ERS-2 SAR Soil Moisture and Herbaceous Biomass Monitoring across a semi-arid transect in Israel

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ABSTRACT

Relationships between radar backscattering coefficient (σ^0) and environmental parameters of volumetric soil moisture and biomass were empirically investigated in two sites. These sites represent an annual rainfall change from 450 mm to 250 mm across a semiarid transition zone between Mediterranean and arid environments in Israel. A strong linear correlation was found between ground measurements of volumetric soil moisture taken place at the two sites in three different dates and corresponding radar backscatter intensities measured from ERS-2 SAR images. The slope and intercept values of the regression equation are similar to those reported in other regions of the world.

Relationships between the radar backscatter and Herbaceous biomass were examined in areas of homogenous vegetation cover. Results show strong linear correlation between Herbaceous biomass measured in the field and the ERS-2 backscatter.

INTRODCUTION

Soil moisture and vegetation biomass are primary parameters needed for understanding the environmental dynamics of Mediterranean regions. Desertification processes which take place at the margins of these regions are characterized by changes in the physical, chemical and biological properties of soils (Lavee et. al., 1993) and in the structure of natural vegetation . Remote sensing have shown its potential for studying relationships between vegetation and soil properties across transition zones (Shoshany et. al., 1995), However, most of the existing remote sensing applications in this field are based on data from sensors in the visible and infrared spectral bands which are limited in their sensitivity to volumetric information. Understanding the relationships between the volumetric properties of soil moisture content and the biomass with radar backscattering will allow better monitoring of the extent and dynamics of desertification using remote sensing data. Numerous radar remote sensing studies have shown the potential of this data source for analysing soil moisture and biomass in various regions of the world, however, there is lack of knowledge regarding the radar backscatter response to moisture content change across transition zones between Mediterranean and arid climates. The objective of this paper is to assess empirically the relationship between the volumetric soil moisture and biomass with the ERS-2 backscatter in two sites along a transect in the semi-arid zone of Israel.

STUDY AREA

The two research sites : Avisur Highland and Lehavim represents semi-arid phyto-geographical zone along a north – south rainfall gradient with annual average betwee 450 mm and 250 mm. The dominant rock formation is mostly chalk with patches of Calcrete and the dominant soil is Brown Rendzina (Haploxerolls). Vegetation in this area varies from shrublands and garigue (dominated by *Quercus calliprinos* and *Phillyrea latifolia*), through dwarf shrubs (dominated by *Sarcopoterium Spinosium*) to open areas with diverse grasslands vegetation (dominated by *Gramineae*). The spatial patterns represent wide range of transitional stages between areas of high homogeneity of mainly tall shrubs and grasslands with different compositions of the three life-forms. This diversity of patterns is a result of a long history (since the late bronze, approximately 5500 years ago) of human activity. Land use in this area is composed of agricultural crops in the wadi's and rangelands with controlled grazing pressures . The study area is characterised by wide range of "regeneration and degradation patterns" (Naveh and Kutiel, 1990) of patches representing various soil-vegetation relationships which will allow generalization of the methods to wider areas of transition between

Mediterranean and arid regions.

SATELLITE IMAGE PROCESSING

Three ERS-2 SAR images of 1997 (March, April and May) were found available for this study representing seasonal soil moisture fluctuations along the climatic gradient . Since the rainfall in this region continues typically until the end of March or mid April , the first characterise almost the highest soil moisture while April and March dates represent the soil drying processes. Radiometric calibration of the ERS-2 images was carried out according to the method described by Laur *et al*. (1997). The derivation the backscattering coefficient (σ^0) from DN value of ERS-2 SAR PRI image is given by :

$$\sigma^0 = [\ N^{-1}\ \Sigma^{ij=N}_{ij=1}\ DN^2_{ij}\ ]\ \ K^{-1}\ \ C\ (\sin\alpha\ \ \sin\alpha_{ref}\ ^{-1})$$

Where :

- DN^2 is given following the application of a median filter to reduce speckle effects;
- K is the calibration constant with reference to the processing centre (I-PAF in this work);
- C accounts for updating the gain due to the elevation antenna pattern;
- α and α_{ref} are the average and reference incidence angle respectively.

In this form, equation 1 neglects two parameters which appear in Laur et. al., (1997): the ratio between PRP (Product Replica Power) and RRP (Reference Replica Power) and the PowerLoss effect. The first ratio can be ignored since there were no variations of the Replica Pulse Power with respect to the Calibration Pulse Power in the ERS-2 data. Since there was not found evidence for saturation in the ERS-2 data , the Power loss effect can be assumed to be of neglected magnitude as well .

Since the study area is characterised by hilly terrain, the backscattering intensity was adjusted according to the local angle of incidence (with respect to the normal of the slope) as derived from a Digital Elevation Model (DEM) using the following equation:

$$\sigma = \sigma_0 \cos\theta_I = \sigma_0 (\cos\theta_n \cos\theta_z + \sin\theta_n \sin\theta_z \cos\phi_z \cos\phi_n + \sin\theta_z \sin\phi_z \sin\theta_n \sin\phi_n)$$

Where θ_z and ϕ_z are the zenith and azimuth angle of the source, θ_n and ϕ_n are the zenith and azimuth angles of the normal to the surface, σ_0 is the backscattering from a unit area perpendicular to the beam measured at the surface of the Earth and θ_i is the angle between the direct radiation and the normal to the surface.

Calculation of the local angle of incidence for each of the ERS-2 image' pixels required accurate co-registration of the image to the DEM. The Root Mean Square error of the registration conducted using the PCI image processing (Version 6.03) was less than one pixel.

RELATIONSHIPS BETWEEN SOIL MOISTURE AND RADAR BACKSCATTER

The microwave backscatter from a given bare soil location is determined by the local slope and aspect, the roughness and the soil dielectric constant. Since the dielectric constant of water is about 80 whereas that of dry soil is less than 5, the dielectric constat of soils is most indicative of their moisture content (Mattikalli *et al*. 1998). Most researches describe the relationship between microwave backscattering and the volumetric soil moisture (for 0 to 5 cm depth) as a strong-positive linear correlation. This relationship found to be valid in different spatial scales provided by three data sources: satellites (Wooding *et al*. 1993), airborne sensors (Estes *et al*. 1977; Prevot *et al*. 1993a) and ground scatterometers (Ulaby *et al*. 1978). The radar backscatter (σ^0) of soil with varying moisture content is given by :

$$\sigma^0[\text{dB}] = a\ m_v + b$$

Where a and b are empirical coefficients and m_v is the volumetric soil moisture.

Relatively high correlation coefficients were reported in various studies (Table 1) under different research configurations including several scatterometer types for radar band C (3.9 – 5.75 GHz) with various spatial resolutions, incident angles and polarizations. The line intercept values as related to dry soil conditions recorded at the different soil types represented in these studies showed only limitted variation between –12.33 to –14.89 dB (except for one case study). Regression line's slopes exhibited relatively much larger variation between the values of 0.2 and 0.4.

In order to assess these relationships across the semi-arid transect in Israel, soil moisture samples were taken from ten bare terrain plots at the time of the ERS satellite passages. The plots were designed to represent different topographic conditions at each of the sites (valley bottom, and several locations across the hill slopes). Approximately ten samples were collected at each plot along a 100 m' length line characterising a relatively homogeneous area (this sampling procedure was carried out under the instructions and supervision of the Soil Conservation Department of the Ministry of Agriculture). Differential GPS readings were taken at each sample to allow accurate linking of the soil data to ERS-2 image pixels. Gravimetric soil moisture was calculated based on the "double weight" method (Kramer 1949, p 73). The samples taken along the plots were collected into sealed plastic bags, weighted before and after burning in 104^0C for 24 hours. Gravimetric soil moisture [%] were calculated and converted then to volumetric soil moisture [%] based on bulk density assessments of both study sites.

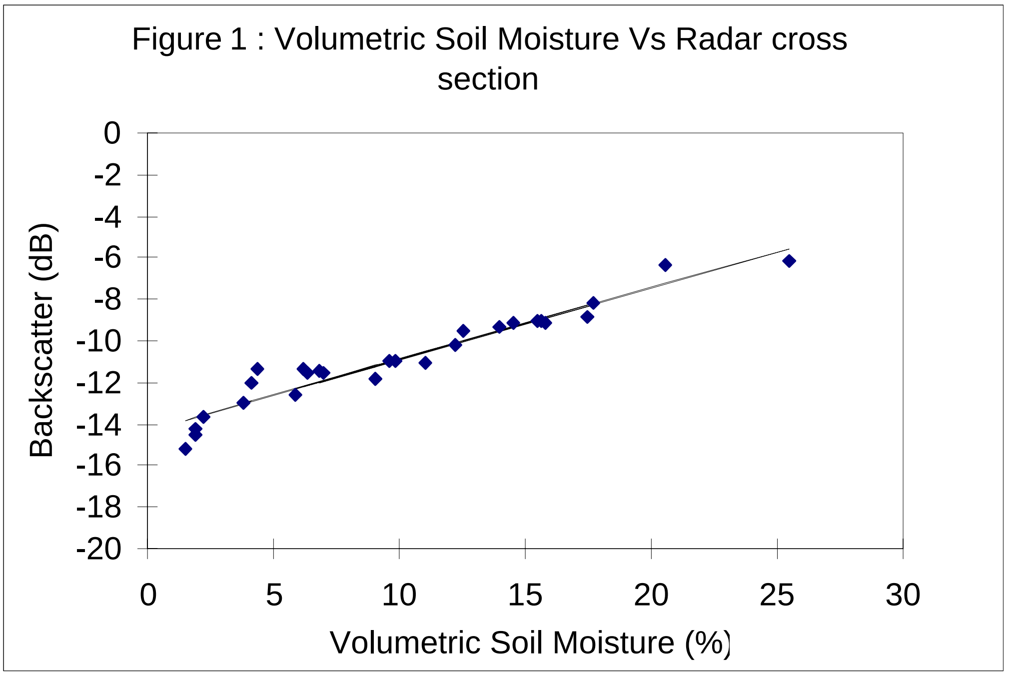
The volumetric soil moisture data were related to ERS-2 backscatter [dB], at both sites, using a linear regression model. Results showed high similarity between the slope and intercept values determined in both sites (Table 2). A statistical test was then carried out using Williams (1984) method, for questioning whether the regression lines obtained in the two sites could be regarded as representing the same phenomenon . This test combines an ordinary two-tailed F test for examining the standard errors of the data points about the regression lines and Student's t tests for examining the slopes and intercepts of the regression lines. Results have shown that the difference between the lines is only due to sample errors which means that these two samples basically represent the same population. Therefore, the two samples can be combined to form a unified model (figure 1) despite the differences between soil characteristics in both areas.

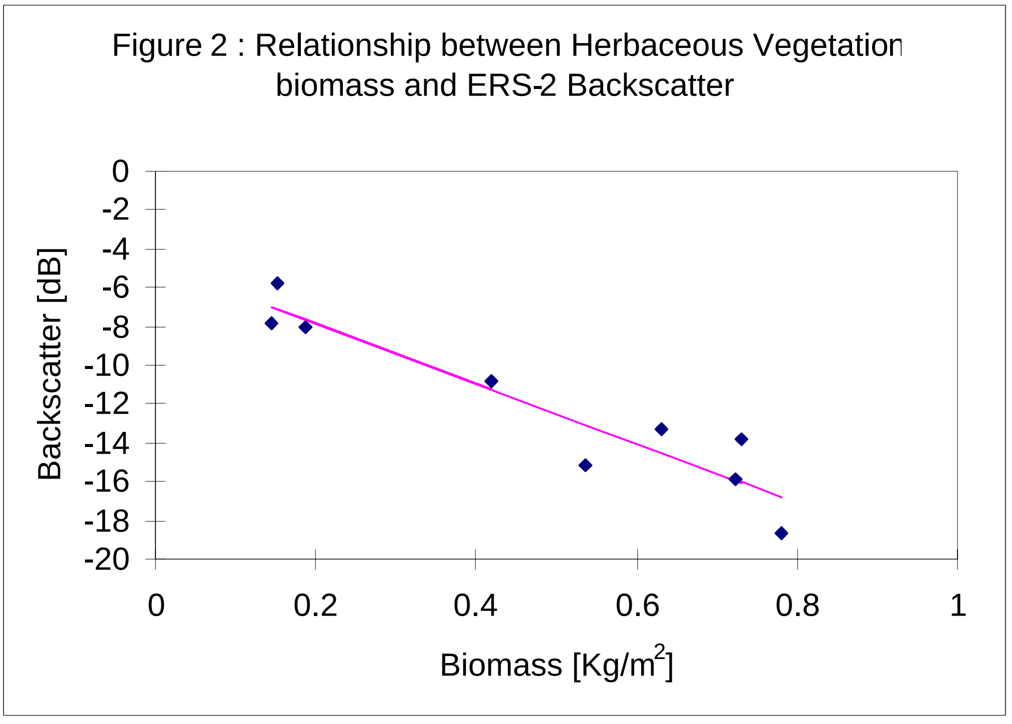
Table 1: Volumetric soil moisture and radar backscattering C band relationship:

Authors	Scale	Polarisation	Incidence Angle [^{0}]	Soil Depth [cm]	Intercept	Slope	Correlation Coefficient R^2
Bernard *et al*, 1982	Ground	HH	12	0-5	-10.48	0.4	0.85
Mo *et al* 1984	Airborne	HH	20	0-2.5	-14.6	0.24	
Bruckler *et al* 1988	Ground	HH	20	0-5	-12.96	0.342	0.92
Prevot *et al* 1993	Airborne	HH	20	0-5	-13.4	0.304	0.82
Wooding *et al* 1993	Airborne	VV	23	0-5	-14.53	0.262	
Ji *et al* 1995	Airborne	VV HH	45	0-5	-13.99 -13.89	0.368 0.384	0.75 0.78

Table 2: Regression Coefficients representing Radar backscatter and soil moisture relationships in the study area :

Site	Slope	Intercept	R^2
Avisur	0.332	-14.125	0.93
Lehavim	0.355	-14.462	0.91
Unified data set	0.34588	-14.332	0.92





The results obtained for the semi-arid transect are consistent with those reported earlier from the litrature as obtained in other parts of the world (Table 1). Both the intercept values and the slope values are within the range of values found there. It is important to note that the intercept values in all of these studies vary in a very limitted range between 12.66 and 14.55, thus suggesting that this value may be indicative of zero soil moisture in wide regions around the world.

HERBACEOUS BIOMASS AND RADAR BACKSCATTER RELATIONSHIPS

Herbaceous yield in the semi-arid region is sensitive to the rainfall . Its phenology in natural conditions and in a year of typical rainfall pattern is characterised by high vegetation cover increase between December and mid February . The state of maximum biomass is reached at the end of March. Field assessment of biomass were conducted according to the "harvest and estimate" method (Tadmor et al, 1975). The data collected included 9 plots of 100 meters length in areas of homogenous cover , were 100 visual estimations were recorded and then calibrated against data from 10 harvests corresponding to 10 visual assessments. Four of the data points (plots) were representative of the February biomass and five data points were collected at the beginning of April. All these biomass measurements were taken place at the same day of the corresponding ERS overpass.

Figure 2 provides a graphic presentation of the relationships obtained between the backscatter data and the biomass. The radar signal was found to correlate very well with biomass changes.

SUMMARY AND CONCLUSIONS

Relationships between radar backscattering coefficient (σ^0) and environmental parameters of volumetric soil moisture and biomass were empirically investigated in two sites. These sites represent an annual rainfall change from 450 mm to 250 mm across a semiarid in Israel characterizing transition zones between Mediterranean and arid environments in other parts of the world. Strong linear correlations were found between ground measurements of volumetric soil moisture and herbaceous biomass taken place at the two sites in three different dates and corresponding radar backscatter intensities measured from ERS-2 SAR images . The regression equations determined can be used in future studies for mapping biomass and soil moisture in the semi-arid zone along rainfall gradients.

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