Using Microwaves for the Assessment of Runoff Risk over Mediterranean Soils : an experiment in the Réart catchment basin (Roussillon, France)

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Résumé

En région méditerranéenne, l'érosion des sols est aujourd'hui un problème de grande ampleur. Les données SPOT, associées à des données de Modèles Numériques de Terrain (MNT), permettent d'établir à l'échelle régionale, un bilan des surfaces sensibles à l'érosion et au ruissellement. Toutefois, et notamment en région de vignoble, la sensibilité à l'érosion de chaque parcelle est notablement influencée par la rugosité induite par les pratiques culturales que les images des domaines "visible" et "proche-infrarouge" ne permettent pas de différencier. Le labour, le désherbage chimique ou l'enherbement, se traduisent par des rugosités du sol qui semblent suffisamment contrastées pour qu'une identification au moyen de données hyperfréquences puisse en être espérée, au moins à l'échelle du groupe de parcelles. Il serait ainsi possible d'affiner l'estimation des surfaces réellement contributives au ruissellement.

Afin de mieux cerner le potentiel d'utilisation des données radar multifréquences et multi-incidence sur la caractérisation des surfaces sensibles au ruissellement, plusieurs images ont été acquises depuis 1992, sur le vignoble du bassin versant du Réart (Roussillon, France). Au cours du mois de décembre 1992, une campagne de mesure radar aéroporté a été conduite par le DLR (Deutsche Forschungsanstalt für Luft und Raumfahrt) à la demande du CNES. Le radar imageur E-SAR a acquis des données suivant deux directions de vol perpendiculaires, et deux configurations X(VV) et L(HH). Dans le même temps, les parcelles de vigne concernées par ces mesures ont fait l'objet d'un contrôle systématique comportant des évaluations de l'état général des surfaces (enherbement, type de pratiques culturales) et des mesures sur la rugosité. De même, une série temporelle d'images ERS1 (bande CVV) et JERS1 (bande LHH) a permis d'appréhender les possibilités des données satellites à l'échelle régionale.

Le site englobe trois échelles de rugosité : relief, rangs de vigne et rugosité du sol. Les parcelles de référence ont été successivement comparées de manière à étudier l'influence des rugosités du sol et des rangs de vigne sur le signal. En première analyse, le rôle de la rugosité des sols reste faible même en bande X. Ceci peut être imputé à la faible diversité des rugosités à l'époque d'observation hivernale. L'orientation des rangs de vigne affecte significativement le signal en bande L ($r = 0{,}68$) et laisse espérer une possible discrimination. Ce résultat est renforcé par les tendances observées à partir de données satellitaires. Ainsi, il est possible d'espérer que les images satellitaires, à des échelles régionales, favorisent une discrimination des surfaces en fonction de leur aptitude à ruisseler, moyennant certaines conditions d'acquisition et de résolution.

Abstract

Soil erosion is becoming an increasingly serious problem in Mediterranean areas. Simultaneously, the regional evaluation of actual or potential soil-erosion conditions is increasingly commonly required in the decision making process. In previous work, remote sensing has been presented as a suitable tool for estimating regional parameters, e.g. land-use, morphology, and drainage patterns, which are used for drawing a map of potential vulnerability to erosion. Among the most important parameters of runoff processes, several, such as roughness, agricultural practices and soil humidity, are difficult to monitor with optical satellite data, particularly in a vineyard landscape.

Radar data might be a way to overcome this problem, and, to test this point, airborne-radar and satellite-radar data have been acquired over the experimental basin of the Réart (Roussillon, France), thanks to the two French scientific programmes of GATT/CNES and PNTS. The objective was to see how microwave data at different wavelengths and incidence angles could discriminate new runoff parameters, like agricultural roughness and vine-row orientation.

In the winter of 1992, the airborne radar E-SAR of DLR (Deutsche Forschungsanstalt für Luft und Raumfahrt) acquired images along two perpendicular flight lines, in the X (VV polarization) and L (HH polarization) bands. The vineyard plots covered by these data were subjected to a systematic field survey of vegetation cover, type of agricultural practice, row orientation and roughness index. Furthermore, a multitemporal series of satellite images from ERS-1 (C band, VV polarization) and JERS-1 (L band, HH polarization) was acquired for 5 dates between April 1992 and April 1993, and a ground survey was carried out.

Several analyses, based on GIS technology between images and ground data, showed that the soil-roughness effect remains minor, even in the airborne X band. This

may be due to a seasonal effect of data acquisition (in winter the soil condition is rather homogeneous) and requires re-examination at other dates. The second level of roughness, vine rows, significantly affects the signal in the airborne L band and indicates that discrimination is possible. This result is confirmed by the trend observed on the backscatterring signal extracted from ERS-1 data, for a sample of plots greater than 1 hectare, which is very encouraging for determining the runoff, and thus erosion, parameters of vineyards.

