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1090

SOIL MOISTURE VERIFICATION STUDY OF THE ESTAR MICROWAVE RADIOMETER: WALNUT GULCH, AZ 1991

T. J. Jackson[1], D. M. Le Vine[2], A. Griffis[3], D. C. Goodrich[4], T. J. Schmugge[1], C. T. Swift[3], P. E. O'Neill[5], R. R. Roberts[1], and R. Parry[1]

1. USDA ARS Hydrology Lab, Beltsville Agricultural Research Center, Beltsville, MD
2. NASA Goddard Space Flight Center, Microwave Sensors Branch, Greenbelt, MD
3. University of Massachusetts, Dept. of Electrical and Computer Engineering, Amherst, MA
4. USDA ARS Southwest Watershed Research Center, Tucson, AZ
5. NASA Goddard Space Flight Center, Hydrological Sciences Branch, Greenbelt, MD

ABSTRACT

The application of an electronically steered thinned array L band radiometer (ESTAR) for soil moisture mapping was investigated over the arid rangeland Walnut Gulch Watershed located in southwestern Arizona. Antecedent rainfall and evaporation for the flights were very different and resulted in a wide range of soil moisture conditions. The high spatial variability of rainfall events within this region resulted in moisture conditions with dramatic spatial patterns. The sensor's performance was verified using two approaches. First, the microwave data were used in conjunction with a microwave emission model to predict soil moisture. These predictions were compared to ground observations of soil moisture. A second verification was possible using an extensive data set collected the previous year at the same site with a conventional L band radiometer (PBMR). Both tests showed that the ESTAR is capable of providing soil moisture with the same level of accuracy as existing systems.

INTRODUCTION

A number of recent investigations designed to study land surface hydrologic-atmospheric interactions have shown the potential of L band passive microwave radiometry for measuring and monitoring surface soil moisture over large areas [1]. These studies have focused on the spatial information provided on soil moisture as well as flux variables that can be inferred through frequent temporal observation. Satisfying the data needs of these investigations requires the ability to map large areas rapidly. With aircraft systems this means a need for more beam positions over a wider swath on each flightline. For satellite systems the essential problem is resolution. Both of these needs are currently being addressed through the development and verification of ESTAR technology [2 and 3]. In this study, the application of an ESTAR L band radiometer for soil moisture mapping was investigated.

EXPERIMENT DESCRIPTION

The ESTAR instrument used in this study is described in [2] and [3]. It is an L band radiometer operating at a wavelength of 21 cm with a capability of providing the equivalent of up to 7 beam position within its +/-45 degree field of view, twice the swath of the PBMR. For this experiment the ESTAR was installed on the NASA C-130 aircraft operated by the NASA Ames Flight Center.

The site chosen for this study was the semiarid rangeland Walnut Gulch Watershed located in southeastern Arizona operated by the USDA-ARS Southwest Watershed Research Center. This watershed contains a relatively long history of detailed hydrologic measurements and associated analysis [4] and had been the focus of a major interdisciplinary experiment in the summer of 1990 [5]. As part of that experiment multi-temporal L band radiometer data were collected using the PBMR [6] and a single swath system with a 2.25 cm and 21 cm radiometers [7]. Extensive ground observations of soil moisture were collected in 1990 to validate the performance of these radiometers.

The same seven flightlines used in the 1990 experiment involving the PBMR [6] were used here. This pattern resulted in contiguous coverage of an area approximately 5 km by 10 km. Flights were conducted on Aug. 1 (Day 212) and Aug. 3 (Day 214).

Ground data collection during this experiment consisted of gravimetric sampling of the surface 5 cm of the soil and the measurement of the 5 cm soil temperature within one hour of the aircraft overflights. Some surface temperatures were obtained with a hand held infrared thermometer. These data were collected at a total of ten locations distributed over the area. Eight of these sites were the same as those used in the 1990 studies [6].

As described in [5], vegetation cover of this watershed consists of sparse grass and shrub which should have minimal effects on the interpretation of the microwave brightness temperatures. Surface soils are mostly sandy loams with varying rock fractions. A summary of the soil physical properties at the various ground sampling sites is presented in Table 1.

Table 1. Walnut Gulch sampling site soil properties.

