Reprinted From

PROCEEDINGS OF THE TENTH INTERNATIONAL SYMPOSIUM ON REMOTE SENSING OF ENVIRONMENT

6 - 10 October 1975

Sponsored by

Environmental Research Institute of Michigan

The University of Michigan

Office of Applications
National Aeronautics and Space Administration

Federal Highway Administration
U.S. Department of Transportation

National Oceanic and Atmospheric Administration
U.S. Department of Commerce

Bureau of the Census
U.S. Department of Commerce

Division of Biomedical and Environmental Research
U.S. Energy Research and Development Administration

U.S. Geological Survey
U.S. Department of the Interior

U.S. Coast Guard
U.S. Department of Transportation

Fish and Wildlife Service
U.S. Department of the Interior

U.S. Army Research Center
Department of the Army

Office of Research and Development
Environmental Protection Agency

Air Force Office of Scientific Research
Department of the Air Force

Division of Water Control Planning
Tennessee Valley Authority

NAC Incorporated
Tokyo, Japan

Taiwan Forestry Bureau
Taipei, Taiwan, Republic of China

Universidad Autonoma
Madrid, Spain

ENVIRONMENTAL
RESEARCH INSTITUTE OF MICHIGAN
P.O. BOX 618 • ANN ARBOR • MICHIGAN • 48107

COMPARISON OF AERIAL PASSIVE GAMMA AND PASSIVE MICROWAVE TECHNIQUES FOR MEASUREMENT OF SOIL MOISTURE

Eugene L. Peck,[1] Lee W. Larson,[1] Richard K. Farnsworth,[1] and Thomas L. Dietrich[2]

ABSTRACT

Passive gamma and passive microwave radiation measurements have been recognized as having potential value for evaluation of mean areal soil moisture. Present procedures using point samples are slow and costly and the extrapolation from point to areal estimates is unreliable.

Assessing the accuracy of these radiation techniques is difficult, primarily because there is no way of determining the true numerical value of the mean areal soil moisture. This paper presents a comparison of concurrent measurements of estimates of soil moisture from ground sampling and from measurements of passive microwave and passive gamma radiation made by aircraft.

The Hydrologic Research Laboratory (HRL) of the National Weather Service (NWS), National Oceanic and Atmospheric Administration (NOAA), in cooperation with EG&G, Inc., has conducted extensive experiments since 1969 on the use of aerial gamma radiation surveys for measurement of the water equivalent of snow cover and of soil moisture.

In June 1972, the NWS, in cooperation with the National Environmental Satellite Service (NESS), NOAA, conducted simultaneous flights of microwave and gamma radiation sensors over a special survey line near Luverne, Minn. Microwave measurements were made at 4.99 and 13.4 GHz (with vertical and horizontal polarization). Gamma measurements were made over the range 0.05 Mev to 3.0 Mev. Extensive measurements of soil moisture and data on ground cover were also obtained. Surveys were conducted on two separate surveys 7 days apart.

In the judgment of the authors, for the conditions existing during the study, the estimates of soil moisture based on the gamma radiation technique most nearly represented the change in soil moisture during the 7-day period. Therefore, the gamma radiation estimates were used as "ground truth" in the comparison study.

[1]Hydrologic Research Laboratory, National Weather Service, NOAA, U.S. Department of Commerce, 8060 13th Street, Silver Spring, MD 20910.

[2]River Forecast Center, National Weather Service, NOAA, U.S. Department of Commerce, 819 Taylor Street, Ft. Worth, TX 76102.

Various computational schemes utilizing the microwave measurements were used to estimate the change for soil moisture conditions. These differences based on the microwave techniques were found to be well related to the change in soil moisture as indicated by the gamma radiation. Various comparisons were made for measurements over fields with different vegetative cover.

Although the good relationships obtained were based on somewhat ideal conditions (minimum change in vegetative cover, excellent ground fix for aerial surveys, extensive ground truth, etc.), they do point to the possible use of microwave techniques for areal measurement of soil moisture under selective conditions for hydrologic purposes.

