

SOIL MOISTURE MODEL WITH MULTI ANGLE AND MULTI POLARISATION RISAT-1 DATA

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KEY WORDS: Soil Moisture, RISAT-1, Multi-Polarisation, Multi-Angle, Dielectric Constant, Backscatter, RISAT Utilisation Programme

ABSTRACT:

Multi dimensional data (multi frequency, incident angle and polarisation) measurements of σ_0 provided better estimates of soil moisture over those derived from single. This particular paper explains a new methodology for soil moisture estimation with the use of multi angle and multi polarisation RISAT-1 data. The roughness component was derived by correlating root mean square height with the differences of cross polarisation and like polarisation backscatter values ($\sigma_{HV} - \sigma_{HH}$) and differences of low and high incidence backscatter values (σ_{HH} high (θ) - σ_{HH} Low). The derived roughness was inputted to the modified dubois model (MDM). The results show both the $\sigma_{HV} - \sigma_{HH}$ & σ_{HH} high (θ) - σ_{HH} Low are sensitive to roughness. The derived soil moisture using the MDM model is shows reasonable correlation with ground soil moisture.

1. INTRODUCTION

The physical models for soil moisture estimation give the site independent results. However physical models involve numerous parameters in it hence often it's difficult to reverse the models. The constrain in the model environment is also a difficult issue, for an example the small perturbation model (SPM), geometrical optic model (GOM) are used for smooth surfaces physical, where as optic model (POM) used in rough surface environment. Thus specific model for specific roughness environment hampers the applicability of these models in the practical situations.

On the other hand the empirical models need a huge amount of ground data regarding target parameters (ie: roughness, soil moisture, vegetation...etc) corresponds to sensor parameters to model and these model are mostly confined to particular site circumstances and can't apply to new study area.

The semi empirical models are compromised between theoretical and physical models by applying some approximation and simplifications while retaining physical meaning. The semi empirical model developed by Oh et al. 1992 and Dubois model et al., 1995 and Water cloud model (Attema, E.W.P. and Ulaby, F.T. 1978) are the notable semi empirical models. Estimation of Dielectric constant with Modified Dubois Model (MDM) developed by Sahebi, M. R., & Angles, J. (2010) shows good agreement with the ground data

with mean error of 2.46 followed by OM and GOM. The study also explains MDM is more exact for estimation of dielectric constant than RMS height. The surface roughness strongly influences the strength of radar return and at times the effect of surface roughness becomes comparable to or even more than the effect of soil moisture (Srivastava et al. 2006). Thus considering roughness in the model is an important issue. In this study roughness was derived with two methods, i.e. i) correlating $\sigma_{HV} - \sigma_{HV}$ with ground RMS height ii) σ_{HH} high (θ) - σ_{HH} Low(θ). This developed method is more simple and realistic for the estimation of soil moisture.

2. STUDY AREA

The study area is located in Vidarbha region of Maharashtra, India centred at 21°07'00"N/78°55'00"E. The majority of the area comes under rainfed with major crops of cotton, soya beans and gram. The study area temperature ranges from 48° C in summer and 7° C in winter. The annual rainfall is around 1100mm with south west monsoon (July to October) contribution almost 80% to this region. Hence usually cultivation starts in mid July and ends in starting of November. The topography is ranging from 280m to 340m. The study area is mostly covered under heavy clay soil. Due to the presence of heavy clay scenario cotton is more preferable crop. Unfortunately making model in such heavy clay condition for soil moisture is a very tedious job.

