Performance Analysis of CS725 Snow Water Equivalent Sensor

Matt Wright
Campbell Scientific (Canada) Corp.

CAMPBELL SCIENTIFIC
WHEN MEASUREMENTS MATTER

Abstract

This poster continues the evaluation of the CS725 snow water equivalent (SWE) sensor as previously conducted by Wright et al. (2011). The CS725 was developed by Hydro Quebec in collaboration with Campbell Scientific Canada Corporation and determines SWE by passively measuring the attenuation of naturally emitted terrestrial gamma radiation from the soil by the snowpack. The CS725 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 CS725 was conducted at Sunshine Village, Alberta (2008-2011), SNOTEL Tony Grove Ranger Station, Utah (2009-2010), and Anestølen, Norway (2011-2012). The CS725 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: CS725, snow pillow, and precipitation gauge. Statistically, all automated methods show strong correlations of 0.96-0.99 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 CS725 suggests that it provides comparable, if not better, SWE accuracy to the snow pillow and precipitation gauge, while eliminating the disadvantages associated with these measurement techniques.

Introduction

With much of Canada's freshwater coming from snowmelt, the accurate assessment of a snowpack's snow water equivalent (SWE) is a vital first step in any water availability forecasting (Osterhuber et al., 1998).

Monitoring of SWE is vital for management of water resources for hydropower (Laukkanen, 2004), domestic use, and industrial extraction (Lundberg et al., 2010) and is essential for flood prediction and prevention (Laukkanen, 2004).

A number of ground-based techniques have been developed for the measurement of SWE:

- Manual Snow Course Measurements, snow pillows, radioactive attenuation, and acoustic sounding

The ideal ground-based snow measurement technique:

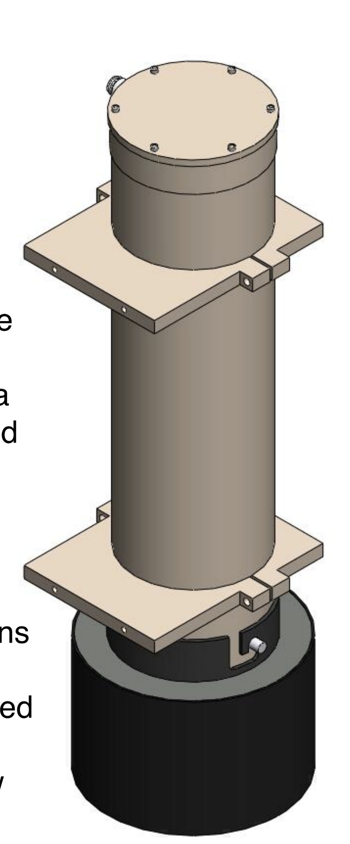
- Does not cause environmental harm, disturb the accumulation pattern by altering the wind field at the measurement site, or influence the exchange of radiation, thermal heat, and water between the snow and the atmosphere and/or ground (Lundberg et al., 2010)
- Monitors SWE on a daily basis to determine what day of the year peak SWE is reached

The CS725

A new SWE sensor developed by Hydro Québec in collaboration with Campbell Scientific (Canada) Corp. (Choquette et al., 2008).

The CS725 is a gamma monitor for snow water equivalent and soil moisture that passively measures the natural terrestrial gamma radiation emitted by the soil and their absorption by the snowpack.

The sensor element utilizes a thallium-doped sodium iodide crystal NaI(Tl) to measure naturally emitted terrestrial gamma radiation. It detects potassium and thallium gamma rays (the most abundant naturally emitted gamma rays) and places counts of each gamma ray detected in a histogram that is used to calculate SWE.



Main Advantages:

- Non-contact
- Performance is not effected by adverse weather conditions
- Effective with any type of ice or snow
- Can cover large surface area (50-100 m2*** when mounted 3 m above the ground)
- Can be post-calibrated if installed after the onset of snow
- Not effected by measurement errors due to bridging or wind
- The CS725 only monitors existing naturally occurring Gamma radiation (No Special licenses or precautions are required to install or operate the CS725)

