L-BAND EMISSION FROM A EUCALYPTUS FOREST IN VARIOUS SOIL CONDITIONS DURING THE NAFE CAMPAIGN

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ABSTRACT

This paper analyzes the L-band radiometric signatures collected over a Eucalyptus forest with moderate biomass, and compares the results with simulations of a theoretical model and a simple model. Due to the limited biomass and the thin litter layer, some sensitivity to variations of soil moisture is observed. Simulations of the theoretical model are in general agreement with measurements, with an overall rms error of 3.7 K. The greatest discrepancy is observed for measurements collected just after a rainfall. The performance of the simple model is only slightly worse than that of the theoretical model, leading to an overall rms error of about 5 K.

Index Terms— Radiometry, soil moisture, forest, modeling

1. INTRODUCTION

A better understanding of forest emission at L-band is important for soil moisture retrieval from the present SMOS radiometer and the upcoming SMAP mission. Experiments using both ground based and airborne radiometers at L-band have provided an insight to the problem [1]-[6], but only a limited number of forests have been observed and definitive conclusions have not yet been reached. While there is general agreement that the soil emission is masked by areas of dense forest, there is still uncertainty about the relative importance of crown attenuation and litter cover. Moreover, several forest types are relatively sparse, and it is important to understand their behavior. Model simulations can help to gain this understanding. Theoretical models have been developed [7]-[8] and in some cases tested with experimental data [9]-[10], but further tests are necessary, in order to cover a variety of forest types and environmental conditions.

This work presents a comparison between L-band experimental data and model simulations for the Eucalyptus forest of the Roscommon farm, located in southeast Australia. Here the forest cover is moderately dense, with LAI equal to about 2.5 and having only a thin litter cover. During the **N**ational **A**irborne **F**ield **E**xperiment 2005 (NAFE05) campaign, radiometric measurements were collected at L-band with various spatial resolutions, various incidence angles, and at two polarizations [11]. Detailed ground truth is also available for soil moisture and a number of fundamental forest variables [11]. Radiometric measurements collected in the Roscommon area were already investigated in [12], with the objective of evaluating the influence of forest cover fraction on soil moisture retrieval from heterogeneous pixels. The retrieval was made using the iterative approach of the SMOS algorithm. It was found that the accuracy of the results is strongly affected by the accuracy of initial values for the model parameters describing the forest emission.

The first objective of this work was to investigate the sensitivity of L-Band radiometers to soil moisture for forests with moderate biomass and thin litter, such as Roscommon. Moreover, radiometric measurements are used to test both the theoretical forest emission model developed at Tor Vergata University [7] and a simple model to be adopted in SMOS Soil Moisture (SM) algorithm [13]-[14].

2. MATERIALS AND METHODS

2.1 The site and the experiment

The NAFE'05 experiment was conducted in the Goulburn river catchment, in South-eastern Australia, with the aim to provide passive microwave airborne data supported by ground measurements of soil moisture. The area of study covered part of the “Roscommon” farm, which is part of the larger 'Krui' study area.

The forest areas consisted mainly of Box (Eucalyptus spp), Ironbark (Eucalyptus spp.) and some Black Cypres-pine. The LAI was estimated to be 2.5 and did not noticeably change during the experiment. Some litter was present on the ground and formed a thin layer of about 0.5 cm.

The airborne L-Band measurements used in the current study were made using the dual-polarised Polarimetric L-band Multibeam Radiometer (PLMR) on 1st, 8th, 10th, 15th and 22nd November 2005. The average soil moisture ranged from 0.184 m^3/m^3 on the first date to 0.02 m^3/m^3 on the last date. At lower altitude, the nominal ground resolution (-3 dB footprint) was 62.5 m at nadir. Observations were made every second at incidence angles of +/-7°, +/-21.5°, +/-38.5°, covering a total swath of approximately 375 m. More details about the measurements are given in [11] and [12].

This paper is aimed at getting an insight into the emissivity properties of the forest. Therefore, we have analyzed radiometric samples with the aid of a Landsat image, by selecting the central part of the forest area, which is homogeneous and shows a brightness temperature more stable than in the outer regions.

