# VEGETATION COVER STUDY OVER ARID SEMI-ARID AREAS : USE OF ERS1 WIND SCATTEROMETER

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## ABSTRACT

The ERS-1 wind scatterometer (5.3 Ghz) operates in VV polarization with a resolution of 50 km. For a particular target, it measures three backscattering coefficients ($\sigma^0$) from its 3 antennas. The aim of this study is to use the information delivered by the wind scatterometer over land surfaces in arid and semi-arid environments to infer soil moisture. The rationale of the approach presented is that, if we assume that the soil/vegetation interaction term can be ignored, the signal is the sum of soil and vegetation contributions. The soil contribution is driven by the soil's dielectric properties and surface roughness. In the presence of vegetation, this contribution is attenuated by a factor which depends on canopy characteristics (water content, shape, height, density) and radiometer viewing characteristics. To assess and monitor soil moisture, a knowledge of the vegetation characteristics is thus required. In order to quantify the influence of vegetation on the signal, we will use a semi-empirical model (first order radiative transfer model), extract canopy optical thickness ($\tau$) and simple scattering albedo ($\omega$) using the angle dependence. The different contributions of the signal will be compared within different angular ranges. The semi-empirical model will be applied at low incidence angles to retrieve soil moisture.


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## Introduction

Vegetation is an important factor affecting radiometric signals. Its effect is known through numerous studies (ULABY *et al.*, 1979 ; 1982 ; 1986 ; BRUNFELDT ; ULADY, 1984). It was shown that, like surface roughness, vegetation can be considered as a noise in term of soil moisture estimation. Over land surfaces, microwave (passive/active) due to their aptitude to penetrate the medium were used to monitor surface characteristics. These *properties* depend on radiometer viewing conditions (frequency, polarization, incidence angle) and the medium wetness. If the signal measured by the sensor includes some information coming from several surface characteristics, in most cases sensor parameters were used to separate the different contributions. In a recent study (KERR, MAGAGI, 1994), we have shown that from the $\sigma^0$ triplets corresponding to different viewing conditions it is possible to :

- — derive for any acquisition the slope and the intercept of the $\sigma^0$ vs angle relationship and relate it to surface roughness (slope) and vegetation biomass/soil moisture (intercept) ;
- — monitor using the temporal variations and variety of view angles obtained by WSC as well as data obtained in the visible near-infrared (NOAA/AVHRR), soil moisture and surface roughness in the absence of vegetation.

Over arid and semi-arid areas, soil moisture is a limiting factor for vegetation growth. Besides, soil moisture influences radiative budget due to its effect on surface hydrology (runoff/infiltration). For this reason, within the Hapex-Sahel framework (GOUTORBE *et al.*, 1994), we intended to estimate and monitor soil moisture. The approach used in this study is based on remote sensing. As Hapex-Sahel is a large field experiment, we will work at satellite scale considering ERS-1 wind scatterometer (WSC) and NOAA-11 AVHRR data. Through a synergistic approach (KERR, MAGAGI, 1994) between active microwave (WSC) and optical data (NOAA/AVHRR, visible and near-infrared) we have shown that WSC data can be used to assess vegetation. Under vegetation cover the signal coming from underlying soil was altered by some mechanisms (absorption, scattering) into the canopy. However it is useful to determine vegetation characteristics (optical thickness ($\tau$), simple scattering albedo ($\omega$)) to study vegetation effect on the signal and then correct its influence in term of soil moisture estimation. A semi-empirical model (ATTEMA, ULABY, 1978) combined with WSC data will be used in our investigation.

## Study area

The area is about 50 by 50 km square around Banizoumbou (13°31'08"N-02°39'37"E), the East super site of Hapex-Sahel experiment. One major aspect of this region which characterises Sahelian zone is the duration of rainy season

(4 months) from June to September. Annual rainfall is about 550 mm (figure 1) with strong spatial and temporal variabilities. This repartition drives vegetation growth and its distribution (sparse). The vegetation is very heterogeneous and is represented by fallow, millet, tiger bush and savannah. Millet is the most important crop. Millet being of erectophil (vertical) structure, soil is never completely covered by vegetation. With regards to relief, it is generally flat but may be altered by agricultural practices and rain events. Most of the soils are lateritic, sandy or sandy-clay. It is worth noting an important problem : the temporal and spatial heterogeneity of soil type which modifies the dielectric properties of the soil and thus its response.