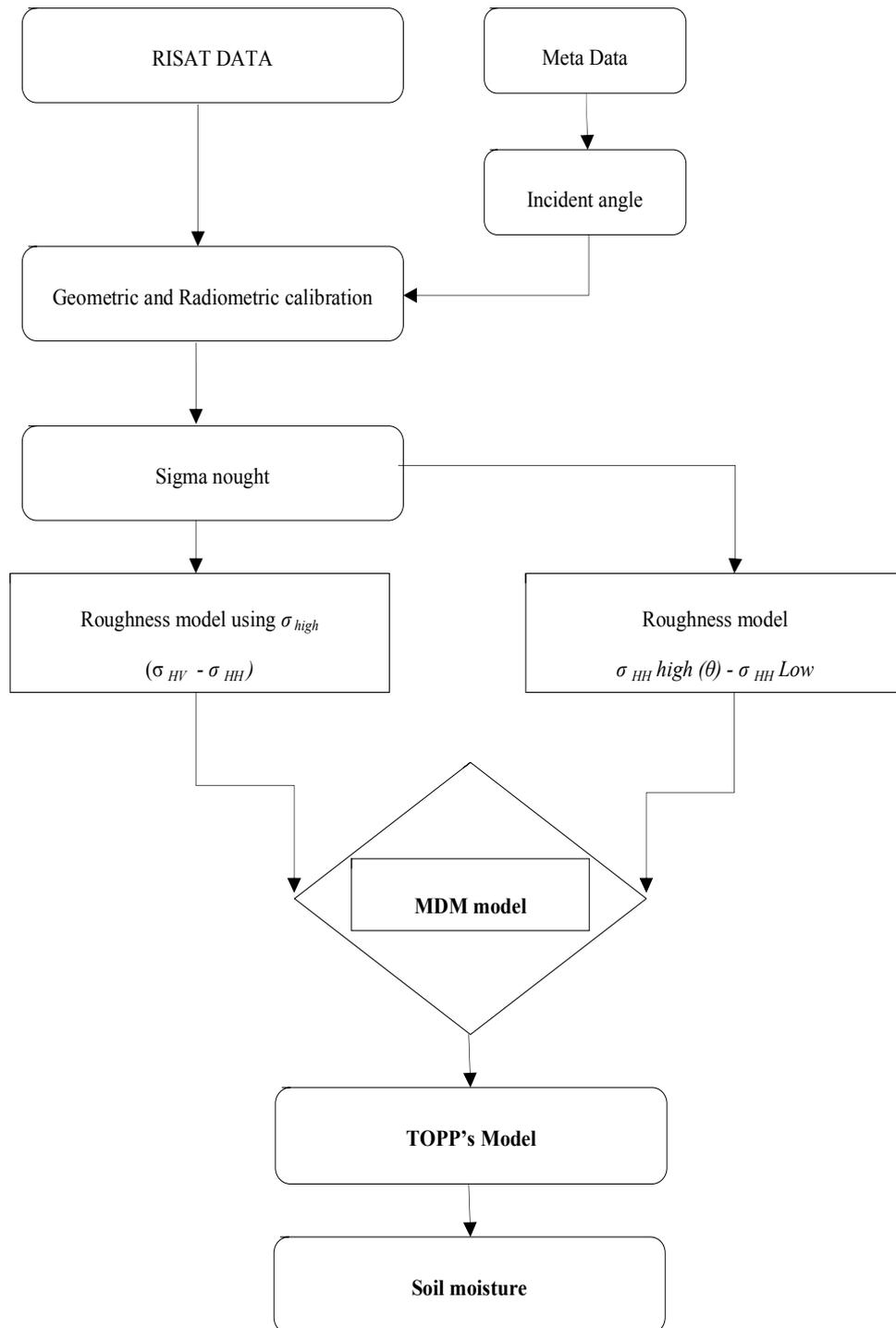


Figure1. Procedure followed in this research

S. No.	Date	Satellite	Imaging Mode	Polarization	Center Incident angle	Resolution (m)
1	04/07/2013	RISAT-1	CRS	HH,HV	22.65	36
	06/07/2013	RISAT-1	CRS	HH,HV	48.71	36
2	25/10/2013	RISAT-1	CRS	HH,HV	24.36	36
	26/10/2013	RISAT-1	CRS	HH,HV	41.43	36

Table.1 details of acquired RISAT-1 data

3. DATA AND METHODS

The RISAT-1 data Course Resolution Data (CRS) were acquired in the ground range. The details of acquired RISAT-1 data with information of Imaging mode, polarisation, incident angle, resolution is shown in table 1.

