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Microwave Remote Sensing of Soil Moisture Content Over Bare and Vegetated Fields

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16. Abstract

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J. R. Wang[1], J. C. Shiue[2], and J. E. McMurtrey, III[3]

ABSTRACT

Remote measurements of soil moisture contents over bare fields and fields covered with grass, corn, and soybean were made during October 1979 with 1.4 GHz and 5 GHz microwave radiometers mounted on a truck. Ground truth of soil moisture content, ambient air and soil temperatures were acquired concurrently with the radiometric measurements. The biomass of the vegetation was sampled about once a week. The measured brightness temperatures over the bare fields were compared with those of radiative transfer model calculations using as inputs the acquired soil moisture and temperatures data with appropriate values of dielectric constants for soil-water mixtures. A good agreement was found between the calculated and the measured results over 10°-70° incident angles. The presence of vegetation was found to reduce the sensitivity of soil moisture sensing. At 1.4 GHz the sensitivity reduction ranged from ~20% for 10-cm tall grassland to over 50-60% for the dense soybean field. At 5 GHz the corresponding reduction in sensitivity ranged from ~70% to ~90%.

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MICROWAVE REMOTE SENSING OF SOIL MOISTURE CONTENT OVER BARE AND VEGETATED FIELDS

1. INTRODUCTION

It is well known that microwave emission from soils depend on factors like soil temperature and moisture content, soil types, surface roughness, row structure, and vegetation cover (Newton, 1977). To assess the soil moisture remote sensing capability by microwave radiometric measurements, it is essential that the relative importance of these factors be understood quantitatively. One of the fundamental means to study these factors is to mount the microwave radiometers on a mobile tower and make radiometric measurements over well-controlled fields. Experiments of this nature had been carried out previously by Newton (1977) and Njoku and Kong (1977). However, the measurements of Njoku and Kong were made only over a bare, sandy field and the results from their report were limited to the frequencies of 10.7 GHz and 31.4 GHz. The measurements of Newton were done at the frequencies of 1.4 GHz and 10.7 GHz over both bare and vegetated fields with a Miller Clay soil. Clearly, more measurements and analyses are needed in order to better understand the various factors affecting soils' microwave emission.

The measurements to be reported in the following were carried out with truck-mounted microwave radiometers at 1.4 GHz and 5 GHz over both bare and vegetated fields on the USDA Beltsville Agricultural Research Center test site. The soil type is of Elinsboro sandy loam and the vegetation covers include grass, soybean, and corn. It was found that the bare field measurement results at 1.4 GHz agreed fairly well with radiative transfer model calculations (Wilheit, 1978) with appropriate values of surface roughness factor and mixing ratio (Choudhury, 1978). The presence of vegetation cover was found to reduce the sensitivity of soil moisture sensing significantly. At 1.4 GHz the reduction in sensitivity ranged from ~20% for surface covered with 10-cm tall grass to over 60% for surface covered with fully grown soybean. At 5 GHz frequency the corresponding reduction in sensitivity ranged from ~70% to ~90%.

2. THE EXPERIMENT

Both the 1.4GHz and 5GHz radiometers measure the microwave brightness temperature T_B of fields in both vertical and horizontal polarizations simultaneously. The radiometers are of the Dicke type with two internal calibration references: a hot load at 300°K and a cold load at the liquid nitrogen temperature of 77°K. In addition, frequent absolute calibrations of the radiometers were made by pointing the antennas to sky ($T_B \sim 5$°K), Eccosorb slabs at the ambient temperature, and smooth water surface. Based on the calibration data, it was estimated that the 1.4GHz measurements were accurate to about ±3°K.

Soil moisture contents at the soil layers of 0-0.5 cm, 0-2.5 cm, 2.5-5.0 cm, and 5.0-10.0 cm were measured by gravimetric technique. Soil temperatures at 0-2.5 cm and 10-12.5 cm and ambient air temperature were acquired simultaneously with the radiometric measurements. Biomass samples on grass, soybean, and corn were made about once a week close to the time of radiometric measurements over the vegetated fields. The soil surface of all the fields were smooth according to the criteria of Choudhury et al. (1979). The entire measurement program was carried out in October 1979.

