MAC-91: POLARIMETRIC SAR RESULTS ON MONTESPERTOLI SITE

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S. Baronti (*), S . Luciani (**), S. Moretti (***),
S. Paloscia (*), G. Schiavon (**) and S. Sigismondi (***)

(*) Istituto di Ricerca sulle Onde Elettromagnetiche - CNR
Via Panciatichi 64, 50127 Firenze (I)
(**) Dipartimento di Ingegneria Elettronica, Università Tor Vergata
Via della Ricerca Scientifica, 00133 Roma (I)
(***) Dipartimento di Scienze della Terra, Università di Firenze
Via La Pira 4, 50121 Firenze (I)

1. INTRODUCTION

The polarimetric Synthetic Aperture Radar (SAR) is a powerful sensor for high resolution ocean and land mapping and particularly for monitoring hydrological parameters in large watersheds. There is currently much research in progress to assess the SAR operational capability as well as to estimate the accuracy achievable in the measurements of geophysical parameters with the presently available airborne and spaceborne sensors. An important goal of this research is to improve our understanding of the basic mechanisms that control the interaction of electromagnetic waves with soil and vegetation. This can be done both by developing electromagnetic models and by analyzing statistical relations between backscattering and ground truth data. A systematic investigation, which aims at a better understanding of the information obtainable from the multi-frequency polarimetric SAR to be used in agro-hydrology, is in progress by our groups within the framework of SIR-C/X-SAR Project and has achieved a most significant milestone with the NASA/JPL Aircraft Campaign named MAC-91. Indeed this experiment allowed us to collect a large and meaningful data set including multi-temporal multi-frequency polarimetric SAR measurements and ground truth.
This paper presents some significant results obtained over an agricultural flat area within the Montespertoli site, where intensive ground measurements were carried out. The results are critically discussed with special regard to the information associated with polarimetric data.

2. EXPERIMENT DESCRIPTION

During the Multisensor Airborne Campaign (MAC-91), the site of Montespertoli (Italy) was imaged on three different dates (22 June, 29 June and 14 July) by the airborne JPL polarimetric SAR (AIRSAR) operating at P-, L- and C- band (Canuti et al., 1992). Three passes were performed during each flight data, in order to cover the most significant sub-areas with different incidence angles θ between 20° and 50°. Nominal pixel sizes obtained on the 16 looks images were 6.6 m in range and 12 m in azimuth. The test site covers the basins of two small rivers and contains a relatively large flat area, along the border of the Pesa river, which includes agricultural fields of various crops (i.e. alfalfa, colza, corn, sorghum, sunflower, wheat) bare soils, olive-yard, vineyards and a few small forests. The area was equipped with two trihedral corner reflectors of 180 cm and one of 240 cm, supplied by the JPL, and deployed along the Pesa river. 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 act as "distributed" calibrators. 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, such as leaf area index (LAI), plant water content (PWC), dimensions of leaves and stalks, soil moisture content and roughness. During the experiment the average gravimetric soil moisture of the first 5 cm layer changed from about 15-20 % (on

June 22) to about 10% (on July 14). At the same time the leaf area index (m^2/m^2) of sorghum and corn increased from ~ 0.5 to ~ 3.5, that of sunflower from ~ 0.5 to ~ 3.5. Alfalfa leaf area index ranged from ~ 0 to ~ 4. Wheat and colza were in the ripening stage and therefore their LAI was almost 0; some of these fields were harvested at the time of the last flight.

3. DATA ANALYSIS

Calibrated (amplitude and phase) polarimetric data, collected over the agricultural area on alfalfa, corn, colza, sunflower, sorghum, bare soil, olives, vineyard and on a few forested areas, at incidence angles of 35° and 50°, have been analyzed.

