by Matt Wright

FROZEN POTENTIAL

The ability to predict snow water equivalent is essential

Increasing global demand on water resources, and the importance of predictive risk management, highlights the need for accurate snow water equivalent measurements

Photos are courtesy of Centre for Hydrology, University of Saskatchewan. Photographed by Angus Duncan

Snow melt is a large source of fresh water in many areas of the world, making its measurement an important source of information for the management of water resources. Snow water equivalent (SWE) is the measurement of how much water is present within a snowpack. In order to make sound water management decisions, it is essential that SWE measurements be as effective and accurate as possible.

Although the concept of SWE is simple, achieving accuracy in its measurement can be very difficult. The ideal SWE measurement system would utilize a non-contact technique that would not affect the accumulation or wind distribution of snow. The system would not have the potential to cause environmental harm and would be easy to install or conduct. It would not modify the interactions of water, temperature or radiation between the atmosphere, snow and/or ground. For modeling and forecasting it is critical that SWE be measured continually to provide the peak SWE and thus an estimation of the maximum amount of water that will be available.

SWE measurement techniques

Common techniques that have been used to measure SWE include snow cores, snow pillows/snow scales, and precipitation gauges.

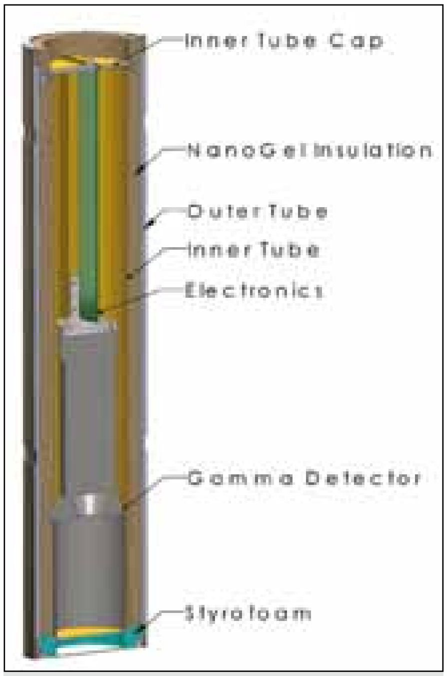
The snow core method involves removing and weighing a core of the snowpack to determine SWE. Measuring SWE using manual snow cores is a fairly reliable technique when measuring dry snowpacks; however, obtaining snow cores requires significant time and labor, making it an expensive method – particularly when conducted in remote areas. It is also a destructive procedure that is prone to human error and does not allow for the same parcel of snow to be measured twice. Under wet snow conditions it is very difficult to obtain accurate snow cores, and this often results in an underestimation of SWE. Snow cores also only provide point measurements and do not allow for continual monitoring of the same snowpack, making it difficult to determine peak SWE.

Snow pillows and snow scales are installed at ground level and use pressure transducers to measure the weight of snow as it accumulates to measure SWE. While this non-destructive technique allows for continual data monitoring and works well in snowpack conditions in which few freeze-thaw events occur over the winter, transport and installation of snow scales and pillows in remote areas can be difficult and expensive. Snow pillows often use a rubber bladder that is filled with glycol to prevent freezing and thus presents an environmental hazard. Both snow pillows and scales are susceptible to bridging, a situation in which ice lenses form in the snowpack and modify the distribution of weight, which results in measurement errors. The pillows and scales also form a barrier between the ground and the snowpack, resulting in a disturbance in the interaction of water and thermal heat between the two mediums. Dark pillows and scales can also absorb more solar radiation than the surrounding environment, potentially resulting in a delayed accumulation on the pillow in the autumn and increased melt rate in the spring.

Precipitation gauges, which collect rain and snow to measure year-round precipitation, can also be used to measure SWE. This method can provide a continuous SWE measurement if the precipitation change from rain to snow can be accurately determined. Again, like the snow cores, snow pillows and snow scales, using the precipitation gauge to measure SWE has its disadvantages; measuring SWE with a precipitation gauge is intrusive as it collects and melts the snow to determine its water equivalent. Errors in SWE measurement can occur due to increased windspeeds, which impact catch efficiency and snow capping on the top of the gauge. Precipitation gauges also cannot provide peak SWE, or SWE during the melt phase when the temperature rises above 0°C. Like snow pillows, they also pose an environmental hazard due to the glycol used to melt snow that has collected in the gauge. Maintenance for these gauges can also be expensive in remote locations as the water in the gauge must be emptied on a regular basis and the correct glycol-to-water ratio must be maintained to ensure the water does not freeze within the gauge.

A new technique to measure SWE

The CS725, developed by Hydro Québec in collaboration with Campbell Scientific Canada, is a gamma monitor that measures SWE. It passively measures the net natural terrestrial gamma radiation emitted by the soil after the radiation is absorbed by the snowpack. The CS725 is a non-contact sensor that is installed well above the maximum snowpack height and provides a measurement of SWE and soil moisture four times a day for a selected site, allowing for unattended monitoring in near real time. The sensor element utilizes a thallium doped sodium iodide crystal NaI(Tl) to measure naturally emitted terrestrial gamma radiation. It detects potassium (40K) and thallium (208Tl) gamma particles (the most abundant naturally emitted gamma rays) and places counts of each gamma ray detected in a histogram. This histogram is used to calculate SWE with the measurement accuracy proportional to the square root of measurement time. The precise measurement of SWE is calculated by detecting the attenuation of naturally occurring gamma rays by the snow cover. As the snowpack accumulates, the CS725 measures a decrease in the gamma ray counts; the higher the water content, the higher the attenuation of the gamma rays.



