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ABSTRACT

The combined use of ERS and multiangle RADARSAT (23 and 38°) data to assess the soil moisture, the roughness and the soil surface degradation is investigated. Twenty SAR images were collected over a flat agricultural area located near Avignon in the South-East of France. Complementary sets of data, collected with the CNES ground based scatterometer RAMSES and IEM simulations were also used in the analysis. Results show that the soil surface roughness affects strongly the s0-qs relation. But the roughness influence cannot be easily accounted for using the IEM model.

From the RAMSES data, we demonstrate that the angular difference of the backscattering coefficient is a very good indicator to track the evolution of the soil surface degradation. Such a result is confirmed by RADARSAT couple (23-38°) measurements on the first development stages of sunflower crops.

INTRODUCTION

In surface hydrology, radar remote sensing provides the possibility of estimating two key variables which are the soil surface moisture (θ_s) and the surface roughness. The fluxes at the soil/atmosphere boundary are strongly influenced by θ_s , whereas the surface roughness is involved in the separation of the water flow into infiltration and runoff. Moreover, temporal variations of surface roughness is a way to determine the sensitivity of the soil to the slaking process that is important to evaluate the erosion risk.

The use of SAR data based on a single configuration is not suitable for retrieving both θ_s and the surface roughness. However, with RADARSAT and in a near future with the ASAR, which will be installed aboard the ENVISAT satellite, we have the possibility to combine several angles of incidence and/or several polarizations. The multi angle capability is possible by combining two satellite passes, which requires a time delay of several days (3 days with RADARSAT). The use of multi-configuration data to retrieve both the θ_s and the surface roughness was one of the Alpilles-Reseda experiment goals [1]. During this experiment, we collected RADARSAT images at 23 and 38° as well as ERS2 images. Thus we got some couples of images that allow the use of bi-polar and bi-angular measurements.

In this paper, we present a first analysis of the results and the potential offered by the combination of radar configuration to measure :

- the surface soil moisture
- the surface roughness
- the change in surface roughness induced by the degradation of the soil surface.

We limited the analysis to the bare soil case in order to eliminate, in a first step, the influence of the vegetation.

MATERIAL AND METHODS

The alpilles ReSeDA experiment

The alpilles-ReSeDA experiment was carried out from October 96 to November 97. The monitored site is a flat agriculture area whose dimensions are 4kmx5km located in Rhône Valley near Avignon, France (N43°47', E 4°45'). The main crops of the area were wheat, corn, sunflower, alfa-alfa and grass. The bare soil conditions were either obtained during the winter for the spring crop (sunflower and corn) or after the harvest with the wheat fields. We can identify four types of surface conditions :

- P : ploughed fields
- S : tilled fields prepared for seeding
- WS : wheat fields after harvesting with the stubble
- PS :wheat fields after harvesting with stubble ploughing

The ground truth measurements were made on 12 test fields covering the experimental area spatially and the main crop. Measurements of the soil moisture within the top 5 cm (θ_{0-5}) were done using the gravimetric method and/or using a TDR probe. The TDR measurements were carried out with a TRASE device (© Soil Moisture Equipment) on buriable waveguides

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installed horizontally at a depth of 2.5 cm. Roughness measurements were made once between two tillage operations. For instance with a wheat field, one roughness characterization was done between the seeding and the stubble ploughing. Three roughness profilometers were used. The first one is a laser profilometer, which made a transect of 1.6m with a horizontal resolution of 2 mm [2]. The other two are needle profilometers with a total length of 1 and 2 m and a resolution of 5 and 10 mm, respectively. The soil texture and the dry bulk density was determined in each test field. As for the roughness, the dry bulk density was mesured once between two tillage operation with a gamma transmission device, which can measure the dry bulk density near the surface [3]. Most of soils are clayey soils with about 40% of clay and 6% of sand particles. However, two fields have a sandy loam texture (17% of Clay and 30% of sand)

SAR images

Eight ERS images and 12 RADARSAT images were collected during the experimental period. Six RADARSAT images were collected in standard mode with a 23.3° angle of incident and a spatial resolution of 25x25 m. The other six were collected in fine mode with a 38.4° angle of incidence and a spatial resolution of 12.5x12.5m. The time delay between a 23° and 38° image acquisitions was 3 days. The dates of measurements are given in Table 1.
Radar images were geocoded using a Digital Elevation Model and the orbit description thanks to a specific software, which has been developed at BRGM and particularly adapted to RADARSAT data.

