PERFORMANCE ANALYSIS OF GMON3 SNOW WATER EQUIVALENCY SENSOR

Matt Wright[1], Jeff Kavanaugh[1], Claude Labine[2]

ABSTRACT

This report evaluates the performance of the GMON3 Snow Water Equivalency (SWE) sensor developed by Hydro Québec in collaboration with Campbell Scientific Canada Corporation. The GMON3 determines SWE by measuring the attenuation by the snowpack of naturally emitted terrestrial gamma radiation from the soil. This provides a non-contact technique for determining SWE that is effective with any type of snow or ice cover and whose performance is not affected by adverse weather conditions. Field testing of the GMON3 was carried out at Sunshine Village, Alberta from 2008-2011 and at the SNOTEL Tony Grove Ranger Station, Utah from 2009-2010. The GMON3 values were compared to other sensors, which produce SWE either directly or indirectly: snow pillow, precipitation gauge, snow depth sensor, and manual SWE values from snow course measurements. Strong agreement is shown both qualitatively and quantitatively between all automated methods of SWE: GMON3, snow pillow, and precipitation gauge. Statistically, all automated methods show correlations of 0.99 over the entire season and up to peak periods. Monthly snow course measurements were found to be the least reliable method for measuring SWE. Analysis of the GMON3 suggests that it provides comparable, if not better, SWE accuracy to the snow pillow and precipitation gauge, while eliminating the disadvantages associated with both of these techniques.
(KEYWORDS: snow water equivalent, SWE, GMON3, snow pillow, precipitation gauge, snow course)

INTRODUCTION

With much of the freshwater in North America coming from snowmelt, the accurate assessment of a snowpack's snow water equivalent (SWE) is vital for water availability forecasting (Osterhuber et al., 1998), flood prediction and prevention (Laukkanen, 2004), and the management of water resources (Lungberg et al., 2010). The ideal ground-based snow measurement technique does not cause environmental harm and does not disturb the accumulation pattern by altering the wind field at the measurement site. It also does not influence the exchange of radiation, thermal heat, and water between the snow and the atmosphere and/or the ground (Lundberg et al., 2010). It is also ideal that SWE is measured on a daily basis in order to determine the day of the year that maximum value of SWE is reached (Vachon et al., 2010), a crucial parameter in hydrological models, as it determines the amount of water that will be released during spring runoff.

A number of ground-based techniques have been developed for the measurement of SWE. Of these, the main techniques include manual measurement of snow courses, snow pillows, and weighing precipitation gauges. However, several disadvantages are associated with each of these methods. Snow course measurements are labor intensive, time consuming, expensive, negate the possibility of around the clock data collection, and are also prone to human error (Pomeroy and Gray, 1995). Snow pillows must be installed before the first snowfall, have logistical and transportation issues around installation (Osterhuber et al., 1981), only measure a surface area of about 10 m^2, and are prone to errors in the form of bridging due to the formation of ice lenses (Osterhuber et al., 1998; Johnson and Schaefer 2002). Pillows may also have greater absorption of radiation, delaying accumulation in the fall, and during spring can block the temperature driven vapor flux at the soil snow interface and the meltwater transport into the soil. Weighing precipitation gauges experience a reduction in the catch efficiency of snowfall with increasing wind speeds (Rasmussen, 2010). Other measurement errors can result due to snow capping if the orifice diameter is not sufficiently large (Rasmussen, 2010). Although precipitation gauges provide a daily measure of SWE, they cannot provide the peak SWE. Also, both the snow pillow and precipitation gauge provide an environmental hazard, due to the potential leaks and spillage of antifreeze solution used by both sensors (Osterhuber et al., 1998).

The GMON3, developed by Hydro Québec in collaboration with Campbell Scientific Canada, is a gamma monitor that measures SWE and soil moisture. It measures the net natural terrestrial gamma radiation emitted by the soil after their absorption by the snowpack. The GMON3 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

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[1] Department of EAS, University of Alberta, mkwright@ualberta.ca, jeff.kavanaugh@ualberta.ca

[2] Chief Science Officer, Campbell Scientific Canada Corporation, claude.labine@campbellsci.ca

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 (^{40}K) and thallium (^{208}Tl) 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 absorption and energy degradation by the snow of the gamma rays emitted from the ground provides the measurement of SWE. In some cases a lead collimator is disposed at the bottom of the GMON3's aluminum cylinder wrapping the Na(Tl) crystal. The collimator has two main functions: the first is to partially shield the effects of the cosmic radiation and the second is to establish the observed ground surface (Martin et al., 2008).