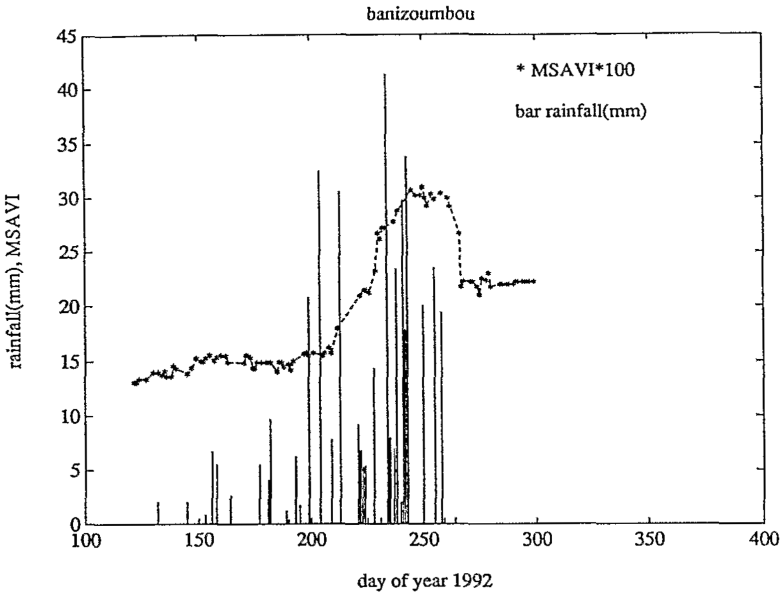


***Figure 1 :***
*Temporal evolution of rainfall(x) in mm, MSAVI*100(o).*

## DATA

During the Hapex-Sahel experiment (August to September 1992), ground data were collected over the study area. We will use in this study volumetric soil moisture measurements (MONTENY *et al.*, 1993 ; VAN OVELEN *et al.*, 1992) in the depth 0-5cm and daily rainfall acquired with Epsat (TAUPIN *et al.*, 1993) network to develop and validate a method for soil moisture estimation over a long period.

Satellite data consisted of NOAA/AVHRR and ERS-1 WSC data from April to October 1992.

### NOAA11/AVHRR (1.1 KM OF RESOLUTION)

The visible ($\rho_1$) and near-infrared ($\rho_2$) daily reflectances were used to compute MSAVI (QI *et al.*, 1993), a vegetation index adapted to estimate vegetation cover over semi-arid areas. To have smoothed temporal evolution, we filtered the MSAVI values using a sliding temporal window (figure 1). The reflectances $\rho_1$ and $\rho_2$ have been corrected from atmospheric effects by using SMAC algorithm (RAHMAN, DEDIEU, 1994). The vegetation fractional cover will be deduced from this index.

### ERS-1 WSC

The sensor is briefly described as : 50 km of resolution, high temporal repetitivity, operation at 5.4Ghz, VV polarization, incidence angle ranging from 18° to 56°. WSC measures quasi-simultaneously the backscattering coefficient $\sigma^0$ coming from the target with its 3 antennas (fore, mid and aft). We will take advantage of this *multiangular* observations to develop our inversion method. A complete description of WSC is given in ESA SP-1148., 1993.

To reduce the angular effects on WSC data, an analysis will be done within different angular ranges. Figure 2 is the temporal evolution of $\sigma^0$ delivred by the mid beam antenna at [18°, 30°], [30°, 40°] and [40°,46°]. We can see a dephasing between the temporal evolution of $^0$ resulted from [18°, 30°] and the other two ranges : within this angular ranges, when vegetation cover is developing, $\sigma^0$ decreased due to the canopy attenuation. In the same time, for the high incidence angles the backscattering coefficient reached its maximum. The high difference which occurs for some dates between [30°, 40°] and [40°, 50°] responses is not an angular effect only, but corresponds to rain events. If we remember that, the vegetation fractional cover never reached 50 %, we understand easily the importance of soil even for great incidence angles.

