RECENT ADVANCES IN MICROWAVE EMISSION FROM VEGETATION

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ABSTRACT

The sensitivity of microwave emission to biomass and biophysical properties of crops and forests has been proved in several experimental and theoretical studies carried out since early 1980s. Recent airborne measurements over forests indicated that microwave emission at the highest frequencies makes it possible to identify some forest types, whereas L-band emission is more closely related to tree biomass. Also microwave radiometers on satellites can contribute to global monitoring of natural vegetation, and a significant improvement is expected by the enhanced ground resolution of the next generation sensors. This paper presents a review of recent achievements in this field.

INTRODUCTION

The sensitivity of microwave emission to vegetation biomass and biophysical properties has been proved in several experimental and theoretical studies[1-5]. At the lower frequencies of microwave band (around 1-3 GHz), and for small incidence angles, emission from a vegetation-covered soil is mostly influenced by soil moisture, whereas, at higher frequencies, the contribution from vegetation to the radiation is significant and the emission can be related to vegetation type and plant water content.

Experimental investigations on microwave emission from crops were carried out since early 1980s by using ground based and airborne sensors. These studies demonstrated that useful information on vegetation covered soils can be obtained by combining brightness temperatures, measured at two or more microwave frequencies and polarizations []. This information is improved by adding data taken in the thermal infrared band. Microwave emission data on forests have mostly been collected by the Helsinki University of Technology (HUT) in Northern Europe on boreal conifer forests using satellite [6] and airborne [7] data. In spite of their coarse ground resolution, which is of the order of several tens of kilometers, also microwave radiometers on satellites, such as SSM/I, can contribute to global monitoring of natural vegetation, and a significant improvement is expected by the enhanced resolution of the next generation sensors such as the AMSR and the SMOS. A study to derive the evolution of water status in the Amazon Forest from SMMR data was performed in [8]. L-band radiometer measurements of conifer forests were performed more recently by Lang et al. [9], who flew ESTAR radiometer over loblolly pine stands in Eastern Virginia.

In the same time of experimental activities, several theoretical approaches, mostly based on radiative transfer theory, were developed to simulate brightness temperature of vegetation covered soils [10-13]. In general, vegetation was represented as a collection of disks and cylinders simulating leaves, stems or trunks. The more sophisticated models took into account multiple scattering, but a comparison with experimental data collected over forests showed that even a simple single scattering model is able to reproduce the relationship between L-band brightness temperature and woody biomass with a reasonable accuracy. In all these models the vertical profile of vegetation was assumed to be uniform and emissivity was obtained from the integral of the bistatic scattering coefficients assuming reciprocity and conservation law. The relation between surface heat fluxes and canopy temperature profiles, and hence canopy brightness temperature has been more recently investigated by integrating and electromagnetic model and a thermal model. The predictions of the integrated model have shown good agreement with the brightness temperature data collected at different frequencies and incidence angles.

This paper presents a review of some recent experimental and theoretical investigations carried out in this field.

EXPERIMENTAL RESULTS

Airborne radiometric measurements were carried on an agricultural area in South France at C and X bands and on six forest stands in Central Italy at L, C, X, Ku and Ka bands by using IROE (Instrument for Radio Observation of the Earth). IROE included a thermal infrared radiometer (8-14 μm) for estimating surface temperature, and a TV camera used for ground reference. The microwave instruments were self-calibrating, dual polarized (H and V) radiometers with an internal calibrator based on two loads at different temperatures (250 ± 0.2 K and 370 ± 0.2 K). Radiometric digital and analog signals were acquired by a PC with a dedicated program for data processing and storage on disk. The instruments were installed on the ARAT aircraft on ultralight airplanes to operate at two incidence angles: 20^o and 40^o.

Agricultural crops

Two flights were carried out, on May 1^{st} and 25^{th}, at suitable altitude (150 m) and speed (150 knots) for obtaining reasonable spatial (<100m) and temporal resolutions. Six flight lines were chosen to guarantee complete coverage of the fields where intensive ground data collection was made during the entire plant growth cycle. For each flight line, two passes at two different incidence angles ($\theta = 20^o$ and 40^o) were carried out. The first flight was disturbed by a strong wind, and some data were lost due to a failure in the data acquisition system. The second flight gave excellent results. Data processing was performed according to the following steps: a) calibration control of the brightness temperature data, b) retrieval of flight lines from GPS data, c) localization of antenna footprint by correcting data for the incidence angle, and identification of the brightness temperature of each field.

