REVIEW OF SNOW MEASURING INSTRUMENTATION AND EVALUATION OF A PRESSURE PILLOW SNOW-MEASURING DEVICE (1)

by

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ABSTRACT

The pressure pillow ("snow pillow") promises to be a valuable research tool and an excellent remote snow survey instrument. The pillow, filled with an antifreeze solution, measures the water equivalent of the snow pack by gage pressure. At Danville, Vt., a 12-foot-diameter pillow was tested during the 1964-65 snow season and in spite of rains, ice lenses, and a relatively small snow pack, its measure of water equivalent agreed closely with rain gage and snow course measurements.

INTRODUCTION

Whether snow is to be treated as a nuisance or a precious natural resource, the quantity must be known. River forecasters must be able to calculate how much melt water they have to route down our river systems. Irrigation engineers must know how much "excess" melt will be available for future use. Reservoirs must be regulated according to the expected melt. Design of flood protection structures may be controlled by a snow melt event. These and many other uses require an exact knowledge of snow water amounts and rates of accretion or melt.

Good snow data are difficult to obtain because of snow variability, access problems during the snow season, and weather conditions. Most snow data have come from point measurements, or an average of point samples. This paper presents a study undertaken to find a snow measuring instrument that would be able to accurately measure rates of snow pack accretion and ablation for research purposes. First a review of most of the more recent snow measuring techniques and instruments is presented. From this, the snow pressure pillow seemed most suited to our research needs. The latter portion of the paper presents an evaluation of a 12-foot pressure pillow during the 1964-65 snow season.

LITERATURE REVIEW

Volumetric Samplers:

In nearly all cases the desired snow data are the water content or water equivalent of the snow pack. The most widely used method for measuring the water equivalent of snow is the weighing of a volumetric sample. A sample core of snow is extracted from the snow pack with a tube of known dimensions and weighed on scales that are calibrated to yield the water equivalent directly. Usually, the water equivalent is calculated from the average of ten or more samples taken in a "course", and taken in the same place each time so that the results will be comparable.

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Historically, the snow tube has graduated from the stove pipe to the Federal, Rosen, Bowman, and Adirondack types (see Freeman (1), for a description of these). In a study of snow sampler accuracy, Freeman (1) lists potential measurement errors from the following sources: tube dimensions, scales (temperature effects), ability to sample a complete core, and operator skill. Errors as large as 12% were found in this study and in most cases the snow tubes measure more snow than actually exists.

Even though the snow tube is a destructive sampler, must be man operated, and is subject to several errors, it is generally considered the standard of snow measurement and gives good comparative results.

Photogrammetry:

Satellite (2, 3, 4) and aerial (5, 6, 7, 8) photos offer a gross measure of snow cover. Photos can show the extent of snow cover, but cannot provide a measure of the water content. However, estimates of water content can be made by correlating point snow course data and runoff records with serially dated photos. Used in this manner, photos showing the extent of the snow field have had some success in forecasting runoff.

The possibility of using satellite pictures for snow surveys came about from discovering the snow fields in the Alps (4). Satellite photos have also been used to determine the extent of ice coverage and floes (4). Conover (2) used tones of white in satellite photos to estimate quantitative depths of snow over the Northeastern United States.

Aerial photographs of snow depth markers (9, 10) have been used to supplement snow course readings. The snow depth markers consist of a vertical post with horizontal depth markings that can be easily read from low level photos. No measure of water content is available from snow depth markers, but can often be closely estimated from nearby snow course measurements.

The use of shadows, dated photos, infrared photos and other special photogrammetric techniques are presently being studied to make this phase of snow survey more quantitative.

Electrical Properties:

The electrical resistance of snow is not a simple parameter by which one can measure the total water equivalent of the snow pack. As stated in SIPRE Report #4 (11), electrical conductivity of snow depends on the following: 1. The presence of melt water. 2. The amount and kind of impurities. 3. Density and porosity. 4. Temperature. Also, Shimada (12) suggests that the grain structure (in effect, contact area between grains of snow) of the snow affects the electrical conductivity. Because of these limitations and the high voltage requirements (12), no adequate depth or water equivalent measuring snow gage using electrical resistance has been developed.

Electrical capacitance, using both high and low frequencies, has been tested for measuring the water equivalent of the snow pack. At low frequencies the dielectric constants for air and water do not change and the dielectric constant for ice approaches a uniform value. Warnick and Penton (13) measured the dielectric constant between two parallel aluminum tubes at a frequency of 1000 cps. Melting at the tubes disturbed early measurements. The addition of a polyurethane foam around the aluminum rods appears to prevent some of the melt problem. Little field data were obtained with this arrangement; however, Hanson (14) did test a model capacitance gage. Each dielectric (snow sample) tested did yield a linear relationship between capacitance and water equivalent. However, unless one can classify each snow sample, the capacitance for any water equivalent will depend on that particular snow sample. Attempts to correlate snow characteristics with a capacitance loss factor were unsuccessful. Undoubtedly, impurities in the snow pack affect the capacitance a great deal.