3. RESULTS

a. The Bare Field Results

Figure 1, a and b, showed the typical responses of the measured T_B as a function of incident angle θ for wet and dry fields respectively. The smooth curves (solid lines for 1.4 GHz and dashed ones for 5 GHz) were the results of radiative transfer model calculations (Wilheit, 1978) based on the acquired ground truth of soil moisture and temperature profiles. There were four adjustable parameters in the model calculations, two of them related to the soil type and the other two to the surface roughness. The two parameters relating to the soil type, W_t (transition moisture) and γ, were chosen to be 0.22 and 0.42 respectively for a typical sandy loam (Wang and Schmugge, 1980). The surface roughness factor h and the polarization mixing ratio Q (Choudhury, 1978) were chosen to be 0.15 and 0.13 respectively. These values remain fixed in all the calculated results presented in this paper.

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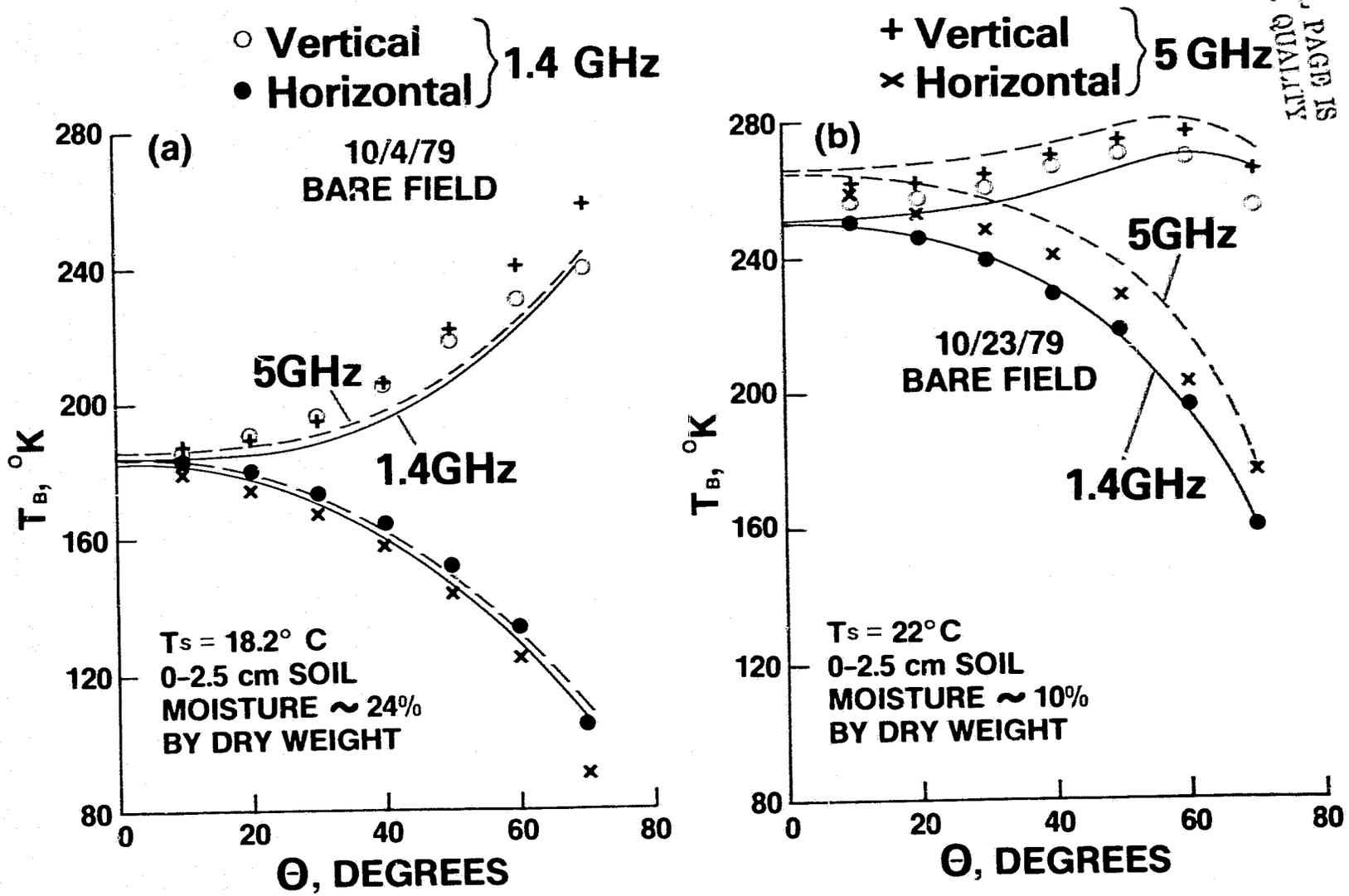

