Soil moisture retrieval under wheat crop using RISAT-1 hybrid polarimetric SAR data

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ABSTRACT

The study aims to retrieve soil moisture from RISAT-1 hybrid polarimetric SAR data. Although the use of linear polarimetric SAR data has been well understood and documented, but hybrid polarimetric SAR data is grossly under explored and under reported for this purpose. Regression analysis has been carried to develop soil moisture retrieval models and validated the same. The retrieval models have been developed from back scattering coefficients (σ_{RH} & σ_{RV}) and m-δ space decomposition parameters (even bounce, odd bounce, and volume component) generated from RISAT-1 hybrid polarimetric SAR data. A total of three models are analyzed in this work, (i) using both σ_{RH} & σ_{RV}, (ii) volume component, and (iii) using even bounce, odd bounce and volume component. The study results showed that the model using m-δ decomposition derived parameters can provide better accuracy with R^2 and RMSE of 0.92 and 2.45 per cent respectively in comparison to other two models.

The knowledge of spatial and temporal distribution of soil moisture is highly desirable for agricultural applications like precision farming, irrigation scheduling and yield estimation in combination with hydrological, meteorological, and ecological applications. Although several advanced ground-based instruments are available to estimate actual soil moisture, but it is laborious and expensive for measurement of large agricultural area and it provides point measurements of soil moisture which are too sparse to represent the soil moisture of surrounding area. Remote sensing becomes as better alternative for soil moisture monitoring by providing high spatial and temporal resolution data from local to global scales. Out of the total range of electromagnetic spectrum, microwave region is more suitable for soil moisture studies due to the large difference between the dielectric constant of water ($\approx$80) and that of dry soil ($\approx$3) at microwave frequencies (Srivastava *et al.,* 2006). Several operational sensors are available in both active and passive modes operating in microwave region of electromagnetic spectrum for soil moisture studies. The data from passive microwave sensors is highly influenced by the vegetation than the soil moisture in vegetation covered areas (Patel and Srivastava, 2015). Coming to the active microwave remote sensing, the return signal is also sensitive to surface roughness and texture over bare

agriculture fields and to crop cover over crop covered agriculture fields along with soil moisture (Sivasankar *et al.,* 2018). Due to its penetration capability and high spatial resolution, SAR has become an important tool for soil moisture studies. But it needs to minimize the crop cover effect within the resolution cell to retrieve underneath soil moisture from crop covered fields (Gherboudj *et al.,* 2011; Srivastava *et al.,* 2015).

The SAR sensor parameters like frequency, incidence angle and polarization plays an important role to enhance the sensitivity of SAR data for a specific application. The penetration depth varies with the frequency of operation, higher the penetration depth for high frequency signals. Srivastava (2007) suggested the high frequency SAR data for deeper layer soil moisture studies and low frequency data for surface soil moisture studies. The increase in incidence angle makes the signal to propagate longer distance through the crop cover due to increase in slant range over crop covered agriculture fields. Whereas, low incidence angle SAR data is more sensitive towards underneath soil moisture over crop covered fields. The illuminated and return signals polarization is also plays an important role in soil moisture retrieval. So far linear polarized signal illuminated data have been used for soil moisture studies by several researchers (Dong *et al.,*2013; Srivastava

et al., 2002). Srivastava *et al.,* (2009) described the methodology to retrieve soil moisture by incorporating the effect of surface roughness and texture over bare agriculture fields and crop covered agriculture fields using linear polarized data. However, researchers found several technical and maintenance limitations in linear polarimetry SAR onboard space-borne platform (Patel *et al.,* 2012). Advancement of hybrid polarimetry, which involves circular polarization transmission and receives coherent orthogonal linear polarizations, designed in such a way to overcome the limitations of linear polarimetry like Faraday rotation effect, available over only restricted swaths, more power requirement etc. Refer Raney (2007), for detailed description of hybrid polarimetry SAR architecture and its importance in earth observation missions. Indian Space Research Organization (ISRO) was launched an operational hybrid polarimetry SAR onboard Radar Imaging Satellite-1 (RISAT-1), the first earth observing space-borne platform acquiring hybrid polarimetric SAR images, in 2012 to make use of hybrid polarimetric SAR data. Later, ISRO team has carried out an extensive research work to calibrate and validate the RISAT-1 hybrid polarimetric SAR data (Mishra *et al.,* 2015). On the other hand, numerous researchers have been intensively using the RISAT-1 hybrid polarimetric SAR data for various remote sensing applications including crop and soil moisture studies (Uppala *et al.,* 2015; Srivastava *et al.,* 2018a).

