World Applied Sciences Journal 4 (3): 377-383, 2008
ISSN 1818-4952

Separation of Soil Surface Componenets of the Radar Signal Backscattered from Bare Soil

H. Fattahi, M.R. Sahebi, M.J. Valadan-Zoej and M.S. Moussavi

Department of Remote Sensing, Faculty of Geodesy and Geomatics Engineering,
K.N. Toosi University of Technology, Tehran 15875-4416, Iran

Abstract: Soil surface parameters (roughness and moisture content) are both positively correlated with microwave backscatter intensity. This work evaluates the potential of a multi angular approach to derive moisture and roughness from SAR data. It is based on a modification of a semi-empirical model initially developed for multi-polarization imagery in order to adapt it for multi-angular single polarization data such as those of RADARSAT-1. The modified model and its limits of validity are presented for an agricultural area. The proposed model was tested over a sub-catchment close to Montreal (Canada) using RADARSAT-1 imagery taken in different modes and the S3 and S7 combination gives the best results for the separation of moisture and roughness components In this regards, various numerical results show the efficiency of Modified Dubois Model rather than Original Dubois Model.

Key words: Radar · Signal backscatter model · Soil moisture · Surface roughness

INTRODUCTION

Microwave remote sensing techniques are of primary interests for monitoring land surfaces, due to their all weather capabilities, their penetration depth through natural media and their sensitivity to surface variables (such as water content) which are difficult to estimate using optical remote sensing sensors [1].

Several studies have been conducted over the last 20 years to study the relationship between the backscattering coefficient and soil parameters [1-11]. Most of the research work was oriented towards the estimation of soil moisture and the development of algorithms for mapping soil moisture distribution. Estimation of surface soil moisture was usually obtained by using an empirical relationship to convert the measured backscatter coefficient ($\sigma°$) into volumetric soil moisture (m_v) [1, 11-12]. The radar specifications for optimum soil-moisture detection with a minimum soil roughness influence were determined to be the C-band with HH polarization and an incidence angle around 10-12° [13].

The synthetic aperture radar (SAR) angle of present and future missions starts around 20° (23° for ERS1/2, 38° for JERS-1, 15-55° for SIR-C and 20-50° for RADARSAT1/2). This means that the incidence angles of operational SAR systems are quite different from the 10-12° optimum angles and that radar results are expected to depend on both soil water content and roughness.

Several studies [8, 14, 15] indicated, based on several studies that the multi-angular approach would be more sensitive to surface parameter conditions than multi-polarization and multi-frequency approaches. They concluded that the RADARSAT-1 satellite with its capability of acquiring data at different incidence angles could be used for estimating soil moisture and surface roughness. However, it is necessary to develop a method adapted to RADARSAT-1 data for estimating these parameters.

The objective of this paper is to formulate and define a transformation approach to solve the inverse problem for the operational retrieval of soil surface roughness and moisture. The strategy consists of formulating the inverse problem in the context of multi-angular RADARSAT-1 data [16].

MATERIALS AND METHODS

Configuration of Inversion: Estimation of surface soil parameters was usually obtained by using a theoretical or empirical relationship to convert the measured backscatter coefficient ($\sigma°$) into soil surface roughness and moisture [1, 11, 12, 17]. As for each target, we had one equation with two unknowns, or three if the model incorporates

Corresponding Author: H. Fattahi, Department of Remote Sensing, Faculty of Geodesy and Geomatics Engineering, K.N. Toosi University of Technology, Vali-Asr St., Mirdamad Cross, P.O. Box 15875-4416, Tehran, Iran

correlation length, using multi-technique concepts (multi-polarization, multi-angular, multi-sensor, multi-frequency, and multi-temporal) to estimate the surface parameters simultaneously, over complex areas, are the main solution.

In this study, the multi-angular configuration is used for the inversion of backscattering models to account for roughness and soil moisture estimation using the RADARSAT-1 data acquired with two different angular ranges.

This process was carried out using two empirical backscatter models, Original Dubois Model (ODM) and Modified Dubois Model (MDM). Then, to validate the proposed approach, the obtained results are compared with measured ground data.

