Comparison of dielectric models and evaluation of the penetration depth of L-band S-band (NISAR mission) microwave SAR signals into the ground

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4 authors:

Abhilash Singh
Indian Institute of Science Education and Research Bhopal

Ganesh Kumar Meena
Indian Institute of Science Education and Research Bhopal

Shashi Kumar
Indian Institute of Remote Sensing (IIRS), Dehradun, India

Kumar Gaurav
Institut de Physique du Globe de Paris

Comparison of dielectric models and evaluation of the penetration depth of L-band S-band (NISAR mission) microwave SAR signals into the ground.

Abhilash Singh[1], Ganesh Kumar Meena[1], Shashi Kumar[2], Kumar Gaurav[1]

[1]Department of Earth and Environmental Sciences
Indian Institute of Science Education and Research, Bhopal

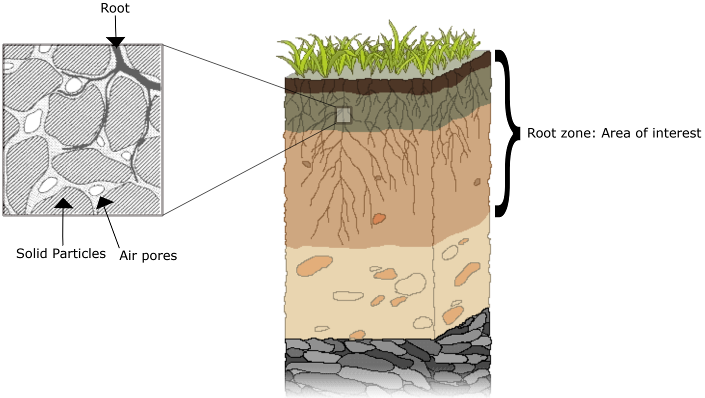
[2]Indian Institute of Remote Sensing, ISRO, Dehradun

Presented by: **Abhilash Singh, DST-INSPIRE Fellow**

Outline

Introduction: Soil moisture and it is important

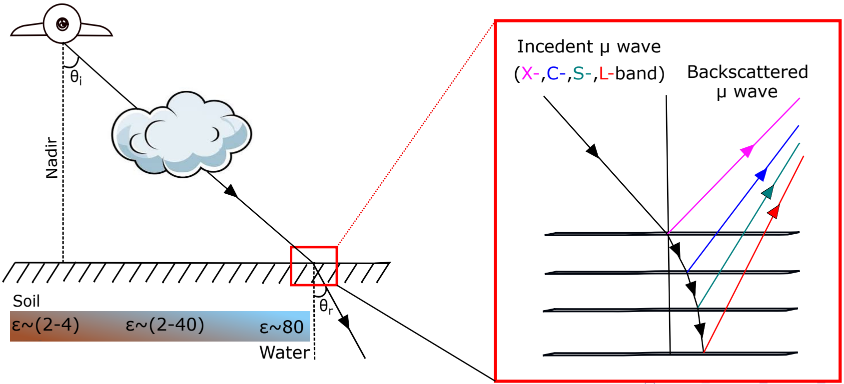
Soil moisture is a measure of temporary storage of water contained in the soil pores.



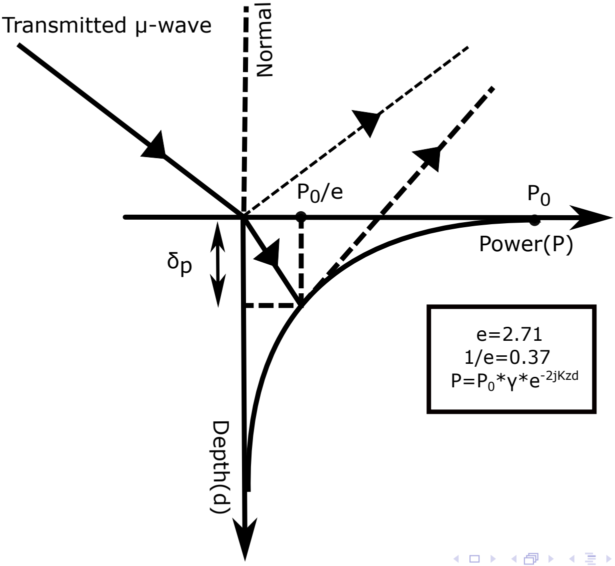
Application of soil moisture: Flood monitoring, Crop monitoring, Hydrological modelling etc.

