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PROGRESS REPORT ON AIRCRAFT GAMMA-RAY SURVEYS FOR SOIL-

MOISTURE DETECTION AT A NOAA TEST SITE NEAR PHOENIX, ARIZONA

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Introduction

Recent experimentation and research by the National Weather Service (NWS) have been centered about remote-sensing measurements of areal snow cover conditions. Peck et al. (1971) have reported on the use of terrestrial gamma-ray measurement from low-flying aircraft (100 m above ground level) in non-mountainous areas as a method of measuring the water equivalent of snow. The results of this research are rather encouraging and additional test sites are being flown to evaluate the technique under varying climatic terrain and geographic conditions. Research on this method has been conducted for several years in the Soviet Union and Norway (Kogan et al., 1965; Zotimov, 1968; Dahl and Odegaard, 1970). Kogan et al. (1971) have reported that the technique is currently used in the Soviet Union on an operational basis.

The technique for measuring the water equivalent of snow cover is based on the attenuation effect of the total water mass interposed between the source of the natural gamma radiation--that is, the underlying soil--and the detectors in the aircraft. The attenuation of the gamma radiation depends only on the total mass of water, regardless of state, i.e., whether snow, ice, or free water. The amount of moisture in the soil affects the amount of radiation that emanates from the soil and therefore the measurement of the water equivalent of the snow cover. Investigators in the Soviet Union regard this variation as low in winter and disregard its effect (Dmitriev, et al., 1971), while those in the United States (Peck et al., 1971) have developed methods to correct for soil moisture variations.

The National Environmental Satellite Service (NESS) and the National Aeronautics and Space Administration (NASA) are engaged in research in the remote sensing of soil moisture, primarily in the microwave region.

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Soil Moisture

Soil moisture is an important parameter in hydrology, and one which is difficult to measure. Its practical relevance to agricultural hydrology is rather obvious, but it is also relevant to many other facets of hydrology. Soil moisture values affect ground-water recharge rates, road and site construction, forest and water management operations, and calculations for water-level or flood forecasting. It is the last-mentioned use that is our primary concern at NOAA.

Remote sensing of soil moisture for our purposes means detecting and measuring, at least semi-quantitatively, the moisture present in the uppermost 20 cm of soil. Ideally, a daily assessment of soil moisture in large river basins or subbasins could be made by a satellite system and fed into existing computer conceptual forecast models as those used by the National Weather Service.

Conventional gravimetric measurements of soil moisture are made by taking soil samples by auger, then weighing the sample in the laboratory, heating it for 24 hours at 105°C, and then reweighing the dessicated sample. The percent soil moisture is then calculated by use of the formula

$$\text{soil moisture (percent)} = \frac{\text{Weight of wet sample-weight of dry sample}}{\text{dry weight}} \times 100$$

Obviously, this technique is costly and time consuming. Synoptic observations of soil moisture are all but impossible. If samples are poorly located or are nonrepresentative, erroneous estimates of soil moisture will result. For these reasons the agricultural, hydrologic, and hydrometeorological communities have been seeking a remote sensing technique that would permit rapid assessment of soil moisture over large areas.

Inadequacy of Ground Truth Measurements

One of the primary limitations in evaluating methods for remote sensing of hydrologic factors such as soil moisture and water equivalent of snow cover is the high degree of difficulty in determining areal averages for these factors using conventional ground truth methods. Soil moisture methods have been used only very little in the field of hydrology for operational purposes, as point measurements or sets of point measurements are of limited value for estimating areal conditions.

The prospect of utilizing the gamma radiation aerial measurement techniques as used for measuring water equivalent of snow cover in order to provide an improved estimate of average soil-moisture conditions appears very promising. The coupling of the ground truth point measurements with the areal measurements of the gamma-ray survey should provide a more suitable indication of average conditions that would be viewed by the microwave system.

Test Site Ground Truth

The ground truth measurements for this experiment (and for the related microwave overflights) were made by Biospherics, Inc. The test site is located in Maricopa County, Arizona, several miles west of Phoenix. (See index map, fig. 1)

A majority of the fields along the north-south line were without vegetative cover on Feb. 25, 1971. The fields are irrigated by canals and ditches, and this type of field-by-field irrigation creates a rather spotty or heterogeneous soil-moisture distribution pattern. The relation between irrigation date and soil moisture is apparent in figure 2, which shows the variation of mean soil moisture with time since the last irrigation.