Original Dubois Model (ODM): The Dubois model was developed using scatterometer data [3]. The model is based on an empirical model for smooth and medium rough surfaces. The model is optimized for bare surfaces and requires radar channels at a frequency between 1.5 and 11 GHz. It gives best results for $ks \leq 2.5$, $\theta \geq 30°$ and moisture contents (m_v) $\leq$ 35% with *NDVI* (Normalized Difference Vegetation Index) less than 0.4; where k is the wave number ($k=2\pi/\lambda$), λ is the wavelength, s is the rms height and θ is the incidence angle. The HH-polarized backscattering cross sections were found to follow Equation 1:

$$\sigma^0_{hh} = 10^{-2.75}\frac{\cos^{1.5}\theta}{\sin^5\theta}10^{0.028\tan\theta\epsilon_r}(ks.\sin\theta)^{1.4}\lambda^{0.7} \quad (1)$$

where ϵ_r is the real part of the dielectric constant.

Modified Dubois Model (MDM): As explained, the OMD model is limited to surface conditions and incidence angle. It can cover neither rough (and/or very humid) surfaces nor the incidence angle less than 30°. In the case of the RADARSAT-1 sensor configuration (band-C, HH-polarized and incidence angles programmable from 20° to 50°) an attempt was made by the Université de Sherbrooke to modify this model for Quebec agricultural areas [16]. This modification presented in Equation 2 can be applied to all bare agricultural surfaces.

$$\sigma^0_{hh} = 10^{-3.76}\times\frac{\cos^{1.5}\theta}{\sin^5\theta}\times10^{0.112\ \tan\theta\ \epsilon}\times(ks.\sin\theta)^{0.883}\times\lambda^{0.7} \quad (2)$$

When applied on RADARSAT data from two different incidence angle of the same target with short interval, this approach generates a two equation system with two unknowns which can be resolved to obtain s and ϵ.

Study Area: The agricultural site chosen for this study is part of the Chateauguay watershed (73°46' W, 45°19' N), located on the south shore of the St. Lawrence River, southwest of Montreal, Canada (Figure 1). The area consists mainly of agricultural fields on a rather flat relief plateau with homogeneous texture composed of about 36% clay, 42% silt and 22% sand. During the ground surveys, the surface condition of the parcels varied from rough to very rough.

Data: Roughness and moisture measurements were carried out over 27 agricultural parcels simultaneously with the image acquisitions (Figure 2). Roughness measurements were made using a homemade needle profilometer measuring 2 meters in length. To calculate rms height, six 2 m long (1.5 cm sampling interval) surface profiles (three parallel and three perpendicular to the soil furrows) were investigated for each parcel. These profiles were photographed and then digitized. The method for extracting and modeling the roughness parameters such as rms height and correlation length has been described in detail in [18].

The roughness and moisture of the surface were measured *in-situ* on November 15 and 18, 1999 (the same dates as the satellite image acquisitions). However, between the periods of data acquisition, the weather condition was stable and surface moisture had not changed significantly because of the low evaporation and temperature at that time of the year. Average temperatures were 2.3°C and there was no recorded rainfall between the two acquisition dates. However, to satisfy completely the conditions of this study, 20 parcels that had nearly the same moisture and roughness for the two dates were chosen.

The satellite data used in this study correspond to a RADARSAT-1 image pair. The first image was acquired on November 15, 1999 in S3 (Standard-3) mode and, the second image was acquired on November 18, 1999 in S7 (Standard-7) mode. The RADARSAT DN values were converted to σ^0 using Shepard [19, 20].

RESULTS AND DISCUSSION

Figures 3 to 6 present a comparison between the values of surface parameters estimated by the radar data inversion technique and those measured *in-situ* for both Original Dubois Model (ODM) and Modified Dubois

