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# Soil Moisture Inversion with Sparse Vegetation Coverage Areas and Analysis of Spatial Characteristics Based on RADARSAT-2

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**Abstract.** Backscatter coefficient of radar imagery is mainly affected by the surface soil moisture and roughness. This paper was based on the RADARSAT-2 polarimetric SAR image data, field measured soil moisture data, surface roughness, soil particle composition and soil bulk density data. The soil moisture from SAR was retrieved by using Oh2004 semi empirical model inversion method, Oh2004 semi empirical model LUT method, AIEM theory model which is based on the effective correlation length and AIEM theory model on account of the effective RMS height. After soil moisture retrieval of the study area sampling points at 0-6cm depth, this study analyzed the corresponding to the four kinds of methods of the optimal filtering window size, made a comparative analysis of the four methods and determined the optimum inversion model of the study area soil moisture microwave remote sensing at 0-6cm depth. This article used the best model for retrieving soil moisture in depth of 0-6cm, made the distribution map of soil moisture at 0-6cm depth, and analyzed spatial distribution characteristics.

## 1. Introduction

Spatial and temporal distribution of soil moisture is an important environmental variable of hydrology, ecology and climatology, and an important parameter in the process of water, heat and momentum exchange between the earth and atmosphere. The spatial and temporal distribution of soil moisture in a large area is different. The traditional soil moisture measurement method is manual measurement. Although it can measure soil moisture at different depths with high accuracy, the measurement range is small, the measuring station is sparse, the speed is slow and the efficiency is low, and the current situation of the data is poor. Obviously, the traditional measurement methods cannot meet the increasingly high monitoring requirements in spatial resolution and temporal resolution, and cannot grasp the spatial and temporal distribution of soil moisture on a macro scale. With the development of microwave remote sensing in recent years, it is possible to monitor the surface soil moisture continuously in a wide range, in real time and dynamically. It is not limited by or rarely subject to light conditions, can be all-weather, all-day monitoring of the ground, and has a certain



penetration. Therefore, microwave remote sensing has become an important means of large-scale, real-time and dynamic soil moisture monitoring.

## 2. Overview of the Research area

### 2.1 Geographical Location of the Study Area

This location in the study area is a (38 ° 40 'N - 38 ° 48' N, 108 ° 42 ' - 108 ° 56' E), located in the junction of Inner Mongolia and Yulin, a total of 310.866 km<sup>2</sup>, belong to the temperate semi-arid continental monsoon climate, wind sand more, for many years the average temperature of 8 ~ 12°C, years of average rainfall is 380 ~ 431 mm, rainfall concentrated in 6 ~ 9 months, from north to south, more for the thundershower, winter cold, dry little rain, for many years the average evaporation from 1800 ~ 2200 mm. The study area is covered with sparse vegetation, mainly low vegetation, such as artemisia argyi, alkali grass and flower stick.

### 2.2 Data Collection

The data used in this study are radarsat-2 fully polarized radar data and field measurement data. Radarsat-2 is a high resolution commercial radar satellite with a c-band sensor. This trial purchase RADARSAT - 2 c band satellite whole polarization radar data (HH and VV polarization), HV, VH, wide beam model for fine full polarization, images acquisition time for the 2014-07-18, incident Angle of 24 ° - 26 °, the average incidence of 25.52, image width 50 \* 25 km. For more applications and information RADARSAT - 2 satellite, visit <http://www.radarsat2.info/>.

## 3 The Experimental Process

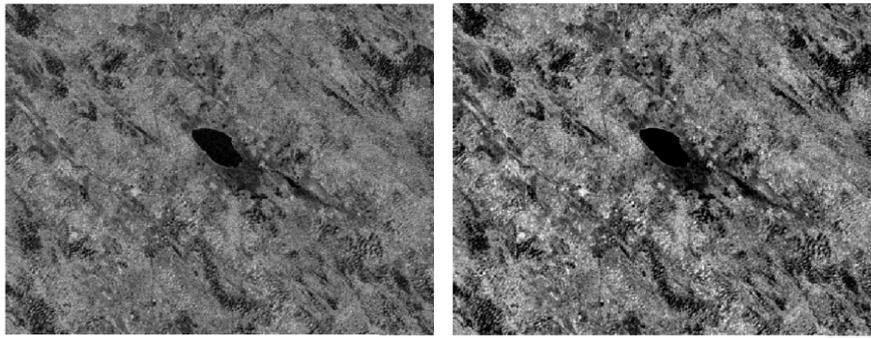
### 3.1 Data Preprocessing

In order to obtain the surface soil moisture information, the radar image needs to be preprocessed with radiation calibration, geographic coding, geometric correction and filtering, etc. The processing steps are as follows:

**3.1.1 Radiation Calibration.** In order to make the radar image backscatter coefficient reflect the surface reflection more truly, the radiation calibration of SLC data is needed. The operator parameter in the processing process selects "Save in dB", indicating that the processed image value is converted to the backscattering coefficient.

