APPLICATION OF RADAR TO SNOW SURVEYING [1]

By

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Introduction

Measurement of precipitation over a watershed has frequently been compared to the taking of national polls. The comparison suggest that the area sampled over a well instrumented watershed is comparable in sample size to that obtained by polling one person in the United States. While the sampled area is no better, the representativeness of the sample is, of course, much better since precipitation over an area has a reasonably high degree of uniformity. Substantial errors in estimates of watershed precipitation can result, however, from limited samples. Areal distribution of snowpack, for example, is frequently highly dependent on prevailing airflow and moisture influx so that large seasonal variations can occur that are frequently not well defined by scattered precipitation observations.

Snowfall information, other than areal distribution of amounts, is frequently desired for purposes such as avalanche forecasting and control, highway clearance, research investigations, etc. The following factors are needed in one form or another to describe snowfall for the various problems for which it might be used:

(1) onset time, (2) duration, (3) intensity with time, (4) direction

of movement, (5) variations within snow area, (6) time of ending,

(7) total snowfall, and (8) snow particle size and shape.

The description of these variables is difficult and becomes even more complicated as the topography ranges from flat to mountainous. Radar techniques are available for defining these factors and rapidly processing the information. Most reports of radar observations of snowfall have been made from low elevations in generally flat terrain. A WSR-57 radar is currently in operation in a mountainous area at Point Six, Missoula, Montana, (Granger, 1963) elevation 8,000 feet msl. The Japanese are in the process of installing a radar on Mount Fujiyama (elevation 12,395 feet msl) for typhoon and short range snowfall surveillance. The purpose of this paper is to discuss certain of the basic and practical aspects of snowfall observation with radar with special reference to the mountainous areas of the Rocky Mountains.

Radar Theory as Applied to Snow

Radar has been defined (Batton, 1959) as "The art of detecting by means of radio echoes the presence of objects, determining their range and direction, recognizing their character and employing the data thus obtained." This, of course, includes the scattering of reflection of energy from ice or snow particles.

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The radar equation, which is used to relate a radio signal to precipitation observed, can be written in the following form:

$$\overline{P}_r = C\left(\frac{P_t\, h\, d^2}{\lambda^4}\right) /K/^2 \frac{Z}{R^2} \qquad (1)$$

$\overline{P}_r$ = average back scattered return power

C = constant

P_t = peak power transmitted

h = pulse length

d = antenna diameter

λ = wave length of radar signal

$/K/^2$ = complex index of refraction

Z = reflectivity factor = $\sum_{vol} D_i^6$

(D_i = equivalent liquid diameter of target)

R = range.

The complex index of refraction, $/K/^2$ for liquid water, is generally considered to be .930, while for ice it is only .197 about 1/5 that for water. Thus, the radar return from snow is about 1/5 that from rain. The equivalent liquid diameters, D_i , of individual snow particles in central Rocky Mountain snows are generally less than for rain droplets. A reduction of equivalent liquid diameter by 1/2 reduces the radar return by 1/64 for the same concentration of precipitation particles since D_i is to the sixth power.

These reductions of the radar return for snow below that for rain by the difference in complex index of refraction and the smaller equivalent liquid diameter requires that every effort be made to maximize the radar sensitivity.

Referring back to the radar equation, it can be seen that this must be accomplished by increasing P_t , h or d or decreasing λ . It is not feasible to greatly increase the transmitted power, P_t , for radars generally available, and increases in the pulse length, h , reduces resolution. The use of larger antenna diameters (d) and shorter wave lengths, λ , can, however, reasonably maximize the radar sensitivity. Increases in diameter can lead to special problems in exposed mountainous areas since it increases the exposure problem to high winds. The reduction of wave length below that used in rain measurements is feasible since the attenuation problem with snow is greatly reduced as the factors causing reduction in power return from ice also serve to reduce attenuation from that experienced with rain.

Several radar sets have been considered or used at Colorado State University for observing snow. Figure 1 shows the comparison in radar sensitivities for various radar considered.