2.2 The theoretical model

Simulations were made using the forest emission model developed at Tor Vergata University. The basic theory is given in [7]. The model is based on the radiative transfer theory. The soil is described as a homogeneous half space, having a permittivity related to soil moisture by means of formulas available in the literature. The litter is modeled as a dielectric layer [9]. Trunks and branches are modeled as dielectric cylinders and leaves as dielectric leaves. Details about the electromagnetic approximations are given in [7] and [9].

In general, only a limited part of the variables influencing the emissivity are available by ground measurements. For this reason, we assign some inputs on the basis of relationships derived by literature. A detailed description of the routines adopted for the geometrical properties of the forest is given in [10].

Basically, it is assumed that the biomass (or the LAI) and the distribution of dbh (diameter at breast height) is known. A distribution of dbh values is considered, centered on the average, and for each dbh the absolute number of trees (per unit area)with that dbh, as well as the subdivision of biomass into trunk, branch and leaf components is computed. Subsequently, the so-called "allometric" equations, available in the literature, are used [10]. The soil permittivity is derived from the ground-measured soil moisture.

For the case of Roscommon forest, soil moisture, LAI and litter parameters were made available by ground measurements. The vegetation temperature was measured at different levels, from the soil surface to 7 m height in the trunks. However, only the value at 7m has been used, since differences with measurements at different levels were lower than 2 K at the time of the flights.

The height standard deviation of soil roughness was set equal to 1.5 cm. The average dbh was estimated to be roughly equal to 30 cm, on the basis of available photographs. The other variables were derived using the procedure described in Section II.B of [10].

2.3 The simple model

Comparisons between experimental data and model simulations were also made by using the simple model being used in the SMOS SM algorithm [14]. This model is based on a first order radiative transfer formulation, with coefficients fitted over parametric simulations.

The roughness coefficient h is set equal to 0.5 [14].

The optical thickness τ is related to the LAI measured in summer by: $\tau = b\ LAI$

For deciduous forests, values obtained after recent refinements [13] are: b=0.23 in absence of litter and b=0.29 in presence of litter. The albedo is equal to 0.106 for all deciduous forests [13].