The GMON3 provides a non-contact technique that measures SWE over a large surface area (50-100 m^2 when mounted 3 m above the ground) that is effective with any type of snow and ice whose performance is not affected by adverse weather conditions. However, the GMON3 is presently limited to a maximum range of about 600 mm of SWE and is dependent on suitable amount of terrestrial gamma radiation. It must also be calibrated under snow free conditions and requires that soil moisture be known at the time of freeze up.

METHODS

Field testing of the GMON3 was conducted at Sunshine Village, Alberta from 2008-2011 and at the SNOTEL Tony Grove Ranger Station, Utah from 2009-2010. At the Sunshine Village test site SWE measurements were compared between a GMON3, a Watersaver 10 ft diameter snow pillow, a Fisher Porter precipitation gauge, and monthly snow course measurements conducted by Alberta Environment personnel. Snow depth and air temperature were measured using a Campbell Scientific SR50AT. At the Tony Grove RS test site SWE measurements were compared between a GMON3, SNOTEL 10' hypalon snow pillow, and a 12" diameter weighing gauge. Snow depth was measured using a Judd Communications ultrasonic snow depth sensor. At both sites, measurements of all parameters of the automatic weather stations were collected using dataloggers, with an ethanol based antifreeze solution used to prevent the fluid of both the pillow and precipitation gauges from freezing.

Analysis of GMON3 performance was conducted by comparing the GMON3 to other sensors that produce a measurement for SWE either directly or indirectly: snow pillow, precipitation gauge, snow depth sensor, and manual snow course measurements. For the 2009-2010 season at Sunshine Village comparisons were also made between GMON3 measurements taken using a collimator and without a collimator. Seasonal graphs were used for qualitative comparison of GMON3 to other SWE measurement techniques. Statistical analysis was conducted using correlation and variance between the GMON3 and other methods of determining SWE over the entire field season and periods up to peak SWE. Correlations between two methods were calculated using linear regression. Variance was calculated using a method of least squares fit (Equation 1).

$$\sigma = \sqrt{\frac{1}{N-2}\sum_{i=1}^{N}[y_i - (A + Bx_i)]^2} \qquad \text{(Equation 1)}$$

RESULTS/DISCUSSION

When the GMON3 was compared to the snow pillow and precipitation gauge at both Sunshine Village and Tony Grove Ranger Station all methods demonstrate a strong agreement (Figure 1). Statistical comparisons of the three automated methods at both sites showed strong correlations (0.99) between the GMON3 and snow pillow and the GMON3 and precipitation gauge (Table 1). When compared the GMON3 with a collimator and GMON3 without a collimator were also found to show a strong agreement (0.98) as shown in Figure 1 and Table 1. However, the GMON3 without a collimator was found to slightly underestimate SWE during the melt period (Figure 1). Monthly snow course measurements of SWE showed weak agreement when compared to the three automated methods (Figure 1 and Table 1). Snow course measurements exhibited the largest variance of any method investigated (Table 1) and appear to be the least reliable method for measuring SWE, confirming the conclusions of Pomeroy and Gray (1995). Deviations between the different measurement techniques were observed for all seasons at both field sites. Although different hypothesis can be formed to explain these deviations, there is no way to determine the true causes without detailed snow surveys on a daily scale. This in reality is impossible, as it would result in destruction of the snowpack at the survey site.

Table 1. Variance (mm) and correlations between GMON3 and snow pillow, GMON3 and precipitation gauge, GMON3 with collimator and GMON3 without collimator, GMON3 and snow course, and snow pillow and snow course for entire season and up to peak periods for Sunshine Village (2008-2011) and Tony Grove Ranger Station (2009-2010). R^2 determined using linear regression, variance determined by least square fitting.