The capabilities of polarimetric parameters have proven better than backscattering coefficients for various applications. It has been reported by Sivasankar *et al.,* (2015) that the hybrid polarimetric parameters (even bounce, odd bounce and volume component) are having more information about land cover targets than the backscattering coefficients ($\sigma°_{RH}$, $\sigma°_{RV}$) generated from hybrid polarimetric SAR data. On the basis of these studies, here it is investigated the sensitivity of hybrid polarimetric parameters generated from RISAT-1 hybrid polarimetric SAR data (RH, RV) towards soil moisture over wheat crop covered agricultural fields. The detailed study methodology and results are discussed in the following sections.

MATERIALS AND METHODS

Dataset and study area

Current study carried out using RISAT-1 hybrid polarimetric SAR data acquired on March 2nd, 2013 over parts of Haridwar district, India. The study area is a relatively flat agricultural region located at 29°58′ N, latitude, 78°13′ E, longitude. The detailed SAR sensor and data specifications are given in Table 1. In addition to the SAR data, Landsat data acquired on March 2nd, 2013 has been used for geo-referencing and to cross check the fields' boundaries on SAR image. One major river, Ganga is flowing from northeast direction to southeast direction in the study area. Due to this, a large amount of study area is covered with irrigation. The study area is dominated with wheat and sugarcane agricultural crops during the image acquisition.

Ground truth data collection

A synchronous detailed ground truth data collection has been carried over study area for actual soil moisture readings. The quantitative number of fields and field specifications (should be 22 x 22 m^2 for FRS-1 mode of RISAT-1) were considered as suggested in Patel and Srivastava (2013), to account the characteristic-fading phenomenon of SAR signal. The complete route plan and field boundaries were recorded using Garmin GPS. Frequency domain radiometry (FDR) probe method has been used to estimate surface soil moisture (volumetric, %) in the 40 wheat crop agricultural fields with 5 samples from each field. Out of 40 samples, 10 randomly selected samples were chosen for model validation and the remaining 30 samples were used for model development.

SAR data processing

The backscattering coefficients (σ_{RH} and σ_{RV}) were generated using PolSDP software from RISAT-1 hybrid polarimetric SAR data, which was supplied by National Remote Sensing Centre. After conversion of DN to backscattering coefficients, enhanced Lee-filtering algorithm was used to suppress the speckle noise. And then, polarimetric parameters viz. even bounce, odd bounce and volume component were generated based on m-δ space decomposition. Further details about backscattering coefficients and m-δ space decomposition technique are given in Srivastava *et al.,* (2018b). The hybrid polarization backscatter can be related with backscattering coefficients generated from linear polarimetric data as given in equation (1).

$$\begin{bmatrix} S_{RH} \\ S_{RV} \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} S_{HH} - iS_{HV} \\ -iS_{VV} + S_{HV} \end{bmatrix} \qquad (1)$$

Where, S_{xy} indicates the complex backscatter observed when signal transmitted in 'x' polarization and received in 'y' polarization, 'H' represents the horizontal polarization, 'V' indicates vertical polarization.

The hybrid polarimetric parameters and backscattering coefficients were stacked into a single file

Table 1: SAR sensor and data specifications used in this study

Parameter	Details
Frequency	C-band (5.35 GHz)
Incidence angle	25.31Ú
Mode	FRS-1
Tx. polarization	Right Circular
Rx. polarization	Vertical & Horizontal
Azimuth resolution	3 m
Range resolution	2 m
Swath width	30 km

and geo-referenced using Landsat image. The SAR signatures from appropriate fields were extracted with the help of the vector layer of route plan and sampled field boundaries. The generated backscattering coefficients (σ°_{RH} and σ°_{RV}) and polarimetric parameters (even bounce, odd bounce and volume component) are related with in-situ volumetric soil moisture as given in equations (2), (3), and (4).

$$SoM = A + B * \sigma^o_{RH} + C * \sigma^o_{RV} \qquad (2)$$

$$SoM = A + B * (Volume component) \qquad (3)$$

$$SoM = A + B * (Even bounce) + C * (Odd bounce) + D * (Volume component) \qquad (4)$$