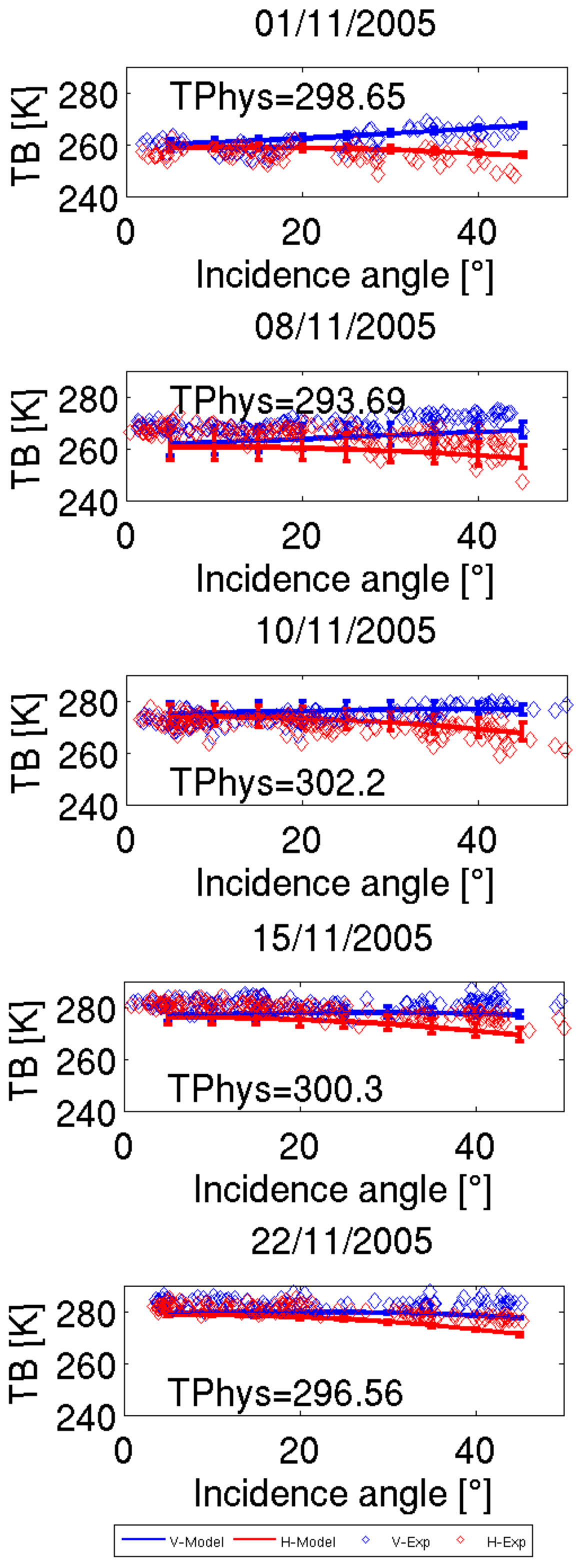

Figure 1: general comparison between experimental data (dots) and theoretical model simulations (lines) of brightness temperature TB[K]. Polarizations: vertical (blue), and horizontal (red). TPhys = physical temperature [K].

Litter parameters are assigned by averaging among data available in the literature [10], [13]

3. RESULTS

Figure 1 shows a comparison between predicted and measured values of brightness temperature for the five dates. The error bars in simulated data correspond to the range of soil moisture measurements. The agreement is good on 1/11/2005, when the average soil moisture was 0.184 (v/v). The brightness temperatures measured on 8/11 are almost 10 K higher (on average) than the ones measured on 1/11, although the physical temperature was lower by about 5 K. The model predicts an increase of emissivity, since the soil moisture decreased to 0.127 (v/v), but this is lower than the increase observed in the experimental data. On this date, the flight took place after a rainfall. The high value of brightness temperature could be related to the effects of raindrops on the vegetation, although the high values of Polarization Index, to be illustrated later, do not agree with this assumption. The problem, which was also found in [12], needs to be investigated further.

In the last flights the agreement is generally good, although with a slight underestimation. The overall rms error in the comparison between model simulations and experimental data is equal to 3.7 K. This figure is significantly lower than the dynamic range of brightness temperature, which is of the order of 20 K (cf. fig. 2 and 3). A different representation of results is given in Figures 2 and 3, where the angular interval 20°-30° is selected and the brightness temperatures at vertical and horizontal polarization are given as a function of soil moisture. For the experimental data, the figure gives the average values (continuous line) and the standard deviation (error bars). Both experimental and simulated data show a general decreasing trend, which is the model mostly attributes to variations of soil moisture, with slight effects due to variations of physical temperature.

A comparison between values of Polarization Index PI is shown in Figure 4, considering all angles. The definition of this index is:

$$PI=2*(Tbv-Tbh)/(Tbv+Tbh) \qquad (1)$$

It is not influenced by the physical temperature. A specific comparison as a function of soil moisture is shown in Figure 5.

Previous theoretical and experimental studies indicate that PI increases with soil moisture (see, eg [15]). A specific comparison as a function of soil moisture is given in Figure 5. Since the PI is more significant at the higher angles, we have selected the interval 30°-40°. The model reproduces the absolute values of PI and its increase with soil moisture**.**

Figure 6 shows comparisons between measured and simulated brightness temperature using the simple model. Also the case of absence of litter is considered. The trends are similar to the ones obtained by the Tor Vergata model (Figure 1). However, the predicted temporal variations of brightness temperature are slightly lower than the measured ones. The overall rms errors are equal to 4.5 K without litter and 5.4 K in the presence of litter. However, it should be noted that in the simple model litter parameters are general, and not based on Roscommon measurements. Also, the assumption to have a unique albedo for all deciduous forests reduces the