Figure 1. The Measured Brightness Temperatures Plotted Against the Incident Angles for a Bare Field; (a) Soil was Wet; (b) Soil was Dry. Smooth Curves (solid ones for 1.4 GHz and dashed ones for 5 GHz) are Calculated Results. Ts is Soil Temperature at Top 2.5 cm Layer.

Clearly, the agreement between the calculated and the measured results shown in Figure 1, a and b, was reasonably good. For the wet field results (Figure 1a) T_B were generally low (compared to Figure 1b) and the Brewster's angle (for vertical polarization) occurred well beyond $\theta = 70°$. For the dry field results shown in Figure 1b, T_B is higher and the Brewster's angle occurred at $\theta \simeq 60°$. However, most of our 5 GHz results analyzed in the same way as Figure 1 or Figure 2 showed that the calculated T_B's were generally higher by about ~8°K. We believe this difference can be attributed to the instrument error peculiar to the 5 GHz antenna. There is a significant sidelobe in the 5 GHz antenna which points above the horizon and sees the microwave brightness of the cold sky.

Comparisons of the measured and calculated T_B's for various soil moisture contents at 1.4 GHz were shown in Figure 2, a and b, for $\theta = 10°$ and $\theta = 50°$ respectively. All the bare field results both in vertical and horizontal polarizations were included in these plots. It is clear that the agreement between the measured and calculated T_B's is quite good over a wide range of T_B. As indicated by the 1:1 line, on the average the measured and calculated T_B's agree to within ±5°K. It can be shown that over the range of θ from 10° to 50°, this result generally holds. For $\theta = 60°$ or 70°, the agreement between measurements and calculations is not as good. Similar analysis like those of Figure 2, a and b, gives an average scatter from the 1:1 line of about ±8°K.

b. The Vegetated Field Results

The typical values of T_B as a function of θ over fields covered with 30 cm tall and 10 cm tall grasses are shown in Figure 3, a and b, respectively. The smooth curves again are the calculated results using the acquired ground truth on moisture and temperature profiles but assuming the fields were bare. Notice that the measured T_B's over the grasslands are higher than those expected from the bare fields at all θ up to 70°, indicating the shielding effect of the vegetation cover. The shielding effect is greater for the 30 cm than for the 10 cm grassland measurements. Furthermore, the shielding effect is more severe at 5 GHz than at 1.4 GHz measurements. Not only are the measured T_B's at 5 GHz are higher compared to those at 1.4 GHz, they also show smaller differences between the vertical and horizontal polarizations over the θ range of 10°–70°.