Microwave remote sensing for soil moisture

- higher sensitivity towards the dielectric properties of soil
- ability to penetrate deep into the soil medium
- weather independent



Penetration depth



Penetration depth: sensitivity

- **Target property**

$$\delta_p = f(\overbrace{S, C, VWC}^{\epsilon=\epsilon'-j\epsilon''})$$

- **Sensor property**

$$\delta_p = f(\theta_i, \lambda)$$

Penetration depth: sensitivity

- **Target property**

$$\delta_p = f(\overbrace{S, C, VWC}^{\epsilon=\epsilon'-j\epsilon''})$$

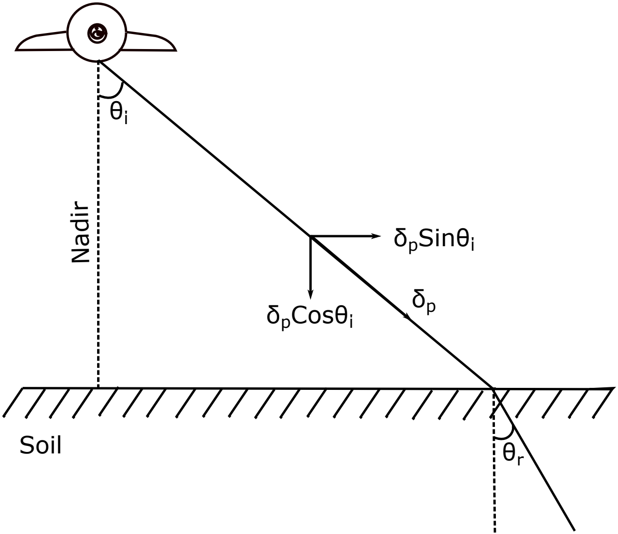
- **Sensor property**

$$\delta_p = f(\theta_i, \lambda)$$

On combining both:

$$\boxed{\delta_p = f(\epsilon, \lambda, \theta_i)}$$

Penetration depth



At Nadir

$$\delta_p = \frac{\lambda * \sqrt{\epsilon'}}{2\pi * \epsilon''}$$

$$\delta'_p \approx \delta_p * cos\theta_i$$

Off Nadir

Unknown : ϵ

Permittivity of material

It is a measure of how easy or difficult to form an electric field inside of a medium.

Complex permittivity (ϵ) is define as

$$\epsilon = \epsilon' - j\epsilon''$$

ϵ'= **Dielectric constant**

ϵ''= **Dielectric loss factor**

ϵ' is the measure of how much energy from an external electric field is stored in a material. ϵ'' measures how much lossy a material is to an external electric field. i.e. how much energy is lost (converted to heat) in the material.

Models: soil moisture Vs. permittivity

- **Empirical models**
  - Dobson empirical model
  - Hallikainen empirical model

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- **Empirical models**
  - Dobson empirical model
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- **Semi-empirical models**
  - Dobson semi-empirical model

Dobson Vs. Hallikainen empirical model

Dobson model: [1.4 GHz, L & 5 GHz, C-band]

$$\epsilon = a_0 + (a_1 + b_1 S + c_1 C)w + (a_2 + b_2 S + c_2 C)w^2 + (a_3 + b_3 S + c_3 C)w^3$$

Hallikainen model: [1.4, 4, 6, 8, 10, 12, 14, 16, & 18 GHz, L, S, C, X, Ku -bands]

$$\epsilon = (a_0 + a_1 S + a_2 C) + (b_0 + b_1 S + b_2 C)w + (c_0 + c_1 S + c_2 C)w^2$$

where, S and C is the percentage of sand and clay respectively. w is the volumetric water content (VWC) in $[\mathrm{m}^3/\mathrm{m}^3]$

