The potential of C- and L- band SAR in assessing vegetation biomass: the Ers-1 and JERS-1 experiments

Pampaloni Paolo Istituto di Ricerca sulle Onde Elettromagnetiche CNR Via Panciatichi 64, 50127 Firenze, Italy pampa@iroe.fi.cn.ir - http://wmicro.iroe.fi.cnr.it
Macelloni Giovanni Istituto di Ricerca sulle Onde Elettromagnetiche CNR Via Panciatichi 64, 50127 Firenze, Italy microrad@iroe.fi.cn.ir - http://wmicro.iroe.fi.cnr.it
Paloscia Simonetta Istituto di Ricerca sulle Onde Elettromagnetiche CNR Via Panciatichi 64, 50127 Firenze, Italy paloscia@iroe.fi.cnr.it - http://wmicro.iroe.fi.cnr.it
Sigismondi Simone Istituto di Ricerca sulle Onde Elettromagnetiche CNR Via Panciatichi 64, 50127 Firenze, Italy microrad@iroe.fi.cnr.it - http://wmicro.iroe.fi.cnr.it

Abstract

The sensitivity to herbaceous and arboreous vegetation biomass of backscattering coefficient measured by ERS-1 and JERS-1 radars is discussed and compared with the best results achieved using the multi-frequency polarimetric AIRSAR data. Experimental results obtained on Montespertoli test site show that, measurements with JERS-1 L-band SAR (θ = 35° incidence angle) are able to detect vegetation growth, while, at the observing parameters of ERS-1 SAR (C-band, θ = 23°), the relation between backscattering and vegetation biomass is more complicated and depends on crop type and appears significantly affected by soil moisture.

Keywords: vegetation biomass, ERS-1, JERS-1, microwave backscattering

Introduction

Experimental and theoretical investigations carried out by many scientists worldwide have shown that microwave backscattering from land surfaces is sensitive to vegetation features. The dielectric characteristics of vegetation material are indeed strongly influenced by moisture content over a wide range of the microwave spectrum. In addition geometrical features of plant constituents affect scattering in a different fashion according to frequency and polarization; so that a properly designed sensor can give significant information on the whole canopy cover.

Although in general the results of the investigations are encouraging [Ref. 1-3], the obtained experimental data are sometimes neither entirely in agreement with each other nor with theoretical models, and research is still in progress to interpret radar backscattering and to model the mechanism of interactions between microwave and natural surfaces.

In order to achieve a detailed prediction of vegetation backscattering, physical models of a canopy should take into consideration several details of soil and crops such as density, dimension, orientation and shape of stalks, stems and leaves. On the other hand, most of the applications require the estimates of global parameters, useful for agricultural management and yield prediction, such as leaf area index (LAI, in m^2/m^2) or plant water content (Q, in kg/m^2). Thus much research has been addressed to the establishment of direct relations (theoretical and experimental) between the remote sensing measurements and the above-mentioned crop global parameters.

A significant experiment for evaluating SAR capability in monitoring vegetation biomass has been carried out on the Montespertoli area, close to Florence, Italy [Ref. 4]. The site has been imaged by ERS1 and JERS-1 satellites and by the NASA/JPL AIRSAR and SIRC at several dates between 1991 and 1994. This experiment allowed us to collect a large data set with multi-temporal, multi-frequency and multi-incidence angle polarimetric SAR measurements together with ground truth data.

This paper intends to single out the contribution achievable from radars onboard of ERS and JERS satellites in assessing vegetation biomass. For the ensemble of crops cultivated in the Montespertoli area, the highest correlations with plant biomass have been noted at L band. Although the more suitable indicator of crop growth seems to be the crosspolarized backscattering, the s° at HH polarization and q = 35° as measured by JERS-1, is also sensitive to the increase of biomass. At the observation parameters of ERS-1 (C-band, VV pol.q=23°) the backscattering is significantly influenced by the soil characteristics and its relation with vegetation biomass strongly depends on crop type. The L-band backscattering has also been found to be sensitive to arboreous biomass, although the signal tends to saturate quite rapidly as woody volume increases.

The test site and the experiment

The selected site "Montespertoli" is located in Tuscany (Italy) south of Florence. The site is a representative area of those ThyrrenianAppennine slopes where bedrock is made up of PlioPleistocene marine and fluviolacustrine soft sediments which are intensively affected by geomorphological processes of erosion and mass movements. More than half of this area is hilly (the average height is about 250 m) with wood, agricultural fields and some urbanization. The remaining part is flat with alluvial wetlands of Pesa river, agricultural fields and urbanization. Crops are mostly vineyards, olive groves, wheat and pasture land, in the hills; corn, sunflower, alfalfa and sorghum in the flatlands. The average fields dimension is about 4 ha.

The site was imaged on different dates by the ERS-1 C-band Synthetic Aperture Radar and by the JERS-1 L-band SAR. On the same site other data have been taken at different incidence angles q between 20° and 50°, by the airborne JPL polarimetric SAR (AIRSAR) operating at P-, L- and C- band, during the Multi-sensor Airborne Campaign (MAC91) in 1991, [Ref.4] and by the SIR-C/X-SAR (X-, C- and L-bands) in April and October 1994.

A summary of SAR data collected with ERS-1 and JERS-1 radars during the experiment is shown in TABLE I

	Freq. Band	**Pol.**	**Theta**	**Ground Resol. (m)**	**Dates**
ERS-1	C	VV	23°	30 x 26.3	29/5/92 07/8/92 24/4/94
JERS-1	L	HH	35°	18.3x24.6	24/6/92 14/4/94

TABLE I: Summary of processed SAR data

The area was equipped with trihedral corner reflectors deployed along the flight lines. In addition, a few "extended homogeneous targets", namely three plots of bare soil with different surface roughness, one field of alfalfa and one of sunflower, had been specifically prepared, in the same sub area, to be used as cross-reference between various missions.

Calibrated backscattering coefficients from ERS-1 C-SAR and JERS-1/L-SAR, including correction for antenna pattern and range spreading loss, have been obtained according to technical documentation respectively provided by ESA and NASDA. The mean value of backscattering coefficient of 92 fields has been obtained by averaging the values of all the pixels belonging to each field. The investigated surface types include: bare soil with different surface roughness, alfalfa, corn, colza, sunflower, and sorghum crops, olive-groves, vineyards and a few forested areas.

The ground data, which were collected on selected fields at the same time as the remote sensing measurements, regarded all the significant vegetation and soil parameters, namely: soil: moisture and surface roughness, crop classification, crop conditions, leaf area index (m^2/m^2), plant water content (kg/m^2), plant height and density, number and dimension of leaves, diameter of stems.

Experimental results

To show the sensitivity of different frequencies to the geometry of various surface types, and so to the different scattering elements, a direct comparison between calibrated ERS-1 C- band SAR data delivered by ESA/ESRIN and data collected at L - band, HH pol, q = 35 with JERS-1 L-band data from JERS-1 has been carried out, as shown in Fig.1 Data refer to 1994 passages. It can be noticed that, as expected at C-band, the backscattering s° is generally higher than at L-band. In addition the two-dimensional diagram shows that herbaceous crops (lowest s°) can be separated from forests and vineyards (highest s°) and from bare soils (intermediate s°).

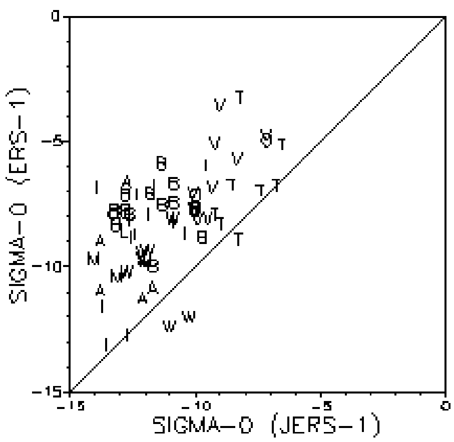

Figure 1 *- $s°_{VV}$ at C-band (ERS-1) as a function of $s°_{HH}$ at L-band (JERS-1). Labels represent: B=bare soil, W=wheat, I=uncultivated, A=alfalfa, M=meadow, O=olive-groves, V=vineyards, T=forest*

Sensitivity to vegetation biomass

Previous investigations have pointed out that biomass retrieval can be satisfactorily achieved only after a correct classification of agricultural fields since different plant geometries produce different biomass sensitivities [Ref. 5]. On the other hand classification is better accomplished by using multi-frequency polarimetric SAR measurements, indeed it has been shown that P-band data are effective in discriminating among broad land surface categories, L-band data allow identification of well developed 'broad leaf' crops (sunflower and corn), whilst C-band are useful for discriminating different kinds of herbaceous crops even in the case of moderate growth [Ref. 6].

Herbaceous crops

From the analysis of multi-frequency polarimetric data it has been shown that the highest correlation of backscattering to plant growth has been noted at L-band in cross polarization, indeed $s°_{HV}$, which is very low for

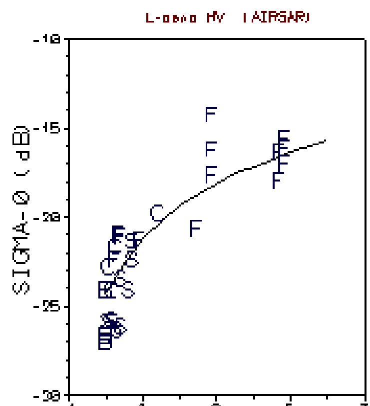

Figure 2 *- $s°_{HV}$ L-band as a function of plant water content (PWC) measured with AIRSAR at q = 35° (B=bare soil, S=sorghum, F=sunflowe, C=corn)*

smooth bare soils, gradually increases with vegetation biomass and saturates when plants are close to the maximum development (Fig. 2) [Ref.6]. However,

although to a lower extent, also $s°_{HH}$ measured by JERS-1 and AIRSAR at q = 35°, is well sensitive to plant growth as shown in Fig. 3 where the lowest backscattering values are associated with moderately (tilled or rolled) rough bare soils and with sorghum fields at a very early stage of growth, while the highest values are associated with well developed sunflower.

The regression equations for the two cases are respectively:

$$s°_{HV} = 10 \log (0.0039 \text{ PWC} + 0.0038) \quad [r^2 = 0.7]$$

$$s°_{HH} = 10 \log (0.026 \text{ PWC} + 0.036) \quad [r^2 = 0.6]$$

At the observation parameters of ERS-1 (q = 23°, C-band, VV pol.) the relation between backscattering and plant water content depends on crop type and results significantly affected by soil moisture, indeed ERS-1 data collected in August, when soil moisture was very dry (<10%), are generally lower than those collected in

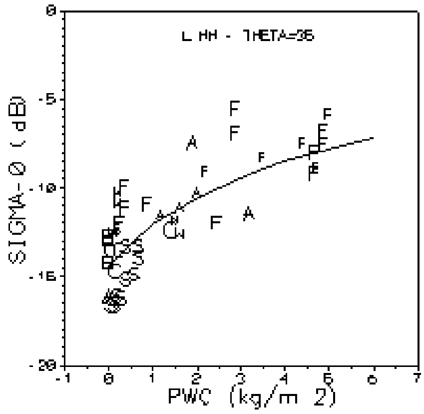

Figure 3 *- $s°_{HH}$ at L-band q= 35°, measured with AIRSAR and JERS-1 (small letters) as a function of plant water content (PWC). Labels represent F=sunflower, C=corn, W=wheat, A=alfalfa, S=sorghum, M=meadows, B=bare soil.*

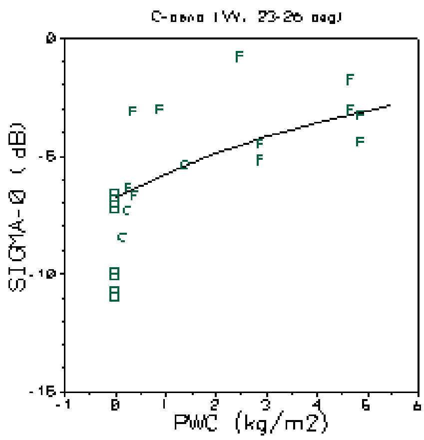

Figure 4 *- $s°_{VV}$ at C-band, q=23°, measured with ERS-1 and AIRSAR as a function of plant water content (PWC) of broad leaf crops (F=sunflower, C=corn, B= bare soil)*

May when the average soil moisture was close to the field capacity. Fig 4 shows that, for broad leaf crops (sunflower, corn), s° increases as vegetation grows and rapidly saturates as soon as the plant water contentattains 2 Kg/m^2 . The regression equation is:

$$s°_{VV} = 10 \log (0.057 \text{ PWC} + 0.21) \quad [r^2 = 0.35]$$

On the other hand, for small leaf crops (wheat, alfalfa) s° decreases as plant water content increases (Fig. 5).

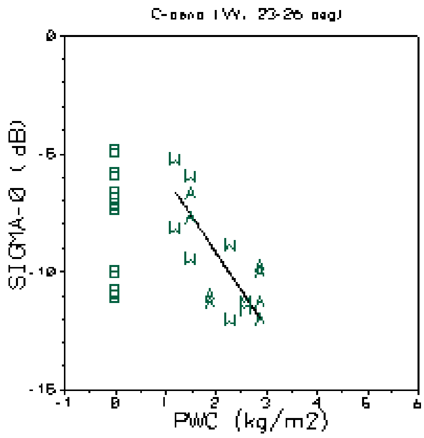

Figure 5 - s_{VV} measured with ERS-1 and AIRSAR as a function of plant water content (PWC) of small leaf crops (W= wheat, A = alfalfa, B= bare soil)

In this case we have the following regression

$$\sigma°_{VV} = - 2,3 \text{ PWC} - 5 \ [r^2 = 0.5]$$

This trend, which was already noted at X band [Ref. 6], can be explained with a major role played by the absorption.

Arboreous vegetation

The best performances for estimating arboreous biomass have been noticed at the lower frequencies (P and L-band) and at cross (HV) polarization. However, also the copolarized signals from JERS-1 and ERS-1 show a significant increase with forest biomassas shown in Fig. 5 and 6, where the backscattering coefficient is compared with woody volume of several small forests. In the first case the woody volume is expressed by the basal area (i.e., normalized trunk base areas in m²/ha) multiplied by the average height of trees (m) and in the second case by the simple basal area. In addition, by combining data fron the two sensors a good separation between clear cut and forest areas has been achieved (Fig. 7)

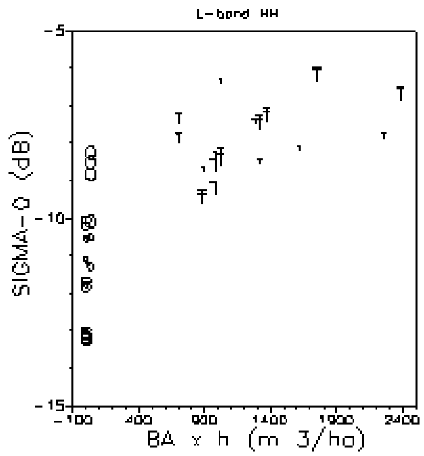

Figure 6 - *$\sigma°_{HH}$ (at L-band, θ=35°) measured with JERS-1 (small labels) and AIRSAR as a function of woody volume of forests (T). In the same diagrams also the $\sigma°$ values of clear-cut (B) and olive-groves (O) are also represented.*

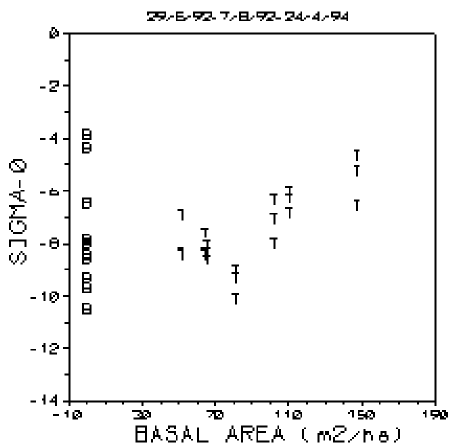

Figure 7 - *$\sigma°_{VV}$ at C- band (ERS-1) as afucntion of basal area of trees*

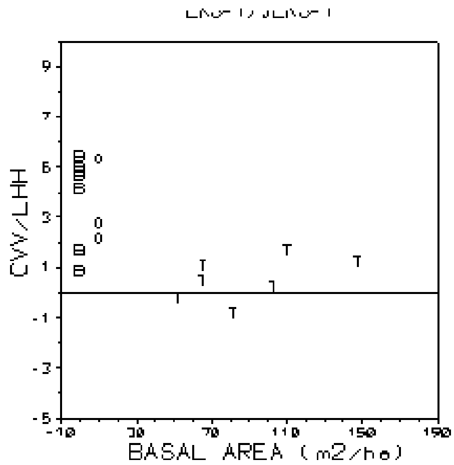

Figure 8 -*$\sigma°_{VV}$ (ERS-1)* ***-****$\sigma°_{HH}$ (JERS-1) as a function of basal area of trees*

Conclusions

In order to retrieve vegetation biomass by means of a microwave sensor we desire a monotonic variation of backscattering from bare soil to developed vegetation with saturation at the highest biomass value.Considering SAR data presentely available to the scientific community this trend is better accomplished at L band HV pol for herbaceous crops and at P band HV pol. for forests. Unfortunately these configurations are not available from satellite. On the basis of data collected on Montespertoli site, L band data from JERS-1 appear, although to a lower extent, still useful to monitor biomass of both herbaceous crops and forests.

As for C band data from ERS-1, the relation betwen backscattering and vegetation biomass is more complicated, since it depends on crop type. However, once broad leaf crops are separated from small leaves, an appreciable sensitivity is noted. Also for detecting biomass of forest C-band data show some usefulness especially to detect clear cut areas.

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