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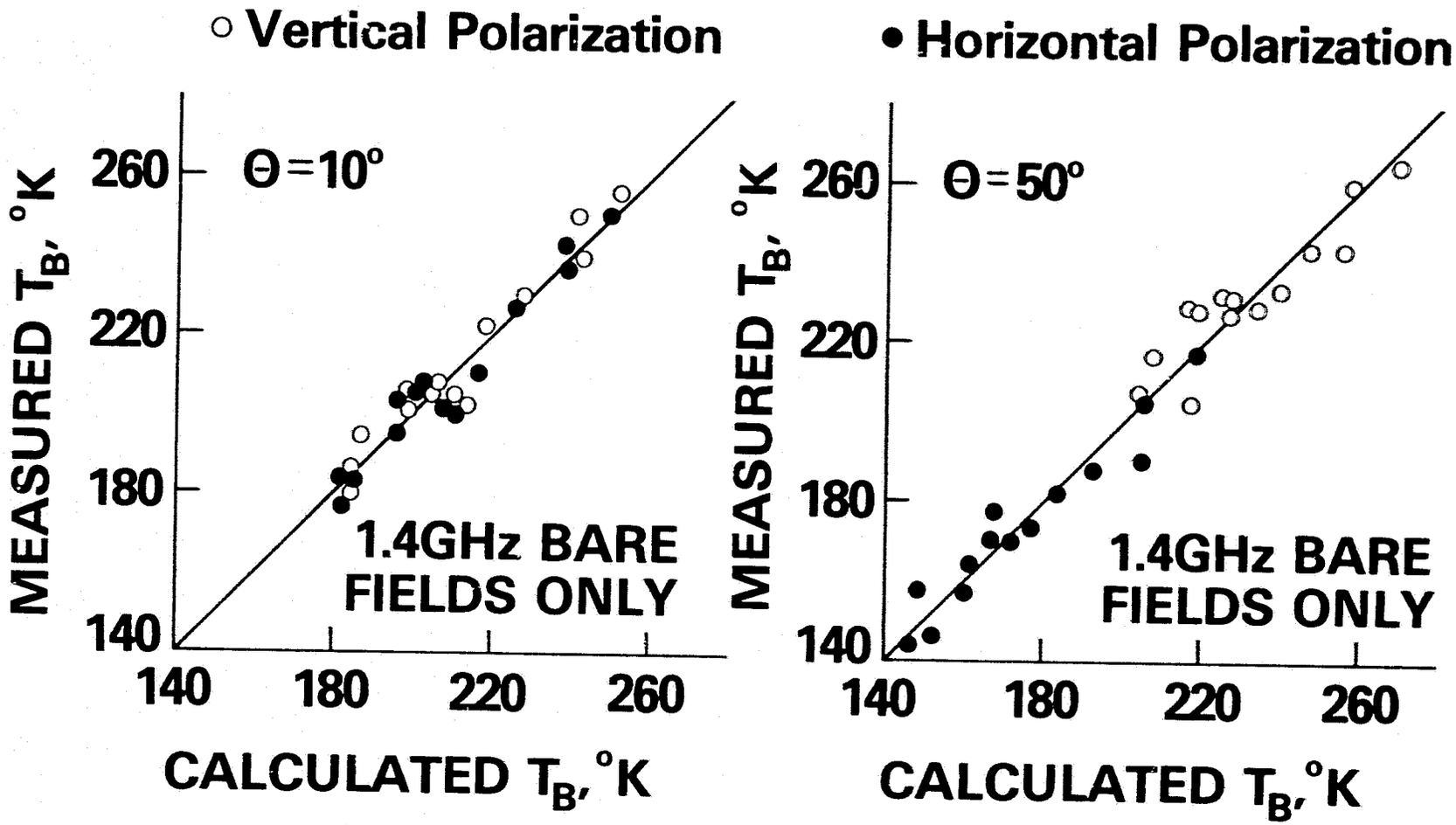

Figure 2. A Comparison of the Measured and the Calculated Brightness Temperatures at 1.4 GHz; (a) Incident Angle = 10°; (b) Incident Angle = 50°.

