Monitoring Snow Water Equivalent by Using Natural Soil Radioactivity

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The attenuation by snow cover of natural gamma radiation emitted from the soil serves as an excellent index to the water equivalent of the snow cover. A small portable gamma ray detector was installed on a boom about 2 meters above the ground at the National Oceanic and Atmospheric Administration–Agricultural Research Service (ARS) cooperative snow study site at the ARS Sleepers River watershed near Danville, Vermont, for the 1970–1971 snow season. Comparison of gamma ray count rates with snow measurements taken at the site indicates that the small unshielded gage could be used to measure snow water equivalent (range 5–40 cm) with a standard error of 1.5 cm without preliminary editing of gamma ray count rates. A major source of this error was the deposition of radioactive aerosols on the snow surface by precipitation. The deviation of gamma ray count rates due to precipitation events is short-lived, and a simple editing procedure on the count rate time trace reduced the snow season standard error to 1.1 cm. The edited count rate yielded 6% error in the 5- to 13-cm water equivalent range, decreasing to 4% in the 25- to 40-cm water equivalent range. This measurement method could be extremely valuable in providing unmanned measurement of snow water equivalents at remote locations.

Measurement of snow water resources at remote locations is of vital importance to water resource planners, river forecasters, reservoir operators, and many others. The commonly used methods of obtaining unmanned measurement of snow water equivalent at remote locations fall into two categories: (1) weighing devices (snow pillows) and (2) nuclear counting devices. The basis of the nuclear counting measurement methods is the attenuation of gamma rays by snow water intervening between the radioactive source and a detector. A common nuclear method [*U.S. Army Corps of Engineers*, 1955] involves placing a strong gamma ray source at ground level, a detector being suspended over the source. The use of a sufficiently strong source allows good point measurement accuracy in deep snow cover, even in the presence of natural background radiation 'noise.' A second and more elaborate nuclear counting method is the double-probe snow-profiling gage [*Smith et al.*, 1970] designed not only to ascertain total snow cover water equivalent but also to determine the density profile within the pack. This paper is concerned with a nuclear counting method that bypasses the need for an artificial source of radioactivity. The attenuation by snow cover of natural background gamma radiation emitted from the soil provides an excellent index to the water equivalent of the snow cover [*Zotimov*, 1968; *Kogan*, 1971; *Peck et al.*, 1971]. The advantages of this method are several:

1. The measurement is representative of a larger area than the three aforementioned 'point' measurements. Since radioisotopes in the soil provide the gamma rays, the 'source' is spread out over the surface of the earth. The effective 'look area' of a detector suspended 3 meters above the ground is of the order of tens of square meters. The effective look area increases with height above the ground and decreases with greater snow water equivalents.

2. The safety in avoiding placement of strong radioactive sources is an attractive feature. In addition, the considerable effort required to meet radiation safety regulations is saved.

3. Since the source is distributed in the soil, count rates obtained during bare-ground periods may serve as a rough index of soil moisture. This capability is presently under

investigation and is not discussed further in this paper.

4. The source may be strengthened by mixing radioactive material into the top soil mantle in the vicinity of the detector as long as dose rates are kept well within allowable limits.

5. The ease of installation is a plus factor. Aside from the data transmission system (necessary for any unmanned measurements), all that is required is placement of a gamma-counting device on a pole or boom at a sufficient height above the ground.

The measurement method is not without its disadvantages. Two of the most important are listed below:

1. The most prominent disadvantage of this measuring procedure is diminished accuracy as water equivalents increase. Gamma radioactivity is always present in small amounts from foliage and atmospheric sources. Since typical bare-ground count rates are larger than noise rates by slightly less than 2 orders of magnitude, the signal-to-noise ratio may decrease significantly as deepening snow cover attenuates more and more of the signal.

