SYNERGY BETWEEN OPTICAL AND MICROWAVE REMOTE SENSING TO DERIVE SOIL AND VEGETATION PARAMETERS FROM MAC EUROPE 91 EXPERIMENT

TACONET[1], O., BENALLEGUE[2], M., VIDAL[3], A., VIDAL-MADJAR[1], D.,
L. PREVOT[4],M. NORMAND[2]

1 Centre de Recherches en Physique de l'Environnement Terrestre et Planétaire
10-12, avenue de l'Europe 78140 VELIZY (France)
2 CEMAGREF, Division Hydrologie- BP 121 F-92185 Antony Cedex (France)
3 CEMAGREF/LCT, 361, rue J-F Breton .B.P. 5095 34033 Montpellier Cedex 1
4 INRA, Bioclimatologie, BP 91, 84140 MONTFAVET (France)

I. INTRODUCTION

The ability of remote sensing for monitoring vegetation density and soil moisture for agricultural applications is extensively studied. In optical bands, vegetation indices (NDVI, WDVI) in visible and near infrared reflectances are related to biophysical quantities as the leaf area index, the biomass. In active microwave bands, the quantitative assessment of crop parameters and soil moisture over agricultural areas by radar multiconfiguration algoritms remains prospective. Futhermore the main results are mostly validated on small test sites (Ulaby et al. 1984), but have still to be demonstrated in an operational way at a regional scale.

In this study, a large data set of radar backscattering has been achieved at a regional scale on a french pilot watershed, the Orgeval, along two growing seasons in 1988 and 1989 (mainly wheat and corn). The radar backscattering was provided by the airborne scatterometer ERASME, designed at CRPE, (C and X bands and HH and VV polarizations). Empirical relationships to estimate water crop and soil moisture over wheat in CHH band under actual field conditions and at a watershed scale are investigated. Therefore the algorithms developped in CHH band are applied for mapping the surface conditions over wheat fields using the AIRSAR and TMS images collected during the MAC EUROPE'91 experiment. The synergy between optical and microwave bands is analysed.

2. THE ORGEVAL CAMPAIGNS ' 88,89 and 91

The characteristics of the scatterometer ERASME is presented in Table 1. The French test site is the Orgeval experimental watershed of 5 by 5 km^2 (France), mainly covered by wheat and corn with silt loamy soils. 49 fields of wheat and 12 fields of corn are identified. During 1988 (AGRISCATT), the scatterometer ERASME was performed along a 17 km axis through the basin during June and July with 17 test fields (wheat and corn). In 1989, it was performed along 14 crossed-axis covering the watershed (21 test fields) for every month from March to December 1989.

During the Mac-Europe Campaign'91, flights of the NASA airborne sensors (the multispectral radiometer TMS, the synthetic aperture radar AIRSAR) have been done, simultaneously with flights of ERASME.The two intensive periods were two weeks, the first mid June and the second mid July. 2 test fields (wheat and corn) were instrumented. Only two enough clear TMS images are available, the 17 July and the 22 July. The concomittant AIRSAR image is the 16 July.Ground truth measurements related to soil and vegetation are soil moisture, soil profiles with a 2 meter pin-profiler, leaf area index, crop height, biomass and water content.

3. EMPIRICAL RELATIONS IN CHH BAND

Considering the distribution of radar cross sections at 20 and 40 degrees of incidence angles with the vegetation water content (Figures 1 and 2), it appears that the behaviour of radar backscattering can be divided in two cases, low vegetation cover and high vegetation cover. For vegetation water content lower than 2, the cross sections for both 20 and 40 degrees are highly variable. The vegetation water content is not the

Table1 Radar Characteristics of ERASME

Type	Forward looking FM/CW
Frequencies	5.35 GHz and 9.65 GHz
Transmitted Power	11.2 dBm at C band 20 dBm at X band
Modulation	Sawtooth, 3ms of period
Antenna Axis Position	23°, 38° and 45°
Range Resolution	0.97m at 23° 1.30m at 38° and 45°
Antenna Range	±10° in elevation ±2° in azimuth
Altimeter Antenna	Nadir Horn
Pixel Size	20m by 10m
Accuracy	1dB ±7° apart the axis