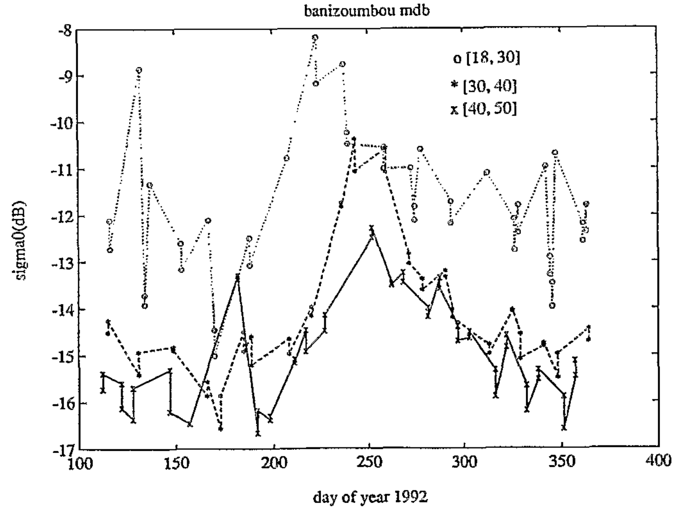


***Figure 2 :***
*Temporal evolution and angular signatures of $\sigma^0$ during the study period.*

## BACKGROUND

As shown by many authors (ULABY *et al.*, 1979 ; 1982 ; 1986 ; BRUNFELDT, ULADY, 1984) the angular behavior of $\sigma^0$ is related to target characteristics (soil moisture, roughness, vegetation properties) for any configuration (polarization, frequency, incidence angle) of scatterometer. In presence of vegetation, two processes appear : surface scattering coming from underlying soil (wet soil) and volume scattering in the vegetation layer. The result is that $\sigma^0$ decreases slowly with incidence angle due to the attenuation of soil contribution by vegetation. The predominant process depends on soil moisture (ULABY, ASLAM, DOBSON, 1982), if the sensor configuration is chosen as : frequencies about 5 Ghz, and ranging from 7° to 17° (ULABY *et al.*, 1986). Recently, a theoretical model of canopy backscatter MIMICS (ULABY *et al.*, 1990) has been developed. But due to its important number of parameters, this model is cumbersome to use. In this paper, we will use a semi-empirical « water-cloud » model (ATTEMA, ULABY, 1978), which parameterizes the backscattering cœfficient within canopy as a function of volumetric soil moisture (sm in Kg/m³), plant water content (W in Kg/m³) and plant height (h in m). In this model, the vegetation is represented by identical water particles characterised by their height and their density related to the volumetric water content of plant; only single scattering is considered. Consequently, this model represented the first-order radiative transfer solution. The backscattering coefficient of the whole canopy includes vegetation contribution and soil signal attenuated by vegetation :

$$\sigma^0_{can}(\theta)=\sigma^0_{veg}(\theta)+\gamma^2(\theta)*\sigma^0_{soil}(\theta) \qquad (1)$$

$$\sigma^0_{soil}(\theta)=A(\theta)*exp(B*sm) \qquad (2)$$

$$\gamma^2(\theta)=exp(-D*W*h*sec(\theta)) \qquad (3)$$

$$\sigma^0_{veg}(\theta)=C*cos(\theta)*(1-\gamma^2(\theta)) \qquad (4)$$

Where $\gamma^2$ is the canopy two-way transmitting factor. As we used the VV polarization, we assumed that the surface-volume interaction term can be neglected (ULABY *et al.*, 1986). *A* and *B* depend on surface roughness for a given configuration of the sensor. *C* and *D* depend on frequency and vegetation type (FUNG, EOM, 1985). Later, describing the canopy as a Rayleigh scattering medium (FUNG, EOM, 1981a), the expressions (3) and (4) were modified using two parameters : the simple scattering albedo and the optical thickness of vegetation.

$$\gamma^2(\theta)=exp(-2*\tau*sec(\theta)) \qquad (5)$$

$$\sigma^0_{veg}(\theta)=0.75*\omega*\cos(\theta)*(1-\gamma^2(\theta)) \qquad (6)$$

quantified the importance of single scattering with regard to absorption in canopy. According to the low values (<0.2) of the albedo of vegetation cover, the assumption of weak scattering medium can be reasonably used. $\tau$ contained together absorption and scattering mechanisms and represented the extinction factor in the cover. To take into account of spatial heterogeneity of natural areas, some authors (ULABY *et al.*, 1982 ; KERR, NJOKU, 1990) include in their equations the term of vegetation fractional cover $C_v$. The backscattering coefficient can then be expressed by :

$$\sigma^0(\theta)=(1-C_v)*\sigma^0_{soil}(\theta)+C_v*\sigma^0_{can}(\theta) \qquad (7)$$

Considering equations (1) and (2), equation (7) becomes

$$\sigma^0(\theta)=(1-C_v(1-\gamma^2(\theta)))*A(\theta)*\exp(B*sm)+C_v*\sigma^0_{veg}(\theta) \qquad (8)$$

## SIMULATION STUDY

The precedent equation expressed the water-cloud model over semi-arid areas. To define the possibility to invert this model, we study the sensitivity of $\sigma^0$ to vegetation parameters ($\tau$ and $\omega$) for different values of soil moisture and different viewing conditions through the simulation analysis (figure 3).

