MICROWAVE X-BAND RADIOMETRIC CHARACTERISATION OF BRAZILIAN SOILS BY MEASUREMENT OF THE COMPLEX PERMITTIVITY (ε*)

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ABSTRACT

This paper describes the main activities and strategies in Microwave Radiometry for applications in Agriculture in Brazil. Some relevant results regarding measurements of the complex permittivity (ε*) and estimates of emissivity for soils from tropical areas in function of soil moisture, at 10.62 GHz, are presented. Difficulties related to the measurement of ε* and μ* of important Brazilian soils (dielectric/ferromagnetic mixture) are highlighted.

Keywords: Microwave, Radiometry, Permittivity, Permeability, Soil Moisture, Dielectric/Ferromagnetic Mixture.

1. INTRODUCTION

Due to the continental dimensions of Brazil spaceborne remote sensing techniques have been used since the 1970's, mainly in the visible and infrared regions of the electromagnetic spectrum, that is, Landsat MSS/ TM and recently Spot images. The high incidence of cloud coverage all over the country has significantly decreased the feasibility of the methodologies based on the above mentioned techniques, especially those regarding Agriculture. Some regions of Brazil are always cloud covered; others are covered during seedtime, growing season or harvest period of important crops, making the monitoring (for crop forecasting for example), in the visible and infrared, an extremely difficult task (Figure 1).

The common occurrence in Brazil and other tropical areas of Ferralsols and Oxisols (highly weathered soils with high iron oxide contents and low cation exchange capacity) in important agricultural areas is a relevant aspect in radiometric studies. Oxisols have a low Bidirectional Reflectance Factor (BDF) in the visible/infrared region (0.52 - 2.32μm) (Ref. 2). Figure 2 presents an example.

Figure 1. Frequency of Landsat-MSS Images with Less than 30% Cloud Coverage for Brazil (period 1973-1980) (Ref. 1).

It has to be pointed out that on most agricultural targets the soil is always contributing to the pixel of an image. This low reflectance associated with the influence of the atmosphere can even come very close to the signal-to-noise-ratio (S/N) of orbital sensor systems, making the interpretation of data doubtful, principally for soil moisture studies. Moreover these soils have abrupt changes in "color" in the visible spectrum depending on the sun/sensor positions.

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2. MATERIALS AND METHODS

Table 1 resumes the basic specification of the X-Band radiometer with antenna and Figure 3 presents the conical corrugated horn radiation pattern at 10.62 GHz (anechoic chamber).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiometer</td>
<td>Dicke non balanced</td>
</tr>
<tr>
<td>Frequency (GHz)</td>
<td>10.62</td>
</tr>
<tr>
<td>RF Band (GHz)</td>
<td>1.0</td>
</tr>
<tr>
<td>Int. Time (ms)</td>
<td>1000/100</td>
</tr>
<tr>
<td>Tsyz (K)</td>
<td>-2000</td>
</tr>
<tr>
<td>Srms (K)</td>
<td>0.6/2.0</td>
</tr>
<tr>
<td>Polarization</td>
<td>V</td>
</tr>
<tr>
<td>Antenna (-3dB)</td>
<td>24</td>
</tr>
</tbody>
</table>

Figure 3. Antenna Radiation Pattern at 10.62 GHz.

Measurements of \( e^* \) of soil and water samples at 10.62 GHz were performed at the Microwave Laboratory of the Instituto Mauá de Tecnologia (IMT) in cooperation with INPE. Figure 4 shows a scheme of the measurement system used. Six agriculturally important soils were selected for this study, with and without remarkable chemical characteristics, as discussed later on. The necessary computations of the dielectric constant \( e^* \), loss factor \( e'' \) and electrical conductivity \( \sigma \) at 10.62 GHz of the soils and water to moisten these soils, were made using a computational programme (Ref. 4). Computer programmes were developed in order to obtain emissivity values for the soils in function of soil moisture, based on electromagnetic theory (Ref. 5-6) and the antenna radiation pattern of the radiometer. The computation assume that the soil samples are homogeneous. For each moisture level five measurements of \( e^* \) were made. Regarding the radiometer extensive tests and calibration were performed. Two field missions on three of the six soils were carried out (truck mounted). The radiometer proved to be sensitive to soil moisture changes.