RESULTS AND DISCUSSION

It is known fact that the depolarization results due to multiple reflections within the vegetation volume from crop covered fields. So, Srivastava *et al.,* (2006) has developed an empirical model using cross-polarized (HV) backscatter to incorporate the effect of crop cover along with like polarization (VV) for soil moisture retrieval. The study results observed the R^2 of 0.92 and RMSE of 1.49 for developed model to estimate soil moisture from Bajra/Jowar crop covered fields. Whereas the hybrid polarization backscatter is a combination of like and cross polarized SAR backscatter as given in equ. (1). This indicates that the hybrid polarized backscatter is combined effect of crop cover as well as underneath soil moisture. However, an attempt has been made to retrieve soil moisture from RH and RV backscatter using empirical regression analysis like as mentioned in equ. (2).

The model coefficients 'A', 'B' and 'C' are optimized based on least square method using in-situ surface soil moisture and RH, RV backscatter coefficients signatures from 30 farmers' fields. The coefficient of determination (R^2)

of 0.82 observed for this model. This has been validated with sample size of 10 fields independent to the development set of samples and observed the RMSE of 4.09 per cent. As anticipated from the literature, the hybrid polarized backscatter coefficients have shown poor performance to retrieve soil moisture under wheat crop due to its inability to incorporate the crop cover effect.

It is well documented that the target decomposition can better represent the target properties than the backscattering coefficients of hybrid polairmetric SAR data (Sivasankar *et al.,* 2018). Hence, m-δ decomposition developed by Raney, (2007) has been used to estimate the even bounce, odd bounce and volume component from hybrid polarimetric SAR data. The volume component is proportional to un-polarized component of return signal, which results when the incident microwave signal interacts with a dielectric discontinue medium. Since, the significant amount of radiation at low incidence angles interacts with underneath soil by penetrating through the crop cover. Volume component has been assumed as sensitive variable to represent the underneath soil moisture, as water content in the soil acts as dielectric discontinue medium. Because of this, present study investigated the sensitivity of volume component towards soil moisture under wheat crop using empirical regression analysis, as given in equation (3). This model observed R^2 of 0.87 with surface soil moisture and volume component signatures extracted from 30 farmers' fields and RMSE of 3.57 per cent observed with the sample size of 10 fields. This indicates that the volume component at low incidence angles can better represent soil moisture under wheat crop than the backscattering coefficients generated from hybrid polaimetric SAR data.

The un-polarized component of the return signal observed at an incidence angle has combined effect of both crop cover and underneath soil moisture (Srivastava *et al.,* 2018 a & b). However it is more sensitive towards underneath soil moisture at low incidence angles and crop cover at high incidence angles. Therefore, an attempt has been made by considering even bounce and odd bounce to incorporate the crop cover effect in the soil moisture model using volume component, as given in equation (4). This model observed the R^2 of 0.92 from the development set of samples and RMSE of 2.45 per cent from the validation set of samples. The improvement of R^2 to 0.92 for (Eq.-4) to R^2 of 0.82 for (Eq.2) and decrease in RMSE to 2.45 per cent for (Eq.4) from 4.09 per cent for (Eq.2), represents that the target decomposition can better incorporate the effect of crop

Table 2: Results of model analysis and validation for wheat covered fields

Model	Model development		Model validation	
	N	R^2	N	RMSE
SM = A + B*σ_{RH} + C*σ_{RV}	30	0.82	10	4.09
SM = A + B * Volume Component	30	0.87	10	3.57
SM = A + B * (Odd Bounce) + C * (Even Bounce) + D * (Volume Component)	30	0.92	10	2.45

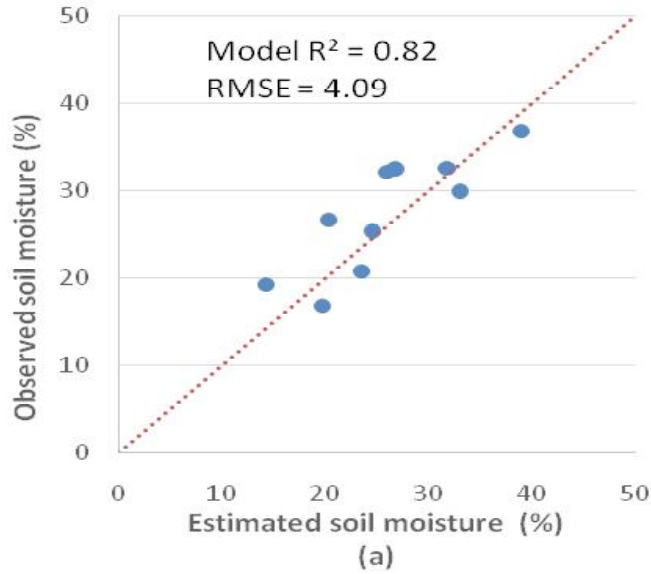Where A, B, C and D represents coefficients; N indicates the number of samples