Crop discrimination

As expected from previous results obtained on the same crops in a different development stage [4], the normalized brightness temperature Tn, obtained by the ratio between microwave and infrared brightness temperatures was found to be very sensitive to the type of surface cover at both C and X bands, and could be used to separate fields and to discriminate crop types. By representing Tn data collected at two frequencies, polarizations and incidence angles in bi-dimensional diagrams, we can isolate clusters for the purpose of establishing useful criteria for separating crops. For example, we see in Fig. 1 that there is a significant correlation between C- and X- band emission, at $\theta = 40^o$ incidence angle and H polarization, and that there is a correspondence between crop type and Tn range. This means that even a single frequency/polarization system could allow the discrimination of a few surface categories. However, a more detailed study has shown that the use of the full set of data appreciably improves the discrimination accuracy. Using a set of two-frequency (6.8 and 10 GHz), two- incidence angle ($\theta = 20^o$ and 40°), H polarized normalized temperatures, collected on a few test fields, a simple algorithm for separating six vegetation classes (dry bare soils, wet bare soils, low vegetated fields, sunflower, well developed wheat and alfalfa) was implemented based on the measurements on training area containing 10 fields. The algorithm allowed one to correctly classify 80% of fields over the whole area containing more than 50 fields.

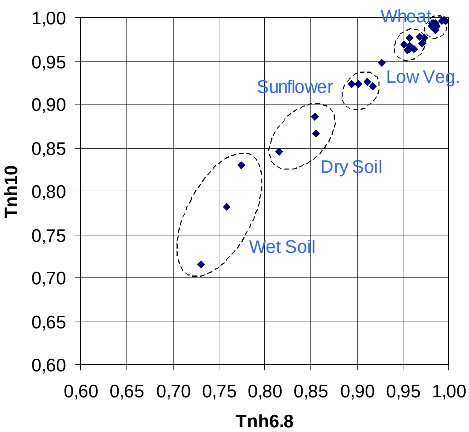

Fig. 1. The normalized temperature Tn at 10 GHz as a function of Tn at 6.8 GHz ($\theta = 40^o$, H pol.)

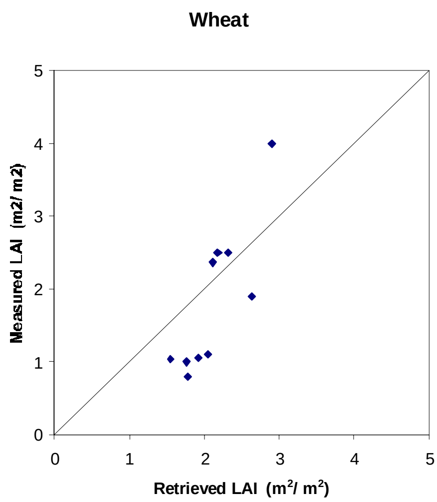

Fig. 2. Measured versus retrieved LAI

Retrieval of crop biomass

Previous investigations had pointed out that the sensitivity of Tb to vegetation biomass depends on crop type and observation parameters (frequency, polarization, incidence angle) [2], so that a simple observation at a single frequency single polarization can be of small relevance. A more significant parameter for detecting vegetation biomass was found to be the polarization index PI = (Tbv-Tbh) /2 (Tbv+Tbh), which has a high value on moist bare soil and decreases as the vegetation grows. Experimental results conducted on various crop types and theoretical analyses suggested relating PI to the leaf area index (LAI) of crop according to the following equation [4]:

$$PI(LAI)= PI(0,\mu)\ e^{(-LAI\ /y\mu o\lambda)} \qquad (1)$$

where: PI(0,μ) is the PI of bare soil, μ = cos θ is the observation direction, y is a crop factor [4], and λ is the wavelength. This equation can be easily inverted to obtain LAI from PI.(Fig. 2).