As we can see on figure 3 (line), for a low value of vegetation simple scattering albedo (=0.05) and soil moisture equals to 5, 10 and 20 % volumetric, $\sigma^0$ decreased with optical thickness even if incidence angles increased. This behavior explains that the predominent process in this case is surface scattering expressed as soil contribution attenuated by vegetation.

For a higher value of $\omega$ ($\omega$ = 0.18), if we keep the other parameters equal to the precedent, figure 3 (dashed curve) shows that the sensitivity (positive or negative) of $\sigma^0$ to $\tau$ depended on incidence angles and soil moisture availability. Consequently for the same viewing conditions, soil moisture determined the signal partition. Also as soil moisture increased, the transition from surface scattering to volume scattering appeared at larger incidence angles. It is important to note that both in surface or volume scattering mechanism, the backscattering coefficient is sensitive to optical thickness; but around the boundary between the two processes, $\sigma^0$ lost its sensitivity to optical thickness. Therefore, in this limit the knowledge of exact vegetation optical thickness is necessary to retrieve soil moisture.

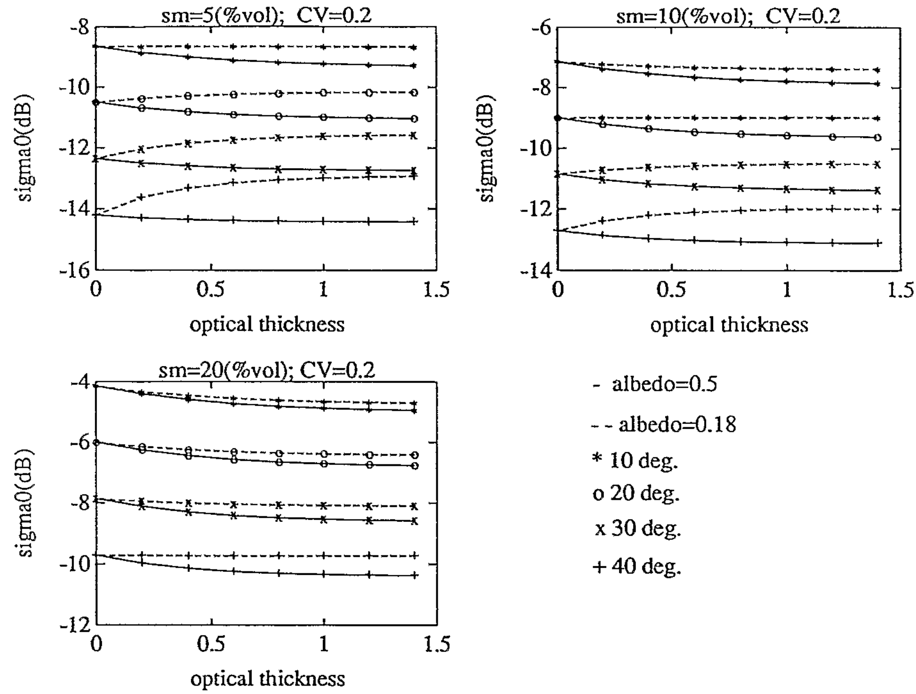


***Figure 3 :***
***Model behavior over semi-arid areas for $\omega$ =0.05 (-) and $\omega$ =0.18 (—).***

## INVERSION METHOD

Equation (8) is governed by soil (roughness, moisture) and vegetation ($\tau$, $\omega$) characteristics. The analysis of equation (2) shows that A($\theta$) is the contribution of dry soil (sm=0). For this reason, $A(\theta)$ is computed through empirical relations using $\sigma^0(\theta)$ data in dry season (April-May). As $A(\theta)$ is linked to surface roughness, this means that we assume the roughness parameters constants during the study period. In order to reduce the number of parameters in (8), we consider for each pixel, fore and mid beam data ; subscripts 1 and 2 denote fore and mid beam data respectively. Using (8), if we assume that the soil moisture sensitivity B is constant in fore and mid beam configurations, we can compute mid beam backscattering coefficients $\sigma_2^0$ as :

$$\sigma^0_2(\theta_2)=f(\theta_1,\theta_2,C_v)*(A(\theta_2)/A(\theta_1))*(\sigma^0_1(\theta_1)-C_v*\sigma^0_{veg}(\theta_1))+C_v*\sigma^0_{veg}(\theta_2) \quad (9)$$