Methods

- 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. At Sunshine Village(2009-2010) and Anestølen, Norway (2011-2012) monthly manual snow course measurements were also conducted.
- Analysis of CS725 performance was conducted by comparing the CS725 to other sensors that produce a measurement for SWE either directly of indirectly: snow pillow, precipitation gauge, and manual snow course measurements.
- Precipitation gauges installed above the ground collect falling snow in a bucket, which is melted in an antifreeze solution, thus providing a representative value for SWE (Rasmussen et al., 2010)
- Statistical analysis was conducted using correlation and variance between the CS725 and other methods of determining SWE for entire season, up to peak SWE, and monthly periods
  - Correlations between two methods were calculated using linear regression
  - Variance was calculated using a method of least squares fit
- Seeding experiments to increase the potassium counts measured by the CS725 were conducted by measuring background potassium counts inside of a building over a 24 hour period. 75 Kg potassium fertilizer (Sulfate of Potash) was then spread below the CS725 and the potassium counts were once again measured over a 24 hour period
- Testing was also conducted at Sunshine Village(2009-2010) and Anestølen, Norway (2011-2012) to compare results between using the CS725 with and without a collimator

Results

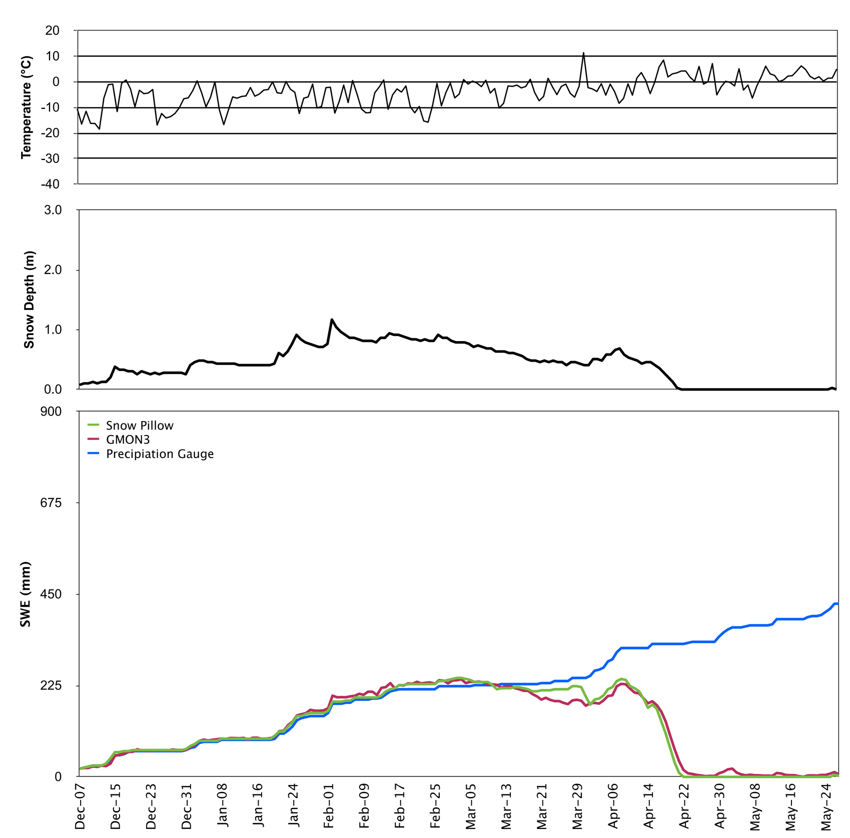


Figure 1: SNOTEL Tony Grove Ranger Station test site comparing SWE measurements (mm) from the CS725 (magenta), precipitation gauge (blue), and snow pillow (green) from December 7, 2009 to May 27, 2010. Snow depth measurements (m) and air temperature measurements (°C) above, are also shown for the same time period.