Variance (σ) - Correlation (R^2)		GMON-Snow Pillow		GMON-Precipitation Gauge		GMON-GMON		GMON-Snow Course		Snow Pillow-Snow Course	
		σ (mm)	R^2	σ (mm)	R^2	σ (mm)	R^2	σ (mm)	R^2	σ (mm)	R^2
Sunshine Village (2008-2009)	Season	10.1	0.99	-	-	-	-	-	-	-	-
	Peak	8.0	0.99	7.8	0.99	-	-	-	-	-	-
Sunshine Village (2009-2010)	Season	-	-	-	-	12.0	0.98	75.0	0.83	46.8	0.79
Sunshine Village (2010-2011)	Season	21.8	0.99	-	-	-	-	-	-	-	-
	Peak	20.4	0.99	19.0	0.99	-	-	-	-	-	-
SNOTEL: Tony Grove Ranger Station (2009-2010)	Season	10.5	0.99	-	-	-	-	-	-	-	-
	Peak	5.3	0.99	4.1	0.99	-	-	-	-	-	-

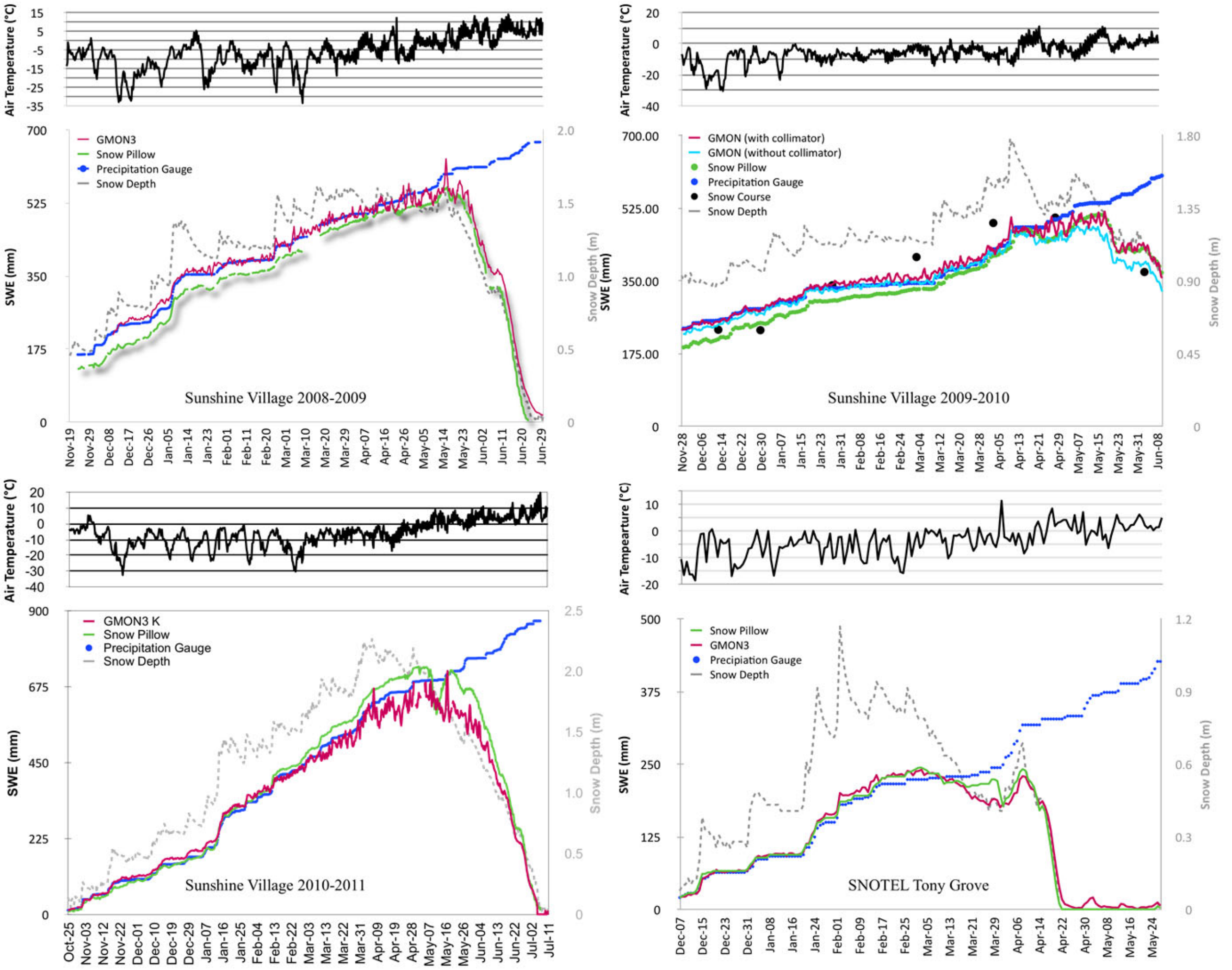
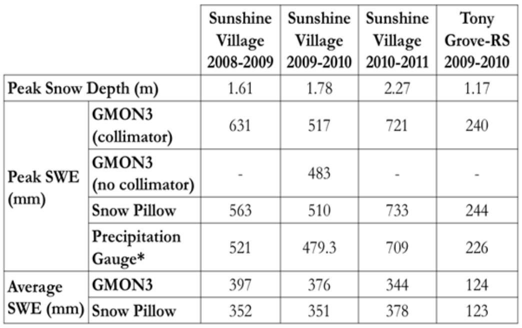


