Calibration of cosmic ray sensors for the measurement of snow water equivalent

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Introduction

Snow data is implemented by groups ranging from local residents, small- and large-scale businesses, and all levels of government. As such, it is vital that this data is as accurate as possible. The issue is that modern day measurement approaches are rooted almost entirely in point-scale techniques such as snow pillows and are not representative of an area, or extremely large-scale methods such as remote sensing which are subject to discrepancies related to sizable resolutions as well as cloud and canopy cover. An approach to measure snow at an intermediate scale that is representative of an area and not impacted by natural conditions is necessary to fulfill this intricacy.

In the past few years, modern approaches such as Unmanned Aerial Systems have seen some success measuring snow at a landscape scale, but issues such as continuous measurements, dependency on weather, and the physical need for the user to be at the site remain unresolved.

This research explores the potential of using cosmic rays sensors to accurately and continuously measure snow water equivalent with minimal concern from environmental or topographic variables.

Study Sites

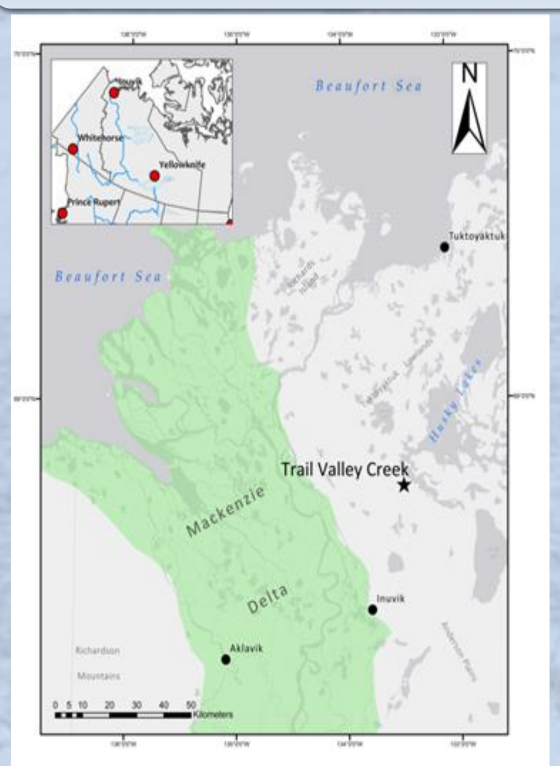

Figure 1. Trail Valley research station

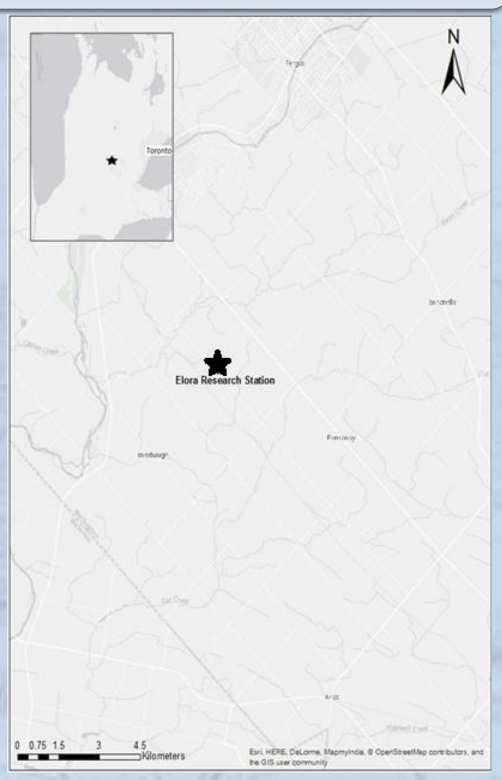

Figure 2. Elora research station

Research focus is set on three sites. Two sites are ~300m apart and are found 50 km north of Inuvik at Trail Valley Creek. One site is characterized by a large shrub patch while the other is characteristic of a tundra landscape.

The third site is found 20 km northeast of Waterloo and is an open rural area with some heterogeneity in the soil, slope, and vegetation.

Objectives

- To test the accuracy of two types of cosmic ray sensors.
- To measure snow water equivalent at an intermediate scale using the 1000-B CRS.
- To measure deep snowpack's using the SnowFox CRS.
- To validate the CRS values with manually observed values.

Methods

- Acquire neutron counts measured by the sensors via an online portal.
- Calibrate for atmospheric water vapour, barometric pressure, and incoming temporal cosmic ray flux.
- Scale for site (adjust for latitude, longitude, elevation).
- Account for statistical noise.
- Validate results by conducting manual snow surveys.

Results

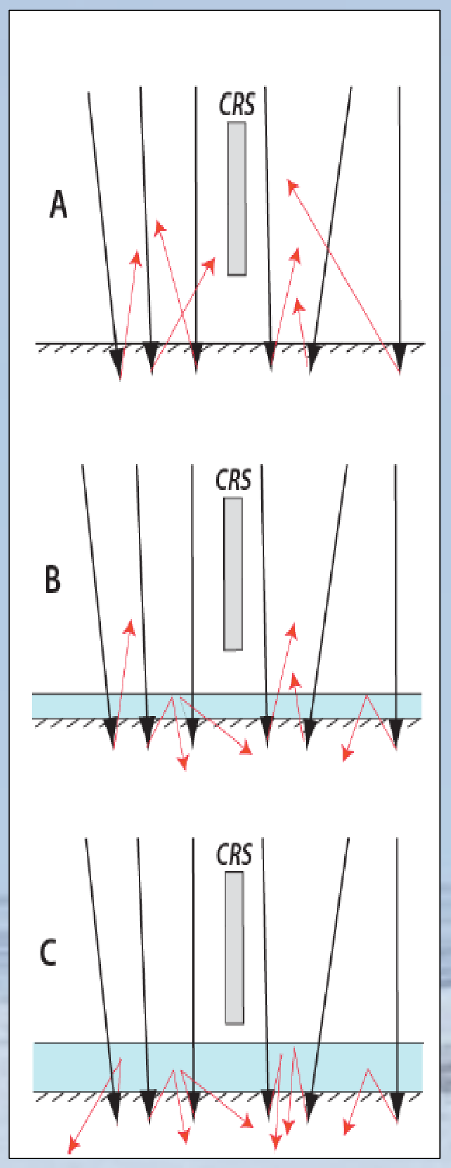

Figure 3. Influence of SWE on cosmic ray neutrons: (A) many neutrons produced in ground escape to atmosphere; (B) some are blocked by snow; and (C) nearly all are blocked by snow. (Desilets et al., 2010)