Gerdel (15) used high-frequency capacitance measurements to determine free water content in the snow pack.

Infrared Radiation:

Experiments (13) utilizing the attenuation of infrared radiation as a measure of snow water equivalent have not been successful. Although two ranges of wave lengths (0.4 to 0.5 and 0.8 to 1.0 micron) transmit visible and infrared energy through snow, most of the measured transmission characteristics are determined by the scattering properties of the snow. In turn, the snow's scattering properties are determined by the density and crystalline structure rather than the water equivalent. There is a possibility that this concept can be used as a research tool for studies of structure and free water.

Radioisotope Snow Gages:

The measurement of snow water equivalent by the attenuation of energies from radioactive decay will be discussed in two parts:

1. Fixed Sources:

The fixed source radioisotope snow gage usually consists of a γ-emitting source (Co^{60} or Sr^{90}) placed in a fixed location such as the ground surface, and a counter mounted 10 to 15 feet above the source (16, 17, 18). The theoretical aspects of this instrument are covered in the "Development and Test Performance of Radioisotope-Radiotelemetering Snow Gage Equipment" (18). The radiation intensity is attenuated linearly by the water content of the snow pack. Martinec (19) found that water equivalent could be measured directly by attenuated radiation regardless of the density of the snow pack. Most workers report an error of less than 5% for measurements up to about 50 inches of water equivalent. The lower limit of measurement seems to be 2 inches of water equivalent (20).

Stability of the electrical components has been a problem in some cases. Higashi and Itagaki (21) reversed the relative positions of the counter and source to eliminate effects due to changing temperatures in the counter.

Telemetering equipment is usually used for data collection (22, 18). Experiments are being conducted for collecting data by flying over the source with a counter.

High cost and the potential health hazard problem are the only two serious disadvantages of the fixed source method.

2. Portable Sources:

Portable nuclear equipment using both gamma and fast neutron radiation sources has been used to measure snow. In most studies the equipment used has been commercially available soil moisture and density probes. With this equipment the source and counter are mounted in the same probe and counting depends on the back scatter of radioactive energy. A theoretical discussion of these methods appears in several publications (17, 23, 24, 25, 26, 27).

With this type of probe, Gay (23) measured water content to within 5% of gravimetric samples with the gamma probe. For densities above 50%, he claimed that a point in density is reached where more gamma radiation is attenuated and absorbed than reflected, causing the count rate to decrease. Measurements with the neutron probe were not successful, because of a large degree of scatter around the mean line (23, 17). Apparently, structure and state of water affect a neutron count.

Since both probes sample a sphere of snow, interface problems are found as one measures near air-snow, and snow-soil interfaces, and ice lenses. The neutron probe was used successfully in finding ice lenses and may be used for finding free water and determining changes of state (23).

More recently, work has been done using a separated source and counter (28) with a single-window pulse discriminator. With this system snow density can be measured accurately with a vertical resolution of 1/2 inch.

Diaphragm Deflection Method:

Circular sheets of aluminum supported on the circumference have been used to measure the snow pack (14). The weight of snow causes the center of the disc to deflect; the deflection is measured by electrical strain gages and the strain readings are related to the water equivalent of the snow pack.

This method has shown some promise but problems encountered were: creep in the diaphragm material, electro-mechanical difficulties, a nonlinear relationship between strain and water equivalent, and only one-half to one inch accuracy.

Tamura and Tsuda (29) reported an analogous system in which they used plates hinged at the circumference and balanced on a mechanical strain meter at the center. The plates were covered with soil to simulate the ground surface. This system was later modified (30) to collect melt water with a tipping bucket apparatus. Although problems of friction, relaxation and hysteresis were encountered, good results were reported.

Pressure Pillow:

The pressure pillow snow measuring system ("snow pillow") consists of a large flat pillow filled with an antifreeze liquid and a pressure measuring instrument. The weight of snow building up on the pillow increases the pressure in the liquid system which is read or recorded as a measure of water equivalent.

Numerous mechanical difficulties were encountered by Warnick (13) in early tests, but results from the 1962-63 Mt. Hood study were promising enough to warrant more work with this system.

Beaumont (31) reported on two years' data from several sizes of snow pillows (5, 6, 8, 10, and 12 foot diameters) at a testing site on Mt. Hood. Corrected snow tube measurements were used to evaluate the pillow's measuring ability with good results up to 90 inches of water equivalent reported. Beaumont suggested that the smaller snow pillows tend to overweigh the snow and that as the snow pack increases, the chances for overweighing increase. Short period snowfall increases were measured by weighing new snow on snow boards. The lack of bridging on the 12-foot pillow was confirmed by digging a trench around it. The response time for the Mt. Hood 12-foot snow pillow was "a matter of minutes". Also, snow increase rates as low as 0.03 inch per hour were measured.

