Multifrequency Microwave Emission from Forests

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Abstract

Retrieving information on forest biomass and soil under vegetation is crucial for all studies concerning global changes and carbon balance. The capability of microwaves in penetrating vegetation covers is well known, but only few studies have investigated emission from soil under forests and the contribution of single tree elements to total radiation. To further examine quantitatively these aspects a study has been carried out by using ground based multifrequency radiometric observations and model analysis. The results of this study made it possible to evaluate the contribution of the tree components to total emission and their effects on soil moisture measurement.

1. Introduction

The management of forests has emerged as one of the most serious and urgent environmental issues of our time. Indeed, human activities have affected natural resources, biodiversity, atmospheric composition, and climate. Moreover, forests are the major sinks/sources of biotic carbon and their role in the carbon cycle is consequently preeminent. Experimental and theoretical studies have shown that microwave remote sensing techniques can contribute significantly to the study of tree parameters [1-3].

In order to investigate the relationships between microwave emission and forest parameters, several experimental campaigns were carried out in Italy by using both airborne and ground-based instruments. The results have shown that for low level of biomass, L-band upward emission is appreciably affected by the soil contribution and is sensitive to the seasonal variation of soil moisture, whereas emission at the higher frequencies is mostly due to crowns. For high values of biomass, emission is affected by tree conditions at all frequencies. As expected, the presence of leaves is almost negligible at low frequencies. These measurements, together with a model analysis, enabled to separate different contributions from soil, trunks and crown [4,5]. Other measurements carried out upward looking on a beech stand made it possible to estimate the transparency of trees [6].

This study was planned to further examine quantitatively these aspects by using radiometric observations and model analysis. Experimental data were collected with ground based multi-frequency (1-37 GHz) radiometers on two forest plots (a deciduous and a coniferous) in different seasons of the year. Observations were made downward and upward looking from top and bottom, and from different levels inside the canopy. A computation of the vegetation transmissivity and albedo at different frequencies was carried out by using upward and downward measurements with a simplified form of the Radiative Tranfer Theory.

2. The Experiment

In 2006 two forest stands of poplar (Populus alba) and pine (Pinus italica) in Tuscany (Italy) were investigated by using ground-based sensors. Both forest stands were characterized by a regular tree plant (6mx5m for poplars and 3mx3m for pines). Radiometric measurements at L- (1.4 GHz), C- (6.8 GHz), X- (10 GHz), Ku- (19 GHz), and Ka-bands (37 GHz) were collected in both H and V polarizations, at different incidence and azimuth angles during a whole vegetative season of the poplar from March to October. Observations were carried out down-looking from the top by using a cherry-picker and up-looking from the terrain. In order to better separate soil and forest contributions additional measurements were carried out down and up at different levels inside the canopy. For each incidence angle the representative value of brightness temperature was obtained by averaging measurements carried out at three azimuth angles ($\phi = 0°$, and $\phi = \pm 45°$).

Ground measurements of tree and soil parameters, such as tree height and density, trunk diameter, ground vegetation, and soil moisture content (SMC) were also carried out. Forest biomass was expressed using the woody volume, WV, in m^3/ha, computed as the volume of the whole tree cylinder. The results obtained during previous airborne campaigns carried out in 1999 and 2000, both in summer and winter, on six broad-leaved forest plots of oak and beech, were compared with these new data sets [4].

3. Experimental Results

A. Downward measurements

The spectra of total emission from poplar and pine stands are in general increasing from L to C bands and, after that, they are flat or slightly decreasing. The difference between March (no leaves) and July (well-developed vegetation) at L-band is mainly due to the variations in soil moisture. Pines show a very high emission with respect to poplars in the same season.

The angular trends are, in general, almost flat (Figure 1). At L-band the trend is flat in July, when vegetation is at its maximum development and SMC is low, and slightly decreasing in March, when SMC is higher. C-band data show the same trend, although less marked. Ku- and Ka-band have very similar values

B. Sensitivity to woody biomass

The sensitivity of L-band emission to woody biomass (VW in m3/ha) is shown in Fig. 2, which represents the normalized temperature (Tn =Tb/Tir) measured in summer and winter. In this figure, and in order to estimate the trend of Tn on a wider range of biomass values, measurements on poplar have been combined with data taken on beech in previous experiments. It should be noted that the difference between winter and summer, more evident for low level of biomass, is mainly due to changes in SMC

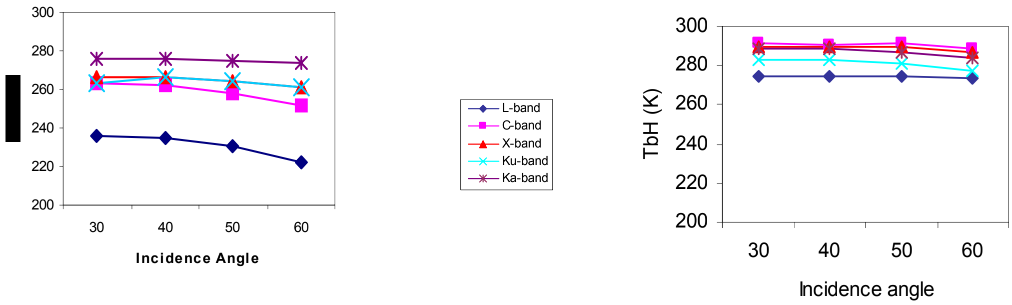

Figure 1. Angular trends obtained on poplar at different frequencies obtained in two seasons: March (left) and July (right)