The field average backscattering coefficient (σ_0) was computed by removing the pixels near the field boundaries in order to remove contaminated pixels.

To compute the σ_0 difference between ERS and RADARSAT 23° couple of measurements or RADARSAT 23° and 38°, we corrected the RADARSAT 23° measurement to account for the variation in soil moisture that occurred between the two dates of acquisition. The correction was made when the moisture variation was less than 0.06 m^3/m^3. The applied correction was 0.3 dB for a moisture variation of 0.01 m^3/m^3. Such a correction was established from the $\sigma_0=f(\theta_{0-5})$ obtained with the measurements collected during the Avignon95 experiment (fig. 2b). This correction is consistent with the 23° RADARSAT data on the Alpilles-ReSeDA test site (Fig. 1b).

Table 1: SAR image Acquisition

Date of SAR Acquisition	Instrument	Incidence
96-12-9	ERS	23
97-1-26	ERS	23
97-2-27	ERS	23
97-3-21	RADARSAT	38.4
97-3-24	RADARSAT	23.3
97-4-6	ERS	23
97-4-14	RADARSAT	38.4
97-4-17	RADARSAT	23.3
97-5-8	ERS RADARSAT	23 38.4
97-5-11	RADARSAT	23.3
97-6-1	RADARSAT	38.4
97-6-4	RADARSAT	23.3
97-6-12	ERS	23
97-7-17	ERS	23
97-7-19	RADARSAT	38.4
97-7-22	RADARSAT	23.3
97-8-21	ERS	23
97-9-5	RADARSAT	38.4
97-9-8	RADARSAT	23.3
97-9-25	ERS	23

The Avignon 95 experiment

A complementary set of data was used for the data interpretation. The Avignon95 experiment was conducted in the experimental site of the INRA research center at Avignon [4] during the summer 1995. In the Avignon 95 experiment, radar measurements were performed by the CNES scatterometer which was suspended under a crane boom. RAMSES measurements were made at 3, 5.3 and 9.4 GHz with HH, VV and HV polarizations. The crane can move along a railway accross the test site to make measurements at the same location under different angles of incidence (20,30, 50°).
Concurrently to the radar measurements, we made measurements of the surface roughness and the soil moisture.
Three fields were studied with roughness conditions that are similar to those encountered in the Alpilles-ReSeDA experiment.

Simulation with the IEM model

Simulations with the IEM model [5],[6] were done with the surface conditions encountered during the Alpilles-ReSeDA experiment. The surface was assumed to be isotropic and we ignored the large scale roughness. The autocorrelation function was fitted to an exponential function. In this study we have selected the simulations that meet the following validity condition :

$$ks<1.3$$

where k is the wave number and s the HRMS height.

RESULTS

Soil surface conditions

Most of the measurements were made under dry or medium soil moisture conditions ($\theta_{0\text{-}5}<0.22$ m³/m³). We only have wet soils at the beginning of the experiment, before 97/02/01, period which involved the two first ERS acquisitions.
Roughness conditions were summarized in Table 2

Table 2 : summary of the surface conditions. The first number corresponds to the average value of the class and the number between brackets corresponds to the minimum and the maximum values.

Surface Class	s (cm)	l (cm)	dry Bulk Density (kg/m^3)
P	1.5 *[1.1,1.9]*	3.9 *[3.1,4.7]*	1.2 *[1.1,1.29]*
S	0.9 *[0.7,1.2]*	3.2 *[2.1,6]*	1.23 *[1.13,1.34]*
WS	0.9 *[0.7,1.4]*	3.3 *[2.9,3.6]*	1.3 *[1.24,1.41]*
PS	1.5 *[0.5,2.1]*	4 *[3.7,4.8]*	1.07 *[1.04,1.1]*

