Retrieval of Soil Moisture using Sliced Regression Inversion Technique

Siddhant Gautam

Sakees V Chidambaram, Niharika Gunturu, Uday K Khankhoje

Electrical Engineering,
Indian Institute of Technology Madras

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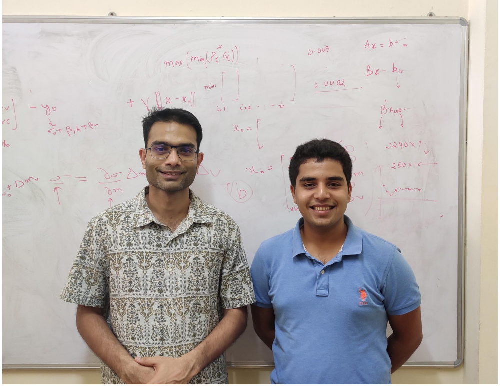
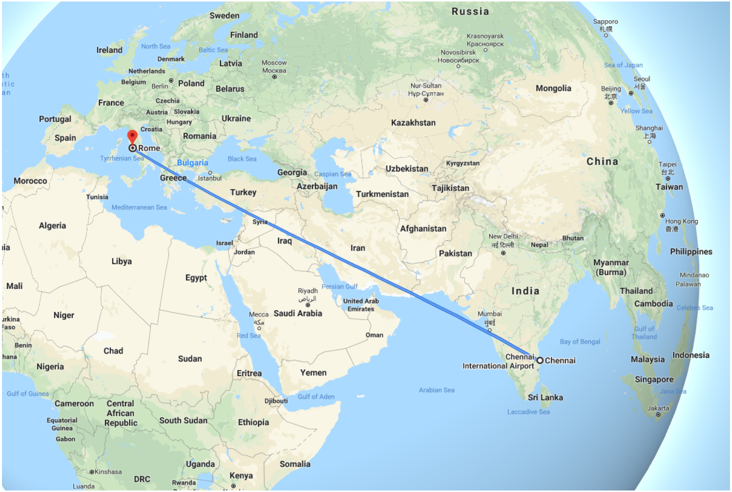
Me and my co-authors!



All roads lead to Rome!



IIT Madras - Wildlife





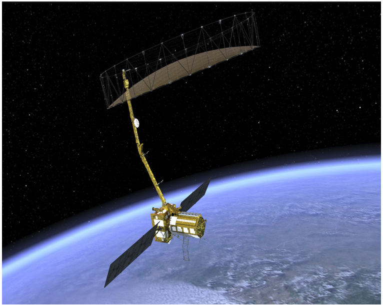

Soil Moisture - Why does it matter?

Figure: Disciplines that benefit from soil moisture measurements [1]

[1] Credits : https://smap.jpl.nasa.gov/

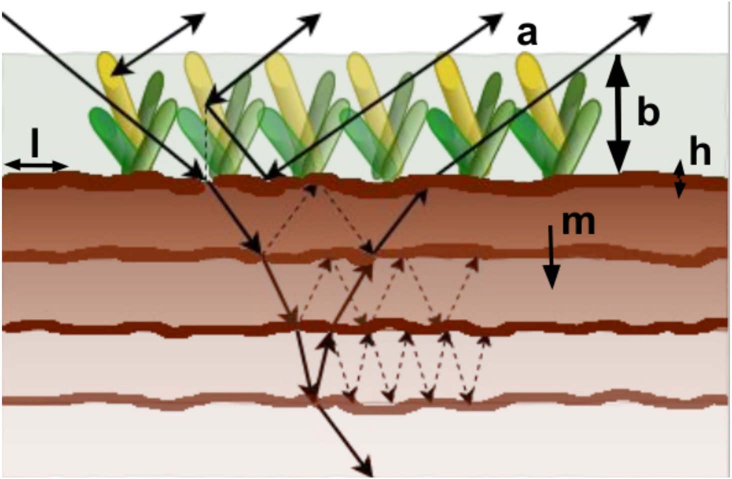
NASA-ISRO Synthetic Aperture Radar (NISAR) Mission

- Joint Mission by ISRO-NASA
- Expected Launch Date : 2021
- Operated bands : L and S
- All-Weather Day and Night Imaging
- Airborne SAR operated by ISRO
- Applications:
  1. Agricultural Monitoring
  2. Glacier and coastal studies
  3. Disaster monitoring and assessment