Introduction

In Mediterranean countries, where erosion problems are becoming disturbing (ROOSE, 1992), the assessment of soil that can be eroded and the determination of the most favourable surfaces for runoff, can help in guiding decision-making for development on a regional scale. When faced with the necessity to draw up maps showing the potential vulnerability to soil erosion, remote sensing is a useful tool for estimating various parameters such as land-use, morphology and incisions (ANYS *et al.*, 1992; PIELESJÖ, 1992; LEEK, 1992; PUECH, 1993; KING *et al.*, 1994).

Roughness and humidity of soils are two more primary factors in erosion and runoff processes, which are required for erosion models (BEASLEY *et al.*, 1980; KNISEL, 1980; MORGAN and RICKSON, 1990). Such parameters are not easily accessible from satellite data in the visible or near-infra-red wavelengths (KING and DELPONT, 1993). However, experimental and theoretical work in the microwave field has shown that such wavelengths can provide access to roughness and humidity data for soil (ULABY *et al.*, 1978; BEAUDOIN *et al.*, 1990; EVANS *et al.*, 1992; RAO *et al.*, 1993). For this reason, a valid contribution can be expected from active microwave sensors when studying soil erosion. Certain studies have already tackled this problem with the objective of determining if radar data on soil roughness can contribute to the assessment of potential runoff areas (SOLBERG, 1992; COMPANY *et al.*, 1994; MICHELSON, 1994).

In Mediterranean areas, vineyards are among the most important landscape features because of their high potential to runoff. In fact, the practice of planting vines in rows generates a plot structure with a directional effect on runoff. Furthermore, both weeding and tilling are common agricultural practices in southern France. These create different levels of soil roughness that influence runoff and erosion rates. Our objective is to analyse how radar data can give access to such characteristics.

Equipment and methods

The test site

The test site lies in the Réart drainage in southern France, about 20 km southwest of Perpignan, in the foothills of the eastern Pyrenees. The entire region is particularly sensitive to erosion under the double effect of climate and a steep relief, and the widespread cultivation of vines further accentuates erosion. In fact, the practice of planting vines in rows generates a plot structure that affects runoff direction. Furthermore, agricultural practices (i.e. tilling or weeding) influence runoff intensity through soil roughness.

Réart Basin Localization

In 1991, a first satellite-image map of vulnerability to erosion was based on a SPOT image and a DEM covering the entire basin of the Réart (DELPONT *et al.*, 1991). Two vineyards, "En Ferran" and "Terrats", are representative for the drainage basin and have been test sites for erosion studies since 1992 (COMPANY *et al.*, 1994; KEIME, 1992; OLIVEROS, 1992). The sites are complementary : "En Ferran" shows a great diversity of slopes for the same N165° orientation of vine rows; "Terrats", uniformly flat, shows a great diversity of row orientations from N060° to N180°. Site monitoring is done at two scales: erosion measurements are made on individual plots, but the basin as a whole is monitored by successive satellite images.

For each monitoring campaign of the site, the plots are classified according to stable criteria, e.g., general morphological parameters of slope angle and row orientation, as well as seasonal parameters that vary with agro-climatic conditions, e.g., general types of cultivation work, soil roughness, percentage of vegetation cover, etc.

Roughness parameters

Backscattering is generally influenced by dielectric and geometric properties of the surface. In southern France, in winter, vineyards can be considered as bare soil with low, dry and dispersed vine stocks that have a negligible influence on radar backscattering. In this case, the studied surface was considered as a superposition of three levels of roughness:

1) relief,
2) periodic soil roughness due to directional planting and tilling,
3) random soil roughness.

This superposition generates a morphology that seems proper to vineyards and permits the study of roughness on the backscattered signal. Runoff intensity and direction are also influenced by these three roughness characteristics, so we tried to underline the relationship that could exist between runoff and microwave backscattering through roughness. Of the three levels of roughness, soil roughness and vine rows were studied in particular.

Random roughness

Random roughness is essentially due to three causes: cultivation practice, the presence of stones, and the growth of weeds and new shoots. Most roughness measurements in the field concerned bare soil. First of all, qualitative estimates of soil-clumps and stone sizes gave a general evaluation of the plots. After this, quantitative measurements provided a general roughness index IRg (BOIFFIN, 1994). The method used consists of measuring the distance between two points :

- by following bumps in the soil (L_0),
- along a straight line (L_1).

The measurements were made on the ground at right angles to the tilling direction, on an inter-row that is representative of the average plot roughness of the plots. IRg, the index of overall roughness, is equal to $(L_0 - L_1)/L_0$ (Fig. 1), used for all investigated plots.