σ_0-$\theta_{0\text{-}5}$ relationship

The Fig. 1a, 1b and 1c represent the σ_0-$\theta_{0\text{-}5}$ relationships obtained with ERS and RADARSAT. In Figure 1a, the σ_0-$\theta_{0\text{-}5}$ relation obtained with ERS is poor and does not allow an accurate estimate of the soil moisture without accounting for the roughness state (the residual standard deviation is larger than 0.10 m³/m³). RADARSAT 23° and 38° data does not show a σ_0-$\theta_{0\text{-}5}$ relation, but the range of moisture is smaller than that considered with the ERS data. When we only considered the range of soil moisture conditions encountered during RADARSAT aquisition, we find that σ_0 measured by RADARSAT and ERS varied in a similar range of values.
There are a few time series of measurements that allows the monitoring of the soil moisture in a given bare field without having a tillage operation between two acquisition dates. However when this is possible we observed that the satellite measurements have a constant sensitivity to the soil moisture which is roughly 0.33 dB for 0.01 m³/m³. Such a result is comparable to previous results obtained with ground based radar as in Ulaby et al. [7]. The homogeneity of the radar sensitivity to soil moisture and the scattering of the σ_0-$\theta_{0\text{-}5}$ observed in Figures 1 stressed out the importance of the geometric factors in the backscattering processes as the soil surface roughness.

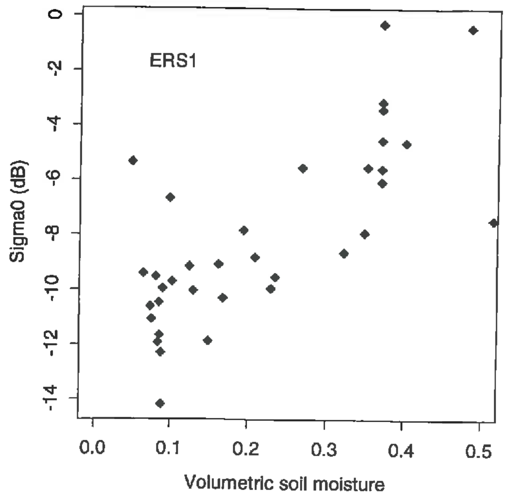

Figure 1a : σ_0-$\theta_{0\text{-}5}$ relationship on bare soils (ERS)

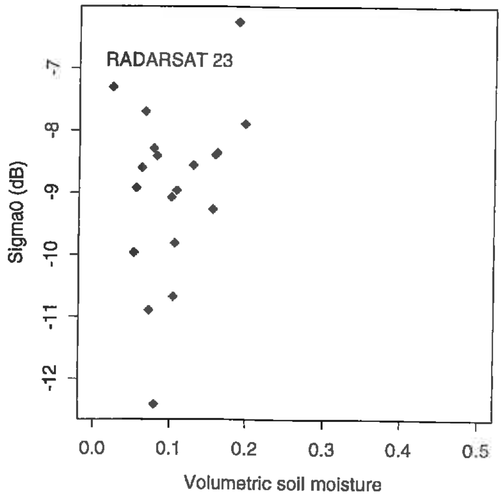

Fig. 1b : σ_0-$\theta_{0\text{-}5}$ relationship on bare soils (RADARSAT 23°)

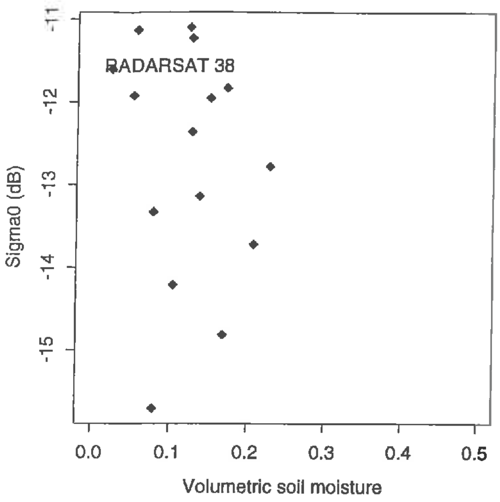

Fig 1c : σ_0-$\theta_{0\text{-}5}$ relationship on bare soils (RADARSAT 38°)

