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PBMR OBSERVATIONS OF SURFACE SOIL MOISTURE IN MONSOON 90

T. Schmugge, T.J. Jackson
USDA Hydrology Lab
Beltsville, MD 20705
301-344-1554
301-344-1931-FAX

D. Goodrich, S. Amer
USDA Southwest Watershed Research Center
Tucson AZ 85719
602-670-6481
602-670-6493-FAX

ABSTRACT

The 21-cm Push Broom Microwave Radiometer (PBMR) was flown on 6
flights of the NASA C-130 to map the surface soil moisture over
the USDA Agricultural Research Service (ARS) Walnut Gulch experi-
mental watershed in southeastern Arizona. It has four beams
which cover a swath of 1.2 times the aircraft altitude, thus, by
flying a series of parallel flight lines it is possible to map
microwave brightness, and thus the soil moisture, over a large
area. In this case the area was approximately 8 by 20 km. The
moisture conditions ranged from very dry,<2%, to quite wet, >15%,
after a heavy rain. The rain amounts ranged from less than 10 mm
to more than 50 mm over the area mapped with the PBMR. With the
PBMR we were able to observe the spatial variations of the rain
amounts and the temporal variation of the moisture content as the
soil dried. The brightness temperatures were registered to a UTM
grid so that they could be compared to the rain gage readings and
to the ground measurements of soil moisture in the 0 to 5-cm
layer. The decreases in brightness temperature were well corre-
lated with the rainfall amounts up to a threshold level of 25 or
30 mm and the comparison of the brightness temperatures with soil
moisture was also good with an r^2 of about 0.8. For the latter,
there was some dependence of the relation on location which may
be due to soil or vegetation variations.

I. INTRODUCTION

The Monsoon 90 experiment had
as one of its goals the evalu-
ation of use of remotely
sensed data for the estimation
of surface fluxes in an arid
environment[1]. The site
chosen for the experiment is
the well instrumented Walnut
Gulch Experimental Watershed
operated by the USDA Agricul-
tural Research Service. It is
located in southeastern Arizo-
na about 120 kilometers south-
east of Tucson. The region
has 250-500 mm of annual pre-
cipitation with the majority
falling during a "summer mon-
soon season" in July and Au-
gust. This was the period
chosen for the experiment.

One of the most important
surface parameters effecting
these fluxes is the moisture
stored in the soil. It ef-
fects the thermal properties

of the soil and serves as the reservoir for the evaporation process. The remote sensing technique of interest in this paper is the passive microwave sensing of soil moisture.[2], [3] This approach uses measurements of the thermal emission from the soil at the longer microwave wavelengths ($\lambda \geq 10$ cm) to determine the moisture content in the surface layer of the soil. It relies on the fact that the emissivity (ϵ) at these wavelengths is a function of moisture content as a result of the large dielectric contrast between water and dry soil. For water the real part of dielectric constant is about 80 while for dry soil it is less than 5 and thus for soils it ranges from about 3.5 to 20. This produces a change in ϵ from .95 to less than 0.6 when wet. This decrease in ϵ is approximately linear with soil moisture and is effected by factors such as soil texture, surface roughness and vegetation cover. The texture effects the slope of the relation between ϵ and soil moisture but not the range of variation. While both roughness and vegetation reduce the range of variation, with vegetation totally obscuring the soil surface if it is present in sufficiently large amounts. This will occur for vegetation water contents in excess of 6 or 7 kg/m^2 at the 21-cm wavelength. The resulting sensitivity of ϵ to soil moisture can be expressed as:

$$\epsilon = 1 + (\epsilon_0 - 1)\exp(-h - 2\tau) \quad (1)$$

where ϵ_0 is the bare smooth soil emissivity and h is the roughness parameter.[4] For the Walnut Gulch site the vegetation consists of sparse grass and shrubs [1] and so we expect it to have a minimal effect on the microwave response at 21-cm.

II. The PBMR

The NASA PushBroom Microwave Radiometer (PBMR) is a 4 beam L-band (frequency = 1.42 GHz; wavelength = 21-cm) aboard the NASA C-130 aircraft. The PBMR has four horizontally polarized beams pointing at $\pm$ 8° and $\pm$ 24° from the nadir. Each of the beams has a full width at half maximum power of about 16° which yields a footprint on the ground 0.3*H for each beam and a total swath of about 1.2*H, where H is the aircraft flight altitude.[5] Additional instruments aboard the aircraft are the PRT-5 thermal infrared radiometer, the NS001 Thematic Mapper Simulator and the Thermal Infrared Multispectral Scanner (TIMS).