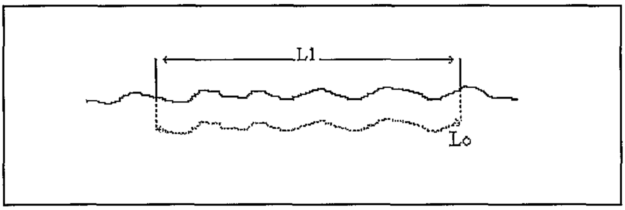


Figure 1. Roughness index IRg

The advantage of this method is that it is very rapid to implement in the field, although it can be affected by local artefacts. The same roughness index IRg thus may correspond to various types of roughness. But, generally, microwave data use stochastic parameters that accurately describe surface roughness (ULABY *et al.*, 1982):

- s: standard deviation of surface height;
- l: correlation length;
- m: standard deviation of surface slope;
- k: wave number.

In 1992, such measurements were not made, but some carried out in 1994 provide an assessment of the soil roughness for a particular season and agricultural practices.

Periodic soil roughness

Plot structure, influenced by the oriented planting of vines and the preferential direction of tilling, generates periodic surface roughness. For modelling this, three parameters were measured or estimated on the ground.

- Azimuth angle φ , measured between the radar beam and vine rows. This angle can vary from 0°, for a beam direction parallel to vine rows, to 90° for a perpendicular view (Fig. 2).

- The two parameters A and P of the sinusoidal curve that represents periodic soil surfaces with vine rows (Fig. 3). This means that soil elevation can be modelled as:

$$z = A \cdot \cos(\frac{2\pi y}{P})$$

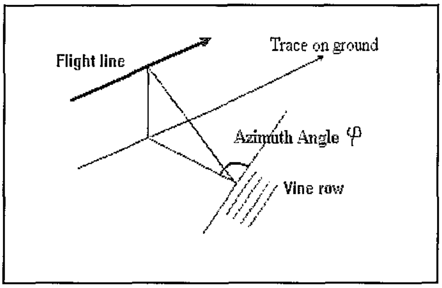


Figure 2. Azimuth angle between rows of vines and the radar track.

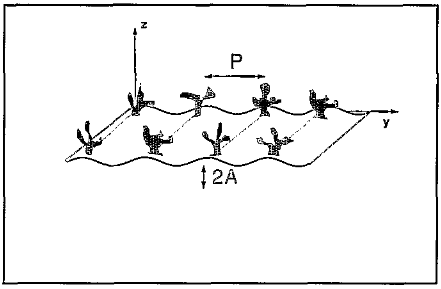


Figure 3. Periodic vine rows model by sinusoidal curve.

The planting generally is governed by slope angle and the direction of maximum insolation, but others situations can exist as well as is demonstrated by the two test sites. "En Ferran" has plots with relatively parallel rows in the direction of the slope (N165°), but "Terrats", on flat ground, has a wide diversity of row orientations, from N 060° to N180°; A and P were considered as equal to, respectively, 0.05 m and 1.5 m.

Relief

Morphologic relief of the test sites is quantified by the slope angle. For "En Ferran", this was calculated from a digital elevation model (DEM) with a spatial resolution of 2 m. The plots lie on the same slope and slope angles thus sufficed for characterizing relief. For the "Terrats" site, all plots were considered as flat.

Radar acquisition

Radar satellites have been operational for several years, and seem to be a new tool for assessing remotely sensed parameters on a regional scale. Airborne data do not provide the same synoptic view as do satellite data, but in a first analysis they do provide accurate spatial information on microwave possibilities. For these reasons, both airborne data; obtained with the E-SAR sensor, and satellite data from ERS-1 and JERS-1, were analysed.

Airborne data

Airborne radar data were obtained in winter 1992, with the E-SAR sensor owned by the German space agency: DLR. This synthetic-aperture radar gives images covering about 4 x 4 km, with a spatial resolution on the ground of 3 m. Three frequency bands, L, X, and C, can be used under two types of polarization, HH and VV. The data acquired for this study were limited to two types of configuration, XVV on December 1st, 1992, and LHH on December 2nd. Two perpendicular lines were flown, whose angle of incidence in the centre of the site is 35°. In view of the constraints generated by radiometric quality and track geometry, 80% of the reference plots was covered, i.e. between 109 and 190 plots according to the flight line.

Satellite data: April and August 1992

Regional studies can only be based on satellite data, which are also cheaper than airborne data. Today, several operational radar satellites can provide the necessary data, i.e. LHH-band data from JERS-1 and CVV-band data from ERS-1. From April 1992 to April 1993, three ERS-1 images and one JERS-1 image were acquired for the Réart test site. Two of the images were selected for comparison with the airborne E-SAR data: ERS-1 from April 1992, which is of the best radiometric quality, and JERS-1 from August 1992 which has the same characteristics as the L band E-SAR image (L band, HH polarization and 35° incidence).