Site	Sand (%)	Silt (%)	Clay (%)	Specific Surface Area (m^2/g)	Bulk Density (g/cm^3)	Rock Volume (%)
1	66	24	10	26	1.64	42
2	69	20	11	30	1.83	51
3	71	20	9	20	1.58	41
4	73	22	5	28	1.82	61
5	69	20	11	54	1.61	56
6	67	25	8	27	1.44	48
7	80	14	6	10	1.74	22
8	72	20	8	21	1.47*	31*
9	63	24	13	84	1.66*	10*
10	67	23	10	52	1.66*	30*

* estimated based on visual field observations

RESULTS

Meteorological conditions during the experimental period resulted in soil moisture conditions that produced the full range of brightness temperatures observed the previous year [6]. Prior to the Day 212 flight there was a localized rainfall event on Day 210 that was centered between sites 5 and 6. An isohyetal map for the rainfall during this event was produced using data collected by 84 raingages distributed over the area and the result is shown in Figure 1A. On the day preceding the second flight there was a large cellular rainfall event that was centered near sites 1 and 2. The isohyetal map for this event is shown in Figure 1B. No rainfall occurred in the vicinity of site 5 on this date.

Data collected using the ESTAR were processed to produce brightness temperatures at four beam positions which were identical to those of the PBMR [6]. The resulting brightness temperature maps for the two dates are shown in Figure 2. As mentioned above, the two dates provide data over a wide range of brightness temperatures and even on a single date (Day 214) due to the cellular nature of the rainfall event.

The brightness temperature patterns of Figure 2 match the rainfall patterns presented in Figure 1 for the respective dates. The fact that an L band radiometer detects whether or not there was rainfall is not surprising. However, there are two features that are surprising. First, the fact that even two days after a rainfall event in an arid environment the rainfall pattern can still be detected (Day 212). The second feature of interest is that on the day following the large rainfall event (Day 214) the sensor is able to discern the difference between areas that received 25 mm of rainfall and those that had 15 mm. This feature suggests that there is a great deal of quantitative rainfall information that can be extracted.

The comparisons described above provide qualitative verification of the ESTAR performance. In addition the instruments ability was evaluated using quantitative soil moisture data. The primary verification was provided by comparing the observed surface soil moisture with the values predicted using a previously established relationship [8] and the observed brightness temperatures at those sites. As described in [7] the predicted relationships are based on analyses of data collected in controlled condition experiments for a similar but not identical soil. The differences are primarily related to the rock fraction which is higher for the Walnut Gulch area. The only study that has considered this is one reported in [8]. In that study it was suggested that changing the rock fraction could have two offsetting effects on the soil moisture-brightness temperature. One effect would result from the fact that the dielectric properties of rocks are different from those of an equivalent volume of soil. The other effect results from the fact that rock volume is correlated to the presence of surface rocks [5]. This results in increased surface roughness.

The apriori relationship from [7] and [8] is plotted in Figure 3 along with the observed brightness temperature and soil moisture data from the sampling sites. Using this model the standard error of estimate for the ESTAR observations was estimated as 2.9% soil moisture. This compares to a value of 2.5% obtained in [8] and leads to the conclusion that the ESTAR can be used to accurately estimate soil moisture.

The ESTAR data were also compared to the PBMR data collected in 1990. As described in [6], this was an extensive data set that covered a wide range of moisture conditions. Using the PBMR data a linear regression equation was developed for the prediction of soil moisture from the brightness temperature. This curve and the PBMR data are shown in Figure 4. The slope of this model is slightly different than the BARC model [8] and its standard error of estimate is 2.5%. When used to predicted soil moisture from the ESTAR brightness temperatures, the error was determined to be 2.6% which was a marginal improvement over the BARC model.

SUMMARY

The ESTAR L band radiometer was evaluated for soil moisture mapping applications over the arid rangeland Walnut Gulch Watershed located in southwestern Arizona. Antecedent rainfall and evaporation for the flights were very different and resulted in a wide range of soil moisture conditions with dramatic spatial patterns. Microwave brightness temperature data were used in conjunction with an a priori model microwave emission model to predict soil moisture and compared to ground observations of soil moisture. A second verification was conducted using an extensive data set collected the previous year at the same site with the PBMR radiometer. Both tests showed that the ESTAR is capable of providing soil moisture with the same level of accuracy as existing systems.