EVALUATION OF THE SNOW PILLOW

Of all the snow measuring devices and techniques studied, the snow pressure pillow seemed most adaptable for use as a research instrument for snowmelt studies because: (1) it is a simple system when pressure is measured by a manometer, (2) cost is not excessive, (3) it is capable of fast response time to changes in the snowpack, and (4) it is capable of measuring small increments of snow water content. For these reasons it was decided to conduct further tests at the Sleepers River research Watershed in Danville, Vermont. The questions to be determined were: (1) What is the accuracy of the snow pillow? (2) What is the smallest increment of water equivalent that it can measure? (3) How does it work under eastern conditions? (4) Can it be used as a research instrument?

The Pressure Pillow:

A 12-foot-diameter snow pillow was purchased in the fall of 1964 from the Carlisle Rubber Company*, Carlisle, Pennsylvania. The pillow is constructed of nylon-reinforced butyl; has an automobile tube valve in the center of the top for removing air when filling;

* Trade names and company names are included for the benefit of the reader and do not imply any endorsement or preferential treatment of the product listed by the U.S. Department of Agriculture.

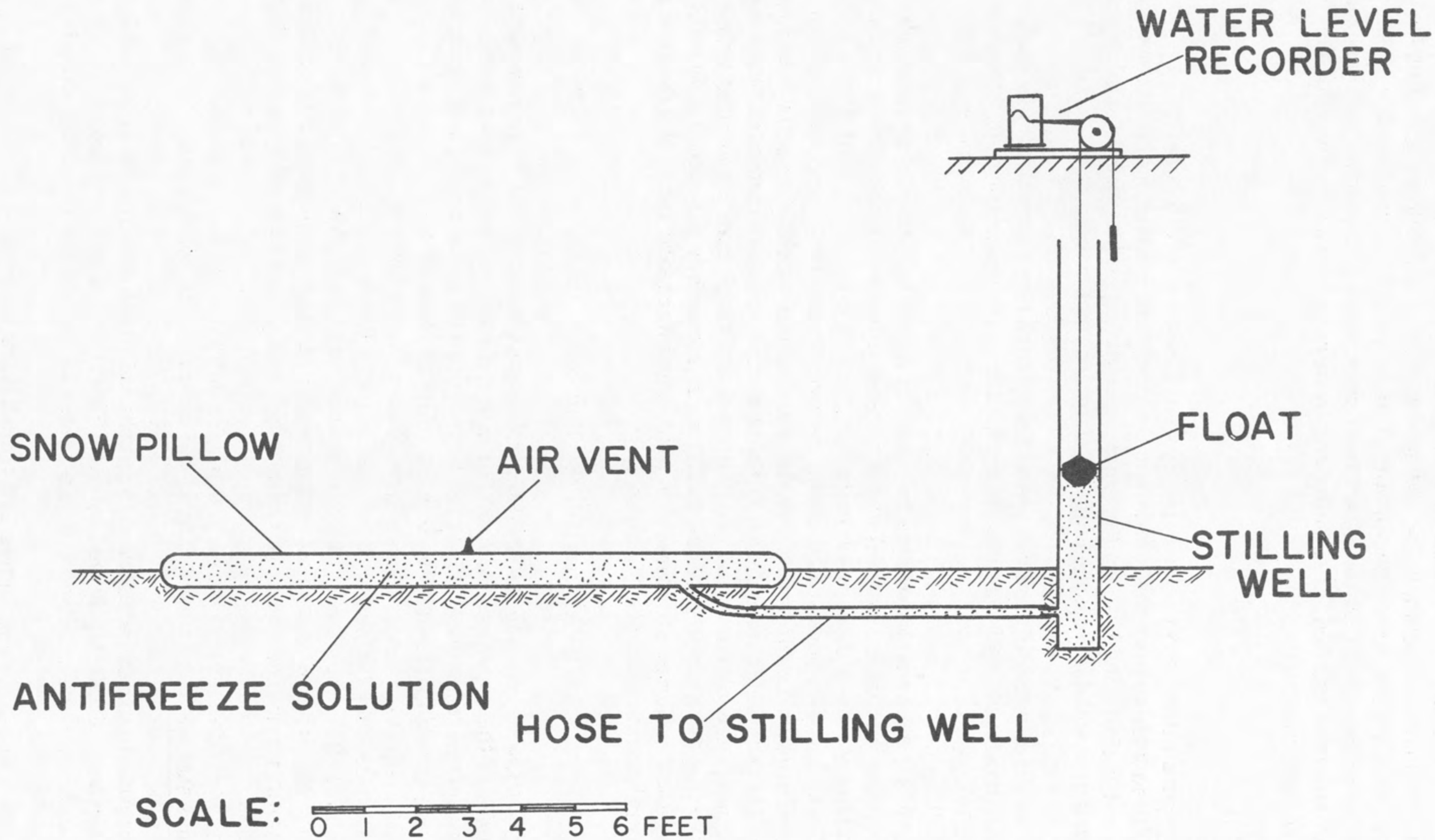

Figure 1. Diagrammatic sketch of the principle components of the snow pillow installation.

and a rubber hose attached to the bottom for filling and installing the pressure reading device. For the installation at Danville, a 6-inch iron pipe stilling well was connected to the rubber hose and a water level recorder incorporated to measure the changes in liquid level (pressure). Figure 1 shows a diagrammatic sketch of the principal components of our system. The photograph in Figure 2 shows how the system looks in the field.