Radar Determination of Precipitation Rate

The radar equation can be simplified to the form of

$$\overline{P}_r = K \frac{Z}{R^2} \qquad (2)$$

for purposes of determining snowfall intensity since all other factors are a function of the specific radar described by the constant K . To determine precipitation rates, then,

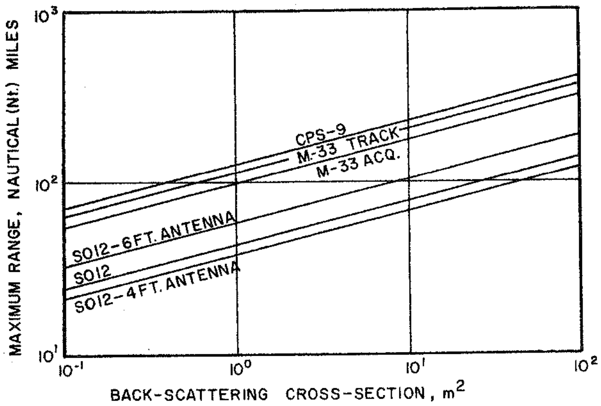


Figure 1.

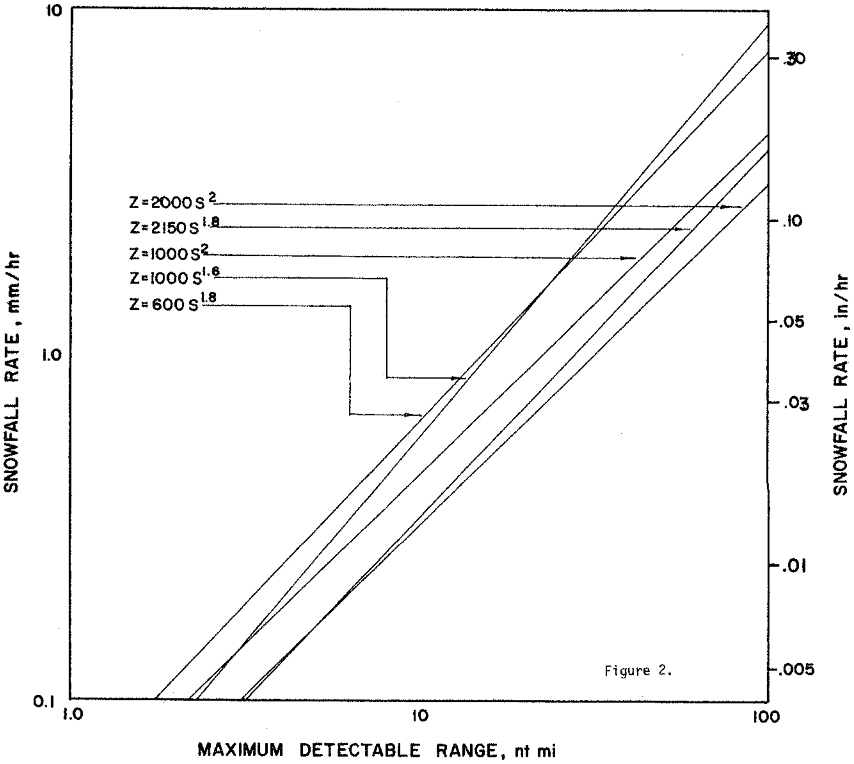


Figure 2.

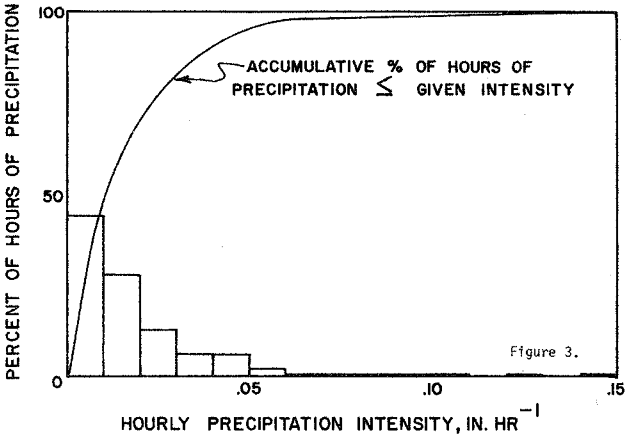


Figure 3.