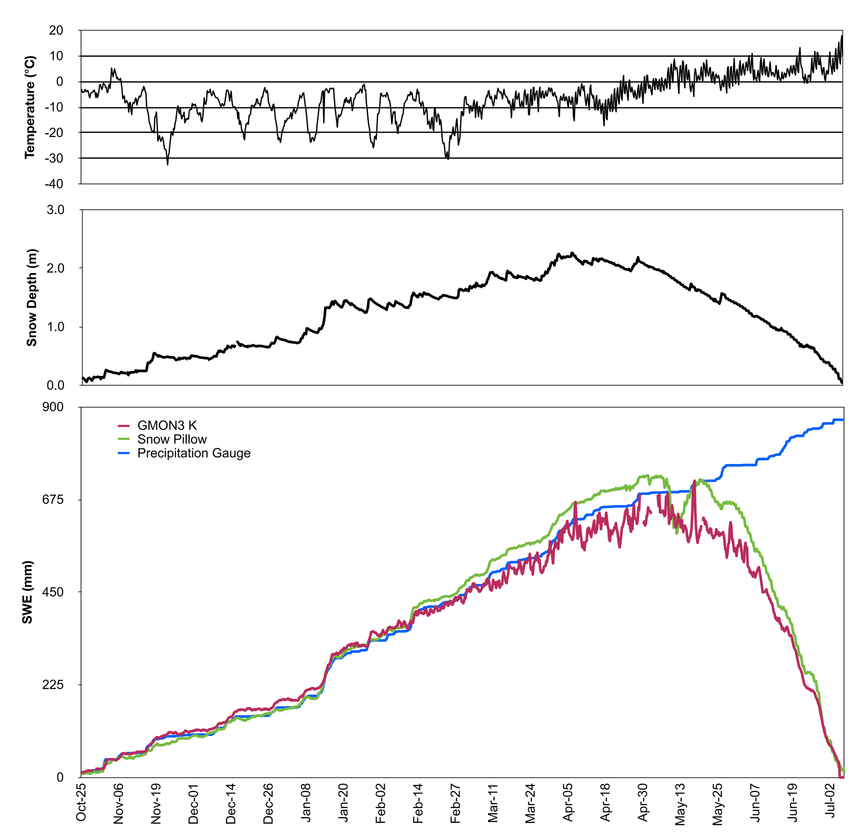


Figure 2: Sunshine Village test site comparing SWE measurements (mm) from CS725 (magenta), precipitation gauge (blue), and snow pillow (green) from November 19th 2008 to June 30th 2009. Snow depth measurements (m) and air temperature measurements (°C) above, are also shown for the same time period.

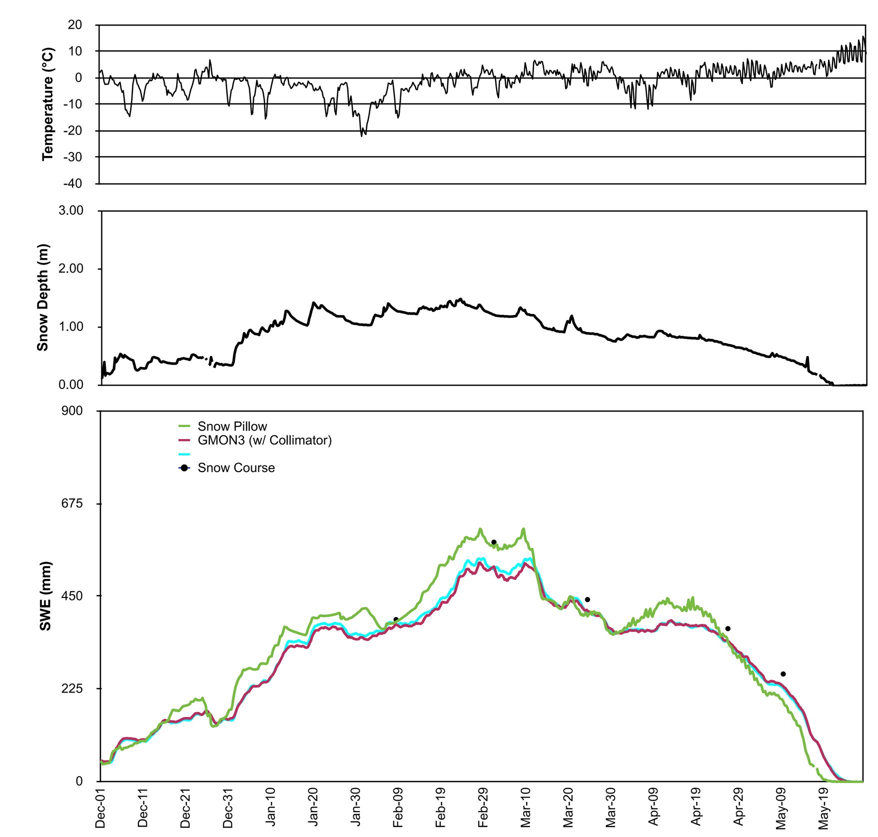


Figure 3: Anestølen, Norway test site comparing SWE measurements (mm) from the CS725 with a collimator (magenta), CS725 without a collimator (light blue), snow pillow (green) and snow course measurements (Black) from December 1, 2011 to May 28, 2012. Snow depth measurements (m) and air temperature measurements (°C) above, are also shown for the same time period.