Dobson Vs. Hallikainen empirical model

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where, S and C is the percentage of sand and clay respectively. w is the volumetric water content (VWC) in $[\mathrm{m}^3/\mathrm{m}^3]$

Both these empirical models are valid only up to a VWC of 50%

Dobson semi-empirical model

$$\epsilon' = [1 + (\frac{\rho_b}{\rho_s})(\epsilon_s^{\alpha}) + w^{\beta'}\epsilon_{f\,w}^{'\,\alpha} - w]^{\frac{1}{\alpha}}$$

$$\epsilon'' = [w^{\beta''}\epsilon_{f\,w}^{''\,\alpha}]^{\frac{1}{\alpha}}$$

$where \alpha = 0.65$ & $\rho_s = 2.66\ g/cm^3$

$$\beta' = 1.2748 - 0.519S - 0.152C \quad \& \quad \beta'' = 1.33797 - 0.603S - 0.166C$$

S and C represent the fraction of sand and clay in the soil

$$\epsilon_s = (1.01 + 0.44\rho_s)^2 - 0.062$$

Its value ranges between $3 \sim 5$

$$\epsilon'_{fw} = \epsilon'_{w\infty} + \frac{\epsilon'_{wo} - \epsilon'_{w\infty}}{1 + (2\pi f \tau_w)^2}$$

$$\epsilon''_{fw} = \frac{2\pi f \tau_w(\epsilon'_{wo} - \epsilon'_{w\infty})}{1 + (2\pi f \tau_w)^2} + \frac{\sigma_{eff}(\rho_s - \rho_b)}{2\pi\epsilon_o f(\rho_s w)}$$

Dobson semi-empirical model

$$2\pi\tau_w = 0.58 \times 10^{-10} \qquad \epsilon'_{wo} = 80.1$$

ϵ_{wo}: static dielectric constant for water

The high frequency limit of ϵ'_{fw} is denoted by $\epsilon_{w\infty} = 4.9$

$$\sigma_{eff} = -1.645 + 1.939\rho_b - 2.25622S + 1.594C$$

Valid for frequencies 1.4-18 GHz .

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What to do for frequencies 0.3-1.3 GHz??

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What to do for frequencies 0.3-1.3 GHz??

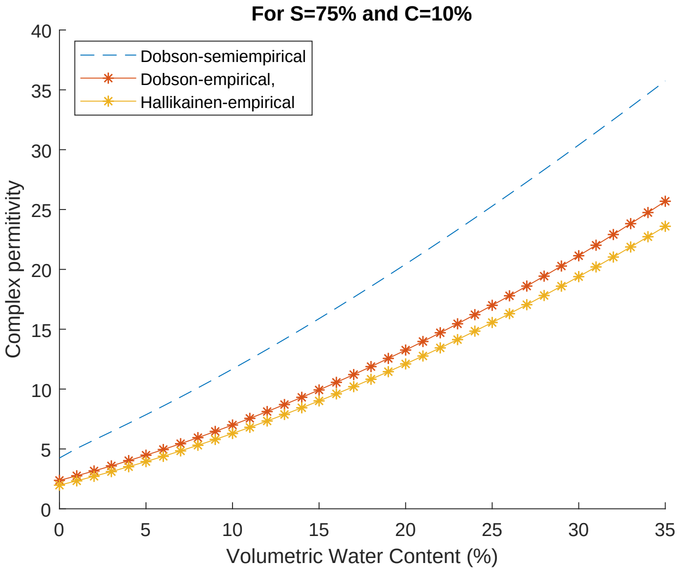
. First change involves a linear correction to ϵ' given by