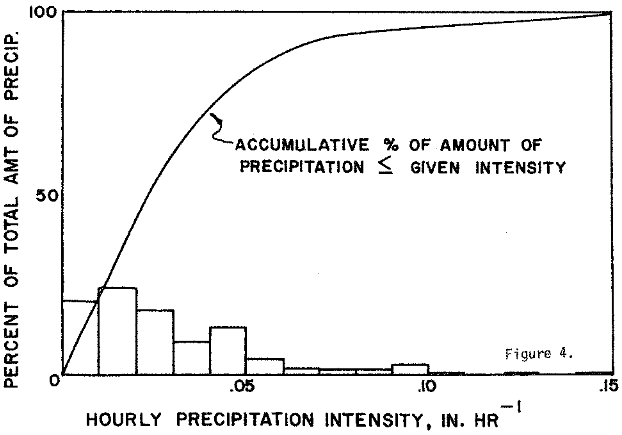


Figure 4.

it is necessary to know the relationship between Z and precipitation rates. It has been shown that this takes the form of an exponential relationship such that for snow aggregates it is approximately:

$$Z = 2000S^2, \text{ where } S = \text{snowfall rate in mm/hour.} \qquad (3)$$

$$\text{Substituting equation 3 into } 2, \overline{P}_r = \frac{K}{R^2} \; 2000S^2 \qquad (4)$$

Figure 2 shows the maximum range which the modified SO-12 radar with a six foot parabolic antenna can detect various snowfall rates assuming various empirical reflectivity factor-snowfall rate relations available in the literature. The ranges at which snowfall can just be detected with this set can be obtained by referring to Figure 3 and 4 which show the frequency distribution of snowfall rates observed in the Climax area of the Central Rockies. Figure 3 shows the percentage of hours with various precipitation intensities while Figure 4 shows the percent of total Climax precipitation which occurs with various precipitation intensities. It can readily be seen that the range limitations are severe in that some 90 percent of the time, precipitation rates are less than .05 inches per hour, which gives a range of only about six miles. As can be seen from Figure 4, these 90 percent of the cases for which the maximum range is about six miles, account for some 75 percent of the precipitation at Climax. Figure 5 shows that the maximum range which the M-33 tracking radar can detect precipitation rates of .05 inches per hour is increased to about seven miles. Two additional factors need special consideration for the use of radar in the Central Rocky Mountains.

Ground Return and Side Lobing

Ground return from side lobes and from other mountains presents a problem even when the antenna is located at a high mountain location. The problem of ground return is even more serious when located below the mountain peaks. Mountain top sites, thus, are at a premium and have essential advantages for mountainous area operation of radar. These mountain top sites, however, present special problems of accessibility and wind protection for the radar antenna. An additional factor, with respect to the mountain top site, is that in certain storm situations a substantial part of the precipitation growth occurs below the mountain peak which forces the antenna probing region to elevations where the ground return causes serious interference. Even with precipitation forming above mountain top levels, the radar will view over the top of many shallow storm situations. Figure 6 shows the maximum elevation to which precipitation can be noted at various ranges before the radar beam will be looking over the storm.

The Chalk Mountain Radar Site

Radar observations of snowfall have been made from Chalk Mountain, 12,000 foot msl, in Central Colorado with an SO-12, M-33 and modified SO-12 radar. The capabilities of these respective sets are shown in Figure 1. Preliminary analysis has provided some useful information on the radar characteristics of snowfalls encountered.

Depth of Snow Producing Storms

While the depth of the precipitation layers have been measured, only a limited number of storms, Figure 7 is typical of most conditions. This shows, for example, that on April 2, 1964, the top of the precipitation layer varied from about 500 feet to a maximum value of only about 9,000 feet above 12,000 foot Chalk Mountain or about 21,000 feet msl. On April 3, 1964, echo tops were generally uniform at about 6,000 feet or about 18,000 feet msl.