1. INTRODUCTION

Reliable estimates of soil moisture are useful in flood and crop yield forecasts and for practical agricultural and water management. Traditional measurements of soil moisture using point samples are slow and costly and, because of the variability of soil, topography, and land use, often give insufficient or even misleading results.

2. BACKGROUND

Studies conducted near Phoenix, Ariz., by the Aerojet Electro Systems Company (AESC) for NOAA have indicated that natural radiation measured from bare soil is very sensitive to changes in soil moisture (Poe et al. Feb. 1971 and Schmugge et al. 1974). They felt that the prospects were very encouraging for mapping soil moisture in the uppermost few centimeters of the soil with negligible amounts of surface vegetation. Other tests (Poe and Edgerton Sept. 1971) indicate that relatively good correlation exists between radiation measured at 1.42 and 4.99 GHz (21 and 6 cm, respectively) and integrated soil moisture in the upper 15 cm, even with the presence of modest amounts of vegetation. Because of the complexity of the factors involved, however, no real method has been developed to make quantitative estimates of soil moisture using microwave data.

The Hydrologic Research Laboratory (HRL), in cooperation with EG&G, Inc. (Las Vegas, Nev.), has conducted extensive experiments since 1969 on the use of aerial gamm radiation surveys for measurement of: (1) water equivalent of snow cover and (2) soil moisture (Fritzsche and Burson 1970 and Peck et al. 1971). Gamma surveys are reported to be in operational use in the Soviet Union (Kogan et al. 1971) and have shown useful results on an experimental basis in this country (Larson 1975). Gamma flux flights are restricted, however, to areas where flights can be made at an altitude of 150 m or below.

Many attempts to make meaningful airborne measurements of soil moisture with microwaves have been unsuccessful (Poe et al. 1973). One reason for the lack of success is the complexity of the factors governing microwave radiation. A second reason is the difficulty in obtaining the true numerical value of the mean areal soil moisture to use as a standard for evaluation.

2.1. GROUND TRUTH MEASUREMENT BY GAMMA FLUX

The experience in developing gamma radiation techniques for measuring water equivalent of snow has included many measurements under "no snow" conditions. These experiments have shown the importance of soil moisture on attenuating gamma radiation. It has been found necessary to use ground truth measurements of soil moisture to make corrections when correlating gamma measurements with water equivalent of snow. It is apparent that changes in gamma measurements (properly accounting for radon effects) are related to changes in soil moisture.

2.2. MEASUREMENT METHODS

The gamma flux originates primarily from radio isotopes in the soil, principally potassium (40) and the decay products in the uranium and thorium series. Zotimov (1968) has reported that 91 percent of the gamma rays emanating from a natural soil come from the top 10 cm and 96 percent from the top 20 cm.

Other sources contributing to the gamma flux are radon gas (222 Rn) and its decay products, upper atmospheric radioactive fallout, and radioactive sources on board the aircraft carrying the detector.

Aircraft radiation and atmospheric fallout are relatively constant and can be considered as a constant background. However, radon gas, formed by the decay of radium 226, is highly variable depending on atmospheric conditions and has considerable influence on the measured gamma flux.

The concept of airborne monitoring of snow cover water equivalent or of soil moisture is based on the premise that water placed between the source (i.e., the ground) and the detector (i.e., in the aircraft) will attenuate the radiation flux arriving at the detector. If the attenuation is known, the water shielding can be calculated.

Microwave radiation incident on an airborne microwave radiometer results from several sources. The principal sources are radiation from the earth's surface layer and reflection at the surface of radiation from the sky. The component of radiation originating at the ground is related to the temperature of the land surface and its emissivity. The reflected sky component is related to sky conditions, the emissivity of the soil, the roughness of the surface, and/or its vegetative cover.

Variability in received radiation is caused by changes in ground surface temperature, emissivity, and roughness. All of these are influenced by changes in vegetation and soil moisture.