Processing and methods of analysis

All pre-processing of the radar data was carried out by CNES, ESA or NASDA (the French, European and Japan space agencies), whereas BRGM handled the geometric and radiometric correction work. Particular attention was paid to the reduction of speckle and the most accurate possible location of the reference plots. Speckle is one of the major problems affecting the quality of radar images, being a specific random noise that causes image modification. Its estimation and reduction can be obtained through filtering techniques (POSNER, 1993). Here, we applied adaptive filtering (Vinci radar module of MAPSAT software) that detects and preserves the image structures (DESNOS and MATTEINI, 1993; LOPES *et al.*, 1993; NEZRY *et al.*, 1991). It enables the conservation and even improvement of boundaries of the reference plots. Location of the plots then is facilitated by interactive recalibration and the use of a geographic information system.

Statistical analysis was based on the correspondence between basic field parameters and the average backscattering values for each plot. Thus, for each image, the mean backscattering per plot was calculated, as well as its standard deviation and the number of pixels involved. Unfortunately, the absence of image calibration on E-SAR images prohibited any absolute comparison between the data from different images. The results correspond to backscattering values calculated for relative intensity (in dB), the references (0 dB) being specific for each image and off-set between them with a constant. This method allows comparison between the relative deviations between targets, regardless of the image. For ERS-1 images, calibration used the method described by LAUR (1992). Finally, JERS-1 data were studied as digital numbers.

Results

Discrimination of vineyards in a Mediterranean environment

Along the flight lines recorded by E-SAR, the land-use components are typically Mediterranean, i.e. vines, bare soil, scrubland, orchards, and copses of green oak. For analysing the backscattered signal of each land-use, homogeneous areas were selected. They are shown on Figure 4 by points and range, using backscattering values from L and X bands respectively as x and y coordinates. Because of the absence of absolute calibration, the backscattering is shown as digital numbers (from 0 to 255).

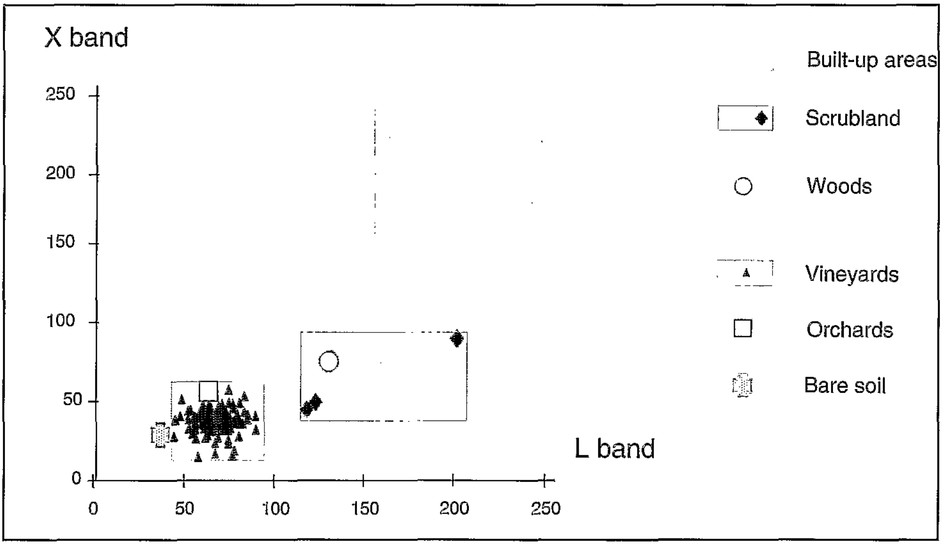


Figure 4. Backscattering fields of some of the surfaces found on the radar images.

Three groups can be distinguished on figure 4:
- built-up areas.
- homogenous vegetation like scrubland and wood.
- and orchards, bare soil and vineyards.

Because of their different behaviour regarding runoff and erosion, these three classes represent a possible classification that would be a first step in erosion assessment.

First of all, built-up areas are clearly extracted from the X band because of their high backscattering. Secondly, the responses in the L band for vines cover a wide range (18-35%) of the total dynamics along the flight line below 100; bare soil and apricot orchards remain on the edge of this range, respectively with minimum and maximum values. Because of the absence of vegetation cover, vines, bare soil and orchards are potential runoff areas. Finally, woods and scrubland, on "illuminated" slopes in the L band, backscatter much more than vineyards, with a digital number above 100, but have a runoff that is lower than that for vineyards.