Fig.1: Scatter plot of the observed soil moisture vs the estimated soil moisture from backscattering coefficients.
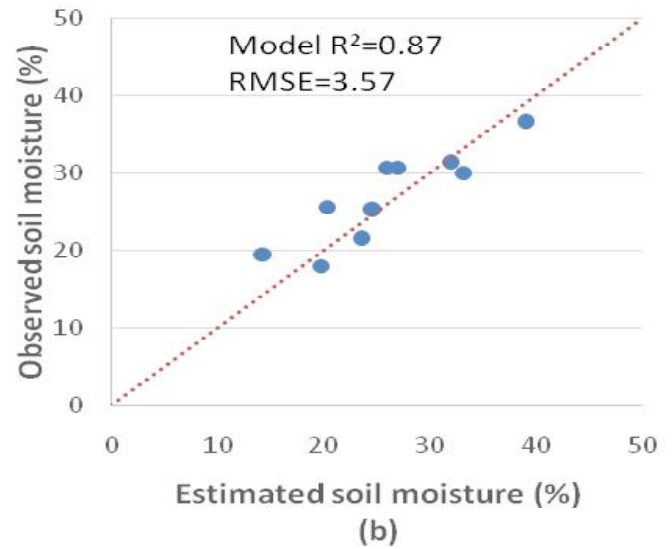

Fig. 2: Scatter plot of the observed soil moisture vs the estimated soil moisture from volume component
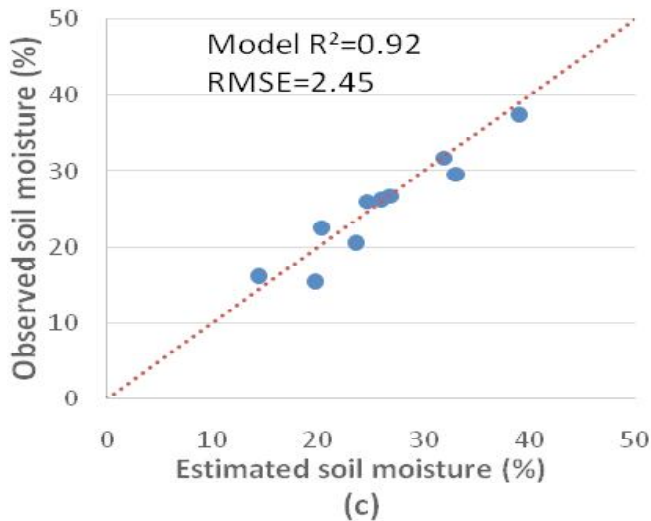

Fig. 3: Scatter plot of the observed soil moisture vs the estimated soil moisture from m-δ space decomposition derived parameters (even bounce, odd bounce and volume component)

cover than the backscattering coefficients generated from hybrid polarimetric SAR data. The scatter plot of observed vs estimated soil moisture from equation (2), (3) and (4) are given in Fig.1, 2 and 3 respectively.

CONCLUSIONS

This study has been carried out to evaluate the capability of hybrid polarimetric SAR data for soil moisture retrieval over wheat crop covered agricultural fields. In this context, the sensitivity of backscattering coefficients (σ^0_{RH}, σ^0_{RV}) and target decomposition generated from hybrid polarimetric SAR data were analysed towards the water content in the Earth's material. The study results successfully demonstrated that the proper use of polarimetric parameters (even bounce, odd bounce and volume component) can significantly enhance the accuracy of soil moisture retrieval than the backscattering coefficients generated from RISAT-1 hybrid polarimetric SAR data. It is also observed that, the volume component at low incidence

angle SAR data is highly sensitive to the water content present in the Earth's material under crop covered agriculture fields due to the increase in dielectric discontinuity with soil moisture. The present study has considered the empirical regression approach to assess the sensitivity, and the accuracy can be improved by adopting physical models using target decomposition. As this study carried out by taking crop type and stage fixed, the future work has to carry to develop a more precise relationship of even bounce, odd bounce and volume component with soil moisture for entire crop season.

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