The PBMR was flown on 6 flights of the C-130 during a 10 day period in July and August of 1990 as part of the Monsoon 90 experiment. The objective was to map the surface brightness temperature (T_B) at the wavelength of 21-cm and to infer surface soil moisture from these data. On each flight a series of 7 parallel flight lines separated by 500 m were flown. Their length was approximately 20 km. The altitude for these flights was approximately 600 m (2000 ft) above ground. At this altitude the resolution was 180 m and the PBMR swath was 720 m. The aircraft posi-
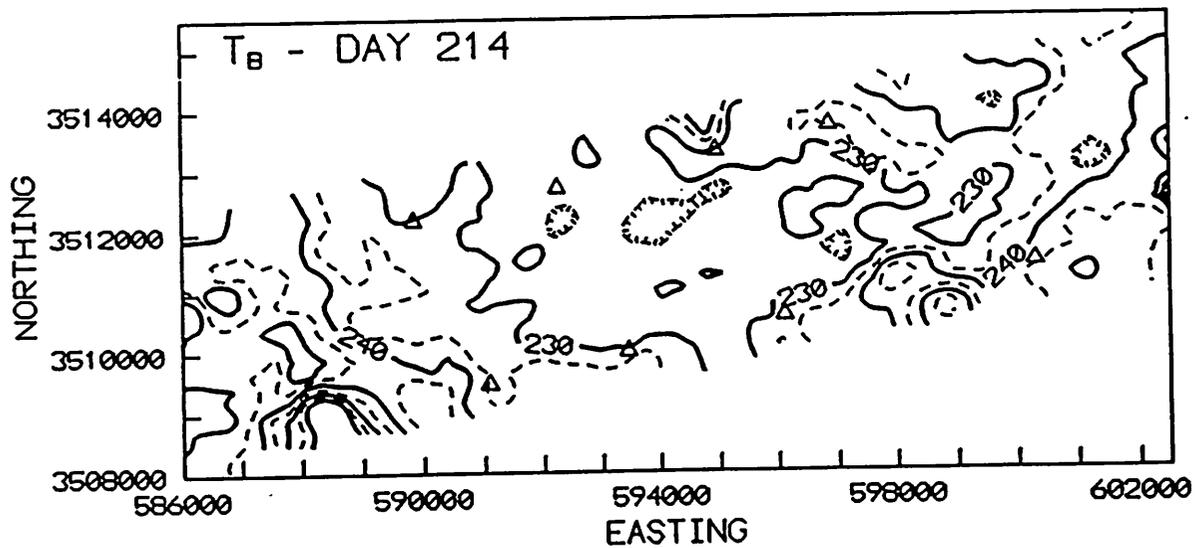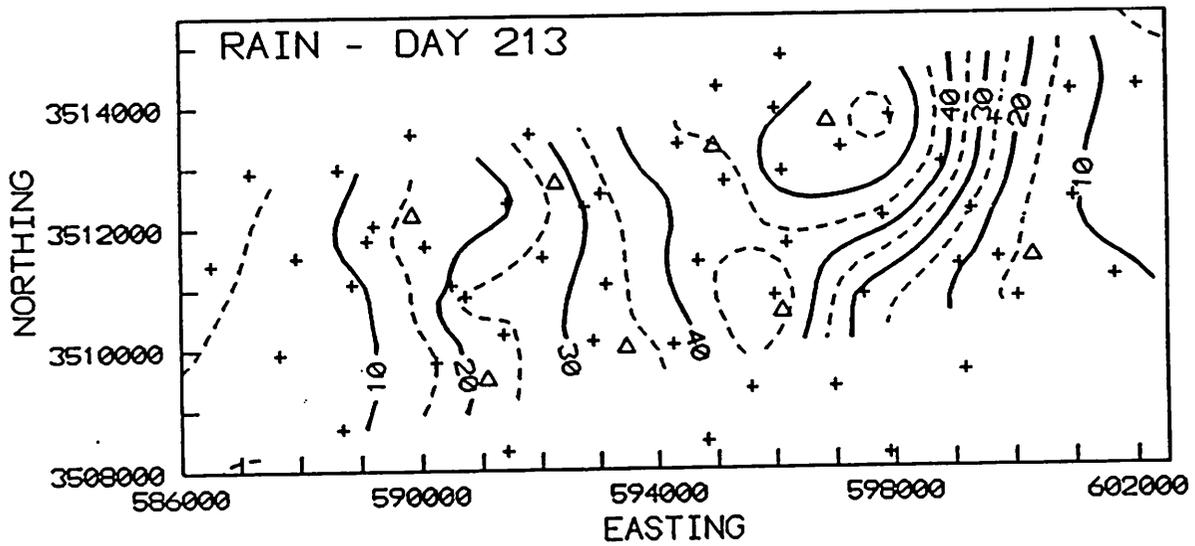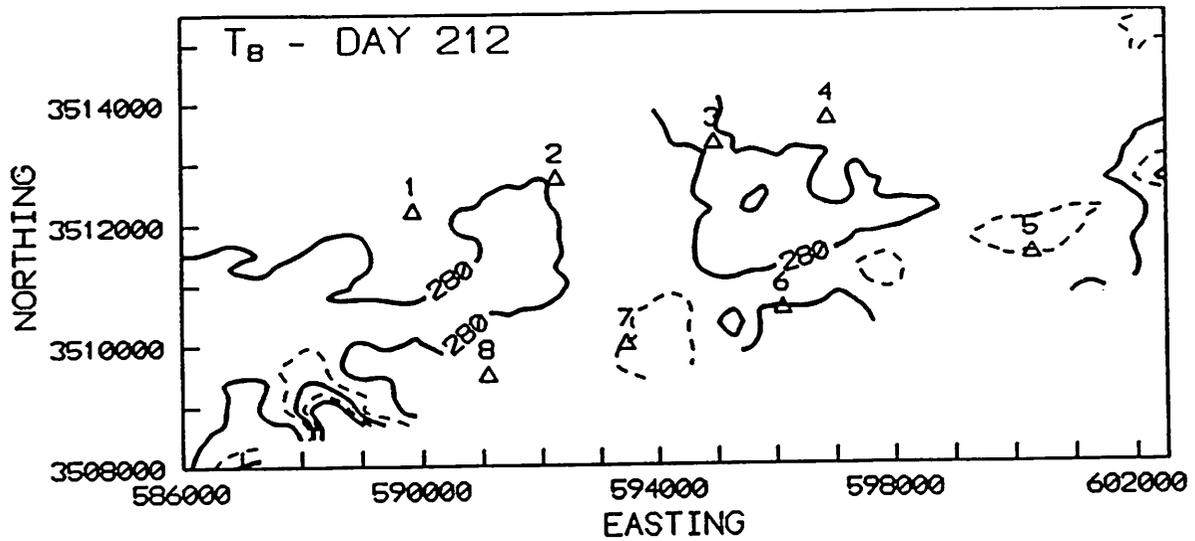
Figure 1. Contour maps of T_B and rainfall during 3 days of Monsoon 90. a) T_B in K for day 212, the Δ's indicate the 8 met sites; b) rainfall in mm on day 213; and c) T_B on day 214.

