

# Quantitative Analysis of SMEX'02 AIRSAR Data for Soil Moisture Inversion

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**Abstract**— In July 2002, the AIRSAR system flew several data acquisition flights during the SMEX'02 field experiment in Iowa. The test site was chosen specifically because of the varying vegetation cover to allow more quantitative testing of the radar inversion algorithms under these conditions. Field conditions were generally favorable for this experiment, and data were acquired during an initial dry period, followed by a wet period after significant rain, and again followed by a drier period. This paper discusses in detail the characteristics of the AIRSAR data acquired, and provides an initial quantitative assessment of the accuracy of the radar inversion algorithms under these vegetated conditions.

**Keywords**-SME02, soil moisture, polarimetry, SAR

## I. INTRODUCTION

Soil moisture is the one of the key state variables in hydrology and largely controls the proportion of rainfall that percolates into, runs off, or evaporates from the land. Soil moisture also integrates precipitation and evaporation over periods of days to weeks and introduces a significant element of memory in the atmosphere/land system.

Several proposals have been made for the continuous global monitoring of soil moisture from space. Key to achieving this goal is the demonstration of the technology that would allow one to monitor soil moisture over a wide range of vegetation conditions. Several experiments have shown that passive and active microwave sensors are capable of measuring soil moisture accurately in the upper 5 cm of the soil when the surfaces are bare, or covered with sparse vegetation [1,2]. Missing is a controlled experiment to extend these results to more heavily vegetated areas.

The SMEX02 experiment took place in Iowa during the summer of 2002, with the objectives to understand land-atmosphere interactions, extend instrument observations and algorithms to a broader range of vegetation conditions, validation of land surface parameters retrieved from SSM/I and potentially AMSR data, and the evaluation of new instrument technologies for soil moisture remote sensing. To achieve these goals, data were acquired simultaneously on the ground, from aircraft and spacecraft.

The main site chosen for intensive sampling is the Walnut Creek watershed just outside Ames, Iowa. Here, 32 field sites were identified and sampled intensively during the summer of 2002. Nearly 95% of the region and watershed is used for row crop agriculture. Corn and soybean are grown on approximately 80% of the row crop acreage, with greater than 50% in corn, 40-45% in soybean and the remaining 5-10% in forage and grains.

Conditions were excellent given the goals of the experiment. Figure 1 shows the soil moisture measured by the Soil Climate Analysis Network (SCAN) station operated in Boone County, outside of Ames, IA, near the SMEX02 Field Headquarters. This is site number 2031. Hourly values are shown for the period a couple of days before the AIRSAR flights to a couple of days after. A precipitation event, concentrated mostly on the western side of the watershed, happened on July 5, and broke previously drier conditions. This event was followed by more widespread precipitation on July 7, followed by a drying period that lasted past the final AIRSAR flight on July 9.

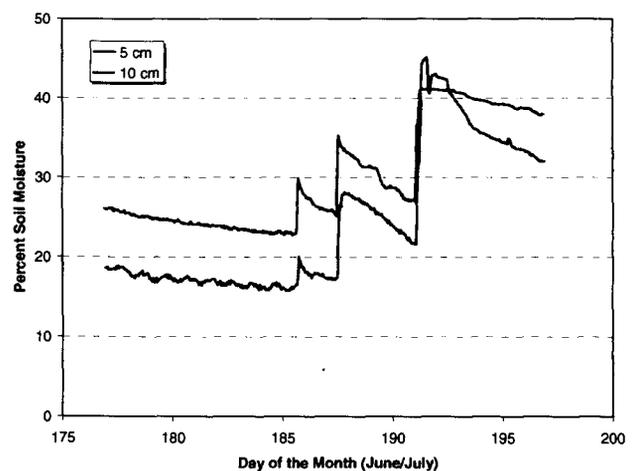


Figure 1. Soil moisture at two different depths as reported by the SCAN station outside Ames, Iowa for the period June 26 – July 15, 2002.

## II. AIRSAR DATA COLLECTION

The NASA/JPL AIRSAR instrument is a fully polarimetric SAR that operates at P, L, and C-Bands simultaneously, and is flown on the NASA DC-8 aircraft. This instrument was flown on five different days during the SMEX'02 experiment, and collected data on July 1, 5, 7, 8 and 9, 2002.