To understand the influence of the roughness in the σ_0-$\theta_{0\text{-}5}$ relation, we have plotted the same relations using the IEM simulations obtained with the surface conditions of the Alpilles-ReSeDA experiment (Fig. 2a and 2b). The point number in Fig. 2 is greater than in Fig. 1 since we made a simulation for all SAR configurations at each SAR acquisition date whatever the SAR configuration at this date. The simulated σ_0 range of variation for a given moisture condition is smaller than the observed one by RADARSAT or ERS. This means that the roughness parameterization in IEM does not allow to fully account for the roughness effect on the soil microwave backscattering in our experimental conditions. The surface roughness parameterization, the row effect and the hypothesis of neglecting volume scattering are among the possible explanations.

In Fig 3a and 3b, we have represented the σ_0-$\theta_{0\text{-}5}$ relation for the Avignon 95 data which were collected with roughness conditions similar to that of the Alpilles-ReSeDA experiment. The Avignon σ_0 values are comparable to those obtained with the satellite observations, whereas the difference in polarization (HH-VV) is consistent with the IEM simulation and the Alpilles-ReSeDA data. Such results give an idea of the external calibration consistency between the sensors used in this study

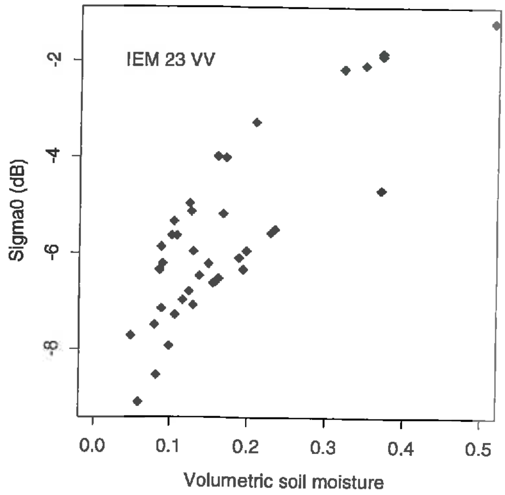

Fig 2a : σ_0-$\theta_{0\text{-}5}$ relationship using IEM simulated data at 5.3Ghz, VV polarization and 23°

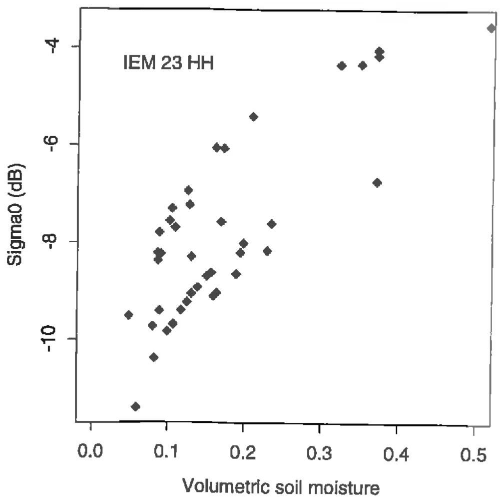

Fig 2b : σ_0-$\theta_{0\text{-}5}$ relationship using IEM simulated data at 5.3Ghz, HH polarization and 23°

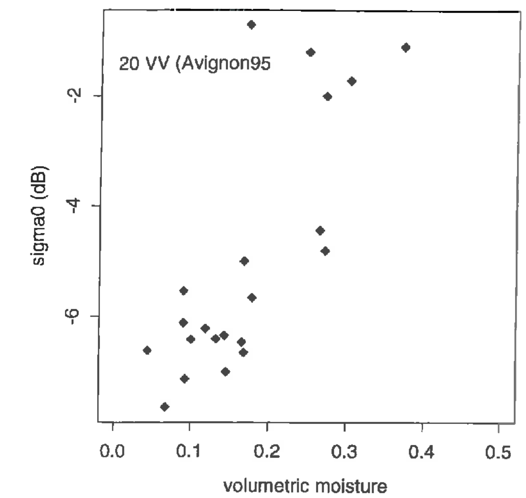

Fig. 3a: σ_0-$\theta_{0\text{-}5}$ relationship obtained at 5.3 GHz, 20° and VV polarization with Avignon 95 data