2. Natural background radiation may differ considerably in magnitude and spectral composition from site to site. Thus snow tube measurements taken at periods of various snow cover would be required in conjunction with gamma count rates to formulate count rate versus

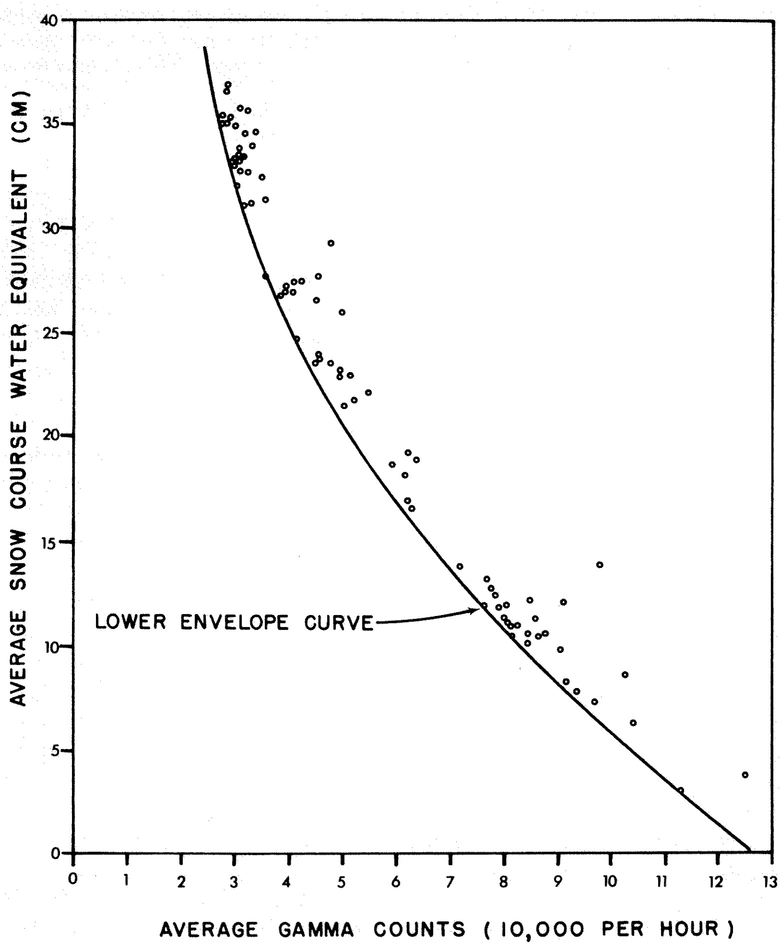

Fig. 1. Average snow course water equivalents versus hourly gamma counts.

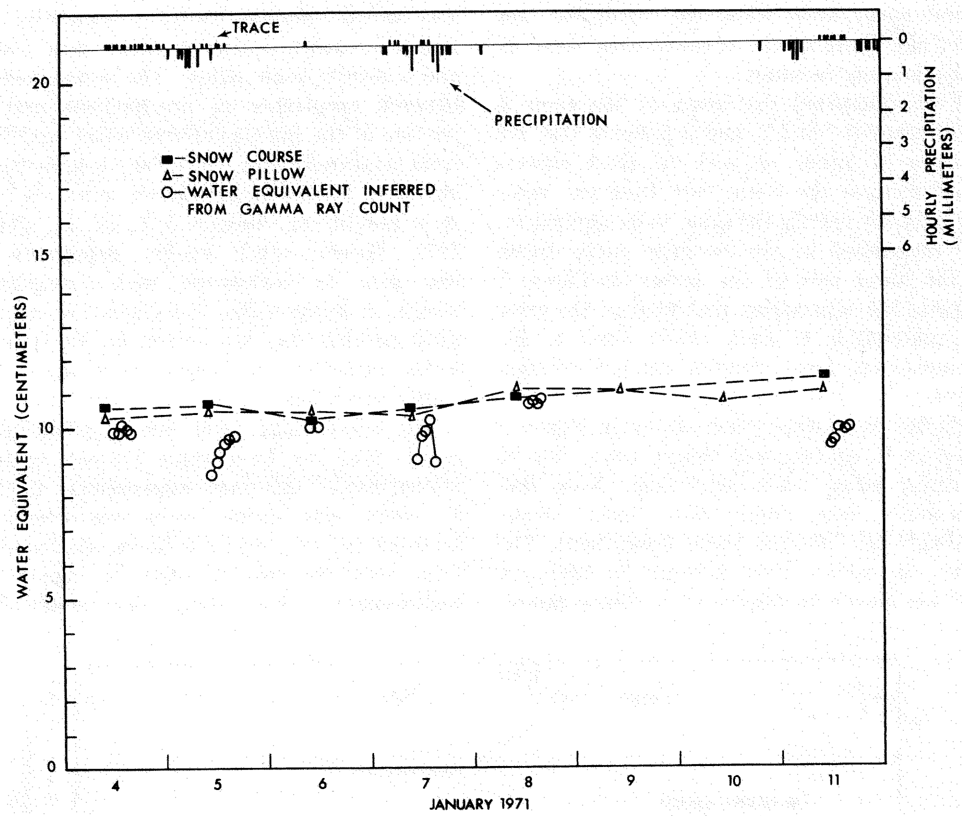

Fig. 2. Measured water equivalents and gamma gage inferred water equivalents, January 4–11, 1971.

water equivalent curves at each site. Fortunately this requirement is only an initial rather than a continuing one.