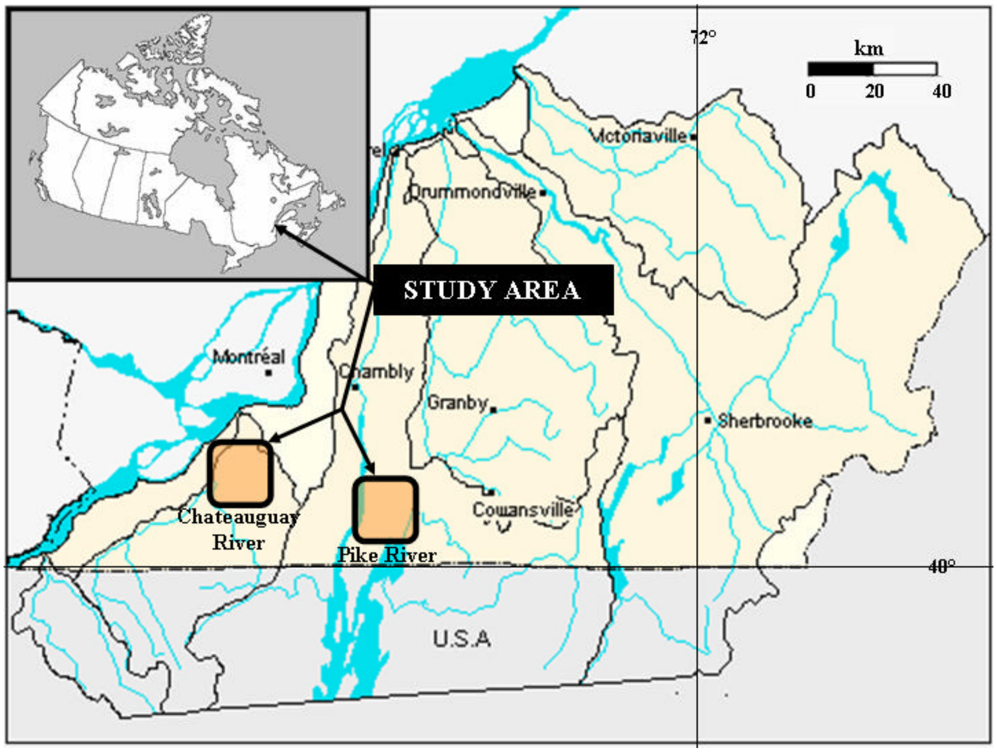

Fig. 1: Location of study area

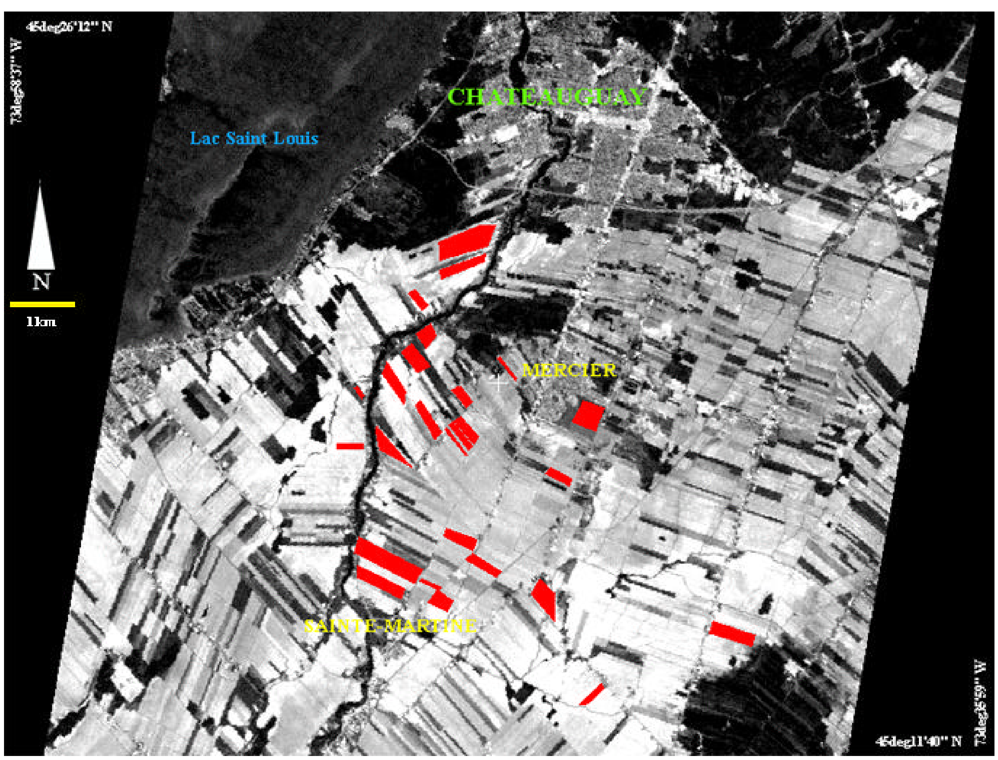

Fig. 2: Location of the parcels (Satellite optic image over Chateauguay watershed)