Forests

The measurements over forests were carried out in 1999 on June 15^{th} -16^{th} and 24^{th} - 25^{th}. At that time the weather was warm and dry and no significant rainfall occurred between the two surveys. The investigated stands were six permanent monitoring plots selected among the most frequent ecosystem types of broadleaved forests in Tuscany, Italy, including: beech, Turkey oak and holm oak . The average size of plots, of the order of some hectares, was large enough to contain several antenna footprints. Ground data available for each forest stand and used in this paper are shown in Table I. Soil moisture data were not available. However, since the measurements were performed in warm weather, two weeks after the last significant rainfall, soil under trees could reasonably be considered rather uniform and dry.

Forest discrimination

The two-dimensional diagram of Fig. 3 shows that, using data at 37 GHz and 10 GHz, four types of forest can be identified: beech, corresponding to the lowest values of Tn at both frequencies; Turkey and holm oaks, which show intermediate and comparable values of Tn and are indeed rather similar trees; and fir which characterized by the highest values of Tn at Ka band. The same diagram shows that, while for the broad-leaved forest Tn at X band is higher or equal than Tn at Ka band, for fir Ka band emission is clearly higher than X band.

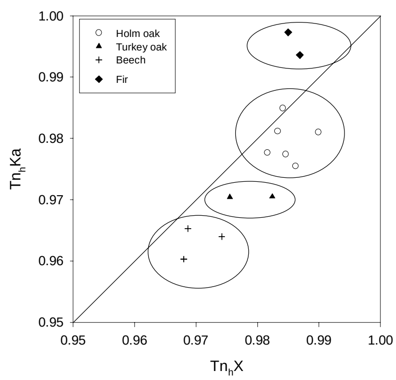

Fig. 3. Tn (Ka band), as a function of Tn (X-band), at ϑ =30°, H pol. Four forest types can be separated.

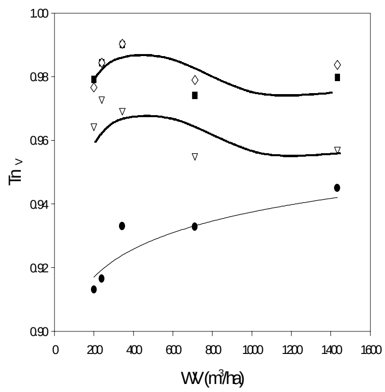

Fig. 4 - Tn, measured at four frequencies, as a function of woody volume (WV) (◇= Ka-band, ■ = X-band, ∇ = C-band, ◆ = L-band). Continuous lines represent regressions: logarithmic at L-band, polynomial at Ka-, X- and C-bands.

Arboreus biomass

The relationships between Tn at Ka, X, C and L-bands and the woody volume, WV, in m^3/ha is represented in Fig. 4. As expected, the highest sensitivity to forest biomass was obtained at L-band where there is an increase of Tn as the biomass increases. This behavior means that the forest stands behave as absorbing layers above the soil surface. It should be noted that a similar trend was obtained by Lang et al. [9].On the other hand, at the higher frequencies , as WV increases, there is a slight increase of Tn for the low values of biomass followed by a decrease for further increments of biomass. This trend can be interpreted as an initial phase, where absorption is still dominant, and a subsequent stage, where scattering plays a major role.

MODEL SIMULATIONS

A theoretical model for microwave emission frpm vegetation that includes multiple scattering and eliminates some restrictions imposed by earlier models with regard to canopy structure, leaf shape, thermometric temperature profiles, and the sky radiations, has been recently developed by Karam [14]. The model depicts a vegetation canopy volume above a rough soil-canopy interface. The canopy volume has a free space background and an arbitrary temperature profile. It also hosts two types of discrete randomly oriented dielectric scatterers: finite cylinders to represent branches, trunks, stems, coniferous leaves, etc, and elliptic discs to represent deciduous leaves, grass blades, corn leaves, wheat leaves, etc. In obtaining the model predictions a gap probability was introduced. The probability values were based on the leaf area index. To account for the gap probability, a stochastic radiative transfer equation, developed in literature for broken clouds, was solved by discretizing the canopy volume into *N* thin sub-layers whose physical temperature *Tn (z)* was approximated by its average value *Tn*. An example of comparison of model simulation with experimental data collected on corn is represented in diagram of Fig. 5

