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16. Abstract

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SOIL MOISTURE DETECTION BY SKYLAB'S MICROWAVE SENSORS

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ABSTRACT

Terrain microwave backscatter and emission response to soil moisture variations are investigated using Skylab's 13.9 GHz RADSCAT (Radiometer–Scatterometer) system. Data acquired on June 5, 1973 over a test site in west-central Texas indicates a fair degree of correlation with composite rainfall. The scan mode was cross-track contiguous (CTC) with a pitch of 29.4° and no roll offset. Vertical polarization was employed with both radiometer and scatterometer. The composite rainfall was computed according to the flood prediction technique using rainfall data supplied by weather reporting stations.

INTRODUCTION

The dielectric properties of soil are strongly dependent on the soil water content. The surface backscattering coefficient σ^o and emissivity ϵ are functions of the surface reflection coefficient, which in turn is a function of the dielectric properties. The scattering and emission processes are modified, however, by other surface features such as roughness, vegetation cover and soil type.

In an earlier reporting by Eagleman and Ulaby [1] data obtained by Skylab's microwave sensors was compared with soil moisture contents determined from samples collected by ground crews. In the present paper, a review of some of the results of the above study will be presented, followed by an extension from comparing the microwave response to soil moisture of the few footprints for which ground samples were available, to the entire test site area of 173 km x 358 km. Since soil moisture samples are not available for the entire test site, composite rainfall is used instead.

TEST SITE DESCRIPTION

The Texas site, shown in Figure 1, lies in the west-central portion of the state. It covers an area approximately 108 miles (173 km) wide and 224 miles (358 km) long extending from near Lubbock southwest to San Saba, Texas. The topography varies from flat plains to gently rolling hills. The major land uses in the area are grassland used for grazing, cropland, the major crop being cotton, scrub brushland, and scattered areas of woodland.

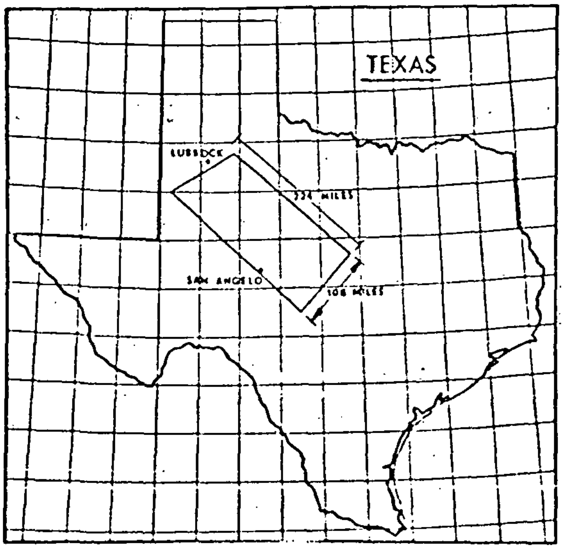

FIGURE 1. THE WEST-CENTRAL TEXAS TEST SITE.

SKYLAB MICROWAVE DATA

The S-193 RADSCAT data used for this analysis was obtained on June 5, 1973 between 18:00:13 and 18:01:16 GMT. The instrument was operated in the RAD/SCAT mode, thus gathering radiometer and scatterometer data alternately. The scan mode was cross-track contiguous (CTC) with a pitch of 29.4° from nadir and no roll offset. Defined according to the effective antenna beamwidth, the size of the radiometer elliptically shaped footprint on the ground is approximately 14 x 21 km. The effective antenna beamwidth of the scatterometer is calculated from the squared antenna pattern, and hence yields a smaller footprint, approximately 12 x 16 km. The radiometer data gathered over this test site was vertically polarized covering an antenna temperature range of 52.43°K, extending between a high of 288.73°K and a low of 236.29°K. The scatterometer data which also was vertically polarized (both transmit and receive), produced a scattering coefficient σ^o_{VV} with a dynamic range of 4.08 dB from a low of -11.4 dB to a high of -7.38 dB.

Incorporated in the data recorded by S-193 are contributions and/or losses caused by atmospheric constituents, particularly clouds. Approximately 60% of the test site was cloud covered during the pass. The areal extent and degree of cloud cover over the test site was estimated from Skylab's S-190A photography taken during the Texas pass. Four categories of cloud cover were determined: no clouds, light clouds, medium clouds, and heavy clouds. The cloud ceiling was obtained from radar weather information and cloud thickness was estimated by measuring shadow length on the photography. For the four cloud categories mentioned above, water contents of 0, 0.3 g/m^3, 0.6 g/m^3, and 1.0 g/m^3, were assigned. Surface humidity, temperature and pressure were obtained from weather reporting stations. This information was then used to calculate the attenuation and upward and downward emission by each cloud category [2]. For each scatterometer footprint, the "measured" scattering coefficient was corrected for the two way attenuation by the atmosphere (atmospheric gases and clouds). The radiometer data were converted to emissivity by assuming a plane surface model:

$$\epsilon = \frac{T_a - T_u - LT_d}{L(T_g - T_d)}$$

where T_a is the recorded radiometer antenna temperature, T_u represents upward atmospheric emission and T_d is the downward atmospheric emission which, upon reflection by a ground reflectivity $(1-\epsilon)$, is propagated up towards the radiometer. T_g is the ground temperature and L is the atmospheric transmittance. T_g was determined from a temperature data provided by weather reporting stations modified by a correction factor based on ground temperature samples collected by the ground crew.