Instrumentation:

The snow pillow was installed at an existing weather station within the experimental watershed. Station R-3, at elevation 1800 feet mean sea level, was chosen because the site is reasonably accessible, well drained, and free from excessive drifting. Sand was used as the foundation material for the pillow. The water level recorder for the snow pillow had a gage scale of 5:12 and a chart revolution of once every 96 hours. The liquid level depth could be read to the nearest 0.02 in. of water equivalent. Time could be read to the nearest five minutes. The pillow was filled by gravity with four 55 gallon drums of a 2:1 mixture by volume of methyl alcohol and water. When the snow pillow was removed in the spring, the antifreeze solution was pumped back into the four drums. No noticeable loss of antifreeze solution could be determined.

Other data collected at this instrument site are: precipitation by a weighing-type, universal recording rain-snow gage, a 10-sample snow course with an Adirondack sampler, air temperature and relative humidity with a hair element hygrothermograph, short wave solar radiation with a metal strip pyrheliograph, wind run with a totalizing anemometer, and soil moisture by the neutron method. Figure 3 shows the plan layout of the various instruments at station R-3.

Analysis:

Evaluation of the snow pillow becomes somewhat subjective because the true water equivalent of the snow volume over the pillow was never known. However, continuous data from the precipitation recorder and the weekly snow course were considered to be good and were chosen to evaluate the snow pillow's performance.

1. Seasonal Performance:

Daily readings of water equivalent as determined by the snow pillow were plotted with precipitation gage data and snow course data in Figure 4. Snow pillow and precipitation gage readings were made at midnight; snow course data were plotted on the date the measurement was made. A plot of daily degree hours greater than 32°F is also shown in Figure 4 to indicate an air temperature heating index during the snow season. Agreement between water equivalent as measured by the snow pillow and cumulative precipitation is excellent between melt periods. Agreement between the snow course data and the snow pillow is good.

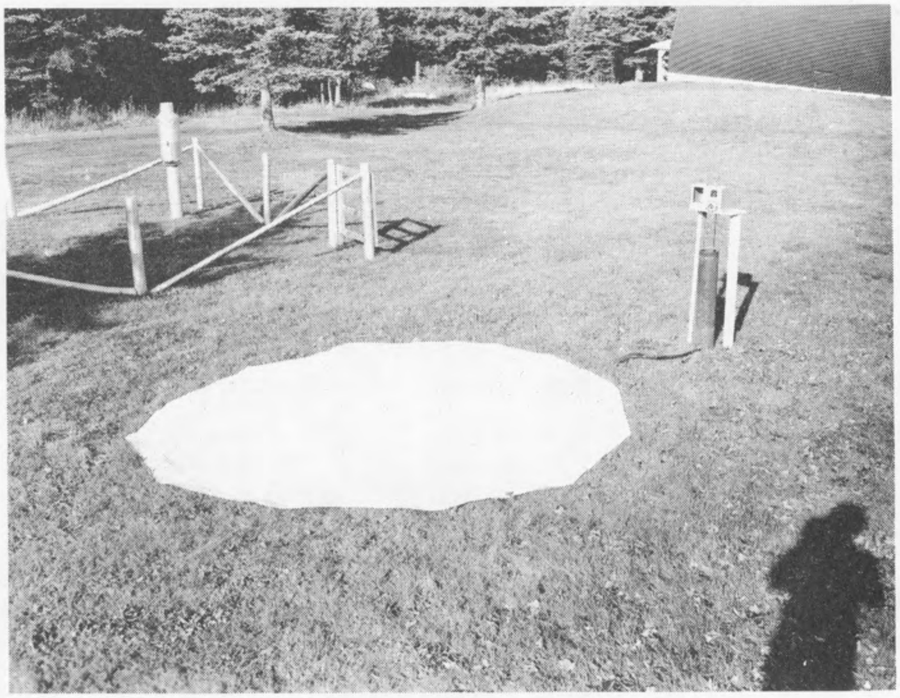

Figure 2. Snow pillow, stilling well, and water level recorder as they look in a typical field installation.