Where :

$$f(\theta_1,\theta_2,C_v)=(1-C_v(1-\gamma^2(\theta_2)))/(1-C_v(1-\gamma^2(\theta_1)))$$
$$A(\theta_1)=0.0932*exp(-0.0297*\theta_1)$$
$$A(\theta_2)=0.1488*exp(-0.0428*\theta_2)$$

Thus (9) is not explicitly dependent on soil moisture parameter. We inverted it to retrieve simultaneously $\tau$ and $\omega$ through $\gamma^2$ and $\sigma^0_{veg}$. To this end, we need more than one observation. Thus, we supposed that the vegetation has a weak growth during a week. The minimization process was then applied for WSC data corresponding to a slight variability of vegetation cover in term of $\tau$ and $\omega$ retrieval using a non linear procedure of minimization of the root mean square error (rmse) between measured and calculated values of $\sigma^0_2$ given by equation (9).

## Results and discussion

### Temporal evolution of vegetation parameters

To consider the path of the signal into the vegetation layer, instead of $\tau$ we will use the oblique optical thickness $\tau_{ob}$=/$\tau$cos($\theta$). On figure 4, the temporal evolution of $\tau_{ob}$ agreed well with MSAVI behavior. This can introduce a qualitative relationship between chlorophyllian and dielectric/structural properties of plant. The advantage of such relationship is that both of chlorophyllian (vegetation index) and structural/dielectric (optical thickness) are accessible by remote sensing. Over agricultural areas, some authors have developed empirical relationships between optical thickness and plant water content (Jackson, *et al.* 1982). But these relationships can not be rigorously applicable over semi-arid regions where vegetation is sparse and heterogeneous and they require many measurements of plants water content.

The temporal evolution of the simple scattering albedo $\omega$ (figure 4) increased with vegetation growth but remains almost constant for a moment. This is probably due to the fact that is related to the plant water content which has a slight temporal variability when vegetation is developed. Contrary to previous study (Van de Griend, Owe, 1993), we find that $\omega$ varies with vegetation.

The main objectif of and estimation is to determine the influence of vegetation dielectric and structural properties on backscattering coefficient. The result allows us to estimate soil moisture through vegetation cover within a suitable viewing conditions.

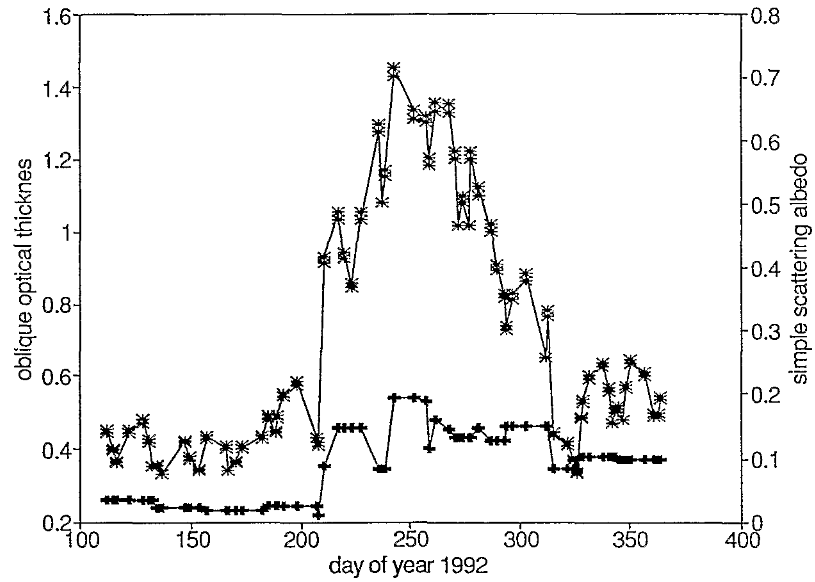


***Figure 4 :***
*Temporal evolution of $\tau_{ob}$ (*) and $\omega$(+).*

## COMPARISON OF DIFFERENT CONTRIBUTIONS OF THE SIGNAL

The sensitivity of the signal to surface characteristics (soil/vegetation) is linked to incidence angles. To reduce this influence on the signal, the results will be presented within given angular range : [18°, 30°], [30°, 40°], [40°, 46°] of the mid beam antenna.