EXPERIMENT AND RESULTS

A small portable gamma ray detector was installed on a boom about 2 meters above the ground at the National Oceanic and Atmospheric Administration–Agricultural Research Service (NOAA–ARS) cooperative snow study site at the ARS Sleepers River watershed near Danville, Vermont, for the 1970–1971 snow season. The detector was mounted in a box insulated with 5 cm of Styrofoam and maintained at a nearly constant temperature throughout the snow season. The detector output pulses were input to a scaler that accumulated the counts for a fixed period of time (usually 1 hour). The accumulated count was then recorded by the station observer, and the scaler reset to 0. Generally four or five hourly totals were obtained on the days the station was attended. As of April 1, 1972, an automatic recorder was installed at the site to give an hour-by-hour trace of the count rate, but the results are not included in this paper.

The average daily count rate is plotted in Figure 1 against the measured water equivalent value obtained by averaging results from three snow courses in the immediate vicinity of the gamma detector. A best-fit line through the points of Figure 1 yielded 1.5 cm of water standard error. Since the snow course measurement should be accurate to at least within a centimeter of water and since the standard deviation of a 30,000-count/hr signal is less than 1%, a considerable amount of error remains to be explained. Additional sources of error may be (1) significant impinging gamma flux from radioactive isotopes in the air, (2) deposition of radioactive aerosols on the snow surface by precipitation, and (3) difference in true snow course water equivalent and true water equivalent of the effective area 'seen' by the gamma ray detector.

It is anticipated that most of the error is due to sources 1 and 2, and it is noted that the presence of either or both of these sources would increase the count rate from the value that properly reflects the snow water equivalent. The smoothness of the envelope curve drawn on the lower side of the points in Figure 1 supports the supposition that most of the error not attributable to snow course error is due to atmospheric noise radiation and precipitation events.

The lower envelope curve shown in Figure 1 was used to convert each hourly count rate to a corresponding water equivalent. Note that erroneously high count rates yield correspondingly low inferred water equivalents. The water equivalents thus inferred for January 1971 are shown in Figures 2–4. These figures also include plotted hourly precipitation and measured water equivalent from snow courses and a nearby snow pillow. The correspondence between occurrence of precipitation and departure of the gamma-inferred water equivalent from measured water equivalents is immediately obvious. Precipitation-induced error is seen most notably on January 5, 7, 14, 21, and 26, 1971. Several other smaller departures are also seen to correspond with precipitation events. It appears that 4–6 hours are required after precipitation has ceased for the inferred water equivalent to 'decay' back up to the equilibrium value.

The considerable error due to precipitation events need not be a major obstacle to operational use of this snow measurement method. If count rate values were telemetered at intervals of, say, every 6 hours, the resulting trace could be visually edited to remove the high-frequency fluctuations that result from