Microwaves, besides being less influenced by clouds (quasi all weather capability), provide higher penetration depths in the soil and generally larger contrast ranges. These aspects have led to considerable research, mainly in the northern hemisphere, about the use of active/passive microwave remote sensing systems/techniques, to estimate soil moisture and monitor soil salinization processes on a regional basis.

Although Brazil was entirely imaged in the X-Band by an airborne system during the early 1970's, the so called Projeto Radambrasil, and later on in part by the SIR-A and SIR-B missions and the MRSE mission, little knowledge has been acquired on the interaction mechanisms between microwave radiation and natural targets. Estimating and monitoring up-to-date soil moisture conditions over extensive areas using active/passive microwave remote sensing techniques requires the knowledge of the complex permittivity \( e^* \) of the soils in function of soil moisture. Particularly for brazilian conditions, again because of the common occurrence of Ferralsols/Oxisols, basic studies on the \( e^* \) of these soils are of fundamental importance to understand the interaction mechanisms in the microwave spectrum, and consequently allow reliable and effective applications in Agriculture. In this context and expecting the operational use of spaceborne microwave remote sensing systems in the next decade, the brazilian Institute for Space Research (INPE) developed in 1985 X-Band radiometer. Besides, in a close cooperation with the Instituto Mauá de Tecnologia/Centro de Pesquisas in São Paulo, measurements of \( e^* \) in function of soil moisture of different brazilian soils and saline water samples were carried out for the first time and used to estimate the emissive characteristics of the soils that would be expected with the X-Band radiometer developed by the Radioastronomy Department and Space Telecommunications Department at INPE.
Figure 4. Measurement System of ε*.

Figure 5 presents the methodology used to obtain emissivity through ε* measurements (LABORATORY) and using the radiometer (CONTROLLED FIELD).

3. RESULTS AND DISCUSSION

Although extensive work has been done related to the field phase, only some relevant results concerning ε* in function of soil moisture and estimates of the emissivity will be presented here, mainly because of the time consuming improvements made on the radiometer, especially those aiming to lower T_{MB} and because of the emphasis given to ε*. (If possible results will be presented during the Symposium).

Results for water were ε''_ε = 51.3, ε''_ε = 25.8 and σ = 152.9 mmho/cm. Figure 6 shows results of ε* vs. volumetric soil moisture for two soils with no remarkable chemical characteristics.

The loamy sandy soil has about 74% sand, 16% silt and 10% clay whereas the very clay soil has about 11% sand, 16% silt and 73% clay. Some important brazilian soils can be included in this group.

The shapes of these curves do agree well with results found by authors from the northern hemisphere, with the existing dielectric mixing models and with the known influence of soil texture on ε* in function of soil moisture - bound and free water concepts - (Ref. 7, 8, 9).

Emissivity estimates for these soils are shown on Figure 7, where ε*(θ) refers to the emissivity at nadir and ε*(θ) to the hemispherical emissivity of the soil. The shift between the two emissivities is related to the influence of the antenna radiation pattern of the radiometer on ε*(θ).

Figure 5. Methodology: Laboratory versus Field.

Figure 6. ε* in Function of Soil Moisture at 10.62 GHz for Two Soils with No Remarkable Chemical Characteristics (n = 30; average values).
1. This soil is an Oxisol due, among others, to its high Fe$_2$O$_3$ concentration (20.6%);
2. agronomically this soil although having a high clay content (27% sand, 16% silt and 57% clay) behaves in the field, because of the iron oxides, as a sandy soil (Ref. 10, 11, 12);
3. and most important, this soil is actually, electromagnetically, a dielectric/ferromagnetic mixture (Ref. 13) probably with $\mu \neq 0$; consequently the data (shape of the curve) for this soil are not totally correct. However it seems that standard $c^*$ and $\mu^*$ measurement techniques are not adequate to characterize and explain $c^*$ vs. soil moisture. This is perhaps the most challenging aspect to be solved in the near future, since Brazil has important agronomical areas on this soil class (LATOSOLS) with variations of Fe$_2$O$_3$ (Magnetite, Hematite and others) ranging from 4 to 80%, with most of them in the 12-30% interval and being the Fe$_2$O$_3$ easily attracted by a magnet. Figure 9 shows the expected emissivity in function of the volumetric soil moisture.