2.3. FIELD MEASUREMENTS

In June of 1972, the NWS, in cooperation with NESS, conducted simultaneous flights of microwave and gamma radiation sensors over a flight line near Luverne, Minn. (fig. 1). This flight line had been flow extensively over a 3-year period as part of snow-water equivalent determination studies. The microwave measurement recorded vertically and horizontally polarized radiation at 4.99 and 13.4 GHz (6 and 2.2 cm). Gamma radiation was measured with NaI scintillation crystals connected to a multichannel analyzer in the energy range from 0.05 to 3.0 Mev. Measurements of soil moisture were also obtained by physically taking soil samples on the ground along the flight line.

Both ground and aerial measurements were made along this flight line on June 12, 1972, and again on June 19, 1972. A comparison of the significant factors influencing radiation on the two flights is shown in table 1.

The gamma flux flights were flown at a nominal altitude of 91 m; and, at this height, the sensor instantaneously sampled a circle on the ground approximately 610 m in diameter. As the plane moved over the ground, the readings were integrated for 2 seconds and then recorded. The number of recordings varied from 6 to 8 per kilometer depending on the aircraft speed and the position of the timer when a given kilometer was entered.

The microwave flights were flown at 152 and 762 m with a 37° forward look angle. The microwave footprints at these altitudes were 21 x 17 and 106 x 83 m, respectively. Both of the microwave flights tended to resolve variations on the ground much more than the gamma flight. The higher altitude microwave flight sampling area was larger and therefore more compatible in sampling size with the gamma flight.

There were 34 ground sampling sites along the 13.7 km (8.5 mile) flight line. Samples were taken for 5, 10, and 20 cm depths. Variation of soil moisture between depths was generally no more than 4 percent.

2.4. RESULTS OF MICROWAVE SURVEY

The microwave data from these flights were published in a report for NOAA (Poe et al. 1973). They reported that a good correlation was obtained between the vertical and horizontal polarizations and between the radiation measured at the two different frequencies. In addition, certain decreases in radiation were collocatable with stream locations. There was, however, little correlation between the microwave measurements and the soil moisture measurements made on the ground.

3. COMPARISONS

A comparison of the two areal measurements was made in the HRL. Initial analyses included all the data for the full flight line and resulted in poor correlation. Measurements were then compared on a field-by-field basis for the following reasons:

1. By taking a relatively large area, the differences resulting from instantaneous sampling size differences could be smoothed and uncertainty as to sensor location during the flight line could be reduced. Field sizes varied from 0.4 to 0.8 km (1/4 to 1/2 mile) in their dimension along the flight line.

2. This allowed crops of a single type to be compared, thus, avoiding variations in measurements that might be due to the type of vegetative cover.

Uncertainty in the microwave sensor location was corrected by adjusting distinct valleys on the microwave trace to stream locations on the map. Field averages were taken by graphically integrating the microwave trace.

3.1. RESULTS

Correlations of the differences measured by the two methods between June 12 and 19 are shown in table 2. Figures 2a and 2b show plots of the measurements for cornfields. Plots and correlations were best for comparisons using only cornfields and microwave flights at 762 m. There were hardly enough other crop types to make comparison. Correlation of gamma flux with microwave measurements at an altitude of 150 m was significantly lower.

Figure 3 shows a smoothed trace of the differences in measurement from June 12 to 19 for the gamma flux and the horizontal polarization of the two microwave frequencies. While the plots in figure 3 show some correlation between sensors as a function of position along the flight line, it is not intended that either the microwave or gamma flux measurement techniques would be useful for this degree of resolution. Practical values would be the average or mean value over a large area such as a river basin. To relate changes of varying magnitude in the microwave radiation to corresponding changes in gamma flux and, thus, to changes in soil moisture, relations such as shown by the best-fit lines in figures 2a and 2b can be used.

4. CONCLUSIONS

This particular set of measurements is unusual in that field and sky conditions were very similar a week apart. Simultaneous areal measurements by both airborne techniques, as well as ground measurements, indicated an increase in soil moisture from June 12 to June 19. In the opinion of the authors, gamma flux is an accurate method of measuring mean areal soil moisture. Therefore, correlation of the two areal measuring methods gives a practical means of evaluating microwave measurements of soil moisture.