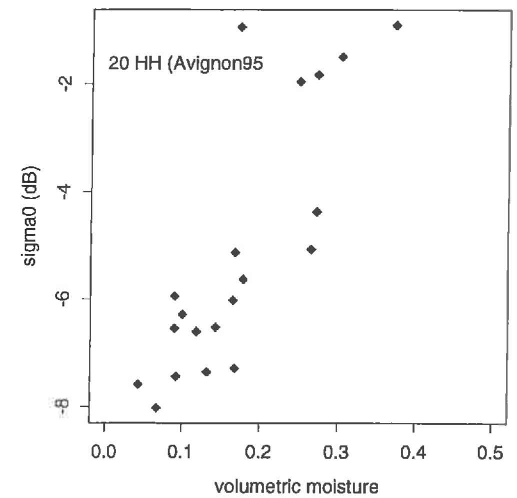

Fig. 3b: σ_0-$\theta_{0\text{-}5}$ relationship obtained at 5.3 GHz, 20° and HH polarization with Avignon 95 data

Results using a multi-configuration approach

One of the Avignon95 goals was to monitor the evolution of a bare surface during a long period. The surface was regularly watered by rains or irrigations The surface moved progressively from a freshly tilled field with small clods to a smooth soil covered by a crust resulting from the slaking process. Between two water supply events (irrigation and/or rainfall), we made radar measurements under a wide range of soil moisture. In Figure 4 we have represented two multi-configuration criteria :

- the σ_0 difference in HH polarization between 20° and 30° ($\Delta_a\sigma_0$)
- the σ_0 difference at 20° between VV and HH polarizations° ($\Delta_p\sigma_0$).

These criteria are close to the use of (RADARSAT 23°,RADARSAT 38) and (RADARSAT 23°,ERS) couples.

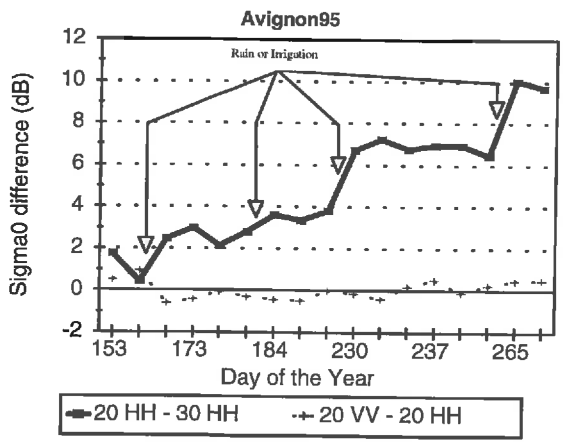

Fig4. Evolution of the σ_0 difference. Comparison between the angular difference and the polarization difference.

The $\Delta_a\sigma_0$ increases after each water supply event, especially after the third and fourth events (Fig. 4). Between two events, the variation in $\Delta_a\sigma_0$ remains small in comparison to those attributed to the surface degradation process. This means that $\Delta_a\sigma_0$ criteria is mainly influenced by the surface degradation and is rather insensitive to moisture variations. Such results are in agreement with earlier results [8-10].

The use of $\Delta_p\sigma_0$ is much less encouraging and does not present a mean to monitor the surface degradation in the case of our experiment (Fig. 4).

An analysis similar to the previous one is done with the Alpilles-ReSeDA satellite data. In Fig 5. we have represented $\Delta_a\sigma_0$ in relation to the soil surface type defined previously. A similar relation is established with HRMS as the roughness parameter (Fig.6). The relations exhibited in Figures 5 and 6 do not show the so nice relation obtained with the Avignon95 experiment. The use of ERS/RADARSAT does not exhibit nicer relation (results not shown in the paper).