tions on these flight lines were digitized into UTM coordinates as functions of time so that the PBMR data could be put into georeferenced images. Before creating the images, the data for the outer beams were corrected for the decrease in ϵ at the larger incidence angle by multiplying them by the ratio of the average of the center beam to the outer beam for each flight line. For the wetter days the ratio was about 1.03 and for the dry day the ratio was 1.01.

III. RESULTS

The period of Monsoon 90 was characterized as being very dry (SM < 2%) for the first flight on July 31 (day 212), followed by up to 5 cm of rain on August 1 over most of the study area. Thus there was a significant decrease (50 to 60K) in T_B observed during the next flight on August 2 (day 214) due to the increase in soil moisture, up to 20%. These data are presented in figure 1. The top panel presents the T_B contours on day before the rain, values are 280K or greater with the exception of the cool spot near the southwest corner of the map. This is the town of Tombstone, Arizona with its many metal roofed buildings. The sites of the eight met stations are indicated by the triangles. Ground measurements of soil moisture for the surface 5 cm of the soil were made at these sites. The middle panel gives the rainfall contours for the rain events on day August 1 (day 213). The + signs indicate the sites of the rain gages

used to create this map. The rainfall amounts range from less than 10 mm at the west to more than 50 mm near site 4. The bottom panel presents the T_B contours for day 214, August 2. Here we can see that T_B has decreased to less than 230K, the lowest areas roughly correspond to the peak rainfall. All of the area which received more that 10 mm of rain had T_B < 240K and that the 240K contour roughly corresponds to that of 10 mm contour.
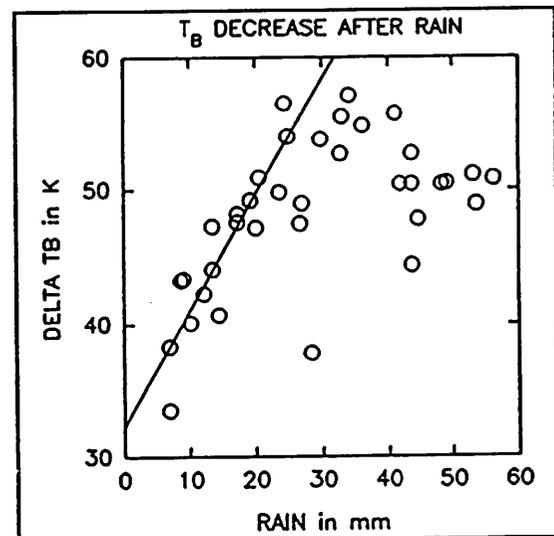

Figure 2. The decrease in T_B versus rain amount for the gages shown in Fig. 1b. The line is the regression for the data with less 25 mm rain, $R^2 = 0.8$.

With the data in this format it was possible to compare the change in T_B to the rainfall amounts at each rain gage. The result is given in Figure 2, there is a linear decrease in T_B with rain amounts up to about 25 or 30 mm of rain. Above that level the soil is apparently saturated and no

further decrease in T_B is observed. We expect that the moisture in the surface 0 to 5 cm layer had stabilized by the time of the flight on day 214 to values between 15 and 20%.

The succeeding flights on 4, 5, 8 and 9 August (days 216, 217, 220, and 221) showed the effects of some smaller rains and the subsequent drydown of the study area. On day 221 the values of TB rose to almost their pre-rain values.
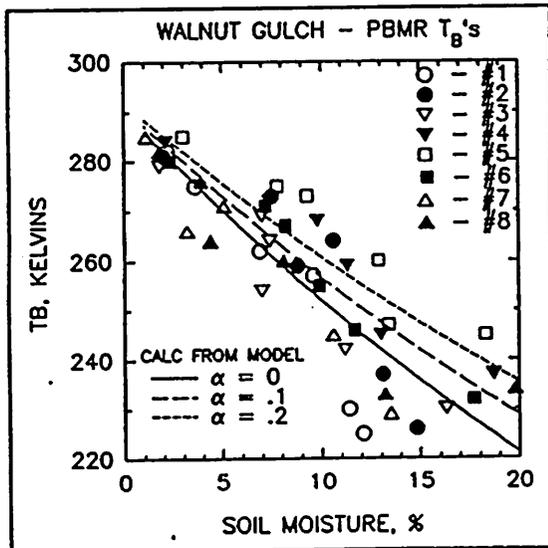

Figure 3. Comparison of T_B with ground measurements of soil moisture in the 0-5 cm layer at the 8 met sites. The curves are model predictions of the variation of ϵ with soil moisture for various values of α.

The comparison between the ground measurements of soil moisture and T_B for the 8 sites from the 6 flights are shown in Figure 3. The curves show the expected behavior for a soil with a texture similar to that found in Walnut Gulch

with a range of surface parameters $\alpha = h + 2\tau$, where h is the roughness parameter and $\tau = 0.1*PWC$ is the vegetation optical depth and is a function of the plant water content. It is seen that the curve with $\alpha = 0$ and $\alpha = 0.2$ roughly bracket the data. The first is the behavior expected for a bare smooth soil and the second is that for a slightly rough soil with a small amount of vegetation cover. On a site by site basis there is an excellent correlation of T_B with soil moisture, $R^2 > 0.9$. However there is considerable variation in the slopes with sites on the western end showing greater sensitivity to soil moisture that those on the east end.

IV. SUMMARY

These PBMR data indicate that microwave radiometer data can be used to map rainfall patterns and the subsequent spatial and temporal variations of the surface soil moisture during the dry down process. The observed sensitivity of T_B to soil moisture was in approximate agreement with expectations but variation in sensitivity from site to site remains to be explained and are currently under study. One of the factors we will consider in this analysis is that of rock fraction. The rock volume varies from 20 to 50% among the sites and can have a significant effect on the microwave response.[6]

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