Figure 1- Radar backscattering at 20 degree of incidence from Orgeval'88-89 related to vegetation water content in kg/m^2 and classified with soil moisture in cm^3/cm^3
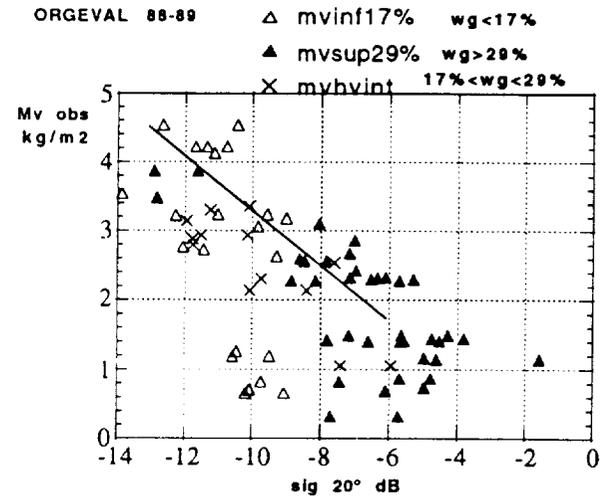
dominant parameter. The relevant parameter for radar cross sections is the soil moisture. For vegetation water content Mv higher than 2, it appears a linear relation between the radar cross sections and the vegetation water content. The radar backscattering is decrasing with increasing crop coverture. The soil moisture is no more an influent parameter.

3.1 Case of low vegetation cover

The relation of cross section with soil moisture Wg for bare soil is established using data points with the lowest values of vegetation cover (Mv<1kg/m2). A linear relation is obtained at 20 and 40 degree as proposed by Ulaby (1978):
The 2 obtained relations at 20 and 40 degrees are:

$$\sigma^0 soil(20)= -12.1+0.18 \ Wg \tag{1}$$

$$\sigma^0 soil(40)=-13.8+0.14 \ Wg \tag{2}$$

with comparable slopes and a shift of about 2dB.
This simple linear relation is obtained only for wheat culture. Linear relations between radar cross sections and soil moistures are no longer available for bare soils in the cases of corn sowing or of ploughs.

Linear relation between radar cross sections and soil moistures are obtained with low vegetation cover, (Mv< 3 kg/m2) (Figure 3). The relations at 20 and 40 degrees are:

$$\sigma^0 soil(20)= -15.6+0.29 \ Wg \tag{3}$$

$$\sigma^0 soil(40)=-14.9+0.14 \ Wg \tag{4}$$

The cloud model has been adjusted over wheat, taking only the attenuated part by the vegetation:

$\sigma^0= t^2 \sigma^0 soil$ and $t^2 = exp(-2B \ Mv/cos\theta)$ and $\sigma^0 soil$ in dB= C1 - C2 θ + D Wg with θ the incidence angle.

$$\sigma^0 \ in \ dB= -8.69 \ B \ Mv/cos\theta \ -C1 - C2 \ \theta + D \ Wg \tag{5}$$

The adjusted coefficients are:B=0.09,C1=-8.32,C2 =0.147,D=0.193 (comparable with results of Prévot et al.1993).

3.2 Case of high vegetation cover

For dense canopy (Mv>3kg/m2), the soil moisture is no more a relevant

70

Figure 2- Radar backscattering at 40 degree of incidence from Orgeval'88-89 related to vegetation water content in kg/m² and classified with soil moisture in cm³/cm³
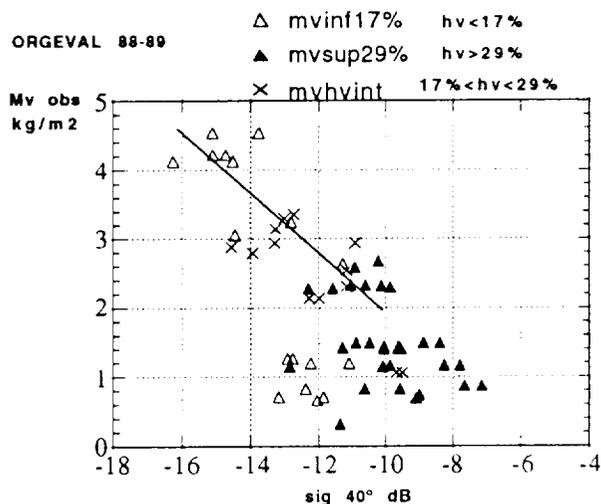
Figure 3: Linear regression between radar cross section and soil moisture over wheat for low cover canopy (vegetation water content<3 kg/m³)