Background - Scattering sources may be grouped in broad categories, each associated to typical scattering behaviors, as shown in recent works (e.g. Ulaby et al. 1990, Van Zyl 1989). In particular: a) Soil response is a surface scattering effect. This effect is important for bare soils and, in general, at low frequencies, where many agricultural crops are rather transparent. σ°_{RL} is appreciably higher than σ°_{RR} and σ°_{HV} is low. At lower frequencies (P and L band) $\sigma^\circ_{VV} > \sigma^\circ_{HH}$, as predicted by the Small Perturbation surface scattering model (Ulaby et al. 1982), while at higher frequencies (C band) $\sigma^\circ_{VV} \approx \sigma^\circ_{HH}$. b) Vertical structures, like forest trunks and crop stalks, produce double-bounce scattering. In general, this mechanism is important at P band for forests and at L band for some agricultural crops like corn and sunflower. σ°_{HV} is low, as in the soil scattering case, but, differently from the soil, σ°_{HH} is generally higher than σ°_{VV} and the large difference between σ°_{RL} and σ°_{RR} disappears. c) Ensembles of inclined cylindrical structures, like forest branches and crop stems, produce volume scattering with an appreciable presence of multiple scattering. The differences $\sigma^\circ_{HH} - \sigma^\circ_{HV}$ and $\sigma^\circ_{VV} - \sigma^\circ_{HV}$ are much lower than those for soil and vertical structures. In circular polarization, $\sigma^\circ_{RL} \approx \sigma^\circ_{RR}$. d) Ensembles of inclined planar structures, like leaves, also produce volume scattering; however, an appreciable amount of single "facet" scattering is present. $\sigma^\circ_{HH} - \sigma^\circ_{HV}$ and $\sigma^\circ_{VV} - \sigma^\circ_{HV}$ differences are relatively low, similarly to the cylinder case, but at circular polarization, the "facet" effect generates appreciable positive $\sigma^\circ_{RL} - \sigma^\circ_{RR}$ differences. The scatterer dimensions have important effects too. Let branches and stems be represented as ensembles of cylinders with the length proportional to the radius. For a canopy of equal cylinders, the backscatter coefficient changes with the cylinder length (expressed in wavelengths) and shows a maximum (Karam et al. 1992). It follows that, for each band, there is a range of cylinder dimensions generating a dominant contribution to the backscatter. For leaves, which can be described as discs, scattering is dependent on thickness and moisture content (Ferrazzoli et al. 1993).

4. SURFACE TYPE DISCRIMINATION

Some significant backscattering features of agricultural surfaces can be inferred from Fig. 1 which represents the cross-polarized backscattering coefficient (σ°_{HV}) of well developed (Plant Water Content - PWC > 1 Kg/m^2) crops measured at L-band and $\theta = 35°$, as a function of the corresponding σ°_{HV} at C-band. At L-band there is a continuous increase of backscatter as the dimensions of scattering elements increase from the 'small leaf' crops such as alfalfa (A) and sorghum (S) to the bigger olive-yards (O) and forest trees (T), passing through 'broad leaf' crops such as sunflower (F) and colza (R). At C-band, bare soil can be discriminated from crops among which colza, which has a well ramified structure, has the highest backscattering value.The relatively strong capability of C-band backscattering to discriminate agricultural surfaces is improved if circular polarization data are used as well (Baronti et al. 1993). Indeed, bare soils and plants characterized by relatively large leaves, like sunflower, corn, sorghum, show a "facet" scattering with $\sigma^\circ_{RL} > \sigma^\circ_{RR}$. while, in the other fields, $\sigma^\circ_{RL} \approx \sigma^\circ_{RR}$. However colza crops show rather high backscatter at both RR and RL polarizations, due to their scattering elements (stems, pods) which are numerous and relatively large, while the elements of wheat and alfalfa crops produce lower backscattering. It must be noted that, unlike L-band, discrimination is feasible also in the case of moderate growth. Figure 2 shows σ°_{HV} versus σ°_{HH} measured at P-band and $\theta = 35°$. According to the previous considerations the scattering in HV pol. is mainly due to inclined and relatively large cylindrical elements, like branches of forest, oliveyard and vineyard, while the agricultural vegetation is rather transparent. Three classes of σ°_{HV} values may be identified corresponding to: forests (T), olive-yard and vine-yard (O and V) and agricultural fields (A). Accordingly P-band backscattering, which is

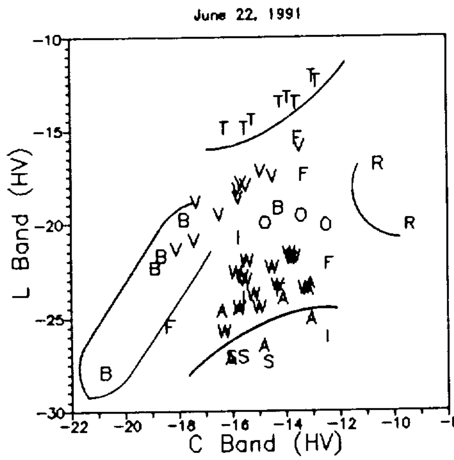

Figure 1 - Backscattering Coefficient (σ°) at L-band vs.σ° at C-band (HV pol. θ=35°) Labels: B=bare soil, T=-forest, V=vine-yard, O=olive-yard, W=wheat, A= alfalfa, S=sorghum, F=sunflower, R=colza, I=uncropped

