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E83-10012

AgRISTARS

SM-A2-04322

NASA-CR-167648

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A Joint Program for Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing

Soil Moisture

May 1982

MEASUREMENT OF SOIL MOISTURE USING REMOTE SENSING MULTISENSOR RADIATION TECHNIQUES

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(E83-10012) MEASUREMENT OF SOIL MOISTURE USING REMOTE SENSING MULTISENSOR RADIATION TECHNIQUES Final Report (Arkansas Univ.) 12 p HC A02/MF A01 CSCL 02C

N83-12491

Unclas

G3/43 00012

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1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
SM-A2-04322		

4. Title and Subtitle	5. Report Date
Measurement of Soil Moisture Using Remote Sensing Multisensor Radiation Techniques	May 1982
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
W. P. Waite	
	10. Work Unit No.
9. Performing Organization Name and Address Department of Electrical Engineering University of Arkansas Fayetteville, Arkansas 72701	11. Contract or Grant No. NAS9-14251
	13. Type of Report and Period Covered Technical
12. Sponsoring Agency Name and Address AgRISTARS - Soil Moisture Project NASA - Johnson Space Center Houston, Texas 77058	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The purpose of this study was to investigate means for the microwave remote sensing of soil moisture. The effort was to be directed toward the specification of sensor parameters and the development of inversion algorithms.

The conduct of the investigation was a mixture of theoretical modeling, laboratory and field measurement, coupled with analysis of aircraft data obtained from controlled sites.

17. Key Words (Suggested by Author(s))	18. Distribution Statement

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified		

*For sale by the National Technical Information Service, Springfield, Virginia 22161

FINAL REPORT

NASA CONTRACT NAS 9-14251

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May 1982

Measurement of Soil Moisture Using Remote Sensing Multisensor Radiation Techniques

INTRODUCTION

The original purpose of this study was to investigate means for the microwave remote sensing of soil moisture. This was both to demonstrate feasibility and to ascertain the effects of perturbing factors such as surface roughness. The effort was to be directed toward the specification of sensor parameters and the development of inversion algorithms. This original goal was subsequently more sharply focussed to concentrate on the development of algorithms specifically useful for agricultural applications, primarily crop yield forecasting.

The conduct of the investigation was a mixture of theoretical modeling, laboratory and field measurement, coupled with analysis of aircraft data obtained from controlled sites. The laboratory and field measurement program was conducted with a bistatic reflectometer. This instrument, while active in nature, was used to measure the specularly reflected component which is more similar to the passive indimetric measurement than the backscattered component measured by a normal radar. This type operation has the advantage of providing swept (continuous) frequency measurement of the basic radiometric behavior which can only be accomplished using multiple direct frequencies with radiometers.

HISTORICAL SUMMARY

The initial thrust of the program was to evaluate both active (radar) and passive (radiometric) techniques. These were viewed at

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the time not so much as complimentary sensors as competitors. The argument favoring radar centered primarily on its ability to provide fine resolution even at spacecraft altitudes. The principle disadvantage was the known extreme sensitivity to surface roughness. The case for the radiometer was precisely the opposite. It had been observed that the roughness sensitivity was substantially less than that of radar, however, resolution could only be provided by the real antenna beam and would be quite large at spacecraft altitudes.

The initial investigations at the University of Arkansas concentrated on the effects of surface roughness as a function of frequency and the analysis of passive data available from the first aircraft missions. The investigation of roughness concentrated on defining the variation of the specularly reflected (coherent) component as a function of frequency (Hancock, 1977). The hope was to use multiple (continuous) frequency measurement to define the rate of decay with frequency of the specularly reflected component. Once this rate was defined, it would be possible to invert to an equivalent smooth surface reflectivity from which the determination of dielectric constant and then soil moisture would be a relatively simple matter.

It should again be noted that although the measurement conducted utilized active swept frequency techniques the implementation method would be multiple frequency passive since it is desired to monitor the coherent component of the scattered signal. This is possible, of course, only over the range where the incoherent (diffuse) component may be neglected in comparison to the coherent component. This study and continuing investigations of rough surface effects generated the following conclusions:

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1) Correction for roughness can be accomplished, however, even for frequencies as low as $1GH_z$ the effective valve of the rms height that can be accomodated is significantly less than 1/cm.

2) The effective roughness of real surfaces with discontinuities is substantially greater than their measured rms height.

3) The measurements exhibited a marked sensitivity to changes in the correlation distance of the surface.

These observations could be further summarized to say that multi-parameter measurement of the exponential decrease in the coherent scattered component does not appear feasible for realistic agricultural surfaces unless frequencies substantially below $1GH_z$ are used.

These conclusions still have significance today in that they imply that the observed decreased sensitivity due to roughness of the passive versus active sensors is due to the fact that the passive system is responding to the diffuse component of the scattered signal. This in turn implies that the exponential correction factor applied to explain the sensitivity compression due to roughness is incorrect. The correction should be a reduction from the plane surface value to the diffuse value since for the measured data the diffuse component is significantly greater than the specular component.