ORGEVAL 88-89

Mv obs kg/m2

Δ mvinf17%   hv<17%
▲ mvsup29%   hv>29%
× myhvint   17%<hv<29%

sig 40° dB

ORGEVAL88-89

sig20=-15.58+0.290wg   R=0.777

sig 20°
dB

wg % cm3/cm3
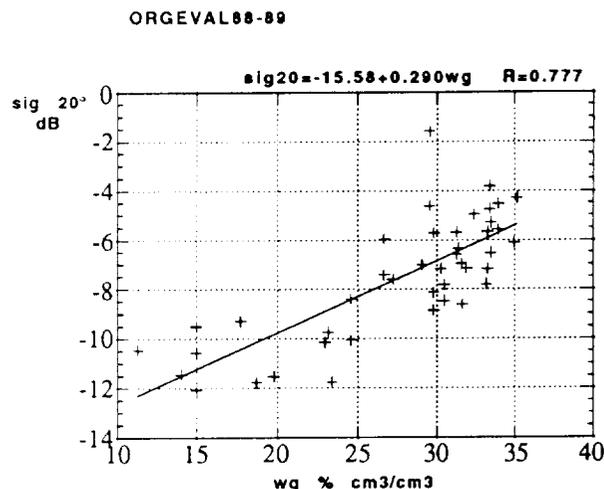
parameter to parameterize the radar cross section (see Figures 1 and 2). The cross sections at 40 degrees are related quasi linearly to vegetation water content. The radar backscattering is attenuated when the foliage density is increasing (Prévot et al., 1993). At 20 degrees, radar cross section is highly variable for the same foliage density indicating that other structural parmeters of canopy have to be accounted. Experimental linear relation between radar cross section and vegetation water content can be proposed from the data set.

At 40 degrees, $Mv=-0.35\sigma^0 dB-1.44$ (6)

But as the dependance of the cross sections with the soil moisture disappears, the formulation given by the attenuated part of the cloud model fitted for $Mv<3kg/m^2$ is no more available.

4. APPLICATION TO THE ORGEVAL'91/MAC-EUROPE EXPERIMENT

A map of the 49 fields of wheat over the basin is given in Figure 4. The synergy between the TMS (17 July) and the AIRSAR (16 July) images is investigated. The TMS image has been radiometrically calibrated and corrected from atmospherical diffusion in visible/near infrared bands. Approximate calibration of LAI (leaf area index) versus NDVI (Normalized Vegetation index) and vegetation water content (Mv) versus LAI are obtained over the reference field:

LAI=- 4.1+11.4 NDVI   (7)
Mv=2.32+0.25 LAI   (8)

Spatial variations of NDVI and Mv over the wheat parcels are derived (Figure 5). As the magnitude of the estimated Mv are between 2.8 and 3.4 kg/m², only a map of the vegetation water content can derived from the radar cross section of the AIRSAR images (2 images around 45 degree of incidence with 2 flight directions, perpendicular and parallel to the average rows direction in the watershed). The algorithm related radar cross section and Mv (Eq. 7) has been used. An intercalibration between the AIRSAR and ERASME data is done before, as the AIRSAR data are systematically lower of about -3.5dB. Therefore AIRSAR data are decreased of -3.5dB and after of +1dB to approximate the cross sections at 40 degrees needed in Eq. 7. The value of -1 dB has been calculated from statistical relation between the ERASME data at 40 and 45 degree.

It has been noted that the derived vegetation (LAI,Mv) parameters from microwave algoritms are lower and more scattered than those deduced from the optical vegetation index. Nevertheless the accuracy of relationships using optical vegetation index is also to be assessed.

71

Figure 4- Map of wheat fields over the Orgeval
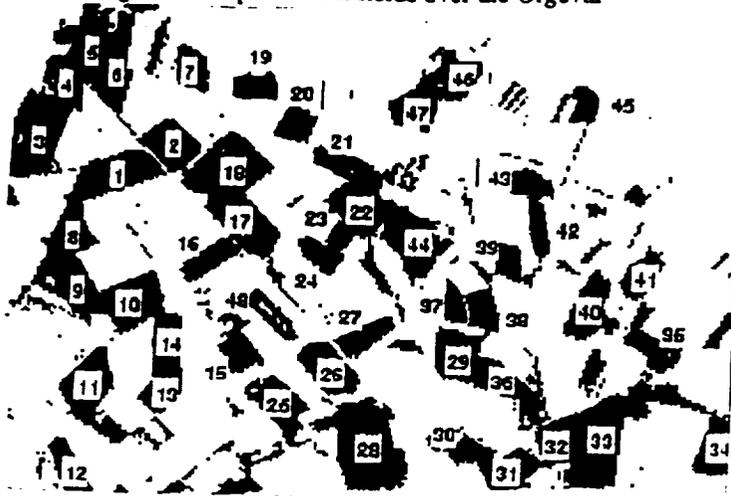
Figure 5: Spatial variations of NDVI and deduced vegetation water content Mv (kg/m^2) over wheat fields.
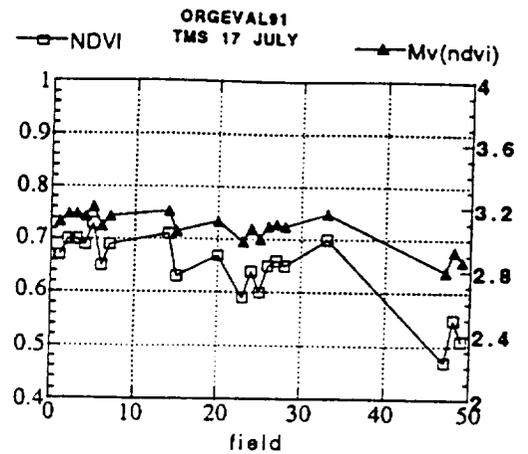
5- CONCLUSION