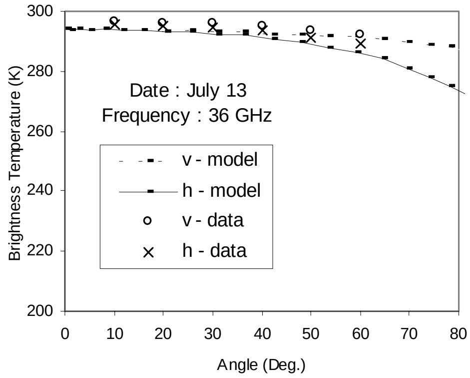

Fig. 5. Simulated and measured brightness temperature as a function of incidence angle

REFERENCES

[1] F. T. Ulaby, M. Razani and C. Dobson, "Effects of Vegetation Cover on the Microwave Radiometric Sensitivity to Soil Moisture" *IEEE Trans. Geosci. Remote Sensing*, vol 21, pp. 51-61, 1983.

[2] P. Pampaloni and S. Paloscia, "Experimental Relationships between Microwave Emission and Vegetation Features," *Int. J. Remote Sensing*, Vol. 6, pp. 315-323, 1985.

[3] R. Huppi, E. Stotzer, and E. Schanda, "Calibrated Microwave Signature Measurements of Soil and Wheat," *Proc. 3rd Intern. Coll. on Spectral Signatures of Objects in Remote Sensing*, Les Arcs, France. ESA SP-247, pp. 351-355, 1985.

[4] S. Paloscia and P. Pampaloni, "Microwave Vegetation Indexes for Detecting Biomass and Water Conditions of Agricultural Crops," *Remote Sens. Environ*., **40**, pp. 15-26, 1992.

[5] J. P. Wigneron, J. C. Calvet, Y. Kerr, A. Chanzy, "Microwave emission of Vegetation: Sensitivity to Leaf characteristics," *IEEE Trans. Geosci. Remote Sensing*, vol 31, pp. 716-726, 1993.

[6] M.T Hallikainen, P.A. Jolma, J.M. Hyyppa, "Satellite Microwave Radiometry of Forest and Surface Types in Finland," *IEEE Trans. Geosci. Remote Sensing*, pp 622-628, 1988.

[7] L. Kurvonen, J. Pulliainen, and M. Hallikainen, "Monitoring of Boreal Forests with Multitemporal Special Sensor Microwave Imager," *Radio Science*, 33, pp. 731-744, 1998.

[8] J-C. Calvet, J-P.Wigneron, E.Mougin, Y.Kerr, J.Brito, "Plant Water Content and Temperature Of The Amazon Forest from Satellite Microwave Radiometry" *IEEE Trans. Geosci Remote Sensing*, 32, 2, 397-408, 1994

[9] R.H. Lang, P. de Matthaeis, D.M. Le Vine, S. Bidwell, M. Haken, N. Chauhan, "L-band Radiometer Measurements of Conifer Forests," *Proc. of Intern. Geosci. and Remote Sensing Symposiunm, (IGARSS 2000),* Honolulu, Hawaii, July 2000, pp 1930-1932, 2000.

[10] P. Ferrazzoli, L. Guerriero, S. Paloscia and P. Pampaloni, 1995, "Modeling X and Ka Band Emission from Leafy Vegetation," *Journal of Electromagnetic Waves and Applications*, vol 9, N 3, pp 393-406.

[11] M.A. Karam, "The Potential of Microwave Radiometers in Monitoring Forest Biomass," *Proc. Geosci. and Remote Sensing Symposium, 1994. IGARSS '94*,.3, pp. 1860 - 1862, 1994.

[12] P. Ferrazzoli, and L. Guerriero, "Passive Microwave Remote Sensing of Forests: A Model Investigation," *IEEE Trans. Geosci. Remote Sensing*, 34, pp. 433-443,1996.

[13] M. A. Karam, "A Physical Model for Microwave Radiometry of Vegetation," *IEEE Trans. Geosci. Remote Sensing*, 35, pp1045-1058,1997

[14] M. A. Karam S. Paloscia, and P. Pampaloni "Impacts of Atmospheric Turbulence on Microwave Radiometry of Vegetation: A Heat Flux Case," *Specialist Meeting on Microwave Remote Sensing* Boulder, Colorado, 5-9 November, 2001