The geometric correction was done using Carto-DEM as a part of pre-processing. The geometric accuracy of the RISAT-1 data was verified with geo-corrected LISS-IV data and Radarsat-2. The acquired scenes had geometric error of 4-5 pixels in common. Geometric correction was performed using Radarsat-2 data as a base image and accuracy was maintained within a pixel. The incident angle was generated from the grid file that was given along with data. In grid file latitude and longitude and incident angle column were used for incident angle generation. The available incident angle in gridded point format was interpolated and incident angle image generated with the same pixel size of RISAT-1 data.

The back scattering coefficient calibrated using the equation 1 below:

$$\sigma_o(dB) = 20 \log_{10}(DN_p) - K_{dB} + 10 \log_{10}(\sin i_p / \sin(I_{center})) \quad (1)$$

Radiometric calibration requires four inputs

DN_p : Digital number, (Image pixel value)

K_{dB} : Calibration Constant in dB, Available in product.xml / Meta data file

i_p : Incident angle for pixel position p, generated from grid file

I_{center} : Incident angle at the scene center, available in BAND_META file in Incidence Angle column

The Sigma nought image generated using the formula given in Eqn.1. It was found that there are some anomalies i.e.: very high and low value of sigma nought observed. Hence all images were filtered using a median filter with 3*3 window size. The median filter was selected based on M.M. Rahman et al.2008, R. van der Velde et al.2012 studies. The low window size 3*3 was chosen since the spatial resolution of CRS data is 36m and soil moisture may vary within the large window size. However roughness model derived without any filtering since roughness is a highly variable phenomenon than soil moisture and filter may reduce the sharpness of data (thus loss of detail about roughness). The methodology is followed as shown in flow sort (figure.1).

4. FIELD DATA CAMPAIGNS

A total of 50 fields sites were selected and following details were taken from the field i.e. three soil samples, a ground roughness graph with 1m length, tilling direction, crop type, and crop height. Soil moisture and roughness details were collected synchronous with the low incident angle data pass. The roughness measurement was done by drawing a graph across tilling direction and it was examined at 1 cm intervals over 1m in total for RMS calculation.

Root mean square height was calculated using equation 2 below:

$$S = \sqrt{\frac{\sum_{i=0}^n (Z_i - \bar{Z})^2}{n - 1}} \quad (2)$$

Here, Z_i denotes the height of the point on X_i , \bar{Z} refers the mean height, n is the total number of points. In the study area the RMS height varied from the 0.25 cm to 3cm.

The three soil samples per site were collected in 0-5 cm depth of soil surface. The bulk density values were analysed for each soil sample. The soil samples were dried in oven at 105°C for 24 hours getting gravimetric soil moisture value, which is converted to volumetric soil moisture by the multiplying bulk density.

5. MODIFIED DUBOIS MODEL (MDM) FOR RISAT-1

Modified Dubois model developed by Sahebi, M. R., & Angles, J. (2010) has the advantage of working condition of $\theta = 20^\circ - 50^\circ$, $1 \text{ cm} < s < 6 \text{ cm}$ and $14\% < \text{mv} < 32\%$. Thus we could able to get rid of one of the drawback of original Dubois model that requires incident angle should be more than 30° . This is very important point since the sensitivity of sigma nought against the soil moisture is inversely proportional to the incident angle.

$$\sigma^o_{hh} = 10^{-367} \frac{\cos^{\frac{\epsilon \theta}{\beta}}}{\sin^{\frac{\epsilon \theta}{\beta}}} \times 10^{0.1 - 2\epsilon \tan \theta} (ks \sin \theta)^{0.8} \lambda^{\sigma} \quad (3)$$

The θ represents the incidence angle, ϵ is the real part of dielectric constant, 'k' is the wave number ($2\pi/\lambda$), and s is the root mean square height represents vertical height variation in the terrain, where the incidence angle (θ) is

calculated from metadata file, wavelength ($\lambda = 5.3$), the unknown parameter RMS height's' will be replaced by roughness model derived by following section.