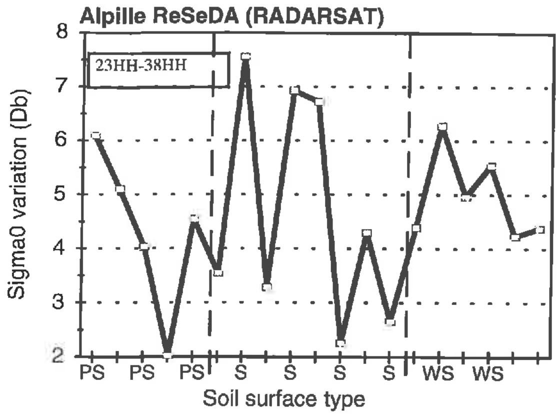

Fig. 5. $\Delta_a\sigma_0$ obtained with the RADARSAT image on the Alpilles-ReSeDA test site in relation to the surface type (WS : Harvested wheat field with stubble, PS, Harvested wheat with stubble ploughing, S: soil prepared for seeding).

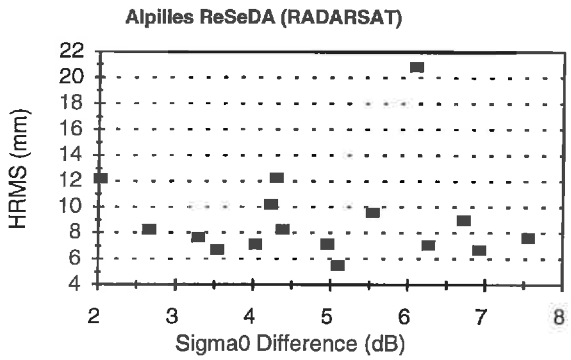

Fig. 6. $\Delta_a\sigma_0$ obtained with the RADARSAT image on the Alpilles-ReSeDA test site versus the soil surface roughness (HRMS)

A more detailed analysis of Figure 5 shows that with the S surface type, the distribution of $\Delta_a\sigma_0$ values is roughly bi-modal. To analyze the origin of $\Delta_a\sigma_0$ variability, we have investigated the evolution of Δ_a σ_0 at field scale. This can be done with the sunflower fields during the implantation phase. As a matter of facts 3 couples (23-38) of RADARSAT images are available during a period between the seed bed preparation and the stage when sunflower development is significant (LAI>0.5). The results are represented in Figure 7.The $\Delta_a\sigma_0$ increases significantly at the third date of observation for every sunflower fields. After a long dry period, rainfall started after on day 475 which fall just after the second couple of RADARSAT images. The total amount between Day 475 and 493 was 43.4 mm with some heavy rains. It was observed in the field that crust appeared after the first rainfall, which was found very damaging for the plant emergence. For Field 501, the first couple (23-38) of RADARSAT measurements present an high value of $\Delta_a\sigma_0$. In fact, sowing occurred between the two angular acquisitions which explained the high level of the first point with this field. With the 102 field, tillage occurred between the first two couples of RADARSAT measurements, whereas for the 304 and 121 fields, the fields were not tilled. With the latter two fields the $\Delta_a\sigma_0$ remained stable for the first two couples of date. As for Avignon 95 experiment, the surface degradation present a clear signature with the $\Delta_a\sigma_0$ temporal variations showing the interest of analysing multiangular data to monitor changes in soil surface roughness

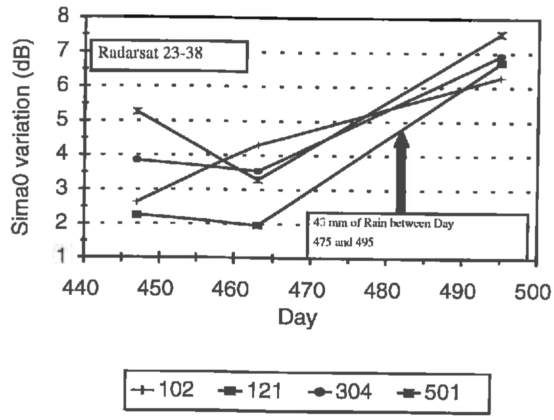

Fig. 7. Temporal evolution of $\Delta_a\sigma_0$ for sunflower fields

CONCLUSIONS

In this study we collected both RADARSAT and ERS data over the same site and during the same period. The results have shown that the roughness influence cannot be addressed easily with the IEM model.

From a ground based experiment we demonstrate that the σ_0 angular variation is a good quantity to track the surface degradation under the slaking process. This is confirmed with the RADARSAT measurements.

AKNOWLEDGEMENT

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