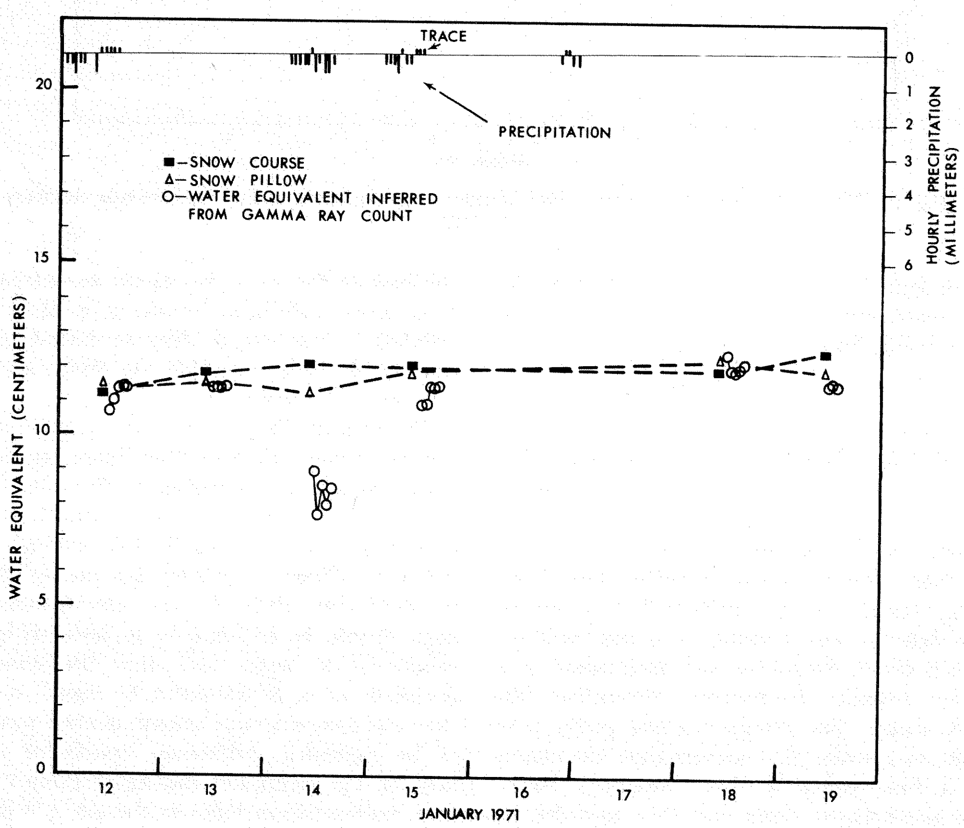

Fig. 3. Measured water equivalents and gamma gage inferred water equivalents, January 12–19, 1971.

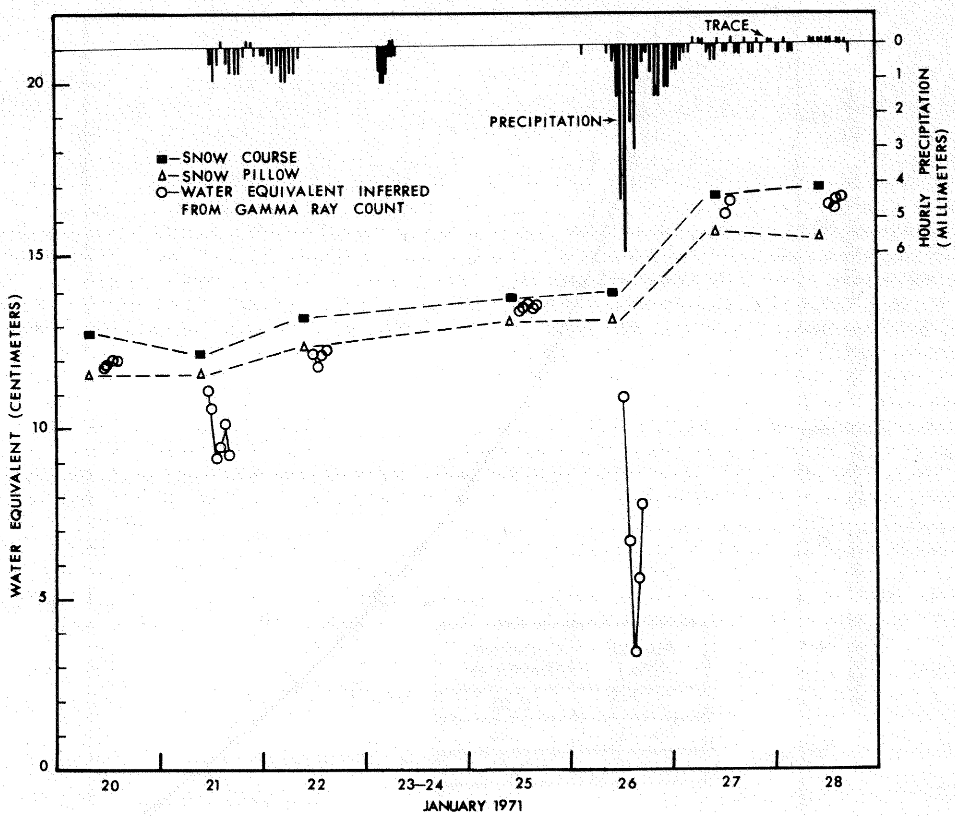

Fig. 4. Measured water equivalents and gamma gage inferred water equivalents, January 20–28, 1971.