In conclusion, it is probable that the directional effect of vineyards will help in distinguishing surfaces with a homogeneous structure, such as scrubland and forest, in the L band, as well as the strongly backscattering built-up areas in both X and L bands.

Random roughness

Introduction

The 190 plots flown by the radar survey are very different in terms of surface area and cultivation practice; they are mixed vineyard systems, where strips overgrown by weeds alternate with strips worked with hoes or tractors. The size of the working samples was thus reduced for each roughness parameter investigated, in order to compare plots that are statistically homogeneous with respect to parameters that were not studied.

he agro-climatic conditions during December 1992 favoured a simplification of the study. Daily rainfall data for the site show a period of 13 days without rain before the study. We therefore assumed a soil-humidity effect that was both minimal and homogeneous for backscattering. Moreover, the leafless vineyards in winter were considered as a discontinuous and periodic target, for which the impact of vegetation can be considered as nil. These considerations are important in microwave studies.

Theory

Several techniques can be used for describing soil roughness. With microwave data, the Rayleigh criterion (ULABY and BARE, 1979) determines an unevenness threshold beyond which roughness can be detected. This threshold depends on the wavelength λ and the incidence angle θ, and corresponds for our study to values of about 0.47 cm for the X band and 3.5 cm for the L band, with a mean incidence angle of 35°. This described by the equation:

$$s_{threshold} = \frac{\lambda}{8\cos\theta}$$

This means that roughness with a standard deviation of height < 0.47 cm, or < 3.5 cm, cannot be detected by the X band (or L band). In the section on Random roughness, we saw that another parameter has been used, but experimental work showed that such thresholds can be converted into the IRg index. This gave approximate values of IRg = 10 cm for the X band and 25 cm for the L band. It is seen for example that the L band must be sensitive to strong roughness (recent ploughing, IRg >25 cm) and that the X band is sensitive to roughness due to sub-soiling (IRg >10 cm).

General analysis on the basis of the soil roughness index IRg

The field work carried out in the winter of 1992, a week after the E-SAR radar survey, provided a complete database that covered not only the three nested roughness scales described above, but also other surface-condition parameters. In all, the field database comprises 21 variables described for 190 georeferenced plots. However, soil-roughness measurements (IRg) could only be carried out on 53 plots. Figures 5a, b, c and d show the mean relative intensity (in dB) of each plot as a function of roughness-index values IRg. An IRg measurement of 0 indicates smooth ground with few stones after weeding. The higher the IRg, the rougher is the soil, up to recently tilled soil for which the IRg value can be close to 25. Vineyards clearly fall within the range of low values, compared with those found for other agricultural surfaces (up to 35 for recent tilling in agricultural soil).

For a first analysis (Figs. 5a and 5b), only plots from the "Terrats" site were selected. Although few in number, they are similar in terms of soil, relief and incidence-angle conditions.

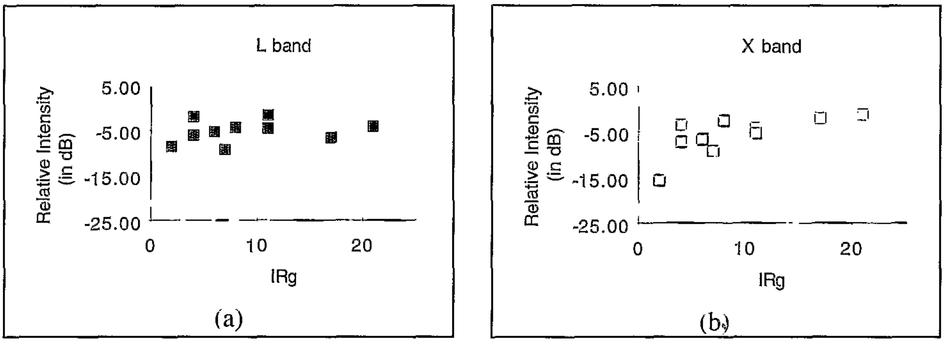


Figure 5a and 5b. Relative intensity (in dB) in the L (a) and X (b) bands, against IRg.

For the L band, backscattering remains stable between 0 and 20 values for IRg, which agrees with the Rayleigh Criterion (see above). For the X band, it can be seen that the extreme values of IRg are coherent with an increasing relation. The coefficient of multiplicative correlation r = 0.76, but the discrimination of IRg using backscattering in the X band seems impossible.