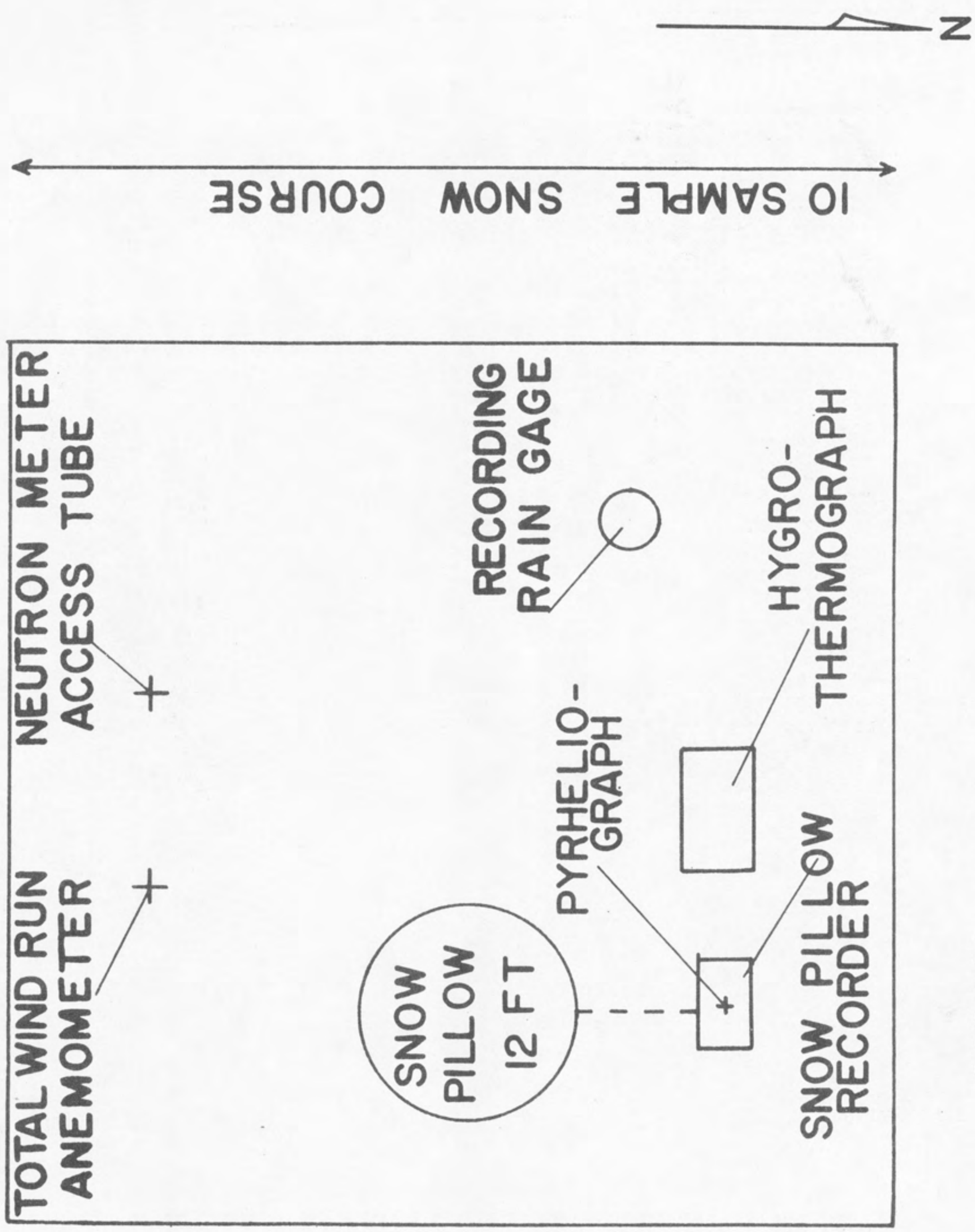

Figure 3. Plan diagram of the instrumentation at weather Station R-3.