Table 1 shows the precipitation that was recorded at the Phoenix Airport in February. Note that six days had elapsed with no measurable rainfall prior to the test.

TABLE 1.

Date	Precipitation (inches)
1 - 16	0
17	0.30
18	0.04
19	0.01
20	Trace
21	0
22	0
23	Trace
24	0
25*	0
26	0
27	0
28	0

* Date of aerial surveys.
Table.--Record of precipitation at Phoenix, Arizona, for February 1971.
Source: National Weather Service.

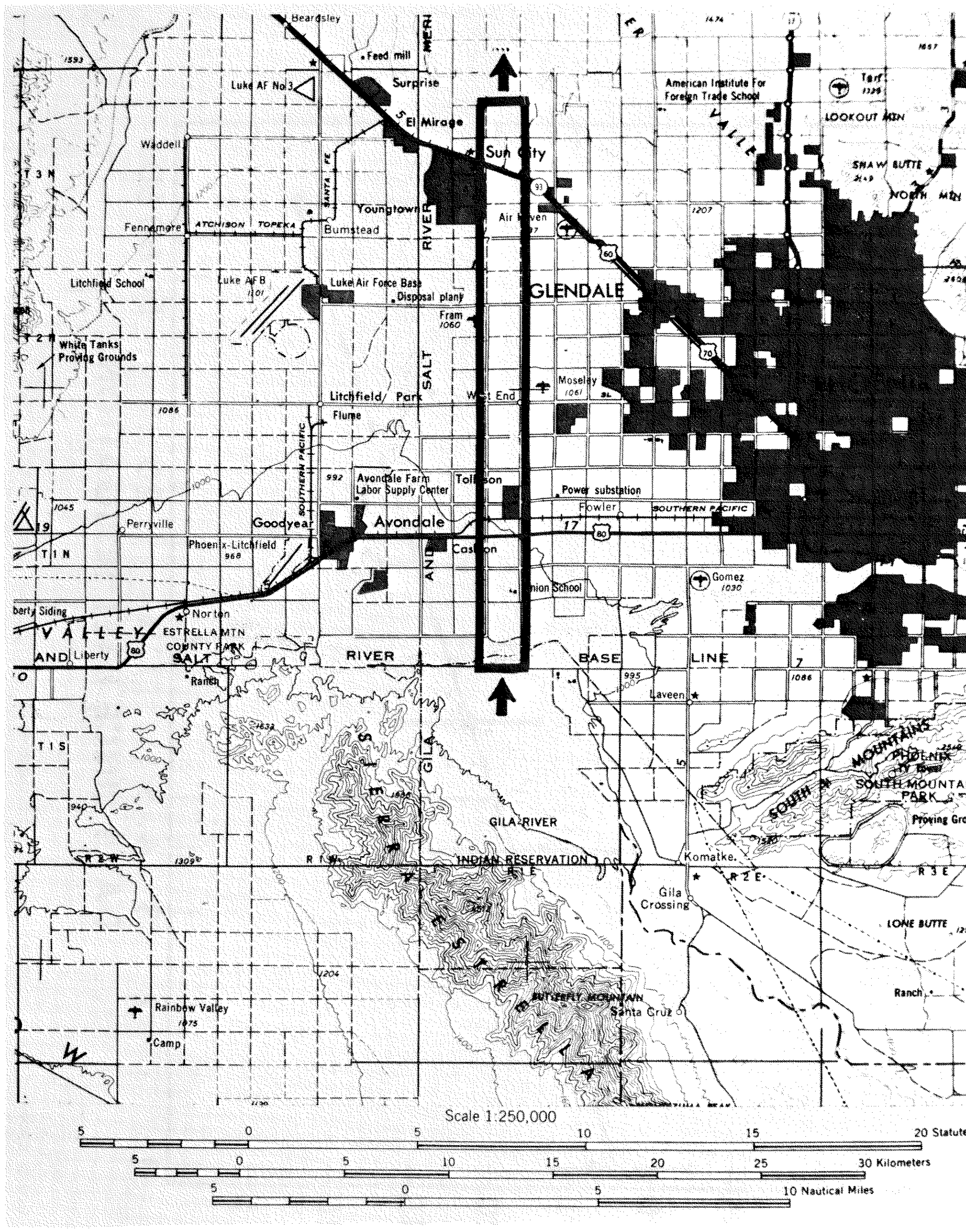

FIGURE 1. Index map showing the test site for this study.