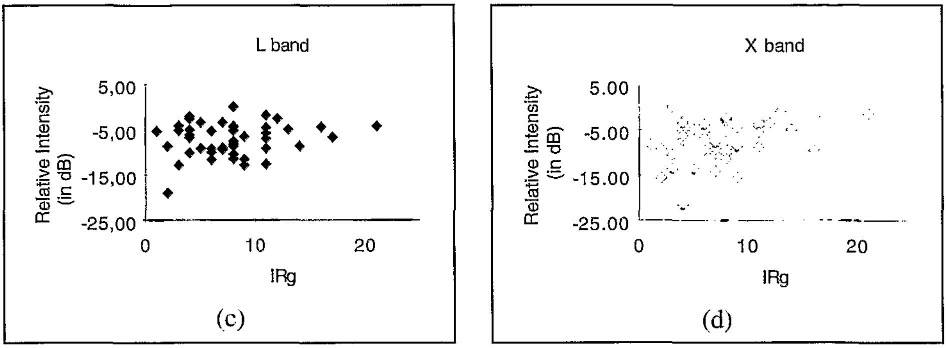


Figure 5c and 5d. Relative intensity (in dB) in the L (c) and X (d) bands, against IRg.

As a second step, all recorded plots were analysed (Figs. 5c and 5d), regardless of whether they lie in the "Terrats" or "En Ferran" test sites.

In both bands, point clusters are strongly dispersed in a field of 0 to -15 dB for such roughness values. No relationship can be seen between the roughness index as used and the backscattered signal. It is clear that the X band, which showed a trend between backscattering and IRg in Terrats only (Fig. 5b), does not permit the general extraction of this parameter.

According to the remarks on the Rayleigh criterion, no relationship can be expected in the L band. In the X band, however, it can help to distinguish plots with an Irg >10 cm from the others, even though this could not be clearly demonstrated with the limited data available. For this reason, we propose the following steps that are confirmed by results. The diversity of agricultural practice would lead to expect a strong diversity in roughness that should be accessible in the X band. During December, the earlier strong autumnal rains had wiped out most traces of tilling, and the recent hoeing led to surface bumps that were only about 1-2 cm high. It thus seems that surface roughness in Mediterranean vineyards during winter is too slight for discrimination from X-band data. For indices less than 10, no variation of consequence is reproduced, but when the IRg becomes 25, some soils with very typical roughness, e.g. after harrowing, can be recognized.

Periodic roughness

Introduction

One approach to calculating the backscattering coefficient of a composite surface such as that of vineyards, is to assume that the scattering is caused exclusively by the random surface and that the periodic component acts as a modulator of the local mean slope of the random-surface component. This method described by ULABY *et al.* (1982), was applied to the Réart vineyards using a sinusoidal surface model. Complex random roughness measurements made in the spring and autumn of 1994 were used to have a approximatively range of roughness according to the season.

The use of a backscattering model depends on roughness parameters and wavelength. Figure 6 shows a possible variation of σ_0/R_0 against vine-row angle, using the Geometric Optic (GO) Model (HALLIKAINEN, 1985), where R_0 is the Fresnel coefficient that determines moisture conditions. This model is easy to use as it includes conditions of the C band (23° incidence) from the April 1992 ERS-1 image, as well as of the X band (35.5° incidence) from the December 1992 E-SAR images.