The analysis of airborne passive radiometric data presented an entirely different problem. The difficulty here was not in showing a pronounced sensitivity due to soil moisture, but in interpreting the significance of the results. The only means of evaluating the data is by linear correlation analysis. The results consistently

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demonstrated a slightly higher correlation with the upper levels of the moisture profile both at X and L band. However, the internal correlation of the profile also leads to correlation of brightness temperature with moisture content at depths well below any reasonable expectation of penetration.

At approximately this time the emphasis of the program was sharply focussed on the application to crop yield estimation. This immediately led to consideration of means to estimate the total plant water availability which in turn leads to requiring a knowledge of the profile to depths determined by root density which may range to six feet or more. Thus, while the measurement technique demonstrated increasingly good correlation with approximately the upper one inch of the surface the application suddenly required estimation to six feet.

A study of soil moisture budget models was conducted to assess the feasibility of periodic surface measurements to update a moisture budget model driven by meteorologic data. This, in essence, periodically corrects the budget model by enforcing a measured boundary condition.

Considerations such as this led to the need for maximizing the actual measurement depth. While there is no hope of performing measurements to the depth required by the application, the greater the depth that can be sampled, the greater will be the accuracy and the longer can be the period between measurements.

At approximately this time it could be concluded that microwave remote measurement of the soil moisture of bare surfaces was certainly feasible. In fact, it appeared this could be done quite accurately

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even with the perturbations introduced by surface roughness. The problem lie in determining the depth to which the moisture might be sensed and defining at least a moisture gradient for the upper surface. In line with this a program of laboratory measurements of artificially constructed and layered moisture profiles was conducted. This program definitly has established the ability to detect discontinuities in moisture to significant depths (greater than six inches). The problem with such artifical profiles was that although the layer interference pattern could be used to accurately measure depth and infer moisture content, it likewise required continuous frequency measurement.

The next step in the process was to conduct a series of field measurements over controlled moisture plots to monitor the effects of natural gradients under controlled conditions. This program offered as well the first opportunity to compare the microwave measurements with soil matric potential rather than with soil moisture. As had been predicted this offered improved correlation.

The field measurement program demonstrated that naturally occurring moisture gradients in the upper surface could in fact yield the effect of a subsurface layer. While for each individual frequency over the range the reflectivity tracks the decrease in moisture with evaporation, the continuous frequency trace may exhibit an interference pattern. The coherent component transmitted into the surface and leading to the interference effect is apparently decreased by the surface roughness. Thus, even natural surfaces, unless sufficiently rough, will produce pronounced coherent effects introducing a scatter into the measurement.

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Also near the end of this program data became available from the Colby test site. The initial analysis of these data confirmed the measurements of SCZ showing row orientation to have a pronounced effect upon the active backscatter return even at K Land. This was in distinct contradiction to the conclusions reached from the measurements of the University of Kansas MAS system from which it was concluded that row effects would be insignificant at C band.

CONCLUSIONS

The preceding has been a brief synopsis of the studies conducted at the University of Arkansas. These were, of course, simply part of an overall program including primarily NASA/JSC, NASA Goddard, the University of Kansas, and Texas A & M University as well. This program has undoubtedly aided substantially in the understanding of the microwave response due to soil moisture. As one example of this the development of models to predict the complex dielectric constant have been produced and have lead to interpretetion of the results in terms of a matric potential rather than simply moisture content. This appears to have both a better theoretical basis and likewise to be the parameter of more concern to the user as it is directly related to the water available to the plant. Similar advances have been made in the development of coherent and incoherent radiative transfer models and rough surface scattering models.

While these advances in understanding have been substantial they have not as yet answered the question of whether satellite remote sensing of soil moisture is feasible or practical for agricultural and hydrologic uses. The greatest single problem is not lack of demonstrated sensitivity but definition as to what moisture the

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instrument is responding. With the internal correlation of virtually any moisture profile, a limited data sample may demonstrate excellent correlation at even substantial depths. It still remains to determine the best inversion algorithm for moisture input to budget models over a wide range of profile shapes.

The degree of the row orientation effect is still to be completely specified and may well force active systems to adopt a cross polarized measurement. The effect of screening vegetation remains somewhat controversial with a wide range of results from differing measurement programs. There is still some disagreement as to the severity of coherent effects for differing profile shapes particularly in the near surface. Efforts in this area are hampered by a lack of data for near surface profiles particularly with the depth resolution needed.

In final conclusion it would appear that the advances in the understanding of microwave soil moisture measurement have been substantial. These have been for the most part accomplished with relatively isolated data sets from both ground measurement and aircraft programs. It would appear that perhaps the most pressing need is for measurement programs relatively small in area but providing continuous measurement over an extended period of time. This should not be surprising as agriculturists have used this approach for years due to the great variability encountered. Since the soil is the object studied here the same method would seem to apply.

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REPORTS AND PUBLICATIONS

The basic reporting mechanism during the conduct of this program was presentation of results at quarterly review sessions held at JSC. Approximately 20 of these presentations were made with the delivery of all presentation material and descriptive synopsis. These formed the basis for directing the program and most importantly for rapid interaction between all members of the investigative team. Publications and in depth reports on specific aspects are listed below:

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