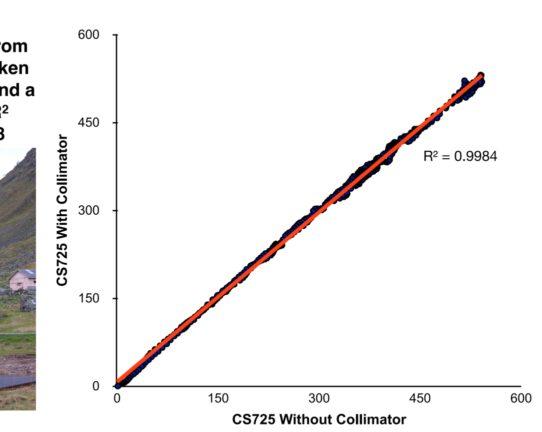
Table 1: Variance (mm) and correlations between CS725 and snow pillow, CS725 and precipitation gauge, CS725 with collimator and CS725 without collimator, CS725 and snow course, and snow pillow and snow course for entire season and up to peak periods for Sunshine Village (2008-2011), Tony Grove Ranger Station (2009-2010), and Anestølen, Norway (2011-2012). R^2 determined using linear regression, variance determined by least square fitting.

Variance (σ) - Correlation (R^2)		CS725-Snow Pillow		CS725-Precipitation Gauge		CS725-CS725		CS725-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	0.99	7.8	0.99	-	-	-	-	-	-
Sunshine Village (2009-2010)	Season	-	-	-	-	12	0.98	75	0.83	46.8	0.79
Sunshine Village (2010-2011)	Season	21.8	0.99	-	-	-	-	-	-	-	-
	Peak	20.4	0.99	19	0.99	-	-	-	-	-	-
SNOTEL: Tony Grove Ranger Station (2009-2010)	Season	10.5	0.99	-	-	-	-	-	-	-	-
	Peak	5.3	0.99	4.1	0.99	-	-	-	-	-	-
Anestølen, Norway (2011-2012)	Season	31.5	0.96	-	-	5.5	0.99	90.3	0.99	86.9	0.98
	Peak	20.8	0.98	-	-	3	0.99	-	-	-	-

Table 2: Peak snow depth (m), peak SWE (mm) and average SWE values for the Sunshine Village Station (2008-2011), SNOTEL Tony Grove Ranger station (2009-2010) and Anestølen, Norway (2011-2012). Peak SWE values were determined for CS725, precipitation gauge, and snow pillow. Average SWE values were determined for the CS725 and snow pillow. *Peak value for the precipitation gauge were determined by using the precipitation value that corresponded with peak SWE for the CS725. **Measurements for Sunshine Village 2010-2011 were taken up to March 28, 2011.

		Sunshine Village 2008-2009	Sunshine Village 2009-2010	Sunshine Village 2010-2011**	Tony Grove-RS 2009-2010	Anestølen, Norway (2011-2012)
Peak Snow Depth (m)		1.61	1.78	1.98	1.17	1.48
Peak SWE (mm)	CS725 (collimator)	631	517	546	240	531
	CS725 (no collimator)	–	483	–	–	542
	Snow Pillow	563	510	581	244	614
	Precipitation Gauge*	521	479.3	543	226	–
Average SWE (mm)	CS725	397	376	257	124	301
	Snow Pillow	352	351	259	123	323

Figure 4: Linear regression comparing SWE measurements from Anestølen, Norway (2011-2012) taken using a CS725 with a collimator and a CS725 without a collimator. The R^2 value shows a correlation of 0.998