the occurrence of precipitation. To get some idea of the accuracy resulting from such an editing procedure, all the events in Figure 1 having no precipitation during the counting period or in the previous 4 hours are plotted in Figure 5. The resulting season standard error for this subset of points was 1.1 cm of water, an improvement of 0.4 cm over the unedited data. The standard errors within the different water equivalent ranges are given in Figure 5. These values correspond to a 6% error in the 5-to 13-cm water equivalent range, decreasing to a 4% error in the 25-to 40-cm water equivalent range. This error could probably be reduced still further by shielding the gamma detector from atmospheric noise by placing an appropriate thickness of lead over the top of the detector (such a shield will be placed over the gamma detector at the Townline snow research station during the summer of 1972). Note further that some of the residual error in Figure 5 must be attributed to error in the snow course water equivalent measurements.

CONCLUSIONS

The use of natural soil radioactivity to infer snow cover water equivalents is certainly an attractive prospect in terms of accuracy and practicality. The method may not be useful, however, in measuring deep snow covers (40 cm or more of water equivalent) without enriching soil radioactivity and/or shielding the detector from atmospheric noise radiation. The results of the 1970–1971 snow season experiment at the NOAA–ARS cooperative research site show that at least operational accuracies can be obtained even without shielding or soil radioactivity enrichment, if simple editing is made on the count rate time trace to remove precipitation-induced error. Implementation of such a system on properly exposed remote data

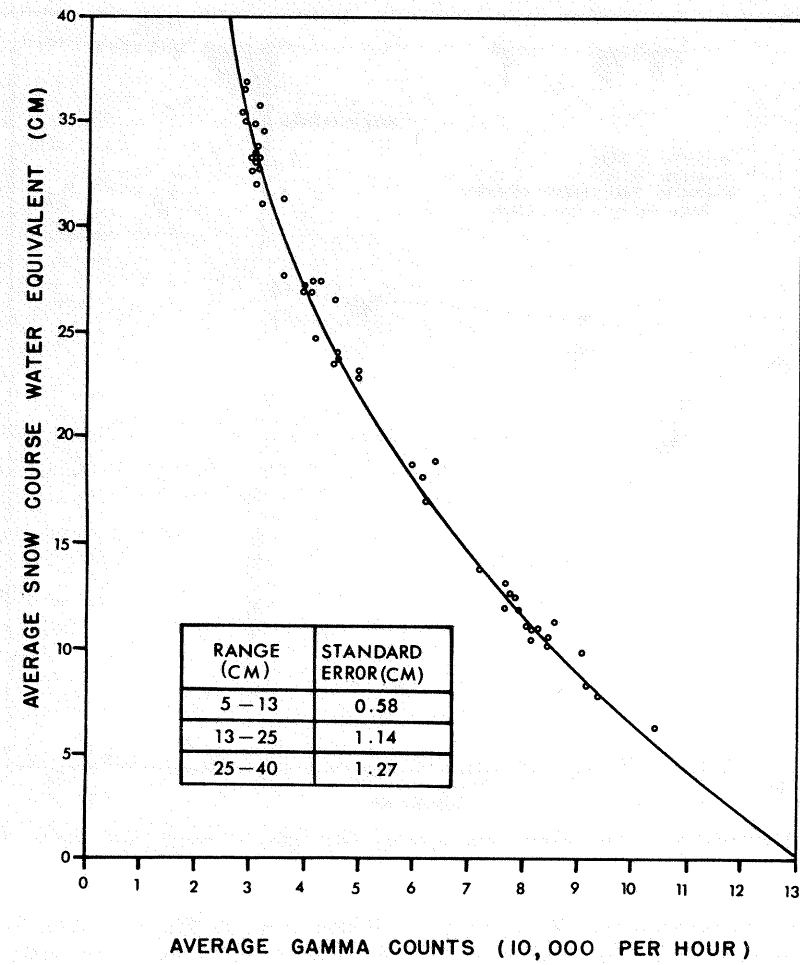

Fig. 5. Relation between snow course water equivalents and hourly gamma counts after removal of precipitation-induced error.

collection and transmission platforms such as the National Weather Service's Data Collection Platform System [*Flanders and Schiesl,* 1972] could be made with a minimum of effort.

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