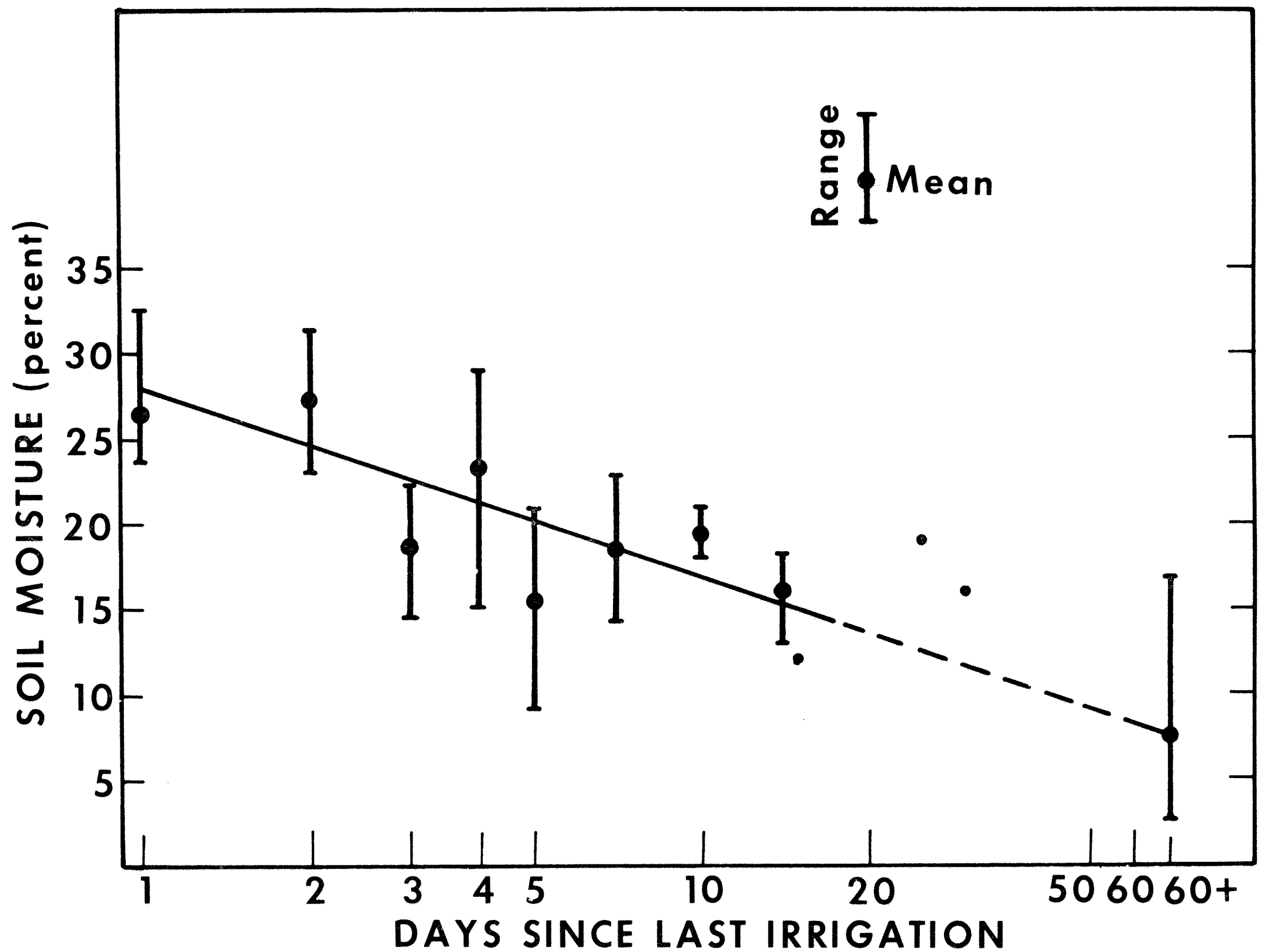

FIGURE 2. Graph showing the variation in soil moisture as a function of the number of days since the last irrigation.