Figure 1. Sunshine Village (2008-2011) and SNOTEL Tony Grove RS test sites comparing SWE measurements (mm) from GMON3 with a collimator (magenta), GMON3 without a collimator (light blue)*, precipitation gauge (dotted blue), snow pillow (green), and snow course measurements (dotted black)*. Snow depth measurements (m), right (dashed grey), and air temperatures measurements (°C), above (black), are also shown for the corresponding time periods. *Only compared at Sunshine Village test site from 2009-2010.

GMON3 SWE measurements using a collimator demonstrated increased variability at snow depths greater than about 350 mm for all field seasons at Sunshine Village (Figure 1). This increased variability in the GMON3 SWE measurement can be explained by the greater possibility of noise caused by the decrease in the counts of potassium and thallium due to increased snow depth. Also, the incoming precipitation has some radiation, which can contribute to the already low counts thereby increasing the variability. However, when peak snow depths were compared for the three automated techniques (Table 2) the largest difference was a 12% larger SWE measured by the GMON3 than the snow pillow during the 2008-2009 season at Sunshine Village, which is in agreement with the manufacturer's published accuracy of ±15% between 300 to 600 mm SWE. Due to this and the qualitative and quantitative comparisons of the three techniques above, it is difficult to determine a significant difference between the three automated measurements. Therefore, at this level of agreement it can be argued that the GMON3 will perform at least as well, if not better, than the snow pillow and the precipitation gauge.

Table 2. Peak snow depth, peak SWE, and average SWE values for the Sunshine Village Station (2008-2011) and Tony Grove Ranger station (2009-2010). Peak SWE values were determined for GMON3, precipitation gauge, and snow pillow. Average SWE values were determined for the GMON3 and snow pillow. *Peak values for the precipitation gauge were determined by using the precipitation value that corresponded with peak SWE for the GMON3.



		Sunshine Village 2008-2009	Sunshine Village 2009-2010	Sunshine Village 2010-2011	Tony Grove-RS 2009-2010
Peak Snow Depth (m)		1.61	1.78	2.27	1.17
Peak SWE (mm)	GMON3 (collimator)	631	517	721	240
	GMON3 (no collimator)	-	483	-	-
	Snow Pillow	563	510	733	244
	Precipitation Gauge*	521	479.3	709	226
Average SWE (mm)	GMON3	397	376	344	124
	Snow Pillow	352	351	378	123

Due to the various errors associated with each measurement technique, there is no single ideal method for measuring SWE. Therefore, in most situations, the choice of which measurement technique to use 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 GMON3 can become cost effective compared to manual snow courses and other automated techniques. The GMON3 is unaffected by most of the disadvantages associated with snow courses, snow pillows and precipitation gauges described above, while adding some advantages not provided by the other techniques. These advantages along with these early but stable results of the GMON3 indicate it can be an effective solution to these long standing measurement challenges.

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