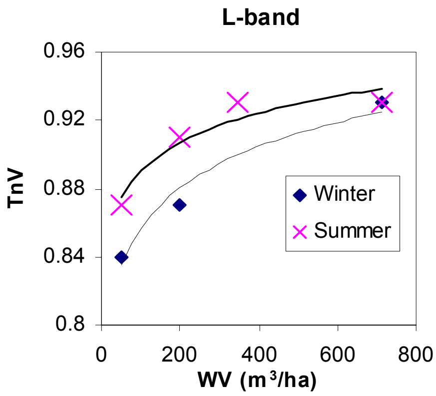

Figure 2. Normalized temperature (Tn) at L-band as a function of the Woody Volume (WV) of some forest stands. Measurement wre carried out both in winter and summer

B. Upward measurements

The upward measurements of brightness temperature Tb as a function of the incidence angle are shown in Figure 3 (a, July and b, October). At low incidence angles the Tb values are very low due to the effect of sky temperature, and Tb increases as the incidence angle increases, since also the contribution of tree emission increases. Since at L-band the trees are rather transparent, the Tb values at this frequency are very low. Tb values are generally higher in July than in October, due to the presence of well-developed leaves in summer, which decrease the forest transmissivity.

The differences between downward and upward emission at L, C, X, Ku and Ka bands at incidence angles 30°, 40° and 60° showed that the highest difference Tb_{down}-T_{bup} was at low incidence angles and in October, due to the effect of tree biomass. The spectra of Tb measurements carried out both downward and upward in July and October showed that the shape of downward measurements did not change during the time, whereas that of upward measurements was influenced by the variations of crown density due to the leaves.

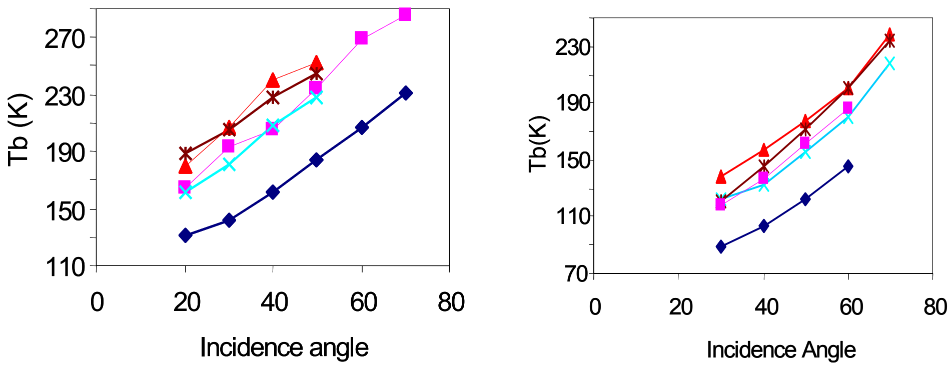

Figure 3. Upward measurements of Tb (H pol.) vs. incidence angle at different frequencies (◆ L-, ■ C-, ▲ X-, × Ku-, ✳ Ka-bands). Top: July, 2006, and bottom: October, 2006

4. Data Analysis

According to the radiative transfer theory, the measured Tb can be expressed as the sum of the contributions of sky and vegetation:

$$Tb = Tb_{sky} \cdot tc + Tv(1\text{-}tc) \qquad (1)$$

where Tb_{sky} is the sky radiation, *tc* is the canopy transmissivity, and Tv the vegetation temperature. *tc* can be expressed, therefore, as following:

$$tc = (Tv\text{-}Tb)/(Tv\text{-}Tb_{sky}) \qquad (2)$$

Combining the measurements carried out both in upward and downward directions and according to eq. (2), tc was computed for the different frequencies both in March and October. The results are given in Table I.

TABLE I. CANOPY TRANSMISSIVITY VALUES

	July	October
tc L	0.58	0.70
tc C	0.37	0.71
tc X	0.33	0.54

Looking at these data, we can observe that, as expected, the canopy transmissivity is higher in October than in June, when crown is less dense and generally higher at L band than at C and X bands. The difference between these two latter frequencies is small, especially in summer.

The Radiative Transfer Theory in the form of the so called omega-tau equation was used to compute the single scattering albedo (ω) of vegetation by using the data gathered on the poplar stand from the top of the forest and under the crowns toward the soil. The equation is:

$$Tb=(1-\omega)(1-1/L)Tv+1/L[R(1-1/L)(1-\omega)T_2+(1-R)T_3 \quad (3)$$

where Tv is the vegetation temperature, L is the loss factor of vegetation, which was computed from the canopy transmissivity values of Table III (L=1/tc), and R is the soil reflectivity. Both Tb and the second term of the equation are known, since they have been measured during the experiment. As a consequence, by solving eq. (3), ω values between 0.10 and 0.15 have been obtained for C and L bands, respectively.

5. Conclusions

Radiometric microwave measurements were carried out on two plots of poplar and pine in at L, C, X, Ku and Ka bands at different incidence angles, both in H and V polarizations. Frequency spectra were in general increasing from L to C bands and flat or slightly decreasing at higher frequencies. Pine showed the highest values of emission at all frequencies. The angular trends were almost flat, mainly at the high frequencies.

The sensitivity of L-band emissivity to forest biomass was generally confirmed, with some saturation at very high values of woody volume (WV>600m3/ha). For low level of biomass, L-band emission is affected by the soil contribution, whereas emission at the higher frequencies is mostly due to tree crowns.

Measurements carried out in upward directions showed increasing values of Tb as the incidence angle increased. The difference Tbdown-Tbup decreases as both the incidence angle and the frequency increase and is in general higher in October than in July.

By using the Radiative Tranfer Theory, the canopy transmissivity was computed, which, as expected, was higher at L-band than at C and X-bands and generally higher in October than in July. From the measurements carried out from the top of the forest and under the crowns and the values of canopy transmissivity, the single scattering albedo was calculated.

6 References

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