REFERENCES

Fritzsche, A. E., and Burson, Z. G., "Water Equivalent of Snow Surveys Using Natural Terrain Radiation," Tech. Rpt. No. EGG 1183-1495, 1970.

Kogan, R. M.; Nazorov, I. M.; and Fridman, S. D., "Gamma Spectroscopy of Natural Environments and Formations," translated from Russian, Israel Program for Sci. Tranl., TT 70-50092, Jerusalem, 1971, 337 pp.

Larson, L. W., "An Application of the Aerial Gamma Monitoring Techniques for Measuring Snow Cover Water Equivalents on the Great Plains," Proceedings of Symposium on Snow Management on the Great Plains, Bismarck, N. Dak., 1975.

Peck, E. L.; Bissell, V. C.; Jones, E. B.; and Burge, D. L., "Evaluation of Snow Water Equivalent by Airborne Measurement of Passive Terrestrial Gamma Radiation," Water Resources Research, Vol. 7, 1971, pp. 1151-1159.

Poe, G.; Stogryn, A.; and Edgerton, A. T., "Determination of Soil Moisture Content Using Microwave Radiometry," Final Tech. Rpt. 1684 R-1, DOC Contract No. 0-35239, Feb. 1971.

Poe, G., and Edgerton, A. T., "Determination of Soil Moisture Content with Airborne Microwave Radiometry," Final Tech. Rpt. 4006 R-1, DOC Contract No. 1-35378, Sept. 1971.

Poe, G.; Meeks, D.; and Edgerton, A. T., "Airborne Passive Microwave Measurements of NOAA Hydrology Sites," Final Tech. Rpt. 1752 R-1, DOC Contract No. 2-37116, 1973.

Schmugge, T.; Gloersen, P.; Wilheit, T.; and Geiger, F., "Remote Sensing of Soil Moisture with Microwave Radiometers," Journal of Geophysical Research, Vol. 79, 1974, pp. 317-323.

Zotimov, N. H., "Investigation of a Method Measuring Snow Storage by Using the Gamma Radiation of the Earth," English translation, Soviet Hydrology: Selected Papers, No. 3, 1968, American Geophysical Union, 1968, pp. 254-266.

TABLE I. MEASUREMENT CONDITIONS ON JUNE 12 AND JUNE 19, 1972

Variable	June 12		June 19	
	Microwave	Gamma	Microwave	Gamma
Flight time, LST	1450-1612	1441	1045-1155	1241
Altitude	762 m	91 m	762 m	91 m
Sky condition	Low thick overcast		Low thick cumulus	
Mean surface temperature measured by thermal scanner	28°C		24°C	
Rain history, Steen, Minn.	No rain previous 5 days.		0.8 mm on 16th; 27.2 mm 2 hours a.m. of 17th; trace 18th.	

TABLE II. CORRELATION OF DIFFERENCES IN MEASURED RADIATION BETWEEN JUNE 12 AND JUNE 19, 1972

Crop	Microwave		Gamma	R
	Altitude	Polarization	Altitude	
Corn only	762 m	Vertical	91 m	0.82
Corn only	762 m	Horizontal	91 m	.84
All crops	762 m	Vertical	91 m	.66
All crops	762 m	Horizontal	91 m	.68
Oats only	762 m	Vertical	91 m	.69
Oats only	762 m	Horizontal	91 m	.72

NOTE: 762 m = 2,500 feet; 91 m = 300 feet.