6. SURFACE ROUGHNESS MODEL DERIVATION

Surface roughness is described as the surface height variance compared to a smooth reference surface. Surface roughness and soil moisture are two important factors that affect SAR backscatter from bare agricultural fields (Ulaby et al. 1978) hence accurate surface roughness parameter is essential for retrieving soil moisture from radar backscatter. Roughness can be modelled with multi incidence angle or multi polarization approach. The ground surface roughness was measured using a graph and RMS heights were calculated as explained in previous section. The ratio polarisation $\sigma_{HV} - \sigma_{HH}$ is found to be sensitive to roughness (S.Srinivasa Rao et., 2013). The depolarization ratio (VH to VV polarization) was found to be very sensitive to soil surface roughness (Srivastava et al., 2008; Oh et.al., 1992). Hence the roughness model was derived using $\sigma_{HV} - \sigma_{HH}$ & σ_{HH} high (θ) - σ_{HH} Low.

7. ROUGHNESS MODEL BY DUAL POLARIMETRIC APPROACH WITH θ_{HIGH} DATA

The ground measured RMS height of 06th July 2013 measurements were plotted against the $\sigma_{HV} - \sigma_{HH}$ of high incidence angle data of same date and its correlated well (Figure.2) with r^2 value of 0.8158.

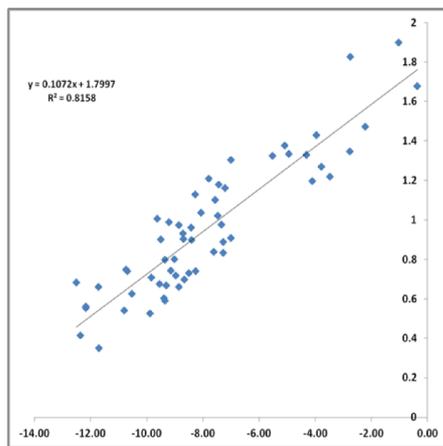


Figure 2. Roughness model by dual polarimetric approach with θ_{high} data RMS height (Y axis) against $\sigma_{HV} - \sigma_{HH}$ (X axis)

8. ROUGHNESS MODEL BY DUAL INCIDENCE ANGLE APPROACH θ_{HIGH} & θ_{LOW}

The ground measured RMS height of July 2013 measurements were plotted against the σ_{HH} high (θ) - σ_{HH} Low (θ) of same date and its correlated well (Figure.3) with r^2 value of 0.811.

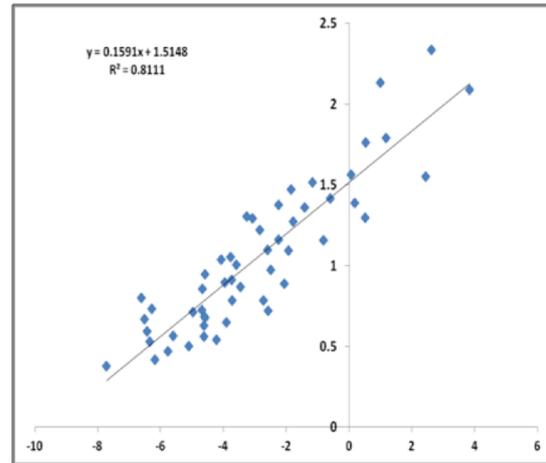


Figure 3. RMS (Y axis) against σ_{HH} high (θ) - σ_{HH} Low (θ) (X axis)