$$\epsilon'_{0.3-1.3GHz} = 1.156\epsilon' - 0.68$$

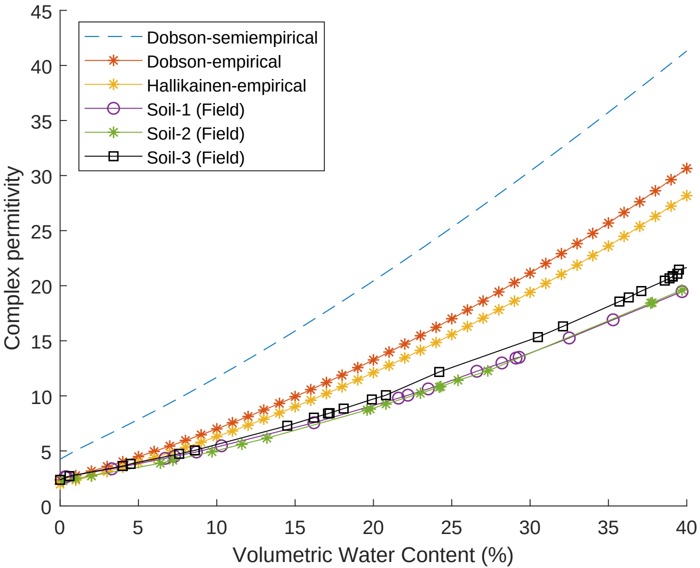
and second change involves in the value of effective conductivity given by

$$\sigma_{eff} = 0.0467 + 0.2204\rho_b - 0.4111S + 0.6614C$$

Comparison between models



Comparison between models

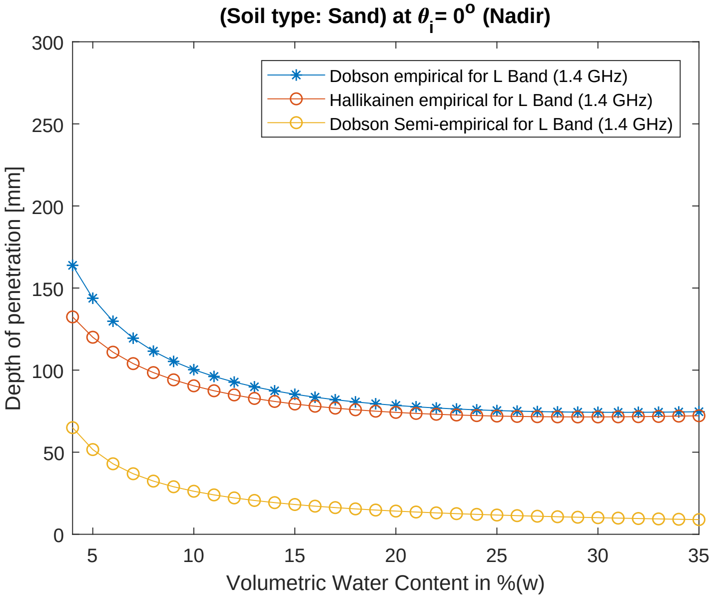


Soil Information

Table: Physical properties of soil

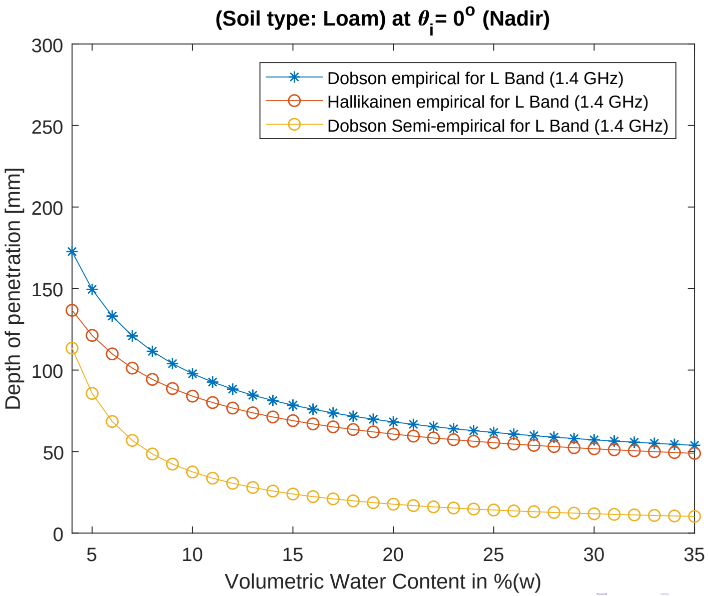
Soil type	Soil proportion (%)			Bulk density (g/cm^3)
	Sand	Silt	Clay	
Sand	86.7	7.8	5.5	1.57
Loam	61.3	23.1	15.6	1.42
Clay	17.79	31.14	51.07	1.28