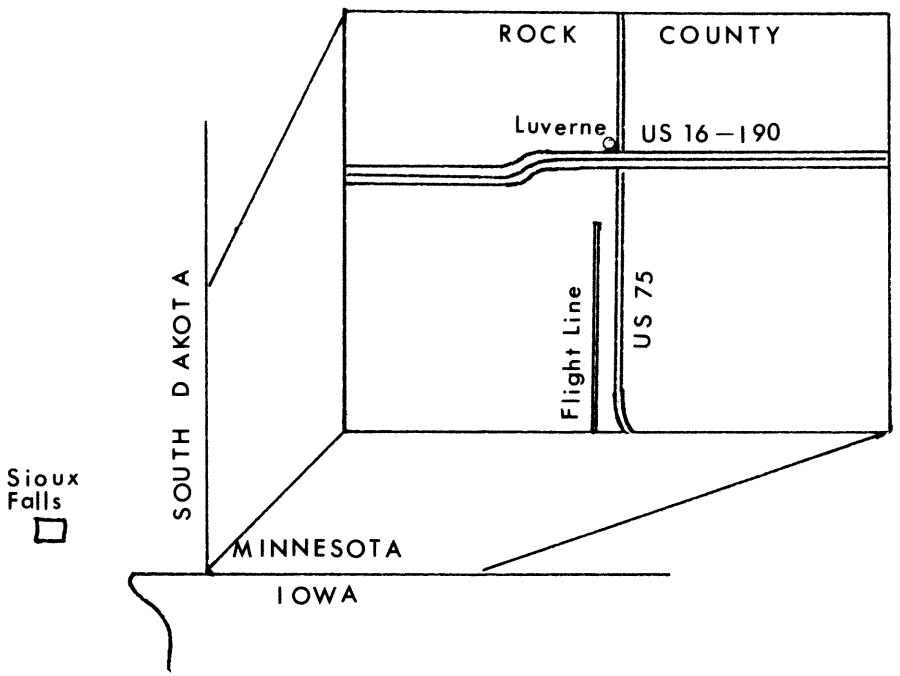

FIGURE 1. FLIGHT LINE IN ROCK COUNTY, MINNESOTA

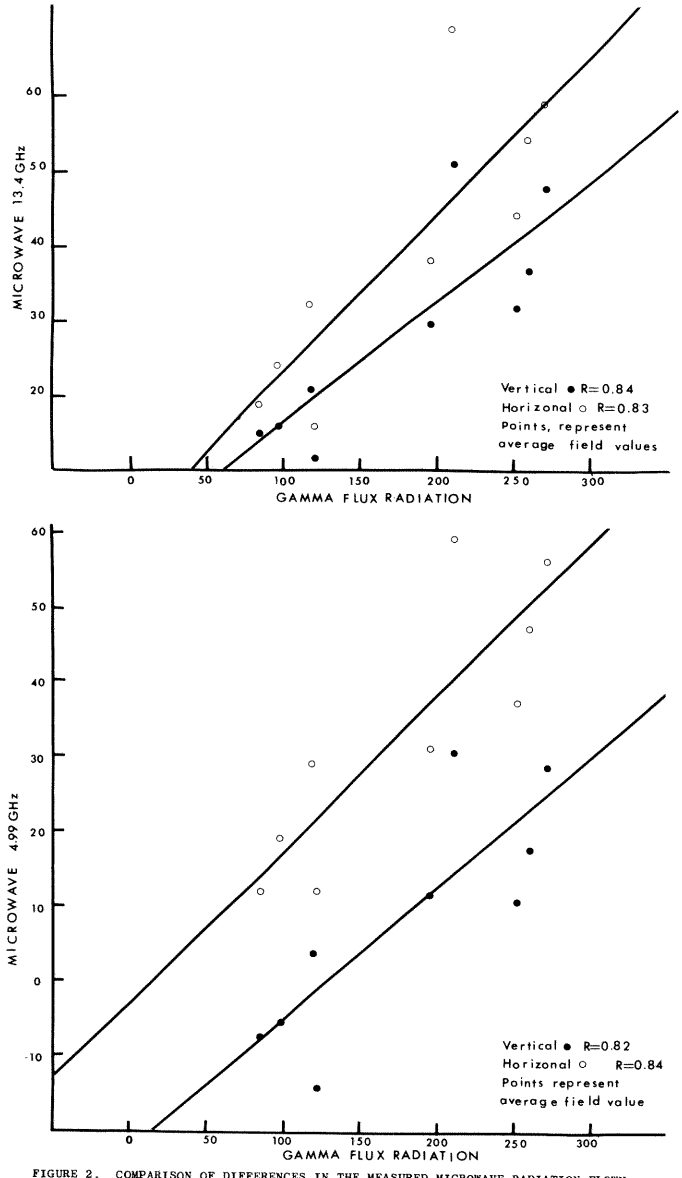

FIGURE 2. COMPARISON OF DIFFERENCES IN THE MEASURED MICROWAVE RADIATION FLOWN AT AN ALTITUDE OF 762 METERS AND THE GAMMA RADIATION FLOWN AT AN ALTITUDE OF 91 METERS BETWEEN 12 JUNE