[1]Credits : https://nisar.jpl.nasa.gov/

Forward Model - Schematic



Forward Model - Block Diagram

1. RMS Surface Height: h
2. Correlation Length: l
3. Soil Moisture Content: mv
4. Transition Rate Factor: m

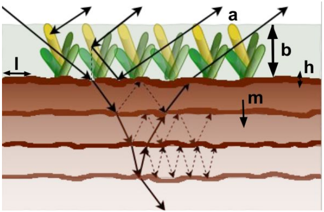
Soil Parameters

1. Frequency : f
2. Polarization : pq
3. Radar Incidence Angle : θ

Radar Parameters

1. Vegetation Water Content : vwc
2. Cylinder Radius : a
3. Cylinder Height : b
4. Density of Scatterers : ρ

Vegetation Parameters



Ground (I^2EM) Backscatter

Vegetation Backscatter

+

$\sigma^f_{pq}(\theta)$

Heterogeneous Soil Moisture Profile

- IEM assumes the soil profile to be homogeneous[2]
- However soil moisture varies as a function of depth
- Need to model the soil profile as a multilayer dielectric surface

[2] A. K. Fung, Z. Li and K. S. Chen, "Backscattering from a randomly rough dielectric surface," in IEEE Transactions on Geoscience and Remote Sensing, 1992

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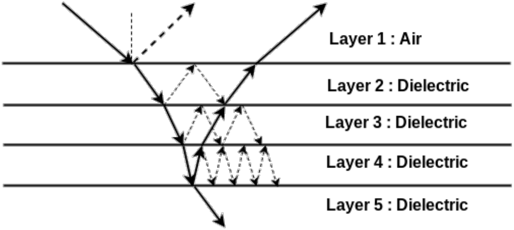

Figure: Multiple radar reflections from dielectric layers

[2] A. K. Fung, Z. Li and K. S. Chen, "Backscattering from a randomly rough dielectric surface," in IEEE Transactions on Geoscience and Remote Sensing, 1992

Modeling Depth Dependent Moisture

Transitional Dielectric Profile[3]

$$\epsilon_r(z) = 1 + \frac{2(\epsilon_0 - 1)}{1 + e^{-mz}}$$

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Modeling Depth Dependent Moisture

Transitional Dielectric Profile[3]

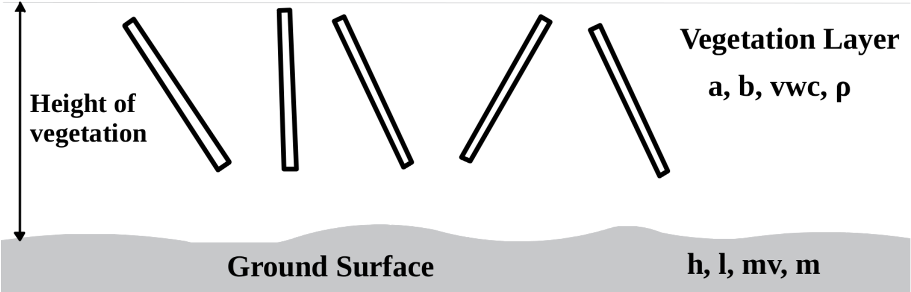
$$\epsilon_r(z) = 1 + \frac{2(\epsilon_0 - 1)}{1 + e^{-mz}}$$

- $m = 0$ corresponds to homogeneous soil profile
- Calculate effective reflection coefficient using Transfer Matrix Method
- Update the Fresnel reflectivities in the original IEM
- Obtain the new backscattering coefficient σ

[3] A. K. Fung et al., "A modified IEM model for: scattering from soil surfaces with application to soil moisture sensing," IGARSS, 1996

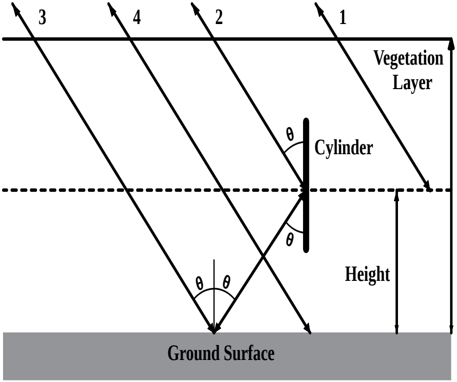
Soil moisture retrieval over vegetated terrain

- A single layer vegetation model
- Describes scattering from grasslands, pasture lands, etc.
- Spatial distribution of cylinders dictated by a pdf e.g. $\cos^2\theta$



Single Layer Vegetation Model

1. Scattering from the Vegetation Layer (Path 1)
2. Double Reflection Scattering (Paths 2 and 3)
3. Backscatter from the Ground Surface (Path 4)



