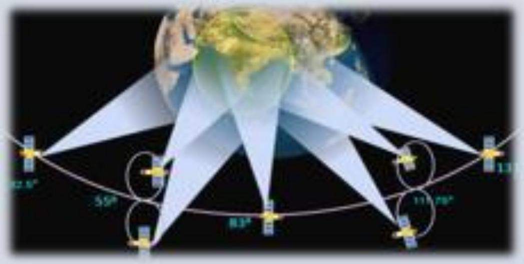
RMSE = 4.03%

Conclusions & Future Scope

- Developed **Soil Moisture inversion algorithm/model over Agricultural croplands using NavIC Data** by integrating concept of **merging multipath phase and penetration depth** as GNSS-IR method.
- Proposed **Phase Normalization Technique to make developed algorithm more robust and** independent of location of observation.
- The established relationship between normalized path difference and penetration depth is capable of retrieving soil moisture using NavIC data with good accuracy (RMSE<4.02%) and Pearson correlation (0.902).
- The proposed algorithm can also be directly used for other L-band signals (L1, L2 etc.) such as GPS, GLONASS, Galileo, and BeiDou GNSS systems.
- This study demonstrated that NavIC can be utilized as ***"Development of Ground based Soil Moisture in-situ Network"*** for calibration/validation of satellite derived products as well as for land applications.
- Multi-frequency NavIC (L1*, L5 & S) data will be more useful for retrieving crops/vegetation information which is the future work to be taken.

Publication

Sushant Shekhar, Rishi Prakash, Dharmendra Kumar Pandey, Anurag Vidyarthi, Shivani Tyagi, Deepak Putrevu and Arundhati Misra (2021), *"Development of Inversion Model for Retrieval of Bare Land Soil Moisture using Navigation with Indian Constellation"*, IEEE Geoscience Remote Sensing Letters, 15 July 2021 (Early Access) **DOI:** 10.1109/LGRS.2021.3090568




Thank You