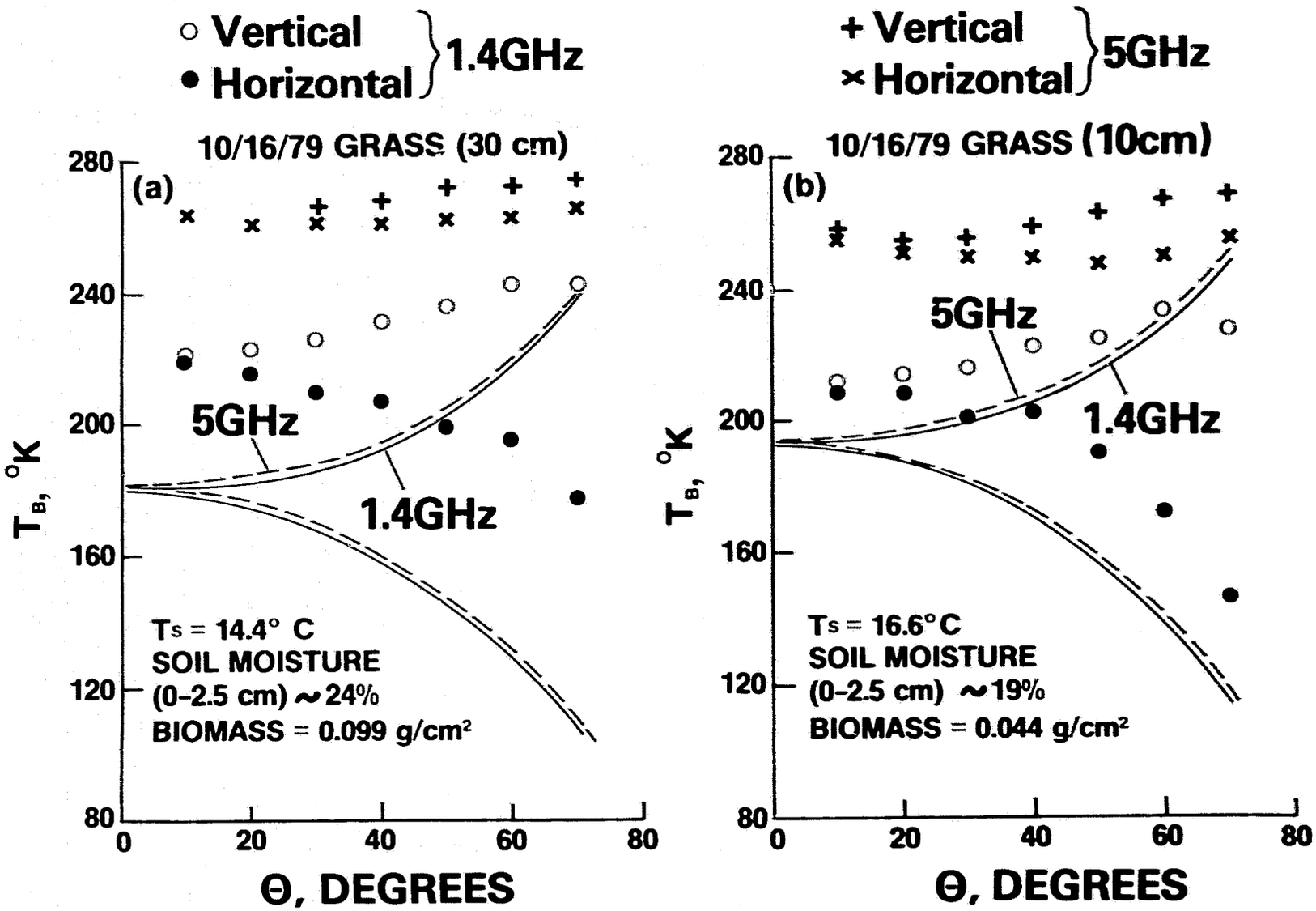

Figure 3. The Measured Brightness Temperatures Plotted Against the Incident Angles for Grasslands; (a) 30cm Tall Grass; (b) 10cm Tall Grass. The Smooth Curves (solid ones for 1.4GHz and dashed ones for 5GHz) are the Calculated Res Its Assuming the Fields were Bare. Ts is Soil Temperature at Top 2.5cm Layer.