[3] van Zyl, Jakob J. Synthetic aperture radar polarimetry. Vol. 2. John Wiley and Sons, 2011

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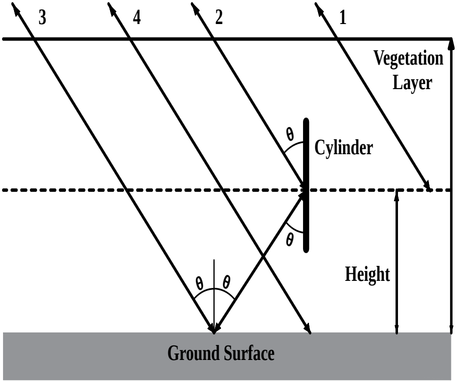
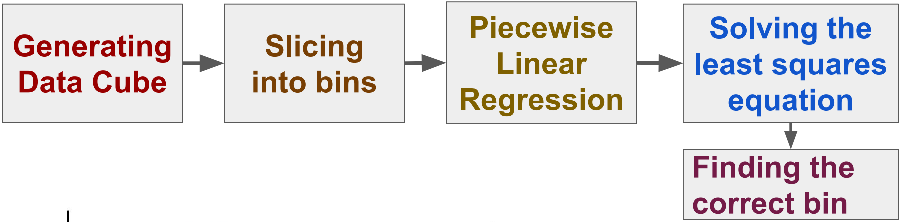


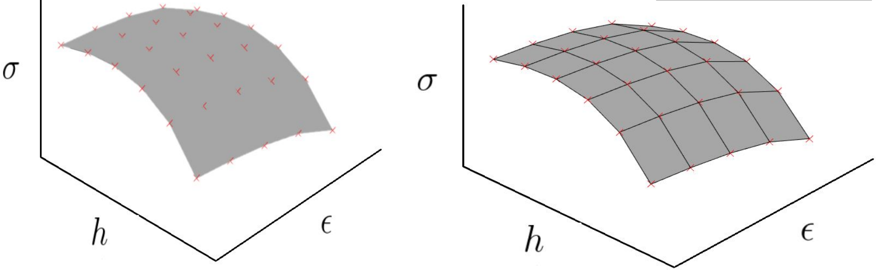
Backscatter Contributions from soil and vegetation

$$\boldsymbol{\sigma}_{\boldsymbol{total}} = \boldsymbol{\sigma}_{\boldsymbol{veg}}(vwc, a, b, \rho_s) + \tau^2 \boldsymbol{\sigma}_{\boldsymbol{IEM}}(h, l, \epsilon) + \boldsymbol{\sigma}_{\boldsymbol{db}}(vwc, a, b, \rho_s, h, l, \epsilon)$$

[3] van Zyl, Jakob J. Synthetic aperture radar polarimetry. Vol. 2. John Wiley and Sons, 2011

Sliced Regression Inversion Algorithm





Matrix Formulation - Forward Model

Linear Regression

$$\sigma = \beta_0 + \beta_1\, h + \beta_2\, l + \beta_3\, m_v + \beta_4\, m + \beta_5\, vwc$$

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$$\sigma = \beta_0 + \beta_1\, h + \beta_2\, l + \beta_3\, m_v + \beta_4\, m + \beta_5\, vwc$$

$$\underbrace{\begin{bmatrix} \sigma_1^{hh,L} & \sigma_1^{vv,L} & \sigma_1^{hh,S} & \sigma_1^{vv,S} & \sigma_1^{hv,L} & \sigma_1^{hv,S} \\ \sigma_2^{hh,L} & \sigma_2^{vv,L} & \sigma_2^{hh,S} & \sigma_2^{vv,S} & \sigma_2^{hv,L} & \sigma_2^{hv,S} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \sigma_n^{hh,L} & \sigma_n^{vv,L} & \sigma_n^{hh,S} & \sigma_n^{vv,S} & \sigma_n^{hv,L} & \sigma_n^{hv,S} \end{bmatrix}}_{\mathbf{Y}} =$$

$$\underbrace{\begin{bmatrix} 1 & h_1 & l_1 & mv_1 & m_1 & vwc_1 \\ 1 & h_2 & l_2 & mv_2 & m_2 & vwc_2 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & h_n & l_n & mv_n & m_n & vwc_n \end{bmatrix}}_{\mathbf{X}} \underbrace{\begin{bmatrix} \beta_0^{hh,L} & \beta_0^{vv,L} & \dots & \beta_0^{hv,S} \\ \beta_1^{hh,L} & \beta_1^{vv,L} & \dots & \beta_1^{hv,S} \\ \vdots & \vdots & \ddots & \vdots \\ \beta_5^{hh,L} & \dots & \dots & \beta_5^{hv,S} \end{bmatrix}}_{\boldsymbol{\beta}}$$