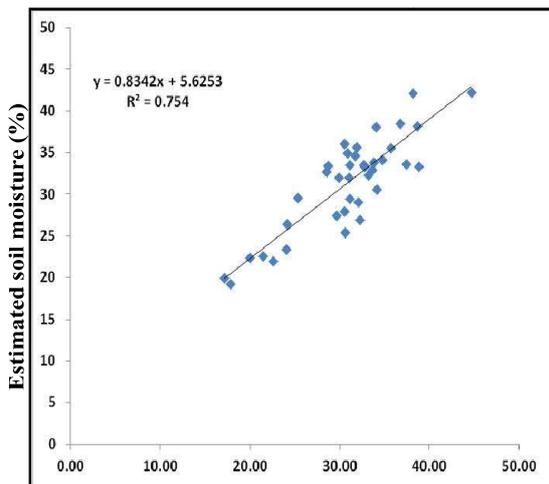
9. TOPP'S MODEL

The soil moisture can be derived from the dielectric constant using (Topp et al.,1980) model. This model has been used by many researchers effectively for retrieving soil moisture (Song et al.,2010). This model doesn't require any prior knowledge about the soil texture, needs only the dielectric constant of the soil. The soil moisture θ_v related with the dielectric constant (ϵ) as follows

$$\theta_v = -5.3 \times 10^{-2} + 2.92 \times 10^2 \epsilon - 5.5 \times 10^{-4} \epsilon^2 + 4.3 \times 10^{-6} \epsilon^3 \quad (4)$$

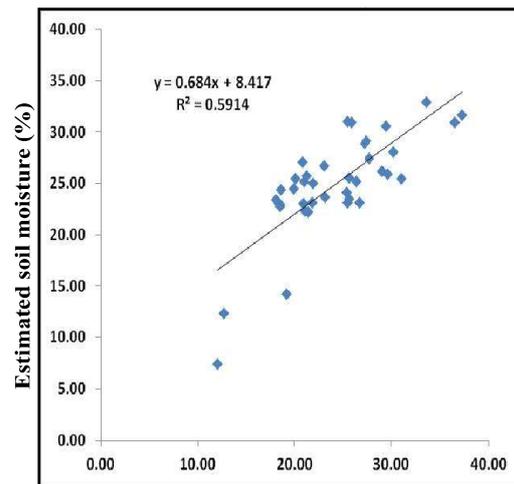
10. SOIL MOISTURE FROM MDM USING σ^0_{HH} LOW(θ) (RMS FROM $\sigma_{HV} - \sigma_{HH}$)

Then RMS height derived from $\sigma_{HV} - \sigma_{HH}$ were substituted to MDM model to retrieve soil moisture. The retrieved soil moisture were plotted against the ground soil moisture for validation. The r^2 of 0.75 & 0.59 was obtained in the 04th July 2014 and 25th October 2014 respectively (Figure 4 & 5). The statistical results are shown in table 2.



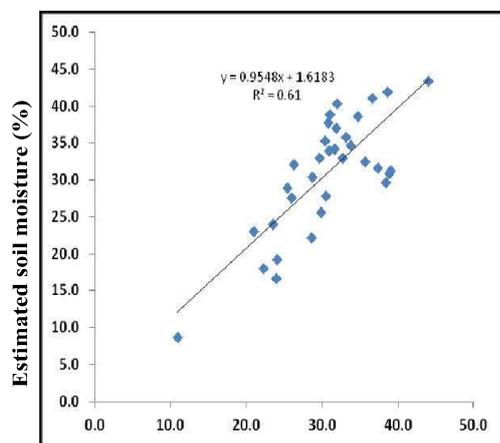
Measured soil moisture (%) – 04th July, 2013

Figure 4. Estimated SM against Measured SM



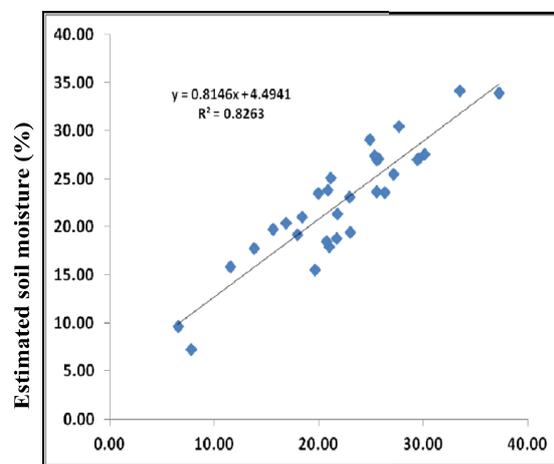
Measured soil moisture (%) - 25th Oct, 2013