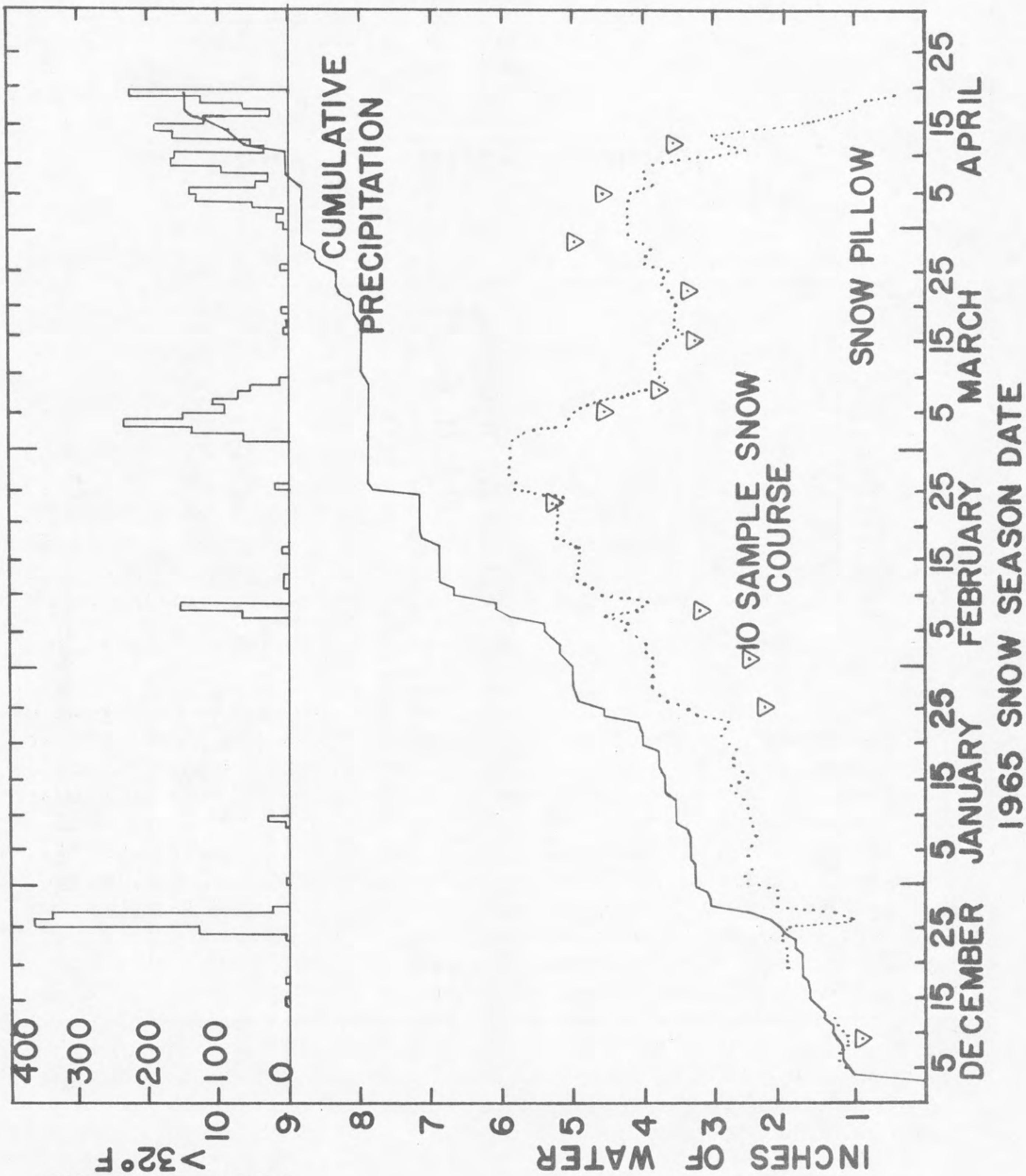

Figure 4. Seasonal performance of snow pillow compared to cumulative precipitation and snow course data. A heating index of degree hours greater than 32°F is plotted to indicate possible melt periods.

A discontinuity in the snow pillow data appears between December 12 and 19 in Figure 4. Since it appeared that the zero water equivalent point changed during the snow year, the true zero point was chosen as the water level recorder reading at the end of the snow season. The data were plotted backwards from this date to December 19. The first storm in December was plotted from the zero point as it appeared when the pillow was installed.

2. A snow Accretion Event:

To be useful as a research tool the snow pillow must have a fast time response to changes in water equivalent. Snow pillow and precipitation gage data are plotted for two consecutive storms in Figure 5. It is seen in this case, as is true in all others, that the pillow shows essentially immediate response to changes in water equivalent.

3. A Snow Melt Event:

Because snow melt is not measured directly and no reliable index of it is available, it is not possible to evaluate the snow pillow's ability to measure melt rates per se. However, an attempt is made to determine whether the melt indicated by the pillow appears reasonable. The decrease in water equivalent for two consecutive days is plotted with solar radiation data and air temperature data in Figure 6.

Discussion:

The installation of the snow pillow was purposefully kept as simple as possible. Our open system and proven water level recorder minimized the possibility of the mechanical and electrical difficulties that plagued Warnick and Penton (9). The open system also eliminated any need for correcting changes in barometric pressure.

The close correlation between the snow pillow and the precipitation data indicates that the snow pillow was successful as a snow measuring instrument. During periods of accretion, the ordinate between the cumulative precipitation curve and the snow pillow is very nearly a constant, indicating that the snow pillow does give a good picture of changes in the snow pack. In spite of the relatively small snow pack (approximately 60% maximum water equivalent based on 4 years' snow course data) and numerous ice lenses, all water equivalent readings were reasonable. Snow courses were taken weekly, and in some cases more often, but many of the 1964-65 data were unreliable due to the number and thickness of ice lenses and the inability to cut good cores. Only snow course data where good, complete cores could be sampled were plotted in Figure 4.

The reason for the differences in the zero points between the beginning and end of the snow season has not been determined. It appears as if the sand foundation settled or shifted or the pillow shifted under the initial loading. This seems possible because the sand foundation was loose and was not perfectly level. This hypothesis may account for the observed discontinuity between December 12 and 19 in Figure 4.