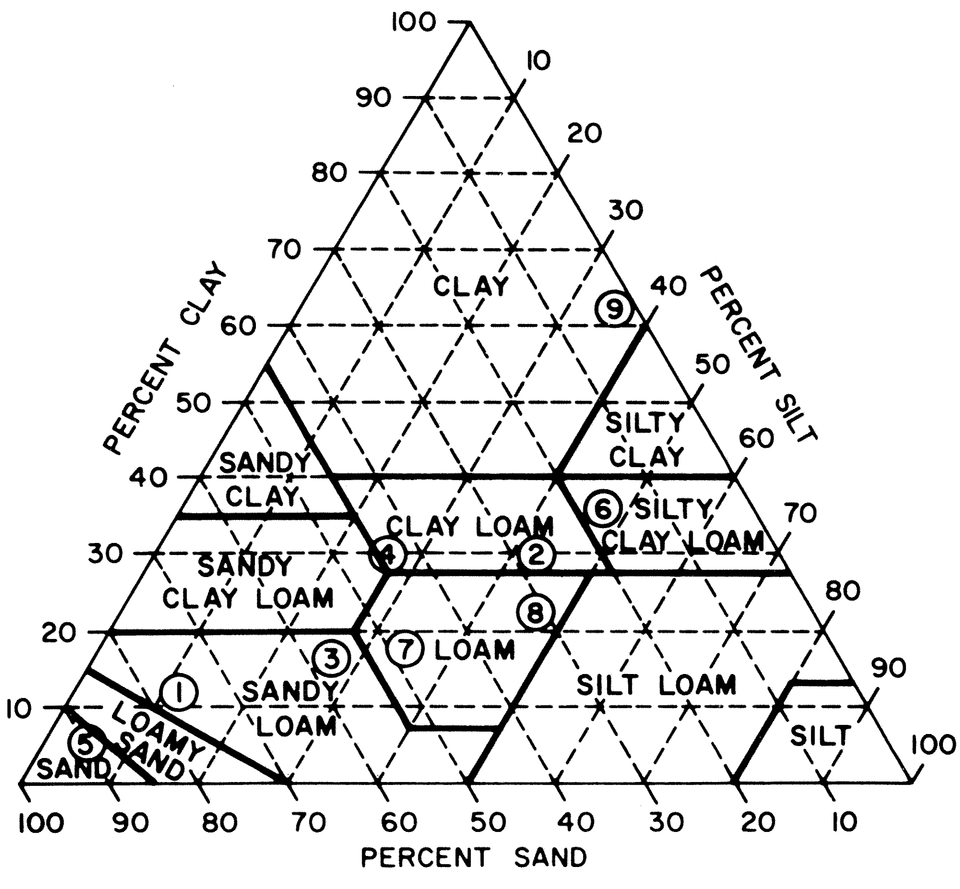

FIGURE 3. Soil samples from the Phoenix test site are shown in a textural matrix. (From Schmugge, et al., 1972). Samples 3-8 are from the Phoenix Test Site.

As pointed out by Schmugge et al. (1972) the type of soil texture is rather inportant in soil-moisture studies. In general, the clayey soils can hold more moisture than sandy soils which have greater permeability. Textural data on the soils at the test site are combined on figure 3.

One hundred fields were sampled on the north-south flight line. Four 6-inch samples were taken in each field. From the four soil-moisture values a mean was obtained for each field.

The test site is relatively homogeneous geologically. It is uniformly underlain by basin-fill deposits, although modern flood plain deposits of silt, sand, and gravel occur in mile segment one and from mile 14 to mile 16. (Thor Karlstrom, personal communication).

Soil texture can have a considerable affect on the distribution of moisture in the upper 30 cm of soil. The sample shown on figure 3 as sand (no. 5) is probably from the flood plain. Such a sandy soil would drain quickly while less permeable silty soils would retain water much longer. A zone of moisture slowly draining downward would have a pronounced effect on gamma radiation originating in that soil at first, but as the moisture moves deeper into the soil, its effect drops off exponentially.

The Aerial Radiological Measuring System (ARMS)

The system employed in this experiment was designed and operated by EG&G, Inc. and was used with the permission of the Atomic Energy Commission. The Aerial Radiological Measuring System (ARMS) is installed in a Beechcraft Twin Bonanza, which is also equipped with a precise positioning system that measures radar altitude, ground speed, drift angle and heading.