Result



(Soil type: Sand) at $\theta_i = 0^o$ (Nadir)
Dobson empirical for L Band (1.4 GHz)
Hallikainen empirical for L Band (1.4 GHz)
Dobson Semi-empirical for L Band (1.4 GHz)
Depth of penetration [mm]
300
250
200
150
100
50
0
5
10
15
20
25
30
35
Volumetric Water Content in %(w)

Result


(Soil type: Loam) at θ_i= 0^o (Nadir)
Dobson empirical for L Band (1.4 GHz)
Hallikainen empirical for L Band (1.4 GHz)
Dobson Semi-empirical for L Band (1.4 GHz)
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0
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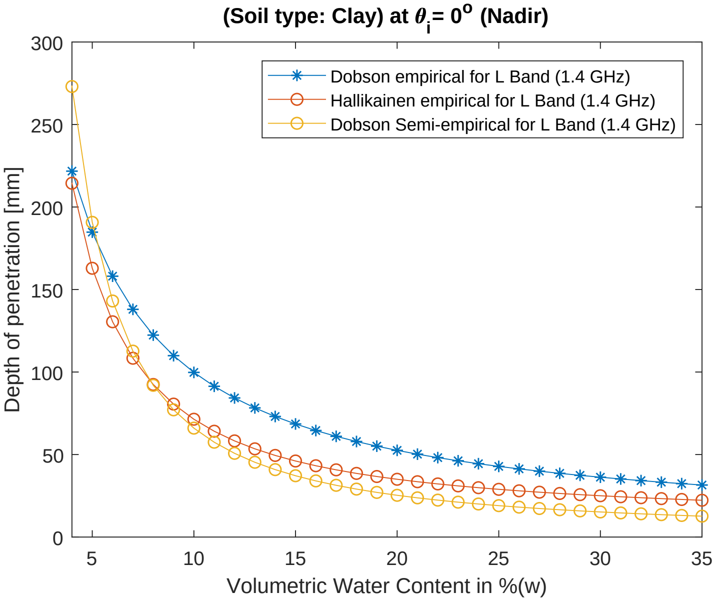
Result



(Soil type: Clay) at θ_i= 0^o (Nadir)
Dobson empirical for L Band (1.4 GHz)
Hallikainen empirical for L Band (1.4 GHz)
Dobson Semi-empirical for L Band (1.4 GHz)
Depth of penetration [mm]
300
250
200
150
100
50
0
5
10
15
20
25
30
35
Volumetric Water Content in %(w)

Result: sensitivity to soil composition?

We can observe different penetration depth for different soil type and Dobson semi-empirical estimated penetration depth varies a lot with soil texture followed by Hallikainen empirical and least variation in Dobson empirical estimated penetration depth. [For w = 0%]

Dobson empirical model

$$\epsilon = a_0 + (a_1 + b_1 S + c_1 C)w + (a_2 + b_2 S + c_2 C)w^2 + (a_3 + b_3 S + c_3 C)w^3$$