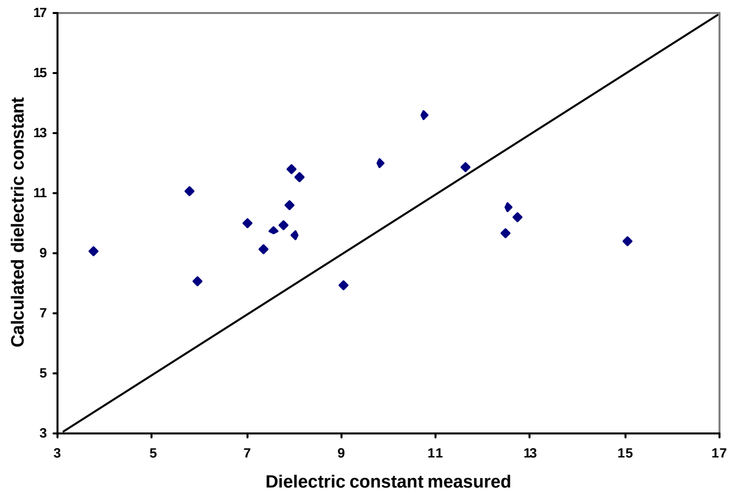

Fig. 3: Comparison between the values of dielectric constant estimated by MDM and those measured *in-situ*

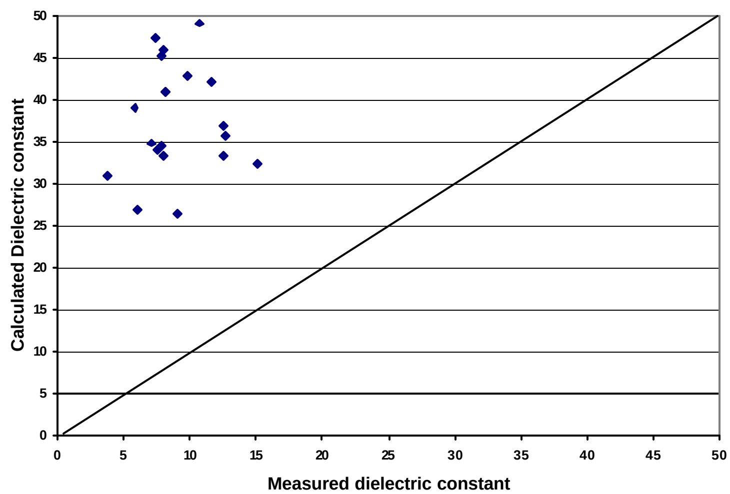

Fig. 4: Comparison between the values of dielectric constant estimated by ODM and those measured *in-situ*

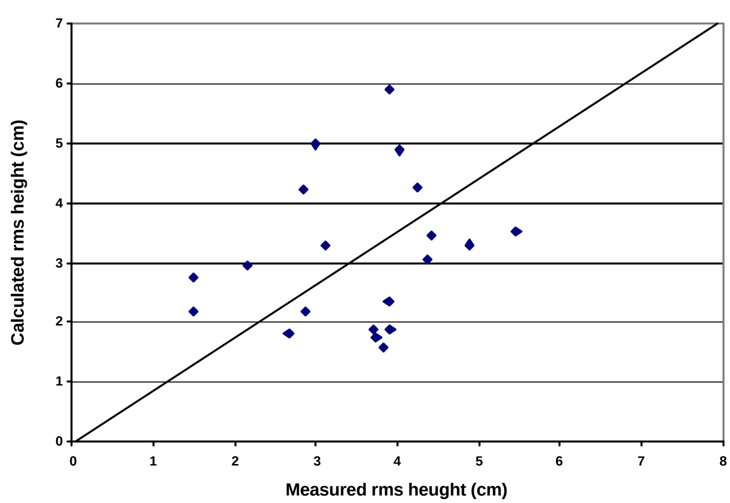

Fig. 5: Comparison between the values of rms height estimated by MDM and those measured *in-situ*