The gamma-ray detection package consists of 14 four-inch by four-inch sodium iodide (NaI) scintillation crystals, thermally insulated and shock-mounted. The large volume of the crystals provides a sensitivity to gamma radiation several thousand times greater than that of a common Geiger-Mueller counter. An on-board computer produces a paper tape record of all flight and radiation data. A complete description of the system has been given by Anderson et al. (1969).

Initial Investigation

An initial investigation of soil moisture has been conducted over flight lines in the vicinity of Phoenix, Arizona, during February and March 1971. Gamma-ray surveys were flown with the Atomic Energy System's ARMS equipment by EG&G, Inc. Concurrent missions were flown by the NASA Convair 990 aircraft with multiband passive microwave radiometers at frequencies of 1.42, 4.99, 19.35, 37, and 94 GH_z. A description of the microwave experiment and its results has recently been published (Schmugge, Gloersen, and Wilheit, 1972). Ground truth measurements were collected over two selected flight lines, the 16-mile north-south line previously mentioned and a 30-mile east-west line by Biospherics, Inc. Radiometric data from the east-west line are not yet available for analysis.

As seen in fig. 1, the flight lines were selected to parallel the road net in this area. This selection was made to insure accurate identification from the air and to facilitate collection of ground truth data. Two passes at 300 feet (90 m) and one at 500 ft (150 m) above ground level were made.

Date	Leg No.	Altitude
2-25-71	102	500'
	108	300'
	111	300'
3-2-71	119	500'
	125	300'
	127	300'

Figure 4 indicates excellent reliability of the ARMS system during one day's operation, but in order to determine a correct base-line background count an additional flight is required during wet conditions. The prolonged record drought in the Phoenix area has forced postponement of this investigation.

Variations in the total gamma count from one day to another are also affected by the radon gas daughter products (^{214}Bi) in the atmosphere. The spectral information collected for selected flight line lengths provide a better measurement of the temporal variations in the soil moisture for the spatial averages. Investigations being conducted for improvement of the snow water equivalent measurements to develop techniques to overcome the adverse effects due to the

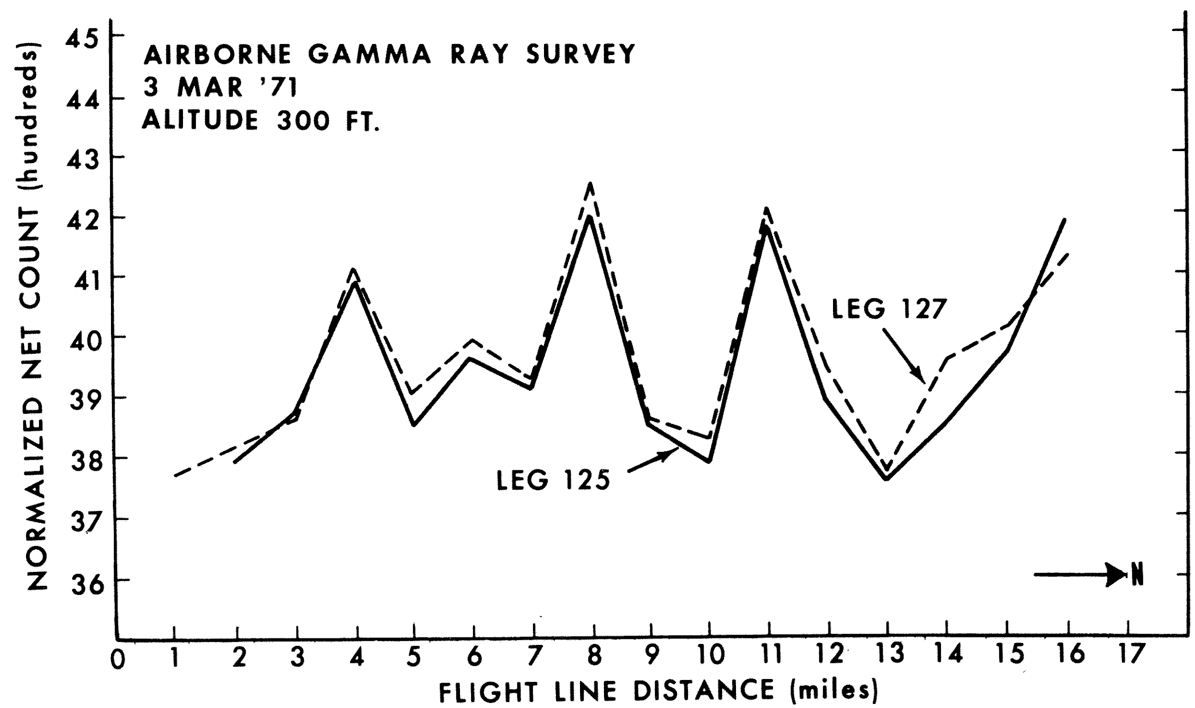

FIGURE 4. Graph showing the variation in gamma count of two flight legs flown a few minutes apart over the NOAA/NASA test site.

radon gas variations should also improve the total count method.