Figures 2 and 3 show the emissivity and scattering coefficient as a function of soil moisture content in the top 2.5 cm [1]. The moisture content of each point shown in Figures 2 and 3 represents the average moisture of two or more soil samples collected within or very close to the footprint. Considering the poor representation of the soil moisture content of an approximately 231 km^2 radiometer footprint and 132 km^2 scatterometer footprint by a few soil samples, the correlations indicated in Figures 2 and 3 are indeed encouraging.

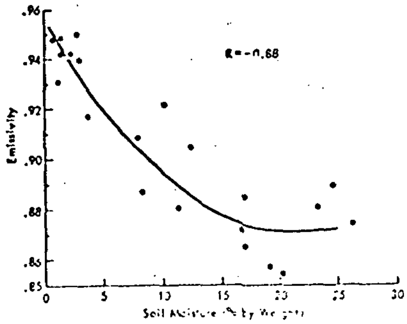

FIGURE 2. THE EMISSIVITY AS A FUNCTION OF SOIL MOISTURE CONTENT IN THE TOP 2.5 CM. The emissivity was determined from S-193 data operating at 13.9 GHz, vertical polarization and 29.4° pitch angle.

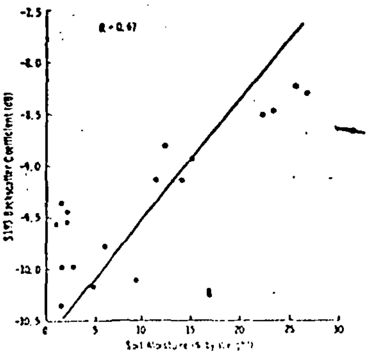

FIGURE 3. THE SCATTERING COEFFICIENT AS A FUNCTION OF SOIL MOISTURE CONTENT IN THE TOP 2.5 CM. The scattering coefficient was determined from S-193 data operating at 13.9 GHz, vertical polarization and 29.4° pitch angle.

CORRELATION WITH COMPOSITE RAINFALL

The analysis in the previous section was limited to a few footprints, namely those for which ground data was available. To utilize the microwave data available for the entire test site, it was decided to represent soil moisture by an indirect, yet related, parameter which can be readily calculated from weather data. This parameter is composite rainfall. The water content in a given soil is a function of several parameters including rainfall history, soil type and management and the evapotranspiration rate. Of all these factors, the only readily available one is rainfall history.

After dividing the test site into 46 rows × 49 columns of grid nodes, the rainfall for each of the four days preceding the pass and the day of the pass were calculated for each grid node by extrapolating data of the four nearest weather stations [2]. A similar program was employed to estimate the emissivity and scattering coefficient at each grid node from data of the neighboring footprints. Composite rainfall R was calculated by a method analogous to flood prediction techniques in that it utilizes an antecedent precipitation index K in an attempt to account for the general soil permeability and run-off characteristics. The expression used is:

$$R = \sum_{i=0}^{4} \left[K^{i} R_{i} \right]$$

where i is an integer representing the number of days prior to the pass (the day of pass is i=0), R_i is the rainfall on the i^{th} day and K is the antecedent precipitation index having a value smaller than 1. The value of K used in this analysis is 0.85.

Figures 4 and 5 are scattergrams of the emissivity and scattering coefficient, respectively, of all grid nodes within the test site as a function of R. The calculated correlation coefficients are −0.81 for emissivity and .62 for scattering coefficient.

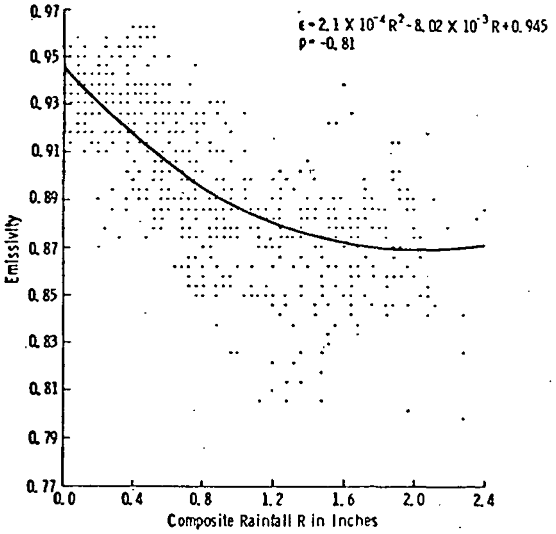

FIGURE 4. SCATTERGRAM OF S-193 CALCULATED EMISSIVITY VERSUS COMPOSITE RAINFALL FOR THE JUNE 5, 1973 PASS OVER WESTERN KANSAS.

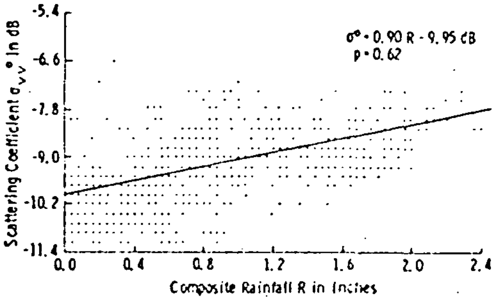

FIGURE 5. SCATTERGRAM OF S-193 SCATTERING COEFFICIENT VERSUS COMPOSITE RAINFALL FOR THE JUNE 5, 1973 PASS OVER WESTERN TEXAS.

CONCLUSION

The results presented in this paper demonstrate the potential of microwave sensors as tools for mapping soil moisture content from satellite platforms. Based on data collected from ground [3-6] and aircraft platforms [7-8], the sensitivity to soil moisture variations can be improved considerably by operating at smaller incidence angles (10°-20°) and lower microwave frequencies (1-5 GHz range).

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