Radar Relationship to Snowfall Rates

The relationship of the radar signal to precipitation rates is of special interest in snow surveying. Numerous values of this relationship have been reported in the literature. Table 1 below shows empirical relationships which have been reported.

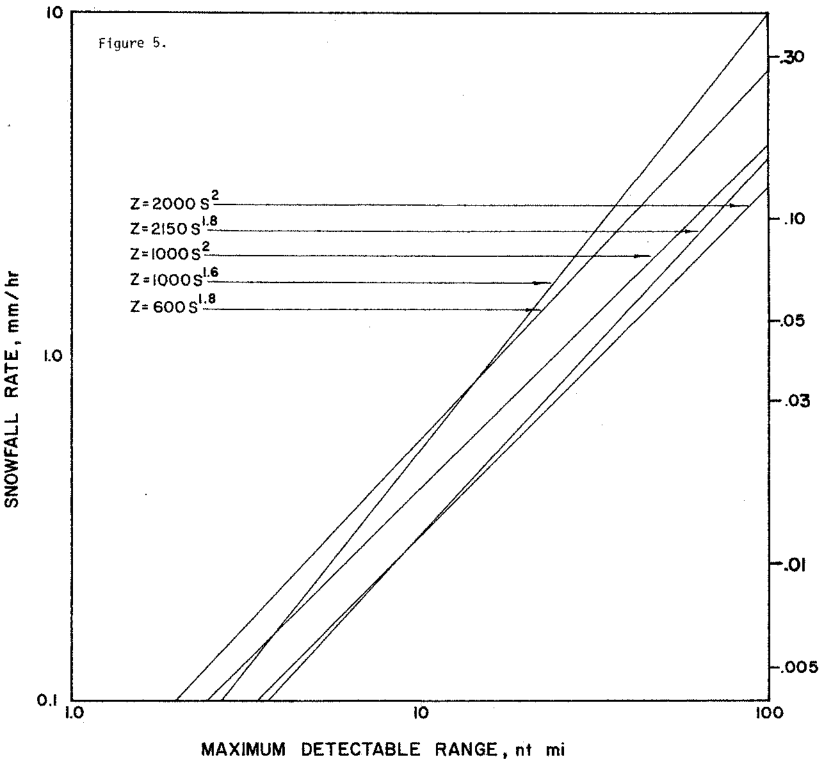
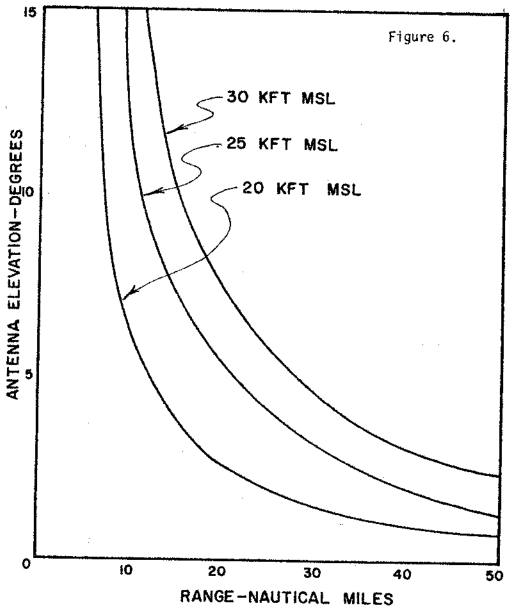