By assuming the validity of water-cloud model over semi-arid areas, the retrieval values of $\tau$ and $\omega$ were used to compute the second part of equation (8). Then from WSC mid beam antenna data and $\sigma^0$ expression given by water cloud model over semi-arid areas we deduced the soil contribution which is the first term of equation (8).

Figures 5.1, 5.2 and 5.3 are the comparison between $\sigma^0$ measured by the sensor and its two components given by equation (8). We can see that the predominant process between surface and volume scattering depends on angular range ; besides for [30°,40°] and [40°, 50°] angular ranges, vegetation stages during the growing season affects strongly the signal partition.

— Within [18°, 30°], the soil contribution is approximately equal to the measured values of $\sigma^0(\theta)$ up to DOY (day of year) 223. After that date, the soil response decreased slightly due to vegetation growth (see figure 1). In this case, the signal weakly attenuated by the canopy penetrated the vegetation layer and thus included some information coming from the underlying soil. Consequently, even at [18°, 30°] range for a relatively small vegetation cover, the soil has a important role in the observed signal.

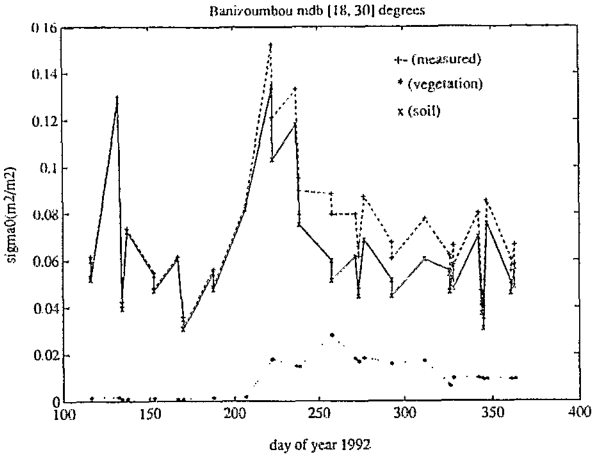


***Figure 5.1 :***
*Comparison between measured signal (+-) and its two components in $m^2/m^2$ for [18°, 30°] range.*

— For [30°, 40°] range, during the growing season the soil contribution is about the 2/3 of the measured signal.

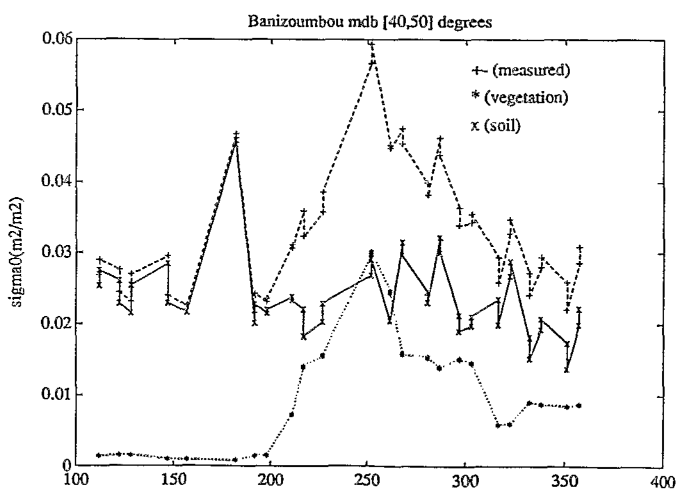


***Figure 5.2 :***
*Comparison between measured signal (+-) and its two components in $m^2/m^2$ for [30°, 40°] range.*

— Within [40°, 50°] range, when vegetation is at its maximum ; soil and vegetation contributions are approximately equal.