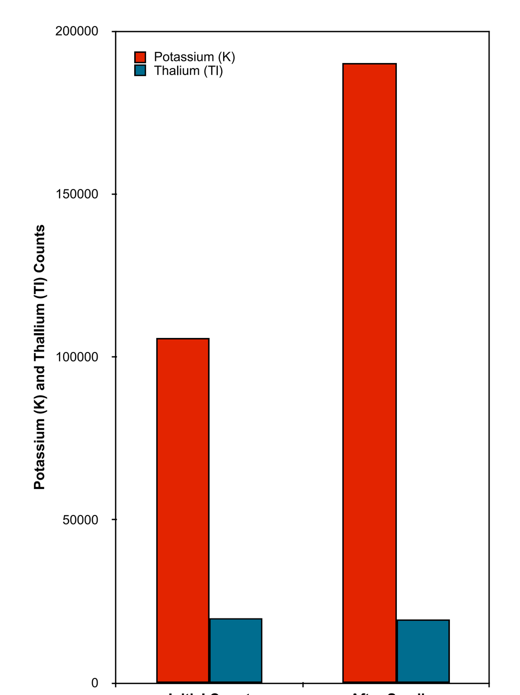


Figure 5: Seeding experiments using Potassium Fertilizer (Sulphate of Potash) comparing initial indoor potassium counts measured using the CS725 before seeding to potassium counts measured after seeding. When seeded with 75 kg of fertilizer potassium counts measured using the CS725 showed an increase of 80%.

Discussion/Conclusions

- There is no standard method to precisely measure SWE values of a snowpack.
- Assessment of SWE accuracy for a measurement technique must therefore be conducted by examining the errors associated with a particular technique and the scale of impact those errors have on the usage of the sensor.
- When the CS725 was compared to the snow pillow and precipitation gauge at all test sites all of the methods demonstrate strong agreement. However, deviations between the different measurement techniques were observed at all sites over all field seasons.
- Although many 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, which would result in destruction of the snow pack at the survey site.
- CS725 SWE measurements demonstrated increased variability at greater snow depths (1.2-1.5 m) for all field seasons (2008-2011) at Sunshine Village (Figure 2). However, this was not observed at the Tony Grove Ranger Station (Figure 1) and Anestølen, Norway (Figure 3) likely due to the lower maximum snow depths at each test site.
- This increased variability in the CS725 SWE measurement may be explained by a decrease in potassium counts as the 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 precipitations gauge (Table 1).
- Comparison of SWE measurements using a CS725 with and without a collimator in Anestølen, Norway (Figure 4) show a very strong correlation (0.99) suggesting that in open sites with a uniform snow pack and no trees present the CS725 can be used without a collimator.
- When peak snow depths were compared for the three automated techniques the difference in peak SWE was found to be small (Table 2).
- Due to this and the comparisons of the three techniques above it is difficult to determine a significant difference between the measurement techniques. Therefore, at this level of agreement it can be argued that the CS725 will perform at least as well, if not better, than the snow pillow and the precipitation gauge.
- However, the disadvantages of monthly snow course measurements, snow pillows and precipitation gauges must be also taken into account:
  - Snow Course measurements are labour intensive, time consuming, expensive, negate the possibility of around the clock data collection (Pomeroy and Gray, 1995), and are prone to human error (Hulstrand, 2003).
  - Snow pillows must be installed prior to the first snowfall, have logistical and transport issues (Osterhuber et al., 1998), measurement can also be prone to errors in the form of bridging due to the formation of ice lenses (Hulstrand, 2003; Osterhuber et al., 1998; Johnson and Schaefer 2002), and dark pillows often absorb more energy than the surrounding area delaying accumulation in the fall.
  - Precipitation gauges experience a reduction in catch efficiency of snowfall with increasing wind speeds (Rasmussen, 2010) and do not provide a peak SWE value crucial for hydrological models.
  - Both the snow pillow and precipitation gauge provide an environmental hazard, due to the potential leaks of antifreeze solution used by both sensors (Osterhuber et al., 1998).
- Seeding experiments (Figure 5) conducted using potassium fertilizer show potential for increasing potassium counts measured by the CS725 at sites where low counts are found. However, significant future development and testing is still required to validate these results and put this theory into practice.

References

1) Arnell NW. 1999. Climate Change and global water resources. *Global Environmental Change* **9**: S31-S49.

2) Bland WL, Helmke PA, Baker JM. 1997. High-resolution snow-water equivalent measurement by gamma-ray spectroscopy. *Agricultural and Forest Meteorology* **83**: 27–36.

3)Choquette Y., Lavigne P., Nadeau M, Ducharme P, Martin J.P., Houdayer A., Rogoza J. 2008. GMON, a New Sensor for Snow Water Equivalent Via Gamma Monitoring. *Proceedings of the 2008 International Snow Science Workshop, Whistler, B.C..*

4) Derksen CR, Walker BA, Brasnett B. 2002. Comparison of model, snow course, and passive microwave derived snow water equivalency data for Western North America. *Proceedings of the 59th Annual Meeting of the Eastern Snow Conference*. Stowe, Vermont.