On each day, six different flight lines were flown. Of these, 4 were considered "local" lines and data were collected primarily of the Walnut Creek watershed while the aircraft was flying with a heading of either 90 degrees (2 lines each day) or 270 degrees (2 lines each day). In addition to these lines, two "regional" lines were flown each day with headings of 360 degrees and 180 degrees, respectively.

The experimental site flight lines were planned to cover the entire experimental site with data within 5 degrees of a nominal 40 degree incidence angle, for comparison to other sensors. All data were acquired using the 20 MHz bandwidth (6.7m slant-range resolution) mode of the AIRSAR instrument, and with all three frequencies operating in the polarimetric mode. The local weather conditions described above were such that AIRSAR data acquisition included "dry fields" prior to rainfall, data acquired after two separate rain events, and data acquired a couple of days after the rains. The flight conditions were excellent during acquisition, and no abnormal instrument conditions were noted.

## III. DATA PROCESSING STEPS

As of the time of this writing, a total of 14 of the 30 data acquisitions have been processed and delivered for analysis. To facilitate extracting data for later analysis, including comparison with data from other sensors, it was decided to first register the radar data with a Landsat Thematic Mapper image. The TM image file is in UTM projection (zone 15) with a resolution of 30 m, and covers the box with latitude 100 degrees West longitude and 44.5 degrees North latitude to 90 degrees West longitude and 34.5 degrees North latitude.

To register the radar data, which was produced in the slant range projection by the standard AIRSAR processor, to the TM data, all radar files were first projected from slant range to ground range. Since the experimental site has little relief, a simple flat earth ground range projection was found to be adequate. For each radar image, a co-registered incidence angle file was also produced in the ground range projection. To complete the registration processing, each individual ground range radar image was registered to the TM scene using a series of tiepoints. Since the scene contains numerous intersecting roads that are clearly visible within each image, selecting tiepoints was easy. Several different methods for projecting the ground ranged radar data were investigated, including a rubber sheet technique previously reported [3]. The goal was to have a registration error, based on analysis of the tiepoints, that is less than one pixel after registration. While this could be improved by picking more tiepoints, it was felt that the field sites were large enough that this accuracy would be sufficient. Mostly because of the absence of significant

relief in this case, it was found that a simple scaling (typically less than one percent) and a rotation of the radar image was sufficient to provide excellent registration. Typical registration accuracy is on the order of half a pixel (r.m.s.) based on the tiepoints analysis.

Once the radar data were registered to the TM data, field averages were extracted for all polarimetric parameters. The fields were identified based on the latitude and longitudes provided for each field corner. In all cases, both the average and the standard deviation of each polarimetric parameter was calculated using a 7 pixel x 7 pixel box in the registered radar image. The size of the box was chosen to have a reasonable number of independent measurements (*i.e.* pixels) while still staying well within the border of each of the fields. Since not all field sites are present in all flight lines, we ended up with between 12 and 14 values for each field from the 14 images processed so far. We shall discuss some of the preliminary results of the data analysis in the next section.

## IV. PRELIMINARY RESULTS

Our main goal with the analysis of the SMEX02 data is to evaluate the expected success of the proposed HYDROS mission quad-polarization radar for inferring soil moisture under vegetated conditions. This proposed system will acquire L-band radar data at  $hh$ ,  $vv$  and  $hv$  polarizations simultaneously. However, the  $hh$  and  $vv$  measurements are made in adjacent frequency bands, so no phase information will be available.

In general, we observe that for all days, the  $hh$  return is larger than the  $vv$  return, suggesting that a double bounce scattering mechanism dominates. This is confirmed when looking at the  $hh$ - $vv$  phase difference, which is closer to 180 degrees, especially on the days after the initial precipitation. The  $hh/vv$  ratio seems to be less correlated with *in situ* measurements than what is observed for the  $hh$  or  $vv$  returns.

Once all the radar data have been extracted from the registered data files, we first performed a multiple linear regression fit to the radar data of the form

$$\hat{m}_v = A + B\sigma_{xx} + C \cos \theta + D \sin \theta . \quad (1)$$

Here,  $xx$  can either be  $hh$  or  $vv$ , and the radar cross-sections are expressed in dB. This choice of function follows the results of Dubois *et al.* [2] for bare surfaces. Also,  $\theta$  is the incidence angle at the center of each 7 pixel by 7 pixel box. We chose this single channel regression to be able to better quantify the improvement from using both co-polarized channels as discussed below. We first performed the regression for each of the field sites separately. We then used the parameters resulting from the regression to invert the radar data for soil moisture and calculated the r.m.s. error as follows

$$Error = \sqrt{\frac{1}{N} \sum_{i=1}^N (m_{vi} - \hat{m}_{vi})^2} . \quad (2)$$

In (2),  $m_v$  is the mean of the *in situ* soil moisture value for each field.