Hallikainen empirical model

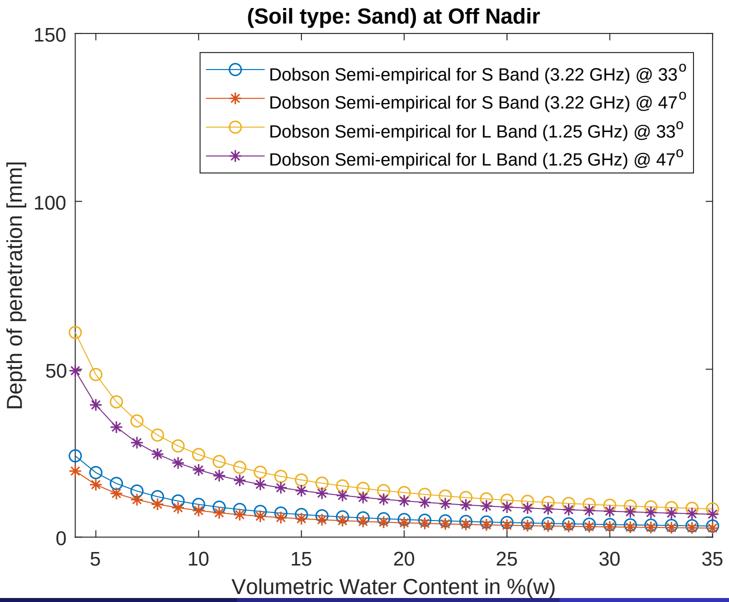
$$\epsilon = (a_0 + a_1 S + a_2 C) + (b_0 + b_1 S + b_2 C)w + (c_0 + c_1 S + c_2 C)w^2$$

Estimation of penetration depth of NISAR sensors

NISAR PARAMETERS

Parameters	NISAR	Hallikainen	Dobson semi-empirical
L-Band	1.25 GHz	1.4 GHz	1.25 GHz
S-Band	3.22 GHz	4 GHz	3.22 GHz
Incidence	$33^o - 47^o$	–	–

Estimation of penetration depth of NISAR sensors



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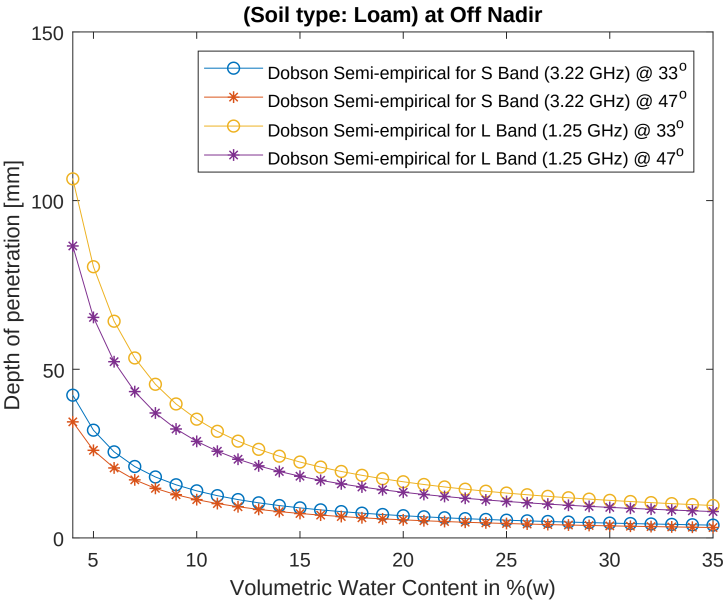
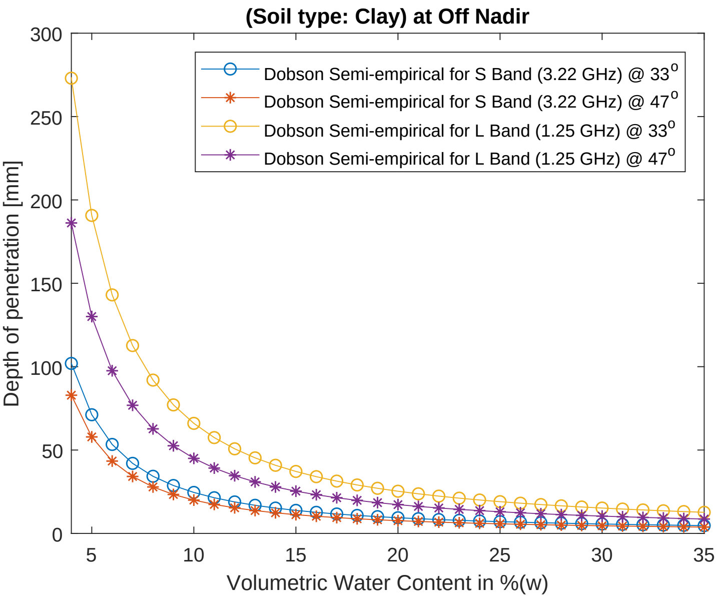