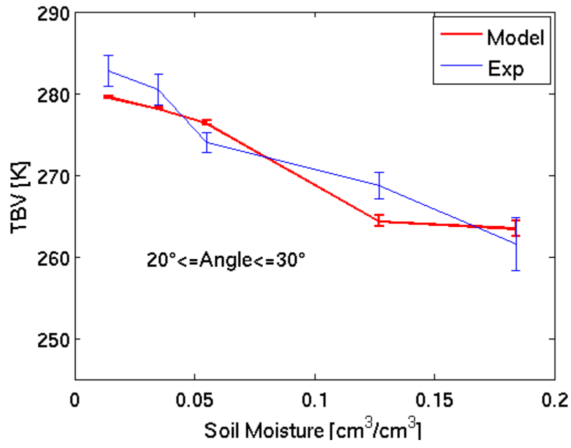

Figure 2: Vertical brightness temperature (TBV) vs. soil moisture. Angles 20°-30°. Experimental data (blue) and theoretical model simulations (red).

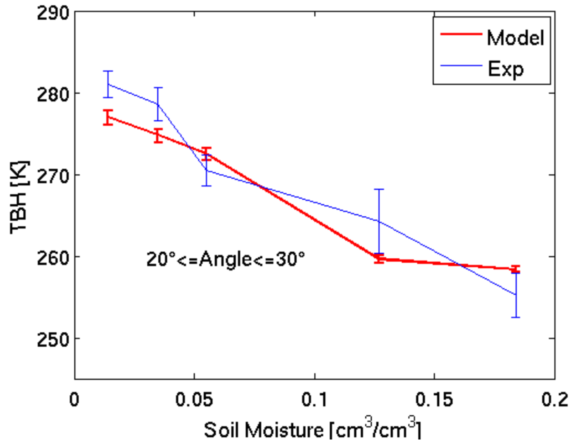

Figure 3: Same as in figure 2 for horizontal brightness temperature (TBH).

accuracy with respect to the theoretical model.

4. CONCLUSIONS

In the Roscommon forest, characterised by moderate biomass and a thin litter layer, radiometric measurements give a dynamic range of about 20K, mostly related to soil moisture variations.

The theoretical model reproduces the experimental data with an error of 3.7 K, which is low with respect to the dynamic range. Moreover the simple model generally reproduces the experimental data, but the dynamic range is slightly underestimated and the rms error is higher than in the case of the theoretical model.