5) Goodison BE, Metcalfe JR, Wilson RA, Jones KH. 1988. The Canadian automatic snow depth sensor: a performance update. *Proceeding of the 56th Western Snow Conference*. Kalispell, Montana, US, April 19–21.

6) Goodison BE, Wilson B, We K, Metcalfe JR. 1984. An inexpensive remote snow depth gauge: an assessment. Proceeding of *The 52th Western Snow Conference*. Sun Valley, Idaho, April 17–19, 1984.

7) Gray DM, Male DH. 1981. Handbook of Snow. Principles, Processes, Management and Use. Pergamon Press: Toronto/Oxford/New York/Sydney/Paris/Frankfurt; 776.

8) Gubler H. 1981. An inexpensive remote snow-depth gauge based on ultrasonic wave reflection from the snow surface. *Journal of Glaciology* **27**: 157–163.

9) Hultstrand DM. 2003. Snow Water Equivalent (SWE): Progression of Snowpack SWE measurements and the Use of a GIS Environment for Spatial Analysis. *Course NR505: Concepts in GIS*. http://warnercnr.colostate.edu/~dmhultst/Lit_Review/Lit_Review2.pdf [Accessed 2010].

10) Johnson JB, Schaefer GL. 2002. The influence of thermal, hydrologic and snow deformation mechanisms on snow water equivalent pressure sensor accuracy. *Hydrological Processes* **16**: 3529–3542.

11) Jonas T, Marty C, Magnusson J. 2009. Estimating the snow water equivalent from snow depth measurements in the Swiss Alps. *Journal of Hydrology* **378**: 161-167.

12) Kinar N, Pomeroy JW. 2007. Acoustic sounding of snow water equivalent. *Hydrological Processes* **21**: 2623–2640.

13) Laukkanen A. 2004. *Short term inflow forecasting in the Nordic power market*. Master thesis, Physics and Mathematics, Helsinki University of Technology, Helsinki. http://www.sal.hut.fi/Publications/pdf-files/tlau04.pdf. [Accessed 2011].

14) Lundberg A, Granlund N, Gustafsson D. 2010. Towards automated 'Ground Truth' snow measurements- a review of operational and new measurement methods for Sweden, Norway, Finland. *Hydrological Processes* **24:** 1995-1970.

15) Osterhuber R, Fehrke F, Condreva K. 1998. Snowpack snow water equivalent measurement using the attenuation of cosmic gamma radiation. *Proceeding of The Western Snow Conference*. Snowbird, UT, US, April 1998.

16) Paul PR, Ramana LV, Sankar ES. 1994. Estimation of basin Snow water equivalent (SWE) using accumulation and depletion patterns of Snowcover from optical satellite Data. *GIS Development*. http://www.a-a-r-s.org/acrs/proceeding/ACRS1994/Papers/WR94-5.htm [Accessed 2011].

17) Percy DR. 2005. Responding to Water Scarcity in Western Canada. *Texas Law Review* **83**: 2091-2107.

18) Pomeroy J, Gray D. 1995. Snow cover. *Accumulation, Relocation and Management*. NHRI Science Report 7; NHRI: University of Saskatchewan, Canada; 134 pp.

19) Rasmussen R, Baker B, Kochendorfer J, Myers T, Landolt S, Fischer A, Black J, Theriault J, Kucera P, Gochis D, Smith C, Nitu R, Hall M, Cristanelli S, Gutmann E. 2010. The NOAA/FAA/NCAR Winter Precipitation Test Bed: How well are we measuring snow? Proceedings of *Comming for Instruments and Methods of Observation (CIMO)-(TECO)*. Helsinki, Finland August 30- September 1, 2010.

20) Wright M, Kavanaugh K, Labine C. 2011. Performance Analysis of the GMON3 Snow Water Equivalency Sensor. *Proceeding of The Western Snow Conference*. Stateline, NV, US, April 2011.

21) Vachon F, Giota K, De Seve D, Royer A. 2010. Inversion of a Snow Emission Model Calibrated with *In Situ* Data for Snow Water Equivalent Monitoring. *IEEE Transactions on Geoscience and Remote Sensing* **48**(1): 59-71.