Potentials of X-band active and passive microwave sensors in monitoring vegetation biomass

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Abstract

A long term analysis of vegetation emission and scattering characteristics was carried out by using microwave airborne and ground-based radiometric systems by the Microwave Remote Sensing Group of IFAC-CNR. A comparison with active sensors at the same frequency became promising after the launch of Cosmo-Skymed and Terra-SARX satellites. In this paper the potentials of both emissivity and backscatter at X-band for the monitoring of plant parameters are investigated and the interrelations between these two quantities are discussed. Remote sensing data collected in agricultural surfaces and for different crop types in Italy have been analyzed and compared with vegetation parameters (mainly plant water content and leaf area index) measured on ground . A discrete element radiative transfer model tuned for both active and passive cases was used to perform a sensitivity analysis. A direct comparison of measure emissivity and backscattering is carried out.

1. Introduction

Remote sensing of vegetation by using both active and passive microwave sensors is important for the possibility of investigating Earth surface at different scales. Radar sensors are the most useful sensors for high resolution surface analysis; whereas radiometers can significantly contribute to large scale approaches and global study of climate changes. Combinations of active and passive sensors are therefore desirable as well as a deeper understanding of the mechanisms which regulate microwave emission and scattering and their interactions with the surface.

Previous investigations pointed out that X-band seems to be the most suitable one for studying well-developed crops. Indeed, this wavelength interacts with the whole vegetation layer, keeping low the contribution from soil surface. At higher frequencies, only the upper layers of vegetation play a significant role, whereas at longer wavelengths the soil contribution becomes dominant. At X-band, both emissivity and backscattering tend to show different behaviors as vegetation grows according to the geometric characteristics of plants. In general, emissivity tends to increase as the biomass of vegetation characterized by narrow leaves and thin vertical stems increases and to remain almost constant or slightly decreasing for vegetation with broad leaves and thick stems (Figs. 1a and b) [1].

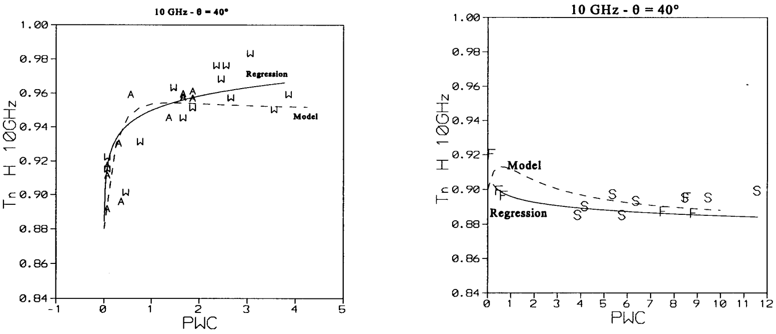

Fig.1 – Normalized temperature at X-band (10 GHz) as a function of the plant water content (PWC, in kg/m2) of wheat (W) and alfalfa (A) crops (a) and sunflower (F) and sugarbeet (S) (b). Labels correspond to experimental data, continuous line to the regression equation and dashed line to a model equation based on the radiative transfer model.

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In the active case the trend is generally the opposite, although very few data at X-band are still available for confirming these considerations. So far, this type of relationship was confirmed at C-band. [2]

In order to further investigate the potential of X band remote sensors and in particular the one of COSMO Skymed mission in vegetation monitoring a model analysis has been first carried out to estimate the sensitivity of microwave emission and scattering to crop type and biomass. Theoretical results are then compared with experimental data taken from Cosmo-Skymed SAR and IFAC microwave radiometers.

2. Experimental data

Experimental X band SAR data from Cosmo-Skymed (CSK) and TerraSAR-X were acquired in 2010-11 on two agricultural test sites (Scrivia basin, and Sesto Fiorentino). Microwave radiometric data were instead collected in various agricultural areas by using airborne and ground-based multi-frequency microwave radiometers (C-, X, Ku and Ka band). Simultaneously to remote sensing data ground measurements of all the most important soil and plant parameters (height, density, leaf and stem dimensions, plant water content, and leaf area index) were performed. Examples of temporal evolution of emissivity and backscattering in different phases of the vegetation growth cycles were considered and empirical relationships between emissivity and backscattering coefficient were investigated for two crop categories: "broad leaf " such as sunflower and corn and "small leaf " such as wheat and alfalfa . The microwave emissivity was approximated by the ratio between brightness temperature and the temperature of the upper layer of vegetation measure with a thermal infrared radiometer.