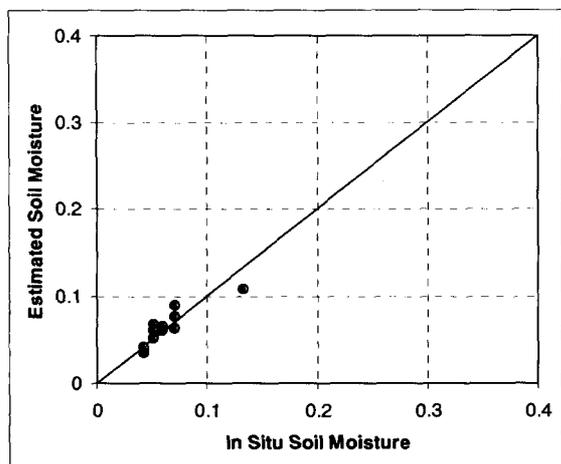


Figure 2. Inversion results using both *hh* and *vv* polarizations for field WC25. The r.m.s. error is 1.2%.

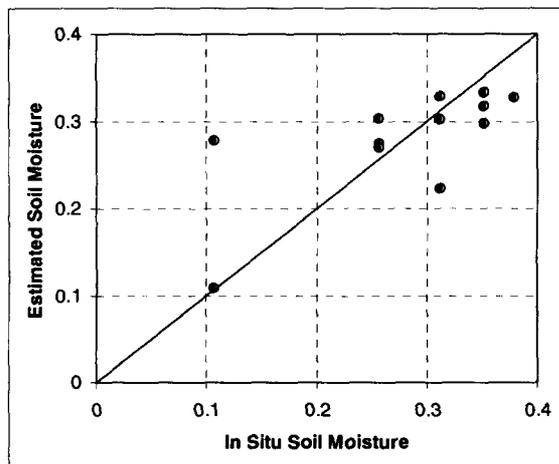


Figure 3. Inversion results using both *hh* and *vv* polarizations for field WC31. The r.m.s. error is 6.6%.

The resulting errors per field vary between 1.5% to 7.4% for *vv* polarization, with the median value 3.5%. For *hh* polarization, the errors range from 1.2% to 7.3%, with the median error equal to 3.2%.

Next, we performed a dual polarization multiple linear regression of the form

$$\hat{m}_v = A + B\sigma_{hh} + C\sigma_{vv} + D \cos \theta + E \sin \theta . \quad (3)$$

We again performed this analysis first on each individual field. We noticed only a slight improvement over the single polarization case, with the resulting errors now ranging between 1.2% and 6.5%, with a median error value of 3%. The fact that we have only a slight improvement for the dual polarization case as compared to each individual co-polarized

measurement is to be expected since the observed *hh/vv* ratio is only weakly correlated with the *in situ* soil moisture.

Figure 2 shows the inversion results for the field with the smallest r.m.s. error, and Figure 4 the same for the field with the largest. We note from these figures that the smaller error is associated with a field that had less of a variation of the *in situ* moisture range, making it easier for the regression to fit all the data well.

## V. NEXT STEPS

The analysis presented above does not take into account the differences between fields. To do this, we have to properly account for the fact that the double bounce scattering is attenuated twice as the signals propagate downwards through the canopy, and again when it propagates upwards out of the canopy. The attenuation will be proportional to the vegetation water content. This effect must be accounted for before the analysis shown in (3). Also, the scattering for both co-polarized channels will be reduced by the surface roughness. At the time of this writing, the surface roughness information from the various field sites is not yet available, so this analysis cannot be completed.

The analysis described here is continuing as more field data becomes available. We expect to include the effects of canopy attenuation and surface roughness in our analysis of the data. Since we now have at least three unknowns (soil moisture, surface roughness, and canopy attenuation, which is related to vegetation water content) we expect to have to use all three measurements (*hh*, *vv* and *hv*) in the analysis. Finally, we also have to account for the fact that the agricultural fields have a geometry that includes a row structure. This effect changes the scattering quite drastically depending on the relative orientation between the rows and the radar look direction.

## ACKNOWLEDGMENT

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