AND 19 JUNE OF 1972. VALUES ARE LIMITED TO THOSE MEASURED OVER CORN FIELDS. FIGURE 2a (TOP) IS FOR MICROWAVE FREQUENCY OF 13.4 GHZ. FIGURE 2b (BOTTOM) IS FOR MICROWAVE FREQUENCY OF 4.99 GHZ.

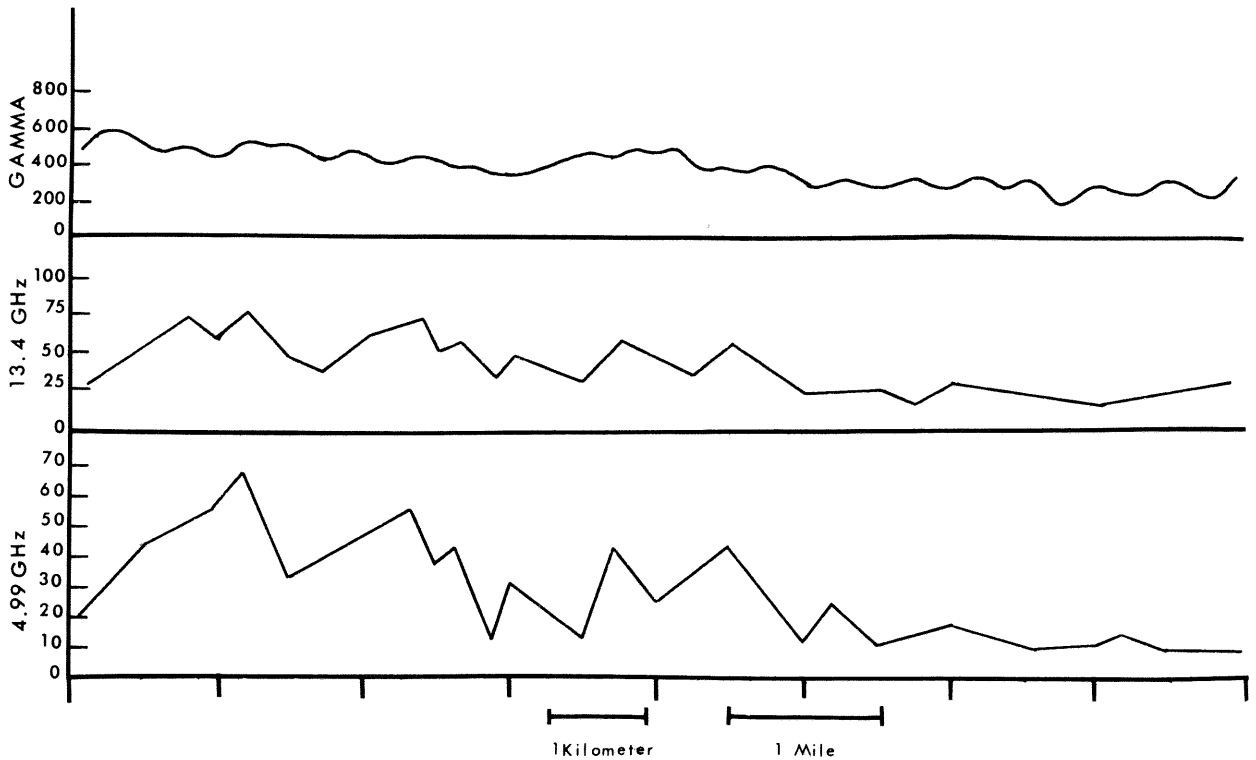

FIGURE 3. DIFFERENCES (6/12–6/19) IN MEASURED RADIATION ALONG THE FLIGHT LINE