Matrix Formulation - Inverse Model

Solve the least squares equation and find the bin with minimum error

$$\underset{x}{\text{minimize}} \quad ||\beta\mathbf{x} - \mathbf{y}||_2^2 \quad \text{subject to} \quad \mathbf{lb} \leq \mathbf{x} \leq \mathbf{ub} \quad \text{for each bin}$$

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$$\underbrace{\begin{bmatrix} \sigma^{hh,L} - \beta_0^{hh,L} \\ \sigma^{vv,L} - \beta_0^{vv,L} \\ \sigma^{hh,S} - \beta_0^{hh,S} \\ \sigma^{vv,S} - \beta_0^{vv,L} \\ \sigma^{hv,L} - \beta_0^{hv,L} \\ \sigma^{hv,S} - \beta_0^{hv,S} \end{bmatrix}}_{\mathbf{y}} = \underbrace{\begin{bmatrix} \beta_1^{hh,L} & \beta_2^{hh,L} & \beta_3^{hh,L} & \beta_4^{hh,L} & \beta_5^{hh,L} \\ \beta_1^{vv,L} & \beta_2^{vv,L} & \beta_3^{vv,L} & \beta_4^{vv,L} & \beta_5^{vv,L} \\ \beta_1^{hh,S} & \beta_2^{hh,S} & \beta_3^{hh,S} & \beta_4^{hh,S} & \beta_5^{hh,S} \\ \beta_1^{vv,S} & \beta_2^{vv,S} & \beta_3^{vv,S} & \beta_4^{vv,S} & \beta_5^{vv,S} \\ \beta_1^{hv,L} & \beta_2^{hv,L} & \beta_3^{hv,L} & \beta_4^{hv,L} & \beta_5^{hv,L} \\ \beta_1^{hv,S} & \beta_2^{hv,S} & \beta_3^{hv,S} & \beta_4^{hv,S} & \beta_5^{hv,S} \end{bmatrix}}_{\boldsymbol{\beta}} \underbrace{\begin{bmatrix} h \\ l \\ mv \\ m \\ vwc \end{bmatrix}}_{\mathbf{x}}$$

Retrieval Results

- SR inversion performs better than SMART inverse model [4]
  Range : $m_v = [0.05, 0.4]$, $h = [0.3, 1.5]$

RMSE	$\mathbf{m_v}$	**h**
SMART Inversion	0.07	0.25
Single band SR	0.05	0.19
Dual band SR	0.03	0.14

[4] Dubois, et. al. "Measuring soil moisture with imaging radars." IEEE Transactions on Geoscience and Remote Sensing (1995)

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Single band SR	0.05	0.19
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- Retrieving moisture in presence of vegetation
  Range : $m_v = [0.05, 0.4], \ vwc = [0.1, 0.5]$

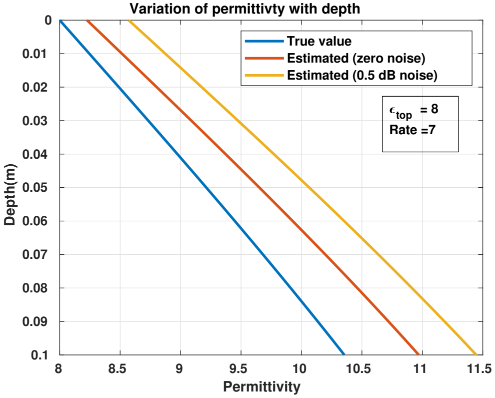
RMSE	m_v	vwc
Zero Noise	0.024	0.001
10 dB SNR	0.046	0.008

[4]Dubois, et. al. "Measuring soil moisture with imaging radars." IEEE Transactions on Geoscience and Remote Sensing (1995)

Retrieval results for depth dependent moisture

- Range : $\epsilon = [5, 15]$, $h = [0.3, 1.5]$

RMSE	ϵ	h
Zero Noise	1.07	0.03
10 dB SNR	1.13	0.11



Conclusion

- Sliced Regression Inversion - an algorithm rooted in electromagnetic theory
- Performs better than SMART Inversion algorithm
- Dual band works better than single band
- Retrieval of depth dependent moisture
- Retrieval of moisture from vegetation covered areas
- Future work
  1. Testing on real datasets
  2. Investigating the backscatter sensitivity to the soil and vegetation parameters