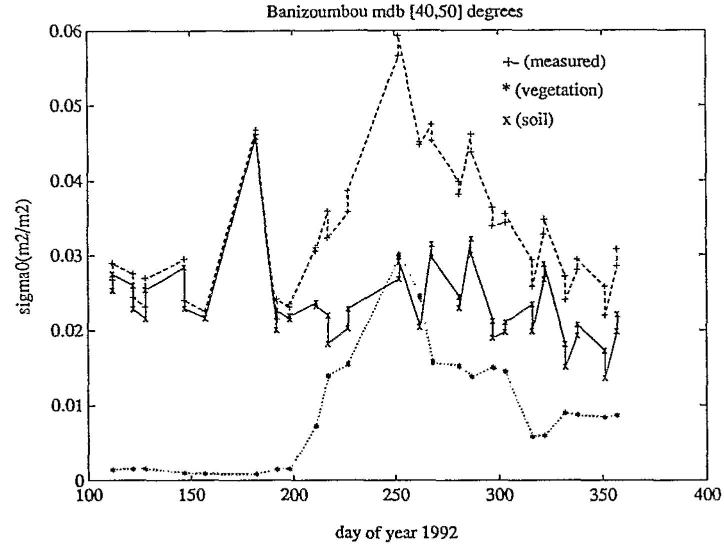


***Figure 5.3 :***
*Comparison between measured signal (+-) and its two components in $m^2/m^2$ for [40°, 50°] range.*

To summarize these results if we analysed simultaneously the temporal evolution of soil contribution within the three angular ranges, we find that this signal decreased strongly with incidence angles. On the other hand, the temporal evolution of vegetation part varied slightly with incidence angles. These results are in agreement with surface and volume scattering theory.

## Application to soil moisture estimation

At this frequency (C band), WSC data were sensitive to land surface features : soil moisture, surface roughness and vegetation cover. Over the study site, the available surface roughness measurements are not sufficient to quantify this parameter. However, as it was underlined in the section related to the inversion method, we made the assumption of constant surface roughness. The knowledge of vegetation parameters is also useful to have an accurate estimation of soil moisture. At low incidence angles, volume scattering can be neglected and optical thickness is the vegetation parameter responsible of the signal attenuation coming from the underlying soil. The retrieval optical thickness will be used in this section to correct the signal from vegetation effects. During the Hapex-Sahel experiment some soil moisture measurements were made in coincidence to the satellite dates overpasses. We used these data to compute the sensitivity of the signal to soil moisture ($d\sigma^0$/dsm).

Figure 6.1, 6.2 and 6.3 represent this quantity *vs* incidence angles, oblique optical thickness and day of year respectively. As expected, we note a loss of sensitivity when incidence angles and optical thickness increases. This resulted from the increasing of the signal attenuation by vegetation. Figure 6.3 shows that the temporal trend of $d\sigma^0$/dsm, decreased with vegetation growth; this is in agreement with figure 6.2. After rainy season when there is no green vegetation, the sensitivity of the signal to soil moisture increased. But the value of $d\sigma^0$/dsm computed on DOY 278 seemed too large.

***Figure 6.1 :***

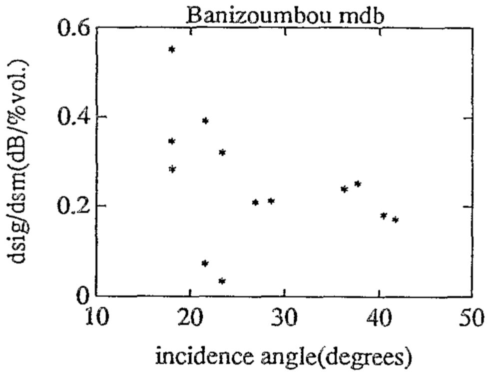


***Figure 6.2 :***

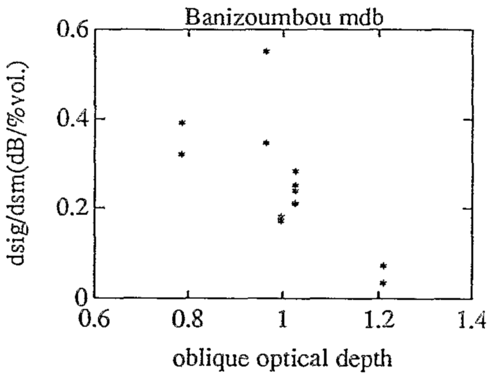


***Figure 6.3 :***

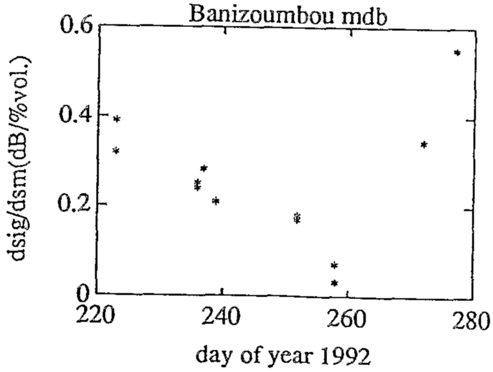


***Figure 6 :***

*$d\sigma^0$/dsm as a function of incidence angles (6.1), optical thickness (6.2) ; temporal behavior of $d\sigma^0$/dsm (6.3).*

## SOIL MOISTURE RETRIEVAL

With these sensitivity values, we deduced from equation (2) the soil moisture using WSC (mid beam antenna) data which were less affected by vegetation effects. To do this over the study period, for each incidence angle we used the corresponding $d\sigma^0/dsm$.