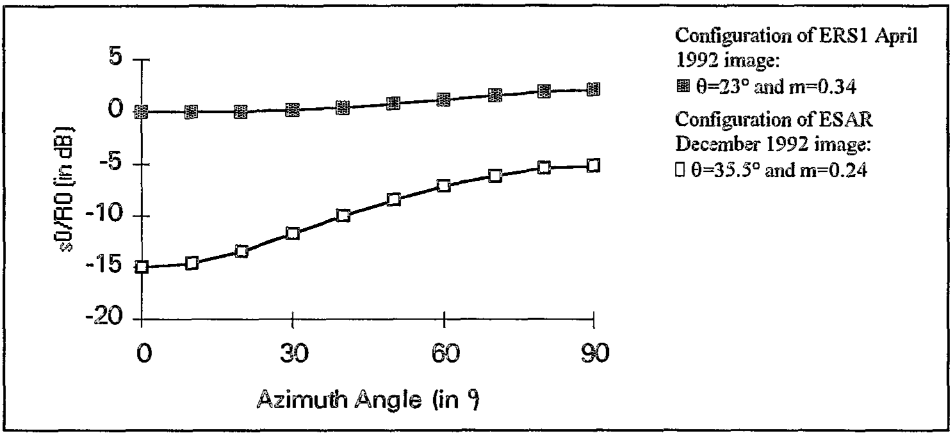


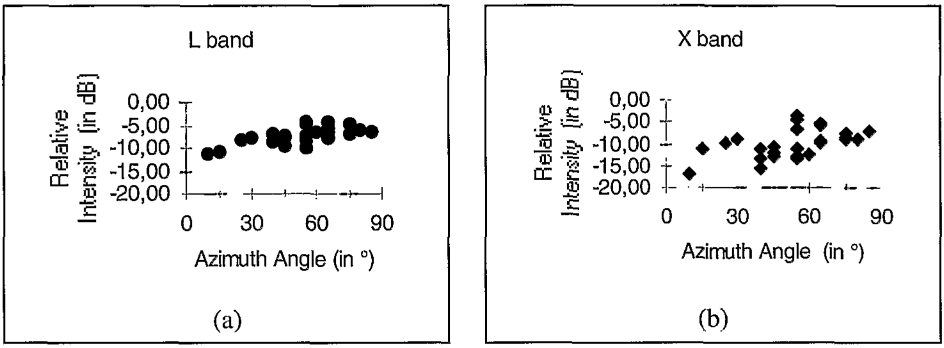
Figure 6. Geometric Optic Model perturbed by a sinusoidal surface: $z = A \cos(2\pi y/P)$, A=5.5 cm, P=1.5 m.σ_0/R_0 (in dB) against azimuth angle φ.

The relationship between backscattering coefficient and azimuth angle increases differently depending on incidence angle (θ) and roughness (m). This means that an incidence angle close to 35° (like E-SAR) provides a better configuration than 23° (like ERS-1) for vine-row discrimination, with a difference of 5 dB and 2 dB respectively from the 90° variation.

If we consider the L band (35° incidence) from E-SAR and JERS-1 data, the GO model cannot be applied. But a wavelength close to 25 cm (L band) provides better conditions than 5 cm (C band) or less (X band), for detecting periodic roughness with a height variation of 11 cm.

E-SAR data

The directional effect of vine rows was especially studied on the "Terrats" site. The plot structure was compared with radar data using the angle φ. In order to maintain an angle of incidence θ that is little variable, but conserving the maximum number of plots, only θ values between 34° and 37° were retained. The absence of calibration between the images making it impossible to compare the same plot for two flight lines, we analysed the influence of the azimuth angle φ for each investigated plot, by assigning it the relative average intensity of the plot (Figs. 7a and 7b).



Figures 7a and 7b. Relative intensity (in dB) in the L(a) and X (b) bands, in terms of the azimuth angle between the radar sight and vine rows.

In the L band, the N-S flight axis (Fig. 7a) shows increased backscattering with the azimuth angle φ (linear correlation coefficient r = 0.68). Row orientation thus seems to play a significant role that agrees with the theory of backscattering from periodic roughness (ULABY *et al.*, 1978; ULABY and BARE, 1979). A difference of 5 dB exists between the extreme φ values, i.e. for 75° variation. However, the E-W flight line (not shown) shows no significant trend and does not confirm this result, possibly due to the poor quality of radar data in this flight direction. In the X band, the correlation is much less clear because the same angle φ can give backscattering that varies up to 10 dB (Fig. 7b). This agrees with the expected results, as such wavelengths in theory should be more sensitive to random roughness. But extreme values correspond to a clearly increasing trend.

In conclusion, even though the data acquired for the E-W line do not provide a comparison, the obtained results are as follows: 1) the directional effect of vine rows is especially sensitive in the L band for an incidence angle θ of 34-37°; 2) good linear correlation exists (r = 0.68) between the azimuth angle φ and backscattered intensity. Where vine rows become perpendicular to the radar beam (increasing φ), the backscattered signal increases as well. This influence of row orientation on backscattering in the L band agrees with theory (ULABY and BARE, 1979) and the experimental work by other teams (e.g., BEAUDOIN *et al.*, 1990).

Satellite data

L-band data from the JERS-1 image, obtained in August 1992, can be compared with E-SAR data of the same frequency. Figure 8a shows backscattering values as a function of φ. The data were obtained over the same plots where the relief effect is nil. The point cloud is dispersed, backscattering is variable for each φ angle, and the correlation obtained from airborne data is difficult to reproduce for the satellite data. This may be due to several reasons. In August, leaves cover the grapevines and strongly modify plot structure, which may explain the strongly different backscattering behaviour for vine rows. Moreover, image quality was not very good and the low-pass filtering did not reduce the very obvious speckle.