Other Investigations

Test sites in other parts of the country have also been flown, notably Luvernne, Minn., and near Syracuse, N.Y. Both sites were flown in June 1972. Data are not yet available for these flights, but at Luvernne the background count baseline is well established and the Syracuse sites will be reflown next week in conjunction with an ERTS-1 investigation for soil-moisture studies in the Lake Ontario basin. The earlier June flights were concurrent with microwave surveys flown for NOAA by Aerojet Electrosystems. The microwave data collected at Syracuse are reportedly of excellent quality (Al Edgerton, personal communication).

Summary

The Phoenix gamma-ray survey is incomplete. It lacks one additional flight under wet conditions to enable calculation of the radioactivity background count. The ARMS system has proved to be reliable for measuring the moisture equivalent of snow and seems to have worked very well in the first Phoenix flights, demonstrating excellent reproducibility of data.

The Phoenix test site has several drawbacks: 1) its soil moisture depends primarily on irrigation of local fields; 2) the unexpected severe drought that has plagued it. It also has several advantages: 1) it has excellent access; 2) it is uniformly underlain by the same basin-fill deposits except for two small areas, thus making it less susceptible to extreme radioactive variation.

Data from a similar experiment, completed in June 1972 for Luvernne, Minn., are being reduced by EG&G. A third similar experiment will be flown next week near Syracuse, N.Y. NOAA/NESS believes the gamma-ray technique will provide the kind of synoptic ground truth necessary to evaluate the ability of microwave sensors to measure soil moisture from high-altitude aircraft and satellites.

References

Anderson, C.N., Bundy, D.H., Cleland, J.R., and Weissman, V.F., 1969, Aerial Radiological Monitoring Surveys (ARMS) Systems and Procedures employed through FY 69. Tech. Rept. No. EGG-1183-1457, EG&G Inc., Las Vegas, Nev., 49 pp.

Biospherics, Inc., 1971, Soil Moisture Ground Truth for Correlation with Microwave Radiation Data, Contract No. NAS5-21610, Rockville, Md.

Dahl, J.B., and Odegaard, H., 1970, Aerial Measurements of Water Equivalent of Snow Deposits by Means of Natural Radioactivity in the Ground, in Isotope Hydrology, 1970, IAEC, Vienna, pp. 191-210.

Domitriev, A.V., Kogan, R.M., Nikiforov, M.B., and Fridman, Sh. D., 1971, Aircraft Gamma-ray Survey of Snow Cover, Nordic Hydrology, v. 2, pp. 47-56.

Kogan, R.M., et al., 1965, Determination of Water Equivalent of Snow by Method of Aerial Gamma-Ray Survey, Sov. Hydrol. Selec. Pap. [Engl. Transl.] No. 2, pp. 183-187.

Kogan, R.M. Nazarov, I.M., and Fridman, S.D., 1971, Gamma Spectrometry of Natural Environments and Formations, TT 70-50092, [transl. from Russian] 337 pp. Israel Prog. for Sci. Transl., Jerusalem.

Peck, E.L., Bissel, V.C., Jones, E.B., and Burge, D.L., 1971, Evaluation of Snow Water Equivalent by Airborne Measurement of Passive Terrestrial Gamma Radiation, Water Resources Research, v. 7, No. 5, pp. 1151-1159.

Schmugge, T., Gloersen, P., and Wilheit, T., 1972, Remote Sensing of Soil Moisture with Microwave Radiometers, Goddard Space Flight Center preprint X-652-72-305, 31 pp.

Zotimov, N.V., 1968, Investigation of a Method of Measuring Snow Storage by using the Gamma Radiation of the Earth, Sov. Hydrol. Sel. Pap. [Engl. transl.] No. 3, pp. 254-266.