3. Physical models

The approach used to simulate both emissivity and backscattering was based on a discrete element Radiative Transfer model aimed at studying the effects of plant shape and dimension on the total emission and backscattering from the vegetation layer. In the model, the canopy layer is represented as an ensemble of sparsely distributed elements (randomly oriented disks and almost vertical cylinders) with permittivity ε_v embedded in a medium with permittivity ε_o (air) upon a homogeneous dielectric half space of permittivity ε_s and with a rough surface. The emission and scattering terms taken into consideration were

- direct contribution from soil,
- direct emission/backscattering from the vegetation layer (leaves and stems),
- soil- vegetation and vegetation-soil interaction (double scattering),
- soil-vegetation- soil interaction.

The scattering amplitudes and the extinction cross sections of circular and elliptic dielectric disks were computed by using the model proposed by Karam in [3]. In this model, the inner field formulation was the product of two factors: a modified polarizability tensor, that is associated with the quasi-static approximation, and an inner field formulation, that is associated with the physical optics approximation. The scattering amplitude tensor elements in the local frame were obtained from this field. It was demonstrated that these scattering amplitude tensor element formulations are similar to those in the quasi-static formulation for a very thin disk, and are similar to the physical optics approximation for a circular disk with a radius much larger than its thickness. The extinction cross sections were obtained from the scattering amplitude tensor elements by applying the forward scattering theorem. Since the crop stems considered were much longer and much thinner than the electromagnetic wavelength, scattering by a finite length cylinder was computed by using the infinite cylinder approximation, i.e. by assuming that the cylinder responds to an incoming wave as though it were infinite in length. According to this approach, the electric field inside the cylinder was represented as a combination of vector cylindrical waves, and the scattered field was expressed by an integration of surface fields, by applying the Huygens principle. The extinction cross sections were computed from the forward scattering theorem also in this case. The scattering amplitudes were transformed from local to reference frame by using the relationships given in [4].

4. Relation emissivity – backscattering coefficient

The fundamental processes of emission and scattering are related to each other according to the reciprocity theorem and energy conservation law. However, reciprocity does not lead directly to a bi-univocal relation between emissivity e and backscattering coefficient σ^0. Indeed the emissivity is reciprocal to the fraction of power which, for a given direction of incidence is globally scattered irrespective of the angular distribution of scattering (reflectivity), whereas the backscattering coefficient is given the power scattered in a single backward direction. Thus, for a given reflectivity, σ^0 can assume different values depending on the geometry of the scattering medium, and only a partial correlation can be expected between the measured e and σ^0 on natural surfaces. In the case of a uniform continuous medium overlaid by isotropic scatterers, Tsang et al. [5] showed that when the layer of scatterers is sufficiently thick to behave as an infinite half-space, a limiting relation holds which directly and biunivocally relates the emissivity to backscattering coefficient. In the case of terrain covered by vegetation the isotropic scattering conditions are not satisfied due to three major effects: 1) the vegetation layer is not infinitely thick, 2) the scatterers (leaves, stems) are not isotropic; 3) the scattering from underlying soil has a specular component whose amplitude, among other parameters, depends on surface roughness. Thus, for a given emissivity different angular patterns of σ^0 may exist depending upon terrain roughness and vegetation characteristics. However, although a general relation between the two quantities cannot be found, model investigations and experimental data have shown that higher backscatter coefficient generally correspond to lower emissivity values.

In order to further investigate how different parameters of the soil vegetation medium affect its emission and scattering properties we have compared experimental values of emissivity and backscattering coefficient of different crop types with the limiting case of isotropic scattering. These data confirm the opposite trends of *e* and σ^0. Moreover, the relation for isotropic scatterers is better approached by well-developed crops than by bare soil. These results also suggest that simultaneous observations with active and passive sensors can be efficient in separating bare soil from different crop types.

5. Conclusion

Model analysis and experimental data made it possible to quantify the sensitivity of X band backscattering and brightness temperature to vegetation biomass parameters. A direct relation between measured emissivity and backscattering coefficient compared with a simplified model of uniform soil covered with a layer of isotropic scatterers has shown that combined observation with active and passive systems can be synergetic in separating bare soil from crops.

6. References

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