Figure 5. Estimated SM against measured SM



Measured soil moisture (%) – 04th July, 2013

Figure.6 Estimated SM against Measured SM



Measured soil moisture (%) - 25th Oct, 2013

Figure.7 Estimated SM against measured SM

Date	Coefficient of determination (r^2)	RMSE	Number of measurements
04 th July 2013	0.75	2.87	38
25 th Oct 2013	0.59	3.20	38

Table 2. Soil moisture from MDM using σ^0 HH Low(θ) (RMS from $\sigma_{HV} - \sigma_{HH}$)

Date	Coefficient of determination (r^2)	RMSE	Number of measurements
04 th July 2013	0.61	4.99	33
25 th Oct 2013	0.82	2.60	33

Table 3. Soil moisture from MDM using σ^0 HH Low(θ) (RMS from σ^0 HH high (θ) - σ^0 HH Low (θ))

11. SOIL MOISTURE FROM MDM USING σ^0_{HH} HIGH (θ) - σ^0_{HH} LOW (θ) (RMS σ_{HH} HIGH (θ) - σ_{HH} LOW)

Then RMS height derived from σ_{HH} high (θ) - σ_{HH} Low (θ) were substituted to MDM model to retrieve soil moisture. The retrieved soil moisture were plotted against the ground soil moisture for validation. The r^2 of 0.61 & 0.82 was obtained in the 04th July 2014 and 25th October 2014 respectively (Figure 6 & 7). The statistical results are shown in table 3.

The first data (04th July 2013) was acquired when the cultivation started, and the second data (25th October 2013) was acquired when the cultivation was in ending stage (matured crop condition). From the ground inference it was known that the in July the cultivation was just started and hence there is very less vegetation influence in the data but there is greater influence from the roughness apart from soil moisture. The first method σ_{HV} - σ_{HH} works well even the roughness influence is high. But the performance of this method becomes poor once vegetation grows. The reverse of this phenomenon observed in the second method i.e. High correlation was observed in the 25th October 2013, when field was almost covered with vegetation. This is due to the fact that high incidence angle is sensitive to vegetation (Gherboudj et al., 2011), thus incorporating σ_{HH} high (θ) is more suitable for retrieval of soil moisture when ground is covered with the vegetation.

12. CONCLUSIONS

The developed method here is more simple and realistic for the estimation of soil moisture. The roughness component was derived by correlating root mean square height with the differences of cross polarisation and like polarisation backscatter values and differences of low and high incidence backscatter values. The derived roughness was inputted to the modified Dubois model (MDM). The results show both the backscatter values and the differences of low and high incidence backscatter values are sensitive to roughness. The derived soil moisture using the MDM model shows reasonable correlation with ground soil moisture.

ACKNOWLEDGMENTS

This work was performed under RISAT Utilization Project funded by Indian Space Research Organization (ISRO). The project team wants to thank Dr. V. K Dadhwal, Director, NRSC for his encouragements and support. We express our thanks to the Dr. Manab Chakraborty, Project Director, RISAT-UP for his help throughout this project. The project team thank D. S Mohekar - NBSS, Nitin Tendulkar, CICR, Siva Prasad Reddy - JRF RRSC/NRSC, I Ramteke, S Verma-MRSAC, S R Potpate, J.P Suman, Arun Kumar Rajwar - SLUSI for their help in soil sample analysis, ground truth collection and process. We also thank Directors of National Bureau Soil Science / Land Use Planning, Nagpur, Central Institute Cotton Research (CICR), Nagpur, Maharashtra Remote Sensing Applications Centre (MRSAC) and Soil and Land Use Survey of India (SLUSI) for their support in throughout the project.

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