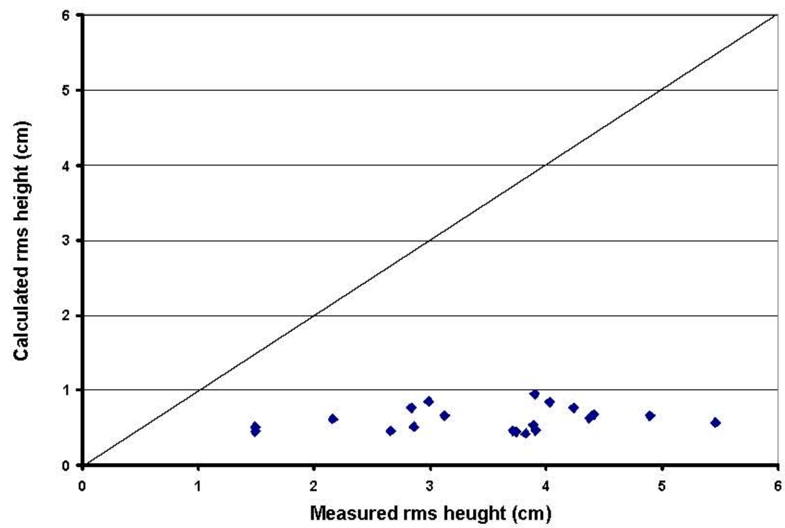

Fig. 6: Comparison between the values of rms height estimated by ODM and those measured *in-situ*

Table 1: Errors of surface roughness estimated from ODM and MDM

Model	Mean Absolute Error (cm)	Mean Square Error (cm^2)	Root Mean Square Error (cm)
Original Dubois Model	2.89	9.35	3.06
Modified Dubois Model	1.30	2.11	1.45

Table 2: Errors of dielectric constant estimated from ODM and MDM

Model	Mean Absolute Error	Mean Square Error	Root Mean Square Error
Original Dubois Model	28.27	845.28	29.07
Modified Dubois Model	2.79	10.36	3.22

Model (MDM). Ideally, we expect the measured and estimated parameters to be the same so as each point in these figures to be located on the diagonal line. However, this situation does not take place in practice, due to various sources of errors and inefficiency of models in relating radar signal backscatter to soil surface parameters. Since the same data for both Original and Modified Dubois Models were used, any differences between results of these two models would be interpreted as their efficiency in relating radar backscatter to soil surface parameters. Various errors including Root Mean Square Error, Mean Absolute Error as well as Mean Square Error have been calculated to evaluate two mentioned models. Obviously lower errors present more correlation between estimated and measured values.

For the surface parameters, MDM definitely gives a better estimation in comparison with ODM, with root mean square errors equal to 1.45 cm and 3.22 for rms height and dielectric constant respectively, however, for ODM, these errors increase to 3.06 cm for rms height and 29.07 for dielectric constant, which are unacceptable. Numerical results for evaluation of both MDM and ODM in soil surface parameters estimation are presented in Table 1 and 2. As can be seen Mean Absolute Error, Mean Square Error as well as Root Mean Square Error of surface parameters obtained from MDM are less than those resulted from ODM.

Table 3 presents further statistical indicators, including range and variance of measured and estimated parameters.

Using MDM, resulted in an rms height and dielectric constant estimation with a 4.34 cm and 5.35 variation range, respectively, whereas these values for ODM

Table 3: Comparison of the range between estimated and observed soil surface parameters

Soil surface parameter	Method	Min	Max	Range	Variance
rms height	Ground Measured	1.490 cm	5.46 cm	3.970 cm	1.0896
	ODM	0.412 cm	0.948 cm	0.536 cm	0.02531
	MDM	1.570 cm	5.910 cm	4.340 cm	1.50780
Dielectric Constant	Ground Measured	3.470	15.070	11.330	6.03820
	ODM	26.448	50.308	23.860	46.30560
	MDM	7.920	13.870	5.950	2.89650

were 0.536 cm for rms height and 23.86 for dielectric constant. Surface parameters, calculated utilizing *in-situ* measurements, varies with a 3.97 cm range in rms height and 11.33 in dielectric constant. Hence, there's more compatibility between MDM results and those measured *in-situ* rather than those of ODM.