A complementary use of the optical and microwave bands is proposed. Over wheat, the knowledge of the vegetation index values appear necessary to discriminate dense or low vegetation cover over the wheat fields and choose the adequate microwave algoritm to derive either the soil moisture, either the water content of the vegetation. In CHH band, radar data at 20 and 40 degree can be used to derive soil moisture for low cover. Radar data at 40 degree are used to derive water content and are not saturating as soon as optical vegetation index NDVI.

Figure 6: Intercomparison of radar cross section from AISAR and ERASME
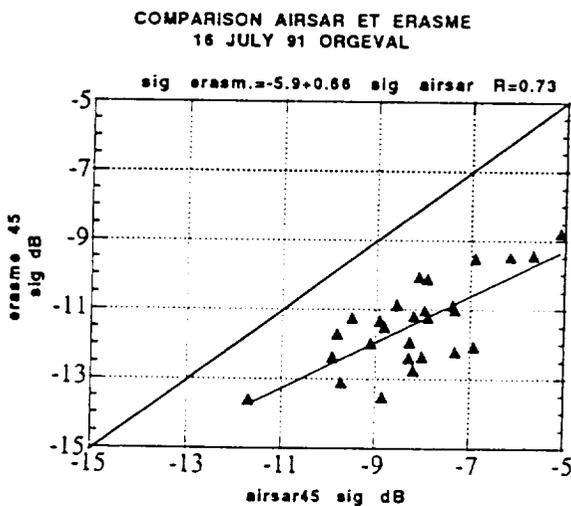
Figure 7: Simultaneous estimation of Leaf Area Index and vegetation water content from optical (TMS)and microwave (AIRSAR) images.
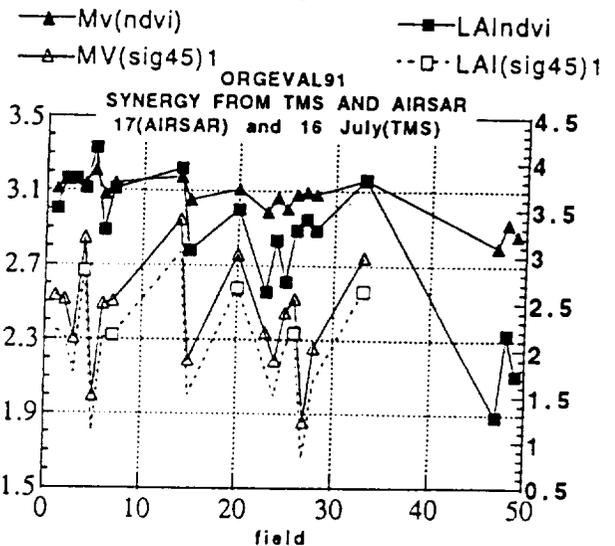
REFERENCES

Prévot, L., M. Dechambre, O. Taconet, D. Vidal-Madjar, M. Normand and S. Galle, 1993," Estimating the characteristics of vegetation canopies with airborne radar measurements, *Int. J. of Remot. Sens.*, to be published.

Ulaby,F., T. et al., 1978,"Microwave backscatter dependence on surface roughness, soil moisture and soil texture: Part 1-bare soil, *IEEE Trans. Geosci. Electron.*, vol. 16, no.4, pp.286-295.

Ulaby, F. T., C. T. Allen, G. Eger and E. Kanemasu, 1984, "Relating the microwave backscatteringf coefficients to leaf area index",*Remote Sens. Environ.*, vol.14, pp.113-133.