Estimation of penetration depth of NISAR sensors



Conclusion

- This study will give us approximate depth at which one should collect the in-situ measurements.
- All the models (Dobson empirical, Hallikainen empirical and Dobson semi-empirical models) are inconsistent, they yield different penetration depth for same set of parameters.
- Dobson semi-empirical estimated penetration depth varies a lot with soil texture followed by Hallikainen empirical and least variation in Dobson empirical estimated penetration depth.
- The penetration depth decreases significantly for first 10% increase in the soil moisture content, however, further increase in the soil moisture has a reduced effect on penetration depth.
- The penetration depth of the SAR signals decreases with increase in the soil moisture content, incident angle and frequency.
- The depth of penetration is more in L-band SAR signals as compared to the S-band SAR signals.
- Empirical models are site specific and valid for discrete sets of freq.

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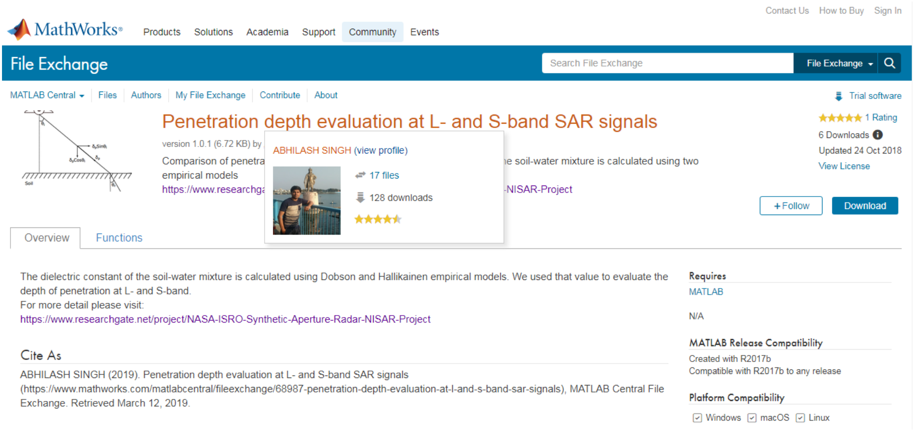
References

A Falk (2018)
NASA-ISRO SAR mission science users handbook

Hallikainen, M. T., Ulaby, F. T., Dobson, M. C., El-Rayes, M. A. and Wu, L.-K. (1985)
Microwave dielectric behavior of wet soil- part 1: Empirical models and experimental observations.
IEEE Transactions on Geoscience and Remote Sensing (1) pp. 2534.

Dobson, M. C., Kouyate, F. and Ulaby, F. T. (1984)
A reexamination of soil textural effects on microwave emission and backscattering
IEEE Transactions on Geoscience and Remote Sensing (6) pp. 530536.

Singh, Abhilash, Meena, Ganesh Kumar, Kumar, Shashi, Gaurav, Kumar (2018)
Analysis of the effect of incidence angle and moisture content on the penetration depth of l- and s-band sar signals into the ground surface.
doi:10.5194/isprs-annals-IV-5-197-2018



https://in.mathworks.com/matlabcentral/fileexchange/68987-penetration-depth-evaluation-at-l-and-s-band-sar-signals

Thank you for your kind attention !