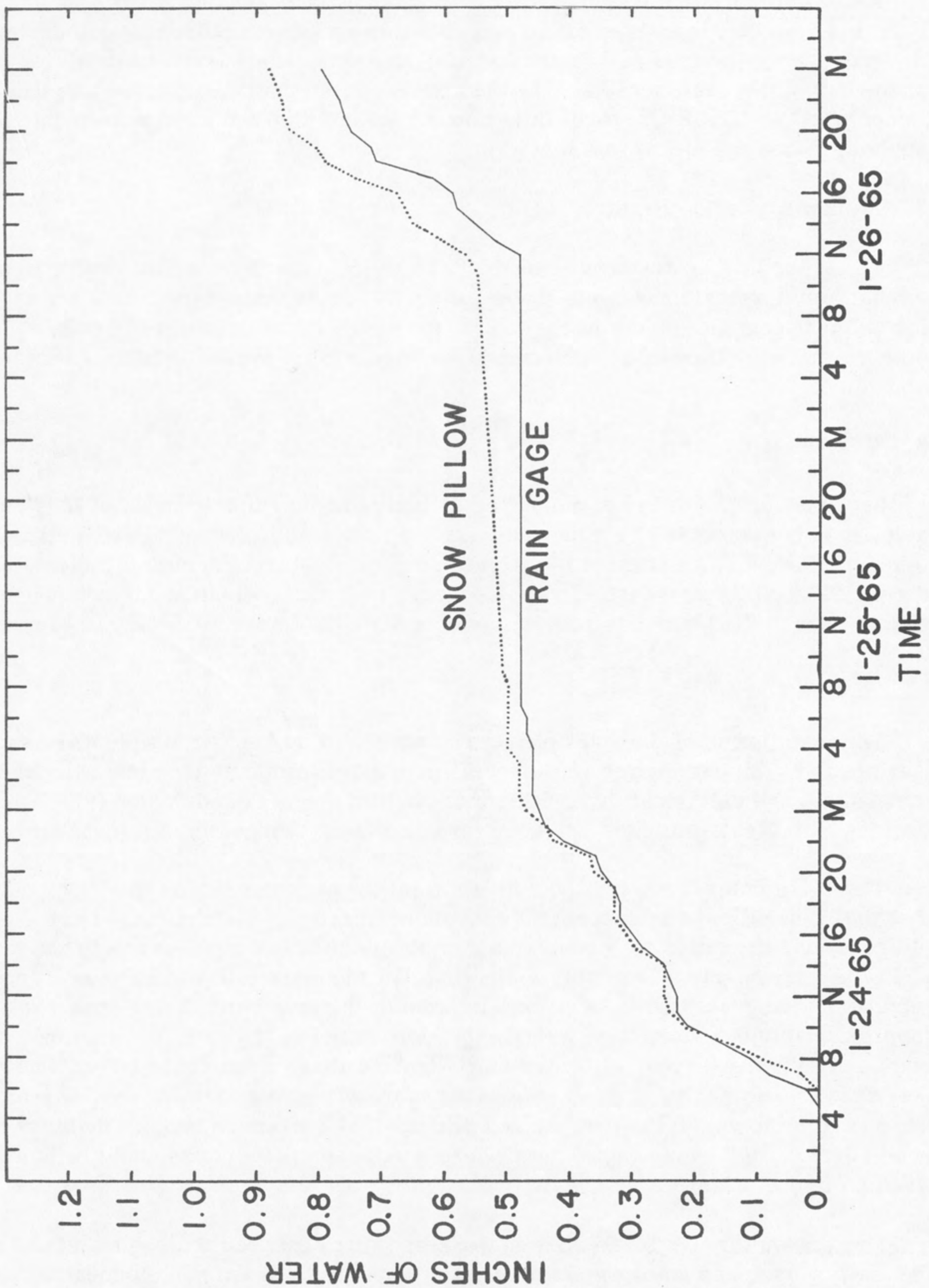

Figure 5. Snow accretion measured by the snow pillow compared with cumulative storm precipitation.