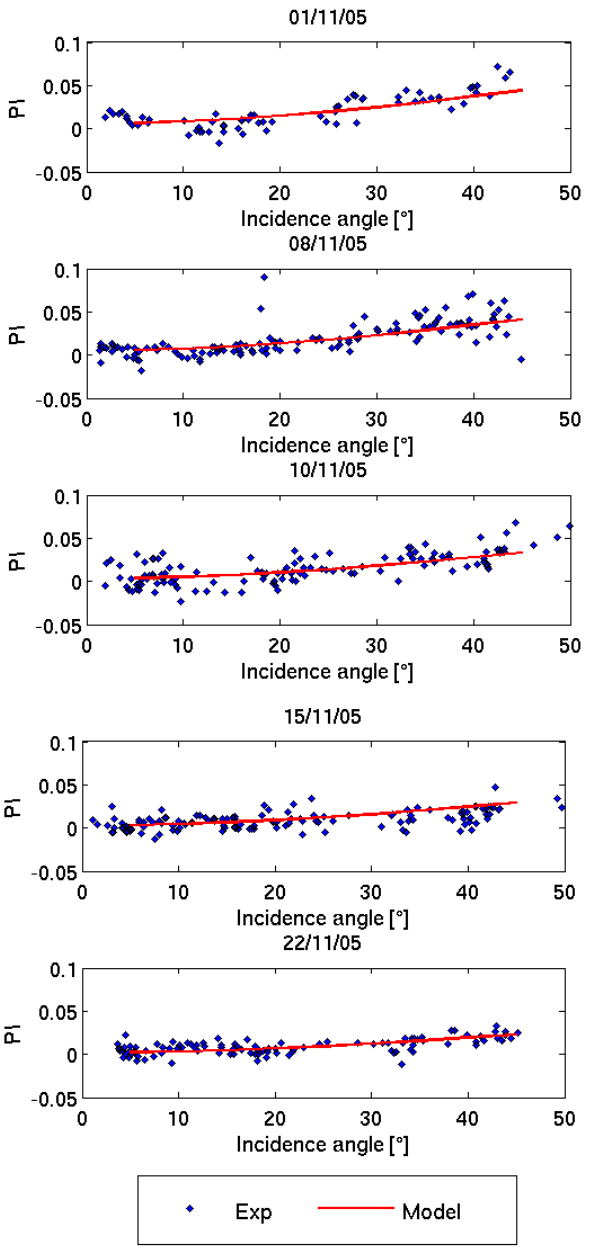

Figure 4: General comparison between experimental data (dots) and theoretical model simulations (lines) of Polarization Index.

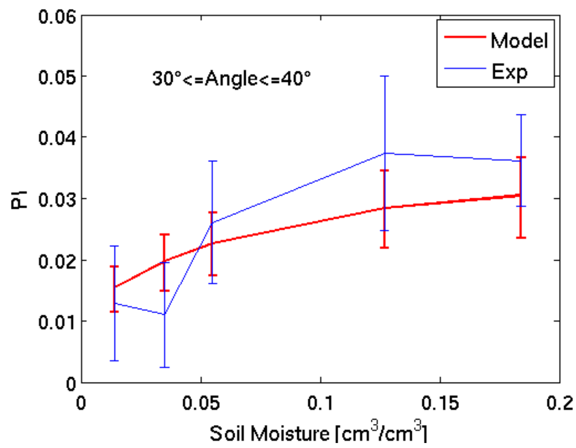

Figure 5: Polarization index vs. soil moisture. Angles 30°-40°. Experimental data (blue) and theoretical model simulations (red).

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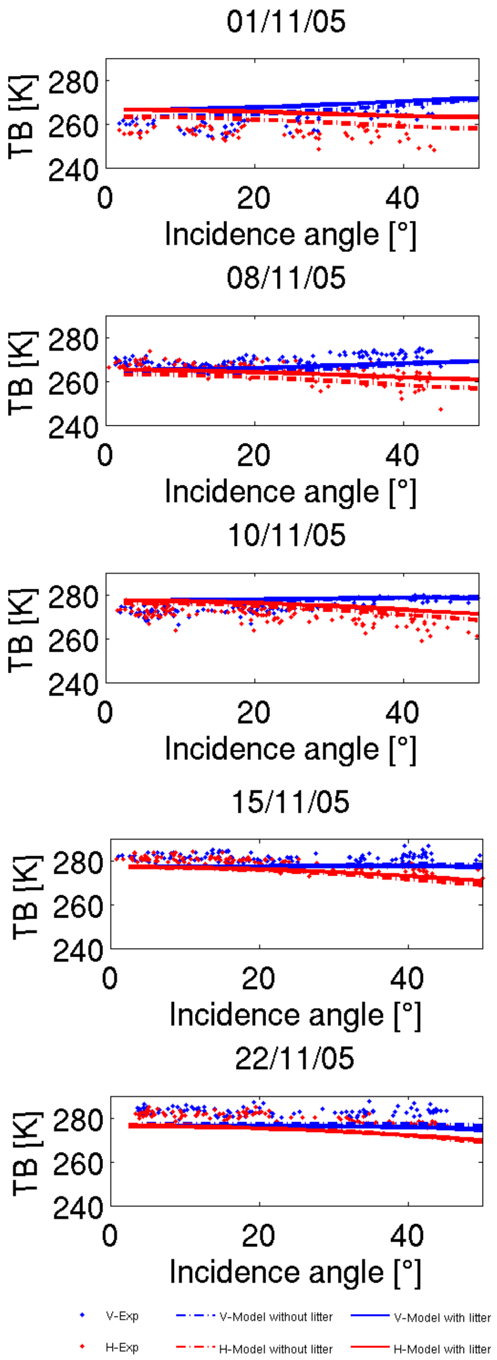

Figure 6: General comparison between experimental data (dots) and simple model simulations with litter (continuous lines) and without litter (dashed lines) of brightness temperature. Polarizations: vertical (blue), and horizontal (red).

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