**3.1.2 Geocoding and geometric correction.** Nest software was used for geocoding, and UTM projection (21 bands) and STRM DEM(90m) elevation data were selected for projection during coding. Then, the geocoded image was input into ERDAS for geometric correction, and 15 evenly distributed control points were used to select cubic polynomial and nearest neighbor domain sampling for geometric correction. The corrected RMS error was no more than one pixel (8m), and the corrected radar image was shown in figure 1.

**3.1.3 Filtering.** In this experiment, mean filter was selected for noise reduction. The filtered image is shown in figure 1. In this study, the mean filtering Windows of 3\*3, 5\*5 and 7\*7 were used to process the geometrically corrected radar images. Finally, 16 radar images including four polarization modes and unfiltered images were obtained. For mean filtering, in fact, different filtering window sizes reduce the resolution scale of radar image by multiples of 8.



**Figure 1.** Comparison before and after radarsat-2 image filtering (left: before filtering, right: after filtering)

### 3.2 The Measured Data

**3.2.1 Design of field sampling method.** The field distribution scheme adopts the network format, and the sampling contents include soil volume moisture content, roughness, soil bulk density and sand content. Soil volumetric moisture content was sampled by WET soil volumetric moisture content temperature conductivity meter. Soil bulk density was measured by ring knife. The roughness plate is used to measure the surface roughness in the east-west and north-south directions, and the measurement of surface roughness in different directions is mainly used for the follow-up research on whether the surface roughness has an effect on the inversion of soil moisture. The statistics of the measured data are shown in table 1 below:

**Table 1** statistical results of image data and field measurement data

Site	Soil volume moisture content (%) [min-max]	East and west soil roughness (cm) [min-max]	North and south soil roughness (cm) [min-max]	Soil bulk density (g/cm <sup>3</sup> )	The amount of sand in the soil (%)
site 1	2.07-42.17	0.411-0.762	0.332-0.631	1.540	98.312
site 2	33.27-55.17	0.263-1.152	0.361-1.042	1.201	97.152
site 3	7.87-36.95	0.252-0.791	0.222-0.464	1.532	92.302
site 4	1.20-23.50	0.652-1.411	0.642-1.143	1.47	98.131
site 5	1.57-6.45	0.490-0.951	0.671-7.522	1.521	97.822
site 6	2.05-42.60	0.311-0.843	0.402-0.893	1.540	95.801

### 3.3 Oh2004 Semi-empirical Model for Soil Moisture Inversion and Validation

The radar image purchased in this test is the full-polarization data of radarsat-2 c band, which includes not only co-polarization data, but also cross-polarization data. In order to make full use of the fully polarized data, VH cross-polarized data was first used to invert surface soil moisture. It can be seen from the introduction of chapter 3 that Oh2004 semi-empirical model is a commonly used model to simulate cross-polarization microwave scattering, and its roughness has a wide range of adaptability and does not require additional surface measurement data. The original expression is as follows:

$$\sigma_{vh}^0 = 0.11M_v^{0.7} \cos^{2.2} \theta [1 - \exp(-0.32(ks)^{1.8})] \quad (1)$$

$$p = \frac{\sigma_{hh}^0}{\sigma_{vv}^0} = 1 - \left(\frac{\theta}{90^\circ}\right)^{0.35M_v^{-0.65}} \cdot \exp[-0.4(ks)^{1.4}] \quad (2)$$

$$q = \frac{\sigma_{hv}^0}{\sigma_{vv}^0} = 0.1 \left(\frac{s}{l} + \sin 1.3\theta\right)^{1.2} \cdot \{1 - \exp[-0.9(-ks)^{0.8}]\} \quad (3)$$

It can be seen that the backscattering coefficient of cross-polarized VH images is a function of soil volume moisture content and surface roughness. For equations (1) and (2), there are only two unknowns,

$M_v$  and  $s$ . Therefore, the volumetric moisture content of surface soil can be calculated through (1) and (2). Firstly, the expression of surface roughness  $k_s$  is inversely solved from (1) expression:

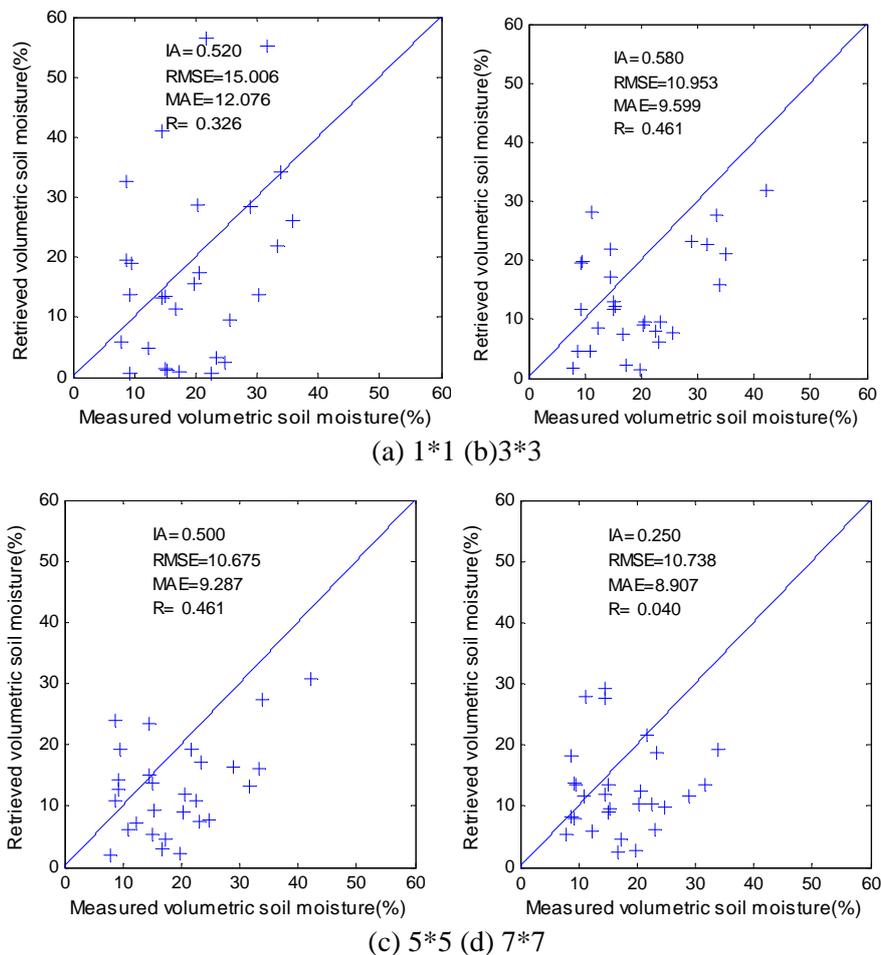
$$k_s = \left( -3.125 \ln \left( 1 - \frac{\sigma_{vh}^0}{0.11M_v^{0.7} (\cos \theta)^{2.2}} \right) \right)^{0.556} \quad (4)$$

Then,  $k_s$  can be substituted into formula (2) to obtain:

$$1 - \left( \frac{\theta}{90^\circ} \right)^{0.35M_v^{-0.65}} \cdot \exp \left[ -0.4(k_s)^{1.4} \right] - P_m = 0 \quad (5)$$

Among them  $P_m = \frac{\sigma_{hh}^0}{\sigma_{vv}^0} = 1 - \left( \frac{\theta}{90^\circ} \right)^{0.35M_v^{-0.65}} \cdot \exp \left[ -0.4(k_s)^{1.4} \right]$

The solution of root mean square height can be obtained by formula (4), and the solution of  $M_v$  of soil volume moisture content can be obtained by formula (5). Therefore, it can be obtained that under different filter window sizes, the inversion results of soil volume moisture content of 0-6cm are compared with the measured soil volume moisture content, as shown in FIG.3



**Figure 2.** comparison between measured soil volumetric moisture content and inverted soil volumetric moisture content under different filter window sizes

Under different filter window sizes, Oh2004 semi-empirical model soil volume moisture content inversion results are statistically shown in table 2 by direct inversion method:

**Table 2.** Error statistics of soil volume moisture content inversion under different filtering Windows

The filter window	Resolution scale (m)	The mean error (%)	Root mean square error (%)	The correlation coefficient	Consistency index
1*1	8	12.076	15.006	0.326	0.520
3*3	24	9.599	10.953	0.461	0.580
5*5	40	9.287	10.675	0.461	0.500
7*7	56	8.907	10.738	0.040	0.250

From the statistical results as you can see, 3 \* 3 and 5 \* 5 filter conditions, soil volumetric moisture content inversion results with the highest correlation coefficient of 0.461 7 \* 7 filtering correlation coefficient of 0.040 is the lowest, 1 \* 1 filter have the greatest average and root mean square error, the average error of the 3 \* 3 filtering and root mean square error is slightly higher than the average error of the 5 \* 5 filtering and root mean square, but the consistency index of IA is higher than 5 \* 5 filtering inversion results. Therefore, Oh2004 semi-empirical model was used to invert surface soil volume moisture content of 0-6cm, and the original formula inversion method was used. The optimal filtering window size was 3\*3, i.e., the optimal cross-polarized image resolution was 24m. Obviously, the correlation coefficient of the optimal inversion result obtained by this method is only 0.461, and the mean error and root mean square are both greater than 9.287%, which generally cannot meet the requirements. Should note that although using Oh2004 semi-empirical model inversion of surface soil volumetric moisture content inversion 0 to 6 cm soil volumetric moisture content is one of the biggest advantages is the measured data, do not need any surface only according to the backward scattering field of the VH cross polarization coefficient with polarization after will be given to the ratio of the scattering coefficient of the surface soil volumetric moisture content, but this inversion method is only on soil volumetric moisture content from 9% to 31% of the area, the inversion accuracy is better, more than the scope of the inversion accuracy is poor. Through sampling point data as you can see, although most of the surface soil volumetric moisture content in the study area is located in the range, but there are a few specific area more than this range, so the following will use the AIEM model inversion surface soil volumetric moisture content in the study area, the theoretical model of surface roughness, soil volumetric moisture content, image Angle of incidence of adaptive scope is large, suitable for most of the region.

#### 4. Acknowledgment

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