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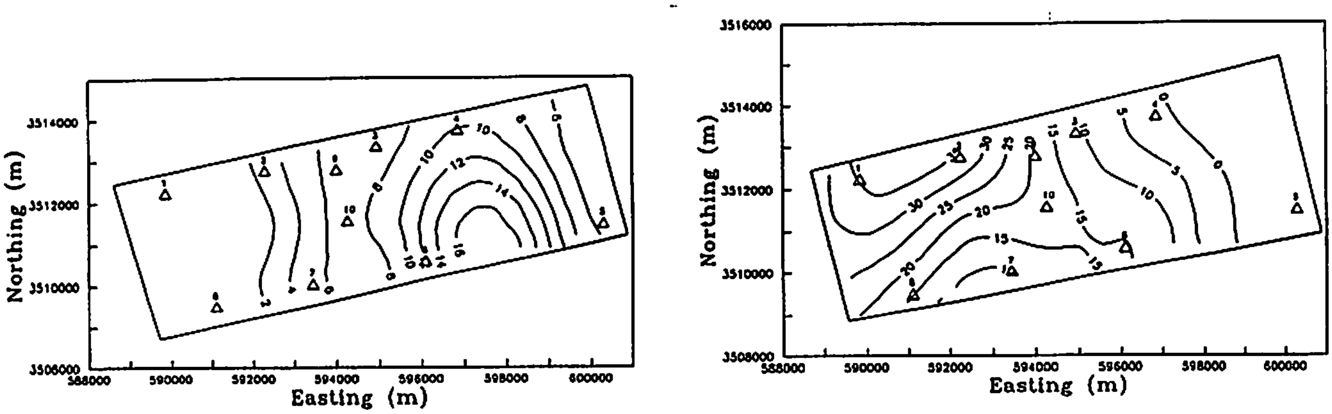

Figure 1. Rainfall contour maps for Walnut Gulch in mm; A) Day 210 event and B) Day 213 event.

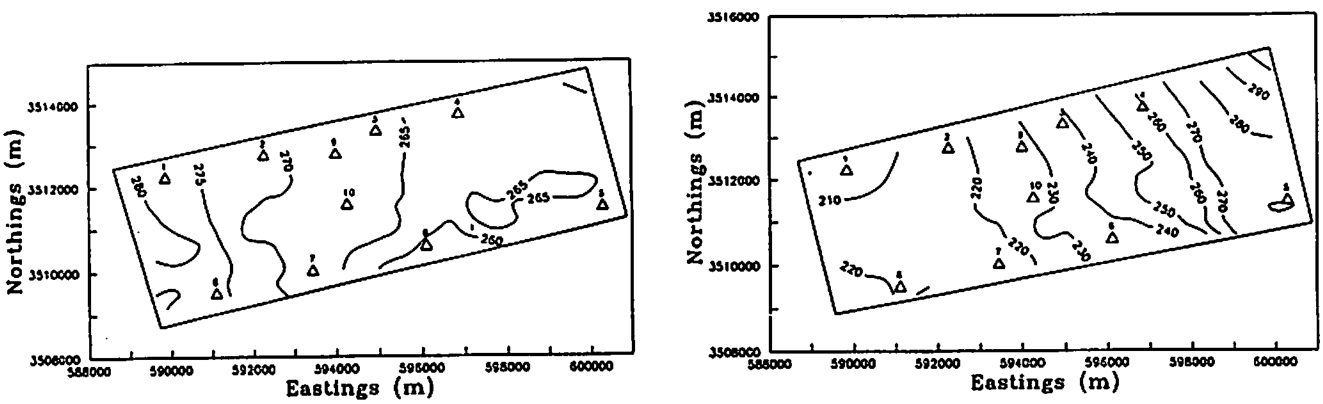

Figure 2. Brightness temperature maps for Walnut Gulch in °K; A) Day 212 and B) Day 214.

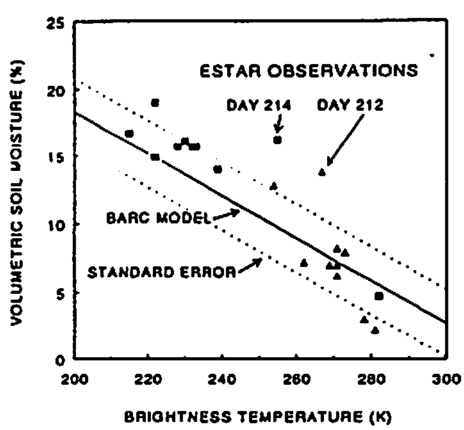

Figure 3. Observed and predicted relationships of soil moisture and ESTAR brightness temperature. BARC model based on ref. 8.

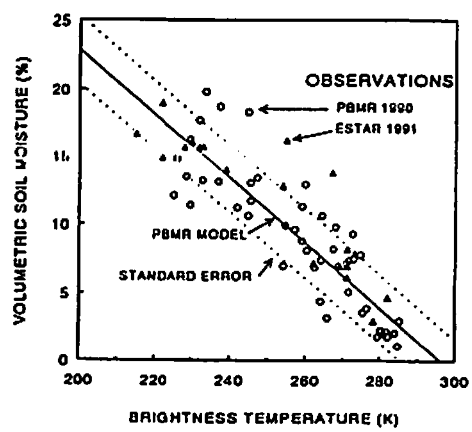

Figure 4. Observed and predicted relationships of soil moisture and 1990 PBMR and 1991 ESTAR brightness temperatures. PBMR model is a linear regression fit to the 1990 data.