In term of soil surface roughness, ground data shows a variation of rms height starting from 1.49 to 5.46 cm, however, ODM gives completely different results with rms height ranging from 0.412 cm to 0.948 cm, While roughness parameter estimated by MDM varies from 1.57 cm to 5.91 cm, and present more compatibility with ground data. These results indicate a lower sensitivity of ODM to roughness variation in this study area in comparison with MDM.

The same situation can be observed in the case of the dielectric constant. For MDM estimated dielectric constant varies form 7.92 to 13.87 which is more compatible with that of measured (3.74 to 15.07), whereas ODM resulted in dielectric constant estimation ranging from 26.448 to 50.308 which is hardly comparable with *in-situ* measured parameter. Calculated variances of estimated and observed parameters are consistent with the ranges results.

This fact can be explained by the behavior of the models. The ODM cannot be used for rough and very rough surface conditions while for MDM, the estimation of the dielectric constant is more exact than the estimation of rms height.

This sensitivity to soil moisture may be explained by the behavior of the Dubois Model. According to this model, the statistical variation of surface roughness is characterized only by rms height and it does not take into account the correlation length. This may introduce an error to present the real behavior of radar signal backscatter.

In fact, similarity between observed ranges of surface parameters estimated from MDM and ground measured data rather than ODM results can be interpreted as the inefficiency of ODM to relate radar backscatter to soil surface parameters in this study area. Consequently ODM can not separate soil moisture and surface roughness parameters in radar backscatter signal from SAR images properly. However, numerical results of various criterions, show efficiency of MDM to separate these parameters correctly for the study area.

CONCLUSION

This work demonstrated the possibility of using the multi-angular approach using MDM backscattering model to derive soil moisture and surface roughness from satellite remote sensing data. Despite of some errors utilizing satellite radar data is a useful tool for estimating the soil surface parameters over wide areas. Various researchers have developed different models to relate radar backscatter to surface parameters [3, 5, 7, 10]. Despite the fact that most of these models may give out good results in some sites in general, they are not applicable throughout the earth. As a matter of fact there is not a perfect model to be used as a universal model that works well in all cases. This is due to variations in soil and environmental conditions in different sites. The best alternative might be developing and using local models instead of using one universal model. Moreover utilizing modified models for various seasons may lead to more proper results. In order to support the proposed alternative, the efficiency of a well known existing model, Original Dubois Model [3], was compared with a modified version of this model developed by [16], Modified Dubois Model, in soil surface parameters estimation in an agricultural bare soil area in Quebec. Various criterions showed MDM's efficiency to separate and estimate soil surface parameters including soil moisture and soil surface roughness in this study area.

Since the same SAR images as well as ground data were used for two models, therefore disability of ODM could be interpreted as inefficiency of this model to relate radar backscatter signal to soil surface parameters and consequently it is inability to separate soil surface roughness and rms height properly in this study area. To minimize the influence of backscatter models, we propose the Modified Dubois Model (MDM) developed for agricultural sites in Quebec. Considering the results of this work, we suggest developing and using local models instead of one universal model to relate radar signal backscatter and soil surface parameters in various regions.

ACKNOWLEDGEMENTS

This study was leaded by Prof. Ferdinand J. Bonn (1943-2006) who was an outstanding researcher. This study was partly supported by FCAR (Action Concertée RADARSAT), NSERC of Canada. The authors want to thank all the colleagues of CARTEL especially J. Angles, P. Gagnon, H. Gwyn, P. Cliche, M. Lambert as well as all colleagues of K. N. Toosi University of technology.

REFERENCES

1. Dobson, M.C. and F.T. Ulaby, 1986a. Active microwave soil moisture research. IEEE Trans. on Geoscience and Remote Sensing, 24(1): 23-36.