Figure 7 is the temporal evolution of the estimated soil moisture and ground measurements done by three teams over the study site.

Considering the ground measurements, we have an idea about the spatial and temporal distributions of soil moisture over the study area. We can see an overestimation of some retrieval soil moisture at the end of rainy season when the surface is slightly wet. Another source of error resultes from the radar penetration depth of the soil which is not necessarily equal to the depth of soil moisture measurements (0-5cm). Besides, soil moisture measurements and satellite overpassess are not synchronous. It should also be stated that the optimal radar incidence angles [7°, 17°] (ULABY *et al.*, 1986) are not available to estimate soil moisture. So, it is certain that surface roughness affects the values of retrieval soil moisture. Although the angular dependance of $d\sigma^0/dsm$ have been taken into account, we must be care of the assumption of constant surface roughness.

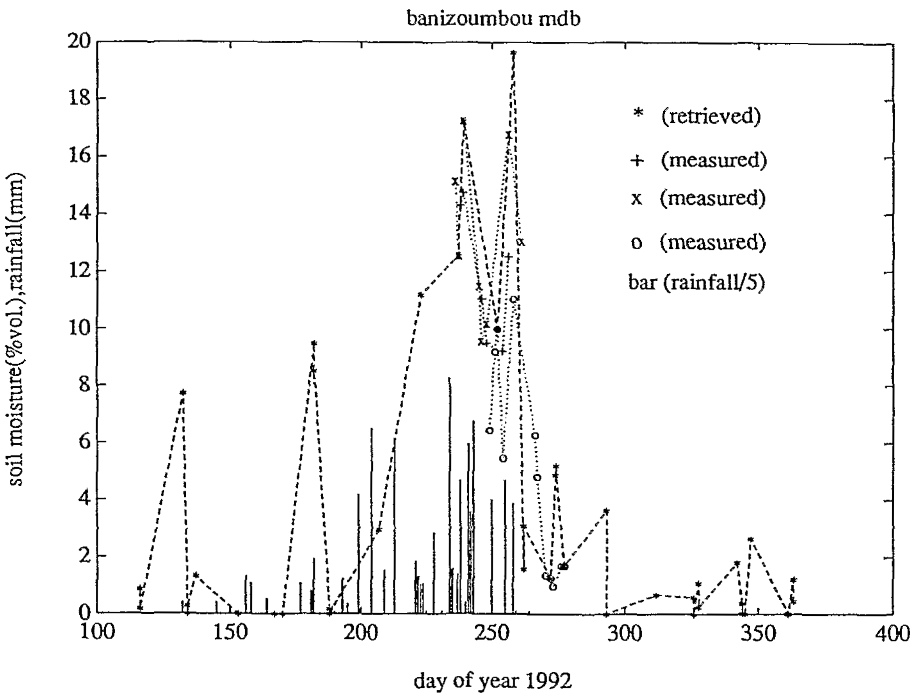


***Figure 7 :***
*Temporal evolution of measured and retrieval soil moisture (% vol.).*

## Conclusion

Over natural areas the signal measured by remote sensing includes the response of whole target without any discrimination between soil and vegetation contributions. A semi-empirical model *water-cloud* combined with NOAA/AVHRR and WSC data permitted to extract vegetation optical thickness ($\tau$) and simple scattering albedo ($\omega$). These two parameters modified the signal coming from the underlying soil and decreased the signal sensitivity to soil moisture. Through an angular and temporal behavior, it appeared that the magnitude of attenuation within the canopy is strongly linked to incidence angle. This property influenced soil moisture estimation. In this paper, synergistic study between optical and radar data allows us to subtract vegetation contribution from WSC measurements for soil moisture estimation. The sensitivities to soil moisture ($d\sigma^0/dsm$) computed for the IOP (Intensive Observation Period) data of Hapex-Sahel experiment and for some given areas have been used for studied period over the 50 x 50km square. This involves an assumption of constant surface roughness. Therefore the problem of spatial and temporal variabilities of surface roughness appeared. For this reason, efforts are devoted to improve this algorithm for an varied surface roughness.

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