The measurements over the soybean and corn fields basically give the same result. The effect of the vegetation cover is summarized in Figure 4 where the 1.4GHz normalized T_B's at $\theta = 10°$ are plotted against soil moisture content W at top 0-2.5 cm layer. The normalized T_B is defined as the ratio of the measured T_B and the top 0-2.5 cm soil temperature and is a measure of soil emissivity nearly independent of soil temperature variations. As expected, the bare field T_B decreases steadily with W in accordance with previous observations (Schmugge, 1978). A linear regression analysis between the bare field T_B and W gives a good correlation coefficient of 0.89. All the normalized T_B taken over the vegetated fields lie above the regression line of the bare fields.

At low W ($\leq$5%) the emissivities from the bare and vegetated fields are expected to be close (Newton, 1977). If the sensitivity of the soil moisture sensing is defined as the slope of the regression line like the one in Figure 4, then the presence of vegetation cover is to reduce the sensitivity. At 1.4 GHz the 10 cm grass cover reduces the sensitivity by about 20% from its bare field value. For the fields covered with 30 cm grass, corn, and soybean, the sensitivity is reduced by nearly 50-60%. A similar analysis on the results at 5 GHz shows a nearly 90% reduction in sensitivity for observations over the 30 cm grass, corn and soybean fields. Even for the 10 cm grassland the sensitivity reduction is well over 60-70%. These results are summarized in Table 1 for comparison with measurements of Kirdiashev (1979).

Table 1
A Summary on the Sensitivity Reduction in Microwave Soil Moisture Sensing Due to the Presence of Vegetation Cover. The USSR Results were Derived from Kirdiashev et al., (1979)

	1.4GHz		5GHz	
	Present Work	USSR Results	Present Work	USSR Results
10cm Grass	~20%		~65%	
30cm Grass	~60%		~90%	
Soybean	~60%		~90%	
Corn	~50%	~60%	~80%	~80%
Winter Rye		~15%		~35%
Forest		~80%		100%