2. Dobson, M.C. and F.T. Ulaby, 1986b. Preliminary evaluation of the SIR-B response to soil moisture, surface roughness, and crop canopy cover. IEEE Trans. on Geoscience and Remote Sensing, GE-24(4): 517-526.
3. Dubois, P.C., J. Van Zyl and T. Engman, 1995. Measuring Soil Moisture with Imaging Radars. IEEE Trans. on Geoscience and Remote Sensing, 33(4): 915-926.
4. Engman, E.T. and J.R. Wang, 1987. Evaluation Roughness Models of Radar Backscatter. IEEE Transactions on Geoscience and Remote Sensing, GE-25(6):709-713.
5. Fung, A.K., 1994. Microwave Scattering and Emission Models and Their Applications. Norwood: Artech House, pp: 573.
6. McNairn, H., E. Gauthier and M.R. Sahebi, 2006. Predicting Surface Roughness for Soil Tillage Mapping Using Satellite SAR Data. IGARSS 2006-July 31 to August 4, 2006, Denver, Colorado.
7. Oh, Y., K. Sarabandi and F.T. Ulaby, 1992. An Empirical Model and Inversion Technique for Radar Scattering From Bare Soil Surfaces. IEEE Transactions on Geoscience and Remote Sensing, 30(2): 370-381.
8. Sahebi, M.R., E. Gauthier and H. McNairn, 2005. Estimates of Bare Soil Surface Parameters from Multi-Polarization and Multi-Angle SAR Data. IGARSS 2005-Proceedings of IEEE 2005 International Geoscience and Remote Sensing Symposium, Seoul, Korea, 25-29 July 2005, pp: 1188-1193.
9. Ulaby, F.T., P.P. Batlivala and M.C. Dobson, 1978. Microwave Dependence on Surface Roughness, Soil Moisture and Soil Texture: Part I - Bare Soil. IEEE Transactions on Geoscience Electronics, 16(4): 286-295.
10. Ulaby, F.T., R.K. Moore and A.K. Fung, 1982. Microwave Remote Sensing Active and Passive. Vol. II :Radar Remote Sensing and Surface Scattering and Emission Theory, Artech House, Ann Arbor Ltd., pp: 457-1064.
11. Ulaby, F.T., P.C. Dubois and J.V. Zyl, 1996. Radar mapping of surface soil moisture, Journal of Hydrology, 184: 57-84.
12. Prévot, L., I. Champion and G. Guyot, 1993. Estimating Surface Soil Moisture and Leaf Area Index of a Wheat Canopy Using a Dual-Frequency (C and X Bands) Scatterometer, Remote Sensing of Environment, 46: 331-339.
13. Benallegue, M., O. Taconet, D. Vidal-Madjar and A. Normand, 1998. The Use of Radar Backscattering Signals for Measuring Soil Moisture and Surface Roughness. Remote Sensing of Environment, 53: 61-68.
14. Sahebi, M.R., J. Angles and F. Bonn, 2001. A multi-angular Radarsat based C-band backscattering model for estimation of bare soil surface roughness. Proceedings of the 23rd Canadian Symposium on Remote Sensing, August 21-24, 2001, Ste-Foy (Quebec), Canada, pp: 865-871.
15. Sahebi, M.R., J. Angles and F. Bonn, 2002. A comparison of multi-polarization and multi-angular approaches for estimating bare soil surface roughness from spaceborne radar data. Canadian J. of Remote Sensing (In press).
16. Angles, J., 2001. Séparation de l'humidité et de la rugosité dans le signal retrodiffusé des images RSO selon une approche multi-angle. Mémoire de Maîtrise, Dép. de géographie et télédétection, Université de Sherbrooke, QC, Canada, pp: 82.
17. Chanzy, A., C. King, L. Prévot and A. Remond, 1998. Comparison of ERS and RADARSAT measurements on bare soils: first results. Second Int. Workshop on Retrieval of Bio-&Geo-physical Parameters from SAR Data, ESTEC, The Netherlands, pp: 471-477.
18. Beaulieu, N., G. Leclerc and Y. Moisan, 1998. Détermination de la rugosité de surface par des méthodes accessibles. Canadian Journal of Remote Sensing, 21(2): 198-203.
19. Shepard, N., 1998. Extraction of Beta Nought and Sigma Nought from RADARSAT CDPF Products. Report No:AS97-5001, ALTRIX Systems, Ontario, Canada, pp: 12.
20. Thetaprobe Soil Moisture Sensor, 1996. User manual, Ml1-UM-2, Delta Devices Ltd, UK., pp: 18.