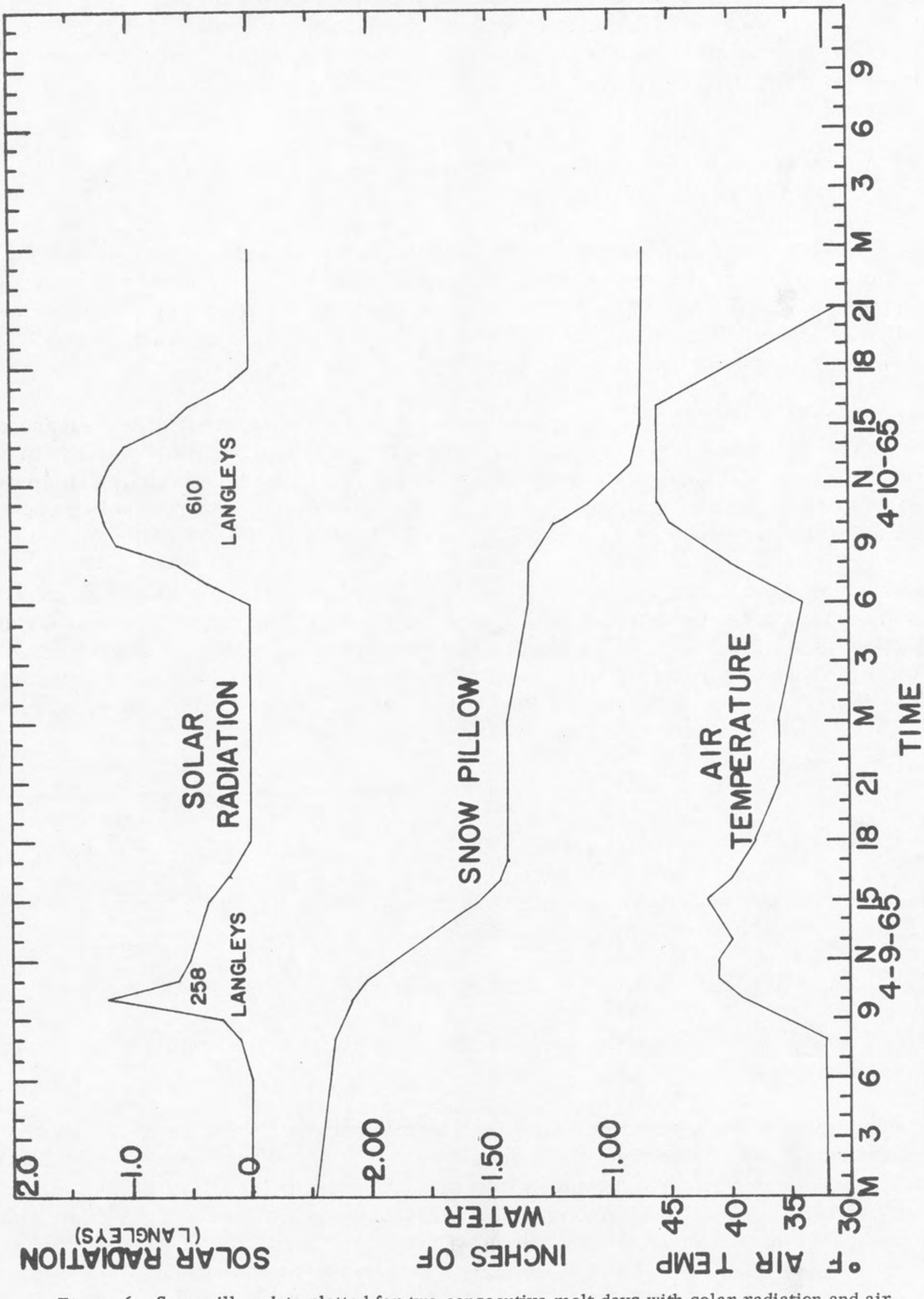

Figure 6. Snow pillow data plotted for two consecutive melt days with solar radiation and air temperature data.

Temperature fluctuations were presumed to be the cause of observed diurnal variations in water equivalent readings. In Figure 4 the readings were taken at midnight to eliminate this effect. The amplitude of the diurnal fluctuations decreased as the snow pack increased. The quality of measurement in general seemed to increase as the snow pack increased.

Apparently, midwinter rain on February 24 was absorbed by the snow pack. Streamflow records corroborate this.

The comparison of snow pillow and precipitation gage data for the two storms shown in Figure 5 indicates that the time response of the snow pillow is essentially instantaneous. Even changes in precipitation intensity are picked up by the snow pillow. A possible time lag of up to three hours was reported by Warnick and Penton (13), but this may be true only for deep snows of the West.

The snow melt event illustrated in Figure 6 indicates that melt can be measured by the snow pillow. A good quantitative evaluation of the snow pillow's ability to measure melt will have to await a good melt standard with which it can be compared. At this time this is no reason to believe that the melt measurement is not as good as the accretion measurement.

Our one year's experience disclosed three pertinent facts that should be considered when installing snow pillows. One, a good, solid, level foundation is necessary to support the pillow. Two, the pillow should be filled to capacity with antifreeze solution. Three, rodents, porcupines and stray (or not so stray) hunter's bullets will be deleterious to the longevity of the snow pillow. If possible, the snow pillow should not be installed until just before the first lasting snow storm.

SUMMARY

Answers to the questions posed above are:

1. Measurement accuracy of the snow pillow appears to be $\pm$ 0.02 inch of water equivalent. Relative accuracy increases with depth of the snow pack.

2. Changes in water equivalent of 0.02 inch can be measured and 0.01 inch estimated.

3. The snow pillow successfully measured a shallow snow pack with ice lenses, typical of eastern conditions.

4. The snow pillow's accurate measurement and fast time response to accretion and melt events make it a very useful research tool. For snow survey use, water equivalent can be determined from a pressure transducer and the results sent to the office by a telemetering unit. As a research tool, use of a pressure recorder gives the scientist a continuous record of snow accretion and melt.

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