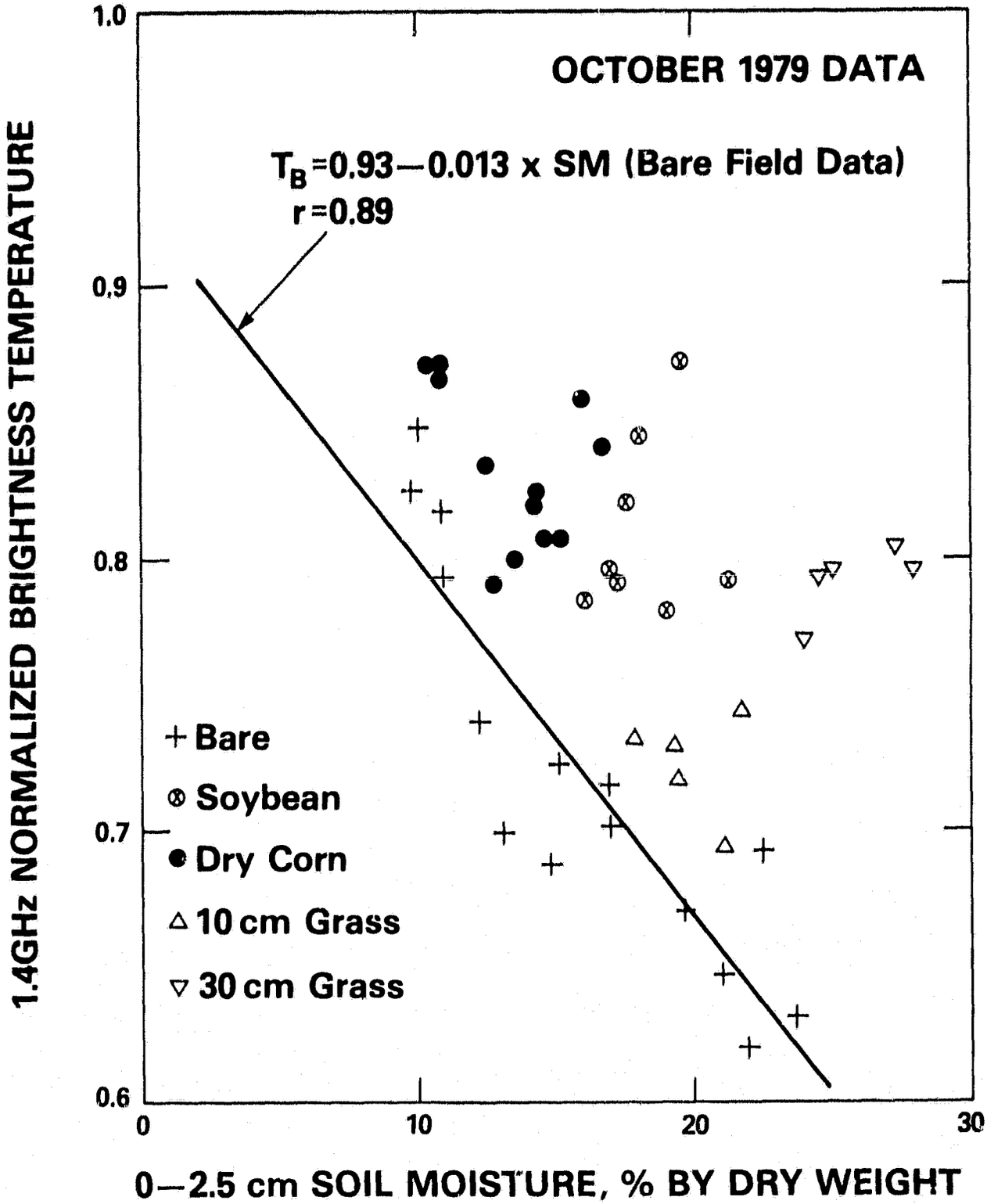

Figure 4. The Normalized 1.4 GHz Brightness Temperatures Plotted Against the Soil Moisture Content at the Top 0-2.5 cm Layer.

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4. DISCUSSION

The results presented in the previous sections demonstrate for the first time that the observed brightness temperature T_B's over a bare field could be modelled over a wide range of incident angles and soil moisture contents. The measurements over the vegetated fields suggest a reduction in the sensitivity of soil moisture sensing. The percentage of the sensitivity reduction depends on microwave frequency and the biomass of vegetation cover. At 1.4 GHz the reduction in sensitivity ranges from ~20% for 10 cm tall grassland to ~60% for dense soybean field. At 5 GHz the corresponding sensitivity reduction ranges from 60% to 90% over the same fields. These results are in qualitative agreement with the observations of Kirdiashev et al., (1979). Although different types of vegetation covers (winter rye, corn, and forest) were employed by these authors, their results showed that the shielding effect increased with frequency of observations and with the biomass of the vegetation cover.

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Figure Captions

Figure 1. The measured brightness temperatures plotted against the incident angles for a bare field; (a) soil was wet; (b) soil was dry. Smooth curves (solid ones for 1.4 GHz and dashed ones for 5 GHz) are calculated results. Ts is soil temperature at top 2.5 cm layer.

Figure 2. A comparison of the measured and the calculated brightness temperatures at 1.4 GHz; (a) incident angle = 10°; (b) incident angle = 50°.

Figure 3. The measured brightness temperatures plotted against the incident angles for grasslands; (a) 10 cm tall grass; (b) 30 cm tall grass. The smooth curves (solid ones for 1.4 GHz and dashed ones for 5 GHz) are the calculated results assuming the fields were bare. Ts is soil temperature at top 2.5 cm layer.

Figure 4. The normalized 1.4 GHz brightness temperatures in horizontal polarization plotted against the soil moisture content at the top 0–2.5 cm layer.