Cross-section of the CS725 system

The CS725 measures SWE over a large surface area (50-100m^2 when mounted 3m above the ground), and provides a technique that is effective with any type of snow and ice. Its performance is not affected by adverse weather conditions or bridging. Once installed, the CS725 can be left in the field for seven years maintenance-free. However, the CS725 is presently limited to a maximum range of approximately 600mm of SWE and is dependent on a suitable amount of terrestrial gamma radiation. It must also be calibrated under snow-free conditions and requires known soil moisture at the time of ground freeze-up at the onset of winter.

Currently, the CS725 is in operational use or has been trialed in Alberta and Quebec (Canada), Anestølen (Norway), and Utah and New York (USA), with comparison to snow core measurements, snow pillow, snow scales and precipitation gauges. In all, Hydro Quebec has 17 sites in operation using the CS725 to measure SWE.

Comparison of different techniques

Field-testing of the CS725 was conducted at Sunshine Village, Alberta (2008-2011); SNOTEL Tony Grove Ranger Station, Utah (2009-2010); and Anestølen, Norway (2011-2012). Automated SWE measurements were made at the various test sites using the CS725, snow pillow and precipitation gauge. Monthly manual snow core measurements were also conducted at Sunshine Village (2009-2010) and Anestølen, Norway (2011-2012). Analysis of CS725 performance was conducted by comparing the SWE measurements of the CS725 to measurements taken by snow pillows, precipitation gauges, and manual snow core measurements at the three test sites.

As there is no standard method to precisely measure SWE values of a snowpack, assessment of SWE measurement techniques must therefore be conducted by examining errors associated with a particular technique and the scale of impact those errors have on usage of the sensor. When the CS725 was compared with the snow pillow and precipitation gauge at all test sites, all the methods demonstrated strong agreement (Figures 1-3); however, deviations between the different measurement techniques were observed at the three field sites for all seasons. Although many hypotheses can be formed to explain these deviations, there is no way to determine the true causes without detailed snow surveys on a daily scale, which would result in destruction of the snowpack at the survey site.

CS725 SWE measurements demonstrated increased variability at greater snow depths (1.2-1.5m) for all seasons at Sunshine Village (Figure 2). However, this was not observed at the Tony Grove Ranger Station (Figure 1), nor at Anestølen, Norway (Figure 3), likely due to the lower maximum SWE and snow depth at each test site. This increased variability in the CS725 SWE measurement may be explained by a decrease in potassium counts as the SWE and snow depth increases, resulting in a greater possibility of noise (non-target sources of potassium gamma rays). Statistical comparisons of the three automated daily SWE measurements at all sites show strong correlations (0.96-0.99) between the CS725 and snow pillow and the CS725 and precipitation gauge. Due to this and the comparisons of the three techniques above, it is difficult to determine a significant difference between the measurement techniques.

This study reminds us of the present issues still faced with the measurement of SWE. Due to the various errors associated with each measurement technique, there is no single ideal method for measuring SWE, thus, in most situations the choice of measurement technique often comes down to cost. Depending on the period of time over which measurements are taken and when personnel, installation and transportation costs are taken into account, the CS725 can become cost-effective when compared with manual snow core measurements and other automated techniques for measuring SWE. The CS725 is unaffected by the majority of the disadvantages associated with snow cores, snow pillows and precipitation gauges as described above, while adding some advantages not provided by the other techniques. These advantages, along with the early but stable results of the CS725 evaluation, indicate it can be an effective solution to these long-standing measurement challenges. ∎

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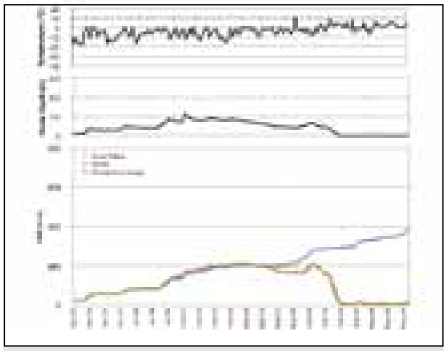

Figure 1: SNOTEL Tony Grove Ranger Station test site comparing SWE measurements from the CS725 (magenta), precipitation (blue) and snow pillow (green) from December 7, 2009

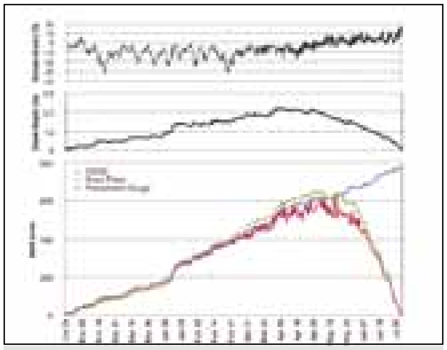

Figure 2: Sunshine Village test site comparing SWE measurements from the CS725 (magenta), precipitation gauge (blue) and snow pillow (green) from October 25, 2008

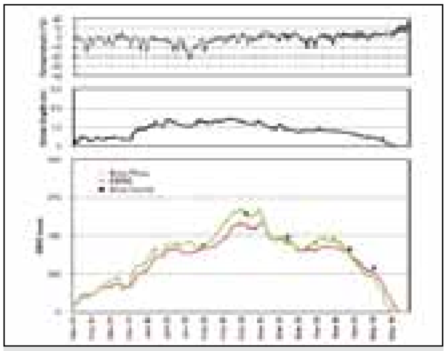

Figure 3: Anestølen test site comparing SWE measurements from the CS725 with collimator (magenta), CS725 without collimator (light blue), snow pillow (green) and snow core (black)