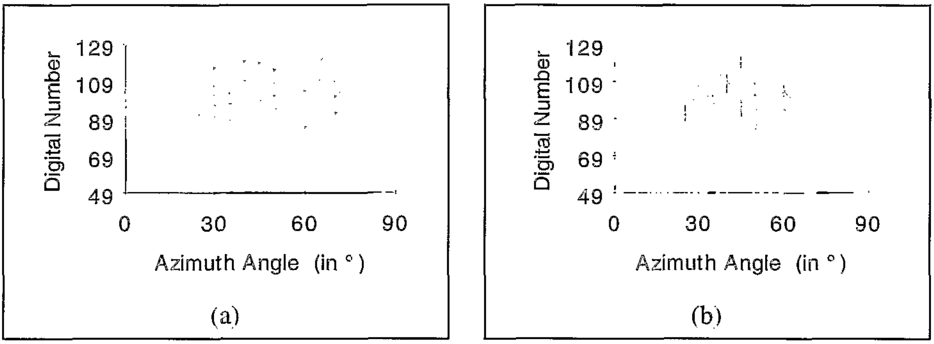
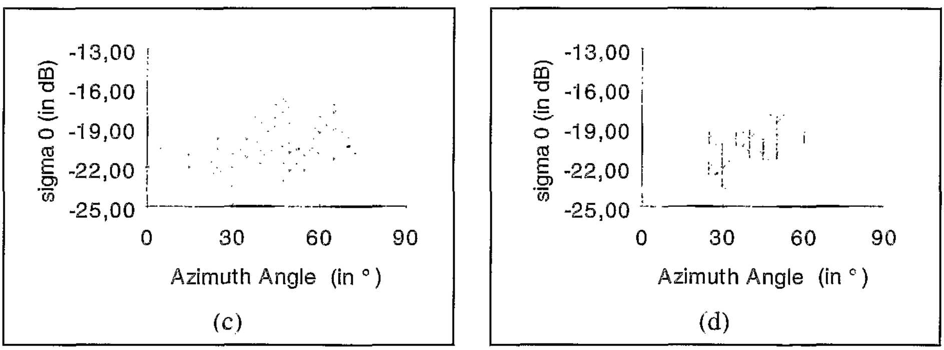


Figure 8a and 8b. Digital Number JERS-1 data plotted against the azimuth angle of vine rows, for all plots (a) and for plots with a surface area greater than 1 hectare (b).

The four images in the C band of ERS-1, acquired during that year, enabled the selection of a favourable date and filter (Vinci radar of MAPSAT software), taking account of the structure and texture of the three other images (LOPES *et al.*, 1993). Figure 8c shows the values of σ_0 (in dB) for the same reference plots. Backscatter variation with row orientation is noticeable. The still considerable dispersion of the point cluster decreases after elimination of plots that are too small for meaningful satellite observations (linear correlation coefficient = 0.63), (Fig. 8d).



Figures 8c and 8d. ERS1 data (in dB) plotted against the azimuth angle of vine rows, for all plots (c) and for plots with a surface area greater than 1 hectare (d).

Both satellite and airborne radar data thus seem to hold an interesting potential that is related to their sensitivity to the effect of row orientation. However, the low resolution from space at present still hinders signal inversion and a discrimination of orientation, in particular in view of the variations in plot size and in leaf cover of the grapevines.

Conclusions

The use of airborne radar provided data on the roughness parameters of vineyards, and enabled the successive analysis of their effect on the radar signal under different configurations. At this stage of the work, three main results can be identified:

- Vineyards have radar backscattering properties that are distinct from those of woods and built-up areas, in both L and X bands. Their distinction from scrubland and orchards is possible, but not systematically, with a clearer confusion in the X band than in the L band.

- The causes of this backscattering behaviour of vineyards were analysed in terms of the different levels of roughness found in wine-growing areas, i.e. soil-surface roughness, vine-row direction, and plot slopes:

- Theoretical considerations of surface roughness indicate that this effect would be noted only in the X band. Under the winter conditions of the radar survey, surface roughness was slight and rather different from that caused by cultivation work in spring. The absence of any effect of this parameter on the signal, agreed with the theory for band L, but was inconclusive for band X. This needs further study during a season with more diverse surface conditions because of agricultural work or another roughness parameter.
- The directional effect of vine rows has little effect on the X band, but is clearly shown in the L band. Correlation $r = 0.68$ between the backscattered signal, and the azimuth angle made by vine rows and the radar beam. This result confirms the theoretical expectations and is very encouraging.

- The long-term objective remains to obtain complementary satellite-data parameters to those provided by sensors in the visible and near-infrared domains. The results from the airborne radar survey and the directional effect of vineyards, were thus transposed to data from the JERS-1 (L band) and ERS-1 (C band) satellites. Strong limitations were imposed by: the plot size that is not very suitable for the 30 m satellite resolution; the uneven quality of the satellite data; and the level of processing needed for speckle reduction. Even so, the average backscattering variation of plots in terms of vine-row orientation was clear from the ERS-1 data, and should be confirmed by better pre-processing of the SAR images.

It is thus clear that hyperfrequencies can provide the key for discriminating vineyards and gaining access to data on the main runoff directions inherent in this type of cultivation. This approach would help to complete the description of catchment areas in terms of runoff and erosion risk, particularly in the wine-growing domain where satellite data from the visible and NIR domains are rather limited.

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