Figure 7. $c(\theta)$ and $\text{ehemis}$ in Function of Soil Moisture at 10.62 GHz for the Data from Figure 6.

However for soils with remarkable chemical characteristics not only the measurement of $c^*$ vs. soil moisture but also the development of physical models seems to be a much greater challenge. Figure 8 presents results for two clay soils (1) with high iron oxides content and (2) with high organic matter content. For soil (2) $c^*$ vs. soil moisture data do not agree well with the existing theories and models although it is correct to assume that this soil is a dielectric. This soil has about 37% sand, 21% silt and 42% clay. This soil contains 14.6% organic matter which is considered an extremely high content. Is a common soil in the Brazilian lowlands on which normally rice is cultivated.

Figure 8. $c^*$ in Function of Soil Moisture at 10.62 GHz for an Oxisol (1) and an Organic Soil (2).

Referring to soil (1) data also do not fit well with standard measurements and models; some additional considerations need to be made.

Figure 9. $c(\theta)$ and $\text{ehemis}$ in Function of Soil Moisture at 10.62 GHz for the Data from Figure 8.

The water used to moisten the soils showed a value for $c(\theta) = 0.40$. The results of $c^*$ in function of soil moisture for the six soils were also used to compute the radiation penetration depth for $1/e$ and $1/7e$, and to plot the directional emissivity on polar graphs. Complete results for the X-Band including the equations used and an extensive statistical analysis can be found in Reference 3.

4. CURRENT ACTIVITIES/FUTURE

The actual team involved in Microwave Radiometry research for Agriculture in Brazil comprises besides INPE, two Universities, namely the Instituto Mauá de Tecnologia/ Centro de Pesquisas (IMT) where measurement techniques of $c^*$ and $\mu^*$ for soil/water are being developed, and the Escola Superior de Agricultura de Lavras (ESAL) - Department of Soil Science - where also the soil analysis are all being performed. Also, the Empresa Brasileira de Pesquisa Agropecuária...
(EMBRAPA), which is the main agency for research in Agriculture, is participating, mainly through one of its centers of research (CPATSA) in the semi-arid northeast of Brazil. The team is currently working on 13 different soil samples and 4 different water samples (being 3 saline). Great emphasis is being given on studies of \( \varepsilon^* \) and \( \mu^* \) of Oxisols (dielectric/ferromagnetic mixture). A system is in development in order to measure \( \varepsilon^* \) and \( \mu^* \) in function of frequency using TDR techniques (Figure 10). Qualitative preliminary investigations using the TDR system show that there might be quite interesting results for some soils even when dry. The team involved understands that the information on \( \varepsilon^* \) and \( \mu^* \) in function of frequency is of fundamental importance to the understanding of the energy/matter interaction mechanisms in the microwave spectrum and consequently to Brazil's participation on the ERS-1 Announcement of Opportunity and other future possibilities, and principally to the development of new passive or active MW sensor systems.

Fig. 10. TDR Measurement System.

For the 1988/89 years activities are planned in Microwave Radiometry together with the Institut f/ür Hochfrequenztechnik/Deutsche Forschungsgemeinschaftsschule und Versuchsanstalt f/ür Luft und Raumfahrt (DFVLR), via International Cooperation. Oxisol/Latosol soil samples will be send to the Federal Republic of Germany and extensive measurement campaigns will be carried out using the MW sensor systems of the DFVLR in order to characterize brightness temperature (Tb) and backscattering coefficient (o) of these soils in function of soil moisture.

5. REFERENCES