Figure 5.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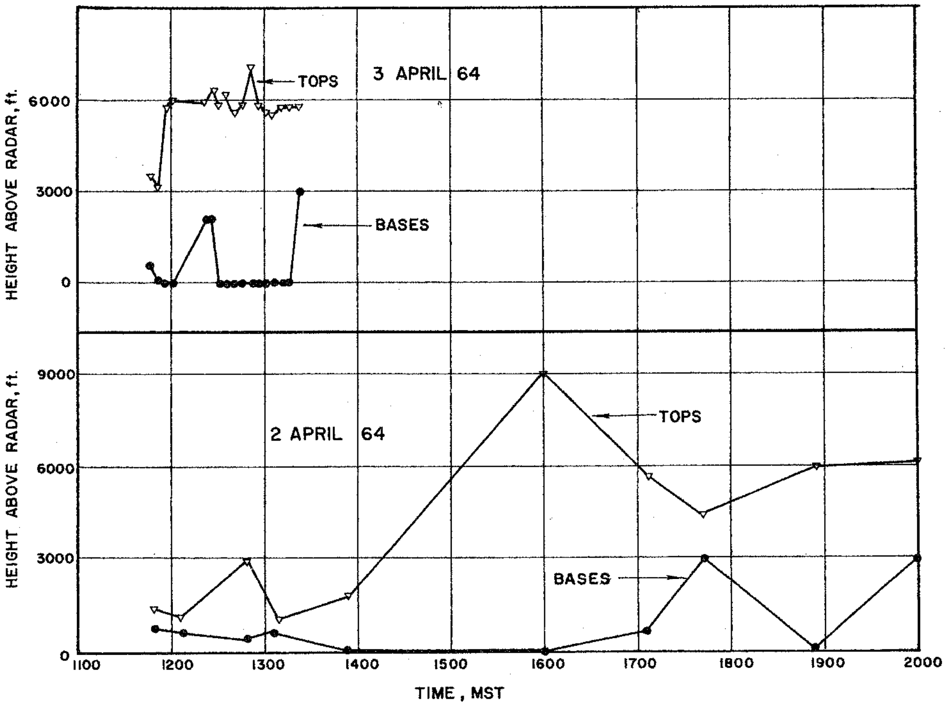

FIG. 7 TIME-HEIGHT CROSS-SECTION OF M-33 RADAR BASES AND TOPS OF CHALK MTN. CLOUDS.

Table 1. Empirical Z - R Relations Obtained by Others

Z - R Relation	Location	Remarks
$Z = 600^{1.8*}$	Japan	Snowflakes, 20 min. one day
$Z = 2150R^{1.8*}$	Japan	Mostly aggregate snowflakes, 1 hour 40 minutes.
$Z = 2000R^{2*}$	Montreal	Aggregate snowflakes, 10 days
$Z = 1000R^{1.6**}$	NE U.S.	9 snowstorms, maximum precipitation 0.5 mm/hr.

* Batton, Louis J., Radar Meteorology. University of Chicago Press, 1959.
** Austin, Pauline, Radar measurements of the distribution of precipitation in New England storms, Tenth Weather Radar Conference, 1963.

These relationships are being studied for various storm types and ice crystal forms at the Chalk Mountain site. It is apparent from Climax data already available that this relationship varies considerably for different snow producing situations.

Cellular Patterns of Snow Storms

Also of considerable importance with respect to snow surveying is the cellular structure of the snowfall patterns. These have been easily and consistently observed with the Climax radar. Even in situations of general snowfall, which visually appear uniform, cells of much heavier snow are embedded in the general snow. These make major contributions to the snow deposited and for a given weather situation frequently follow a definite pattern and account for large local snowfalls.

SUMMARY

Many problems exist in the use of radar for snow surveying and will in the near future preclude the use of ground-based radar to replace the snow tube or pillow.

However, for many uses it can provide a valuable supplement. It can produce detailed information on snowfall to describe (1) onset time, (2) duration, (3) time of ending, (4) intensity with time, (5) direction of movement, (6) rate of movement, (7) variation with the snow area, (8) total snowfall and probably, (9) information on particle sizes and shapes. With most radar equipment currently available, the maximum usable range for most snowfalls of the type experienced in the Central Rockies is of the order of 5 to 10 miles.

Scope integration techniques are available to integrate accumulations over moderate sized watersheds. Radar can be particularly valuable in determining the representativeness of spot snow tube or pillow observations. Radar can also provide a unique tool for summarizing the rate of accumulation at all stage of snowpack developments.

REFERENCES

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LIST OF FIGURES