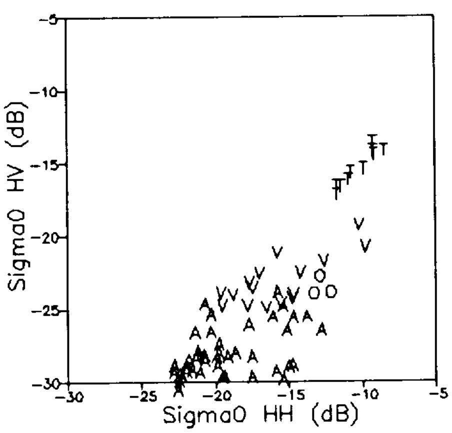

Figure 2 - σ°_{HV} vs. σ°_{HH} at P-band, θ=35°

dominated by the tree branches and the soil trunk interaction, appears rather effective in discriminating broad classes of surfaces (forest, olive-yard, vine-yard, agricultural fields) but their utility in discriminating the various agricultural crops is poor. At L-band, where scattering is mainly due to stems and large leaves, the SAR data appear more suitable for separating the 'broad leaf' crops (corn and colza) from other crops; this discrimination is improved using C-band data which are particularly sensitive to small stems and leaves (Coppo et al. 1989). Note that a discrimination between alfalfa and wheat fields does not appear feasible at C-band; however, recent works indicate that it becomes possible by means of both active and passive remote sensing systems if higher frequencies (X- and K- bands) are used (Ferrazzoli et al. 1992).

SENSITIVITY TO SOIL MOISTURE AND VEGETATION BIOMASS

Soil Moisture - The measurement of soil moisture (SMC) with radar has been the subject of much research over the past years. However, a reliable extraction of such information from SAR data is still questionable in that the signal is strongly influenced by surface roughness and vegetation cover. In our case data collected at L and C-band show very little correlation with SMC even at $\theta = 35°$. A slightly better result has been obtained at P-band where the σ°_{HH} has shown a sensitivity to SMC equal to 1.0 dB/% SMC and a correlation coefficient equal to 0.7.

Herbaceous crops - In this experiment the agricultural vegetation was rather transparent at P-band while, at C-band, it generated considerable scattering effects even in the case of moderate growth. Indeed, the highest correlations with plant growth have been noted at L-band. On the other hand σ°_{HV}, which is low for bare soils and is mainly associated to the presence of inclined stems and large leaves, is a relatively good growth indicator. Figure 3 shows L-band σ°_{HV} as a function of the Plant Water Content (PWC, kg/m^2). Samples of sorghum (S), corn (C), sunflower (F) and bare soil have been included. Very rough (ploughed) bare soils are labeled 'PB', while moderately rough (tilled or rolled) bare soils are labeled 'TB'. The correlation is generally good; the lowest σ°_{HV} values are associated with moderately rough bare soils and with sorghum fields at a very early stage of growth, while the highest values are associated with well developed sunflower crops.Ploughed bare soils show relatively high values,indicating that the roughness plays a role similar to that of vegetation growth. The dynamic range is notable, in the order of 10 dB. The plant growth may be also related to σ°_{HH} - σ°_{VV} at L-band. In fact, for bare soils, $\sigma^\circ_{HH} < \sigma^\circ_{VV}$ while, for developed crops, the soil plant double bounce scattering, which may be rather important at L-band, produces a positive σ°_{HH} - σ°_{VV} difference.

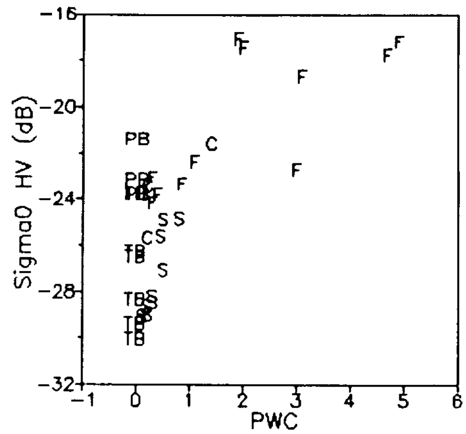

Figure 3- σ°_{HV} vs. PWC (Kg/m^2) at L-band, θ=50°

CONCLUSIONS

Polarimetric SAR measurements carried out over forests, oliveyards, vineyards and agricultural fields indicate that P-band data are effective in discriminating among broad surface categories, L-band data allow identification of well developed sunflower, corn and colza crops, and C-band data discriminate among different kinds of herbaceous crops even in the case of moderate growth. A fairly good sensitivity of σ°_{HV} and σ°_{HH} - σ°_{VV} to the Plant Water Content of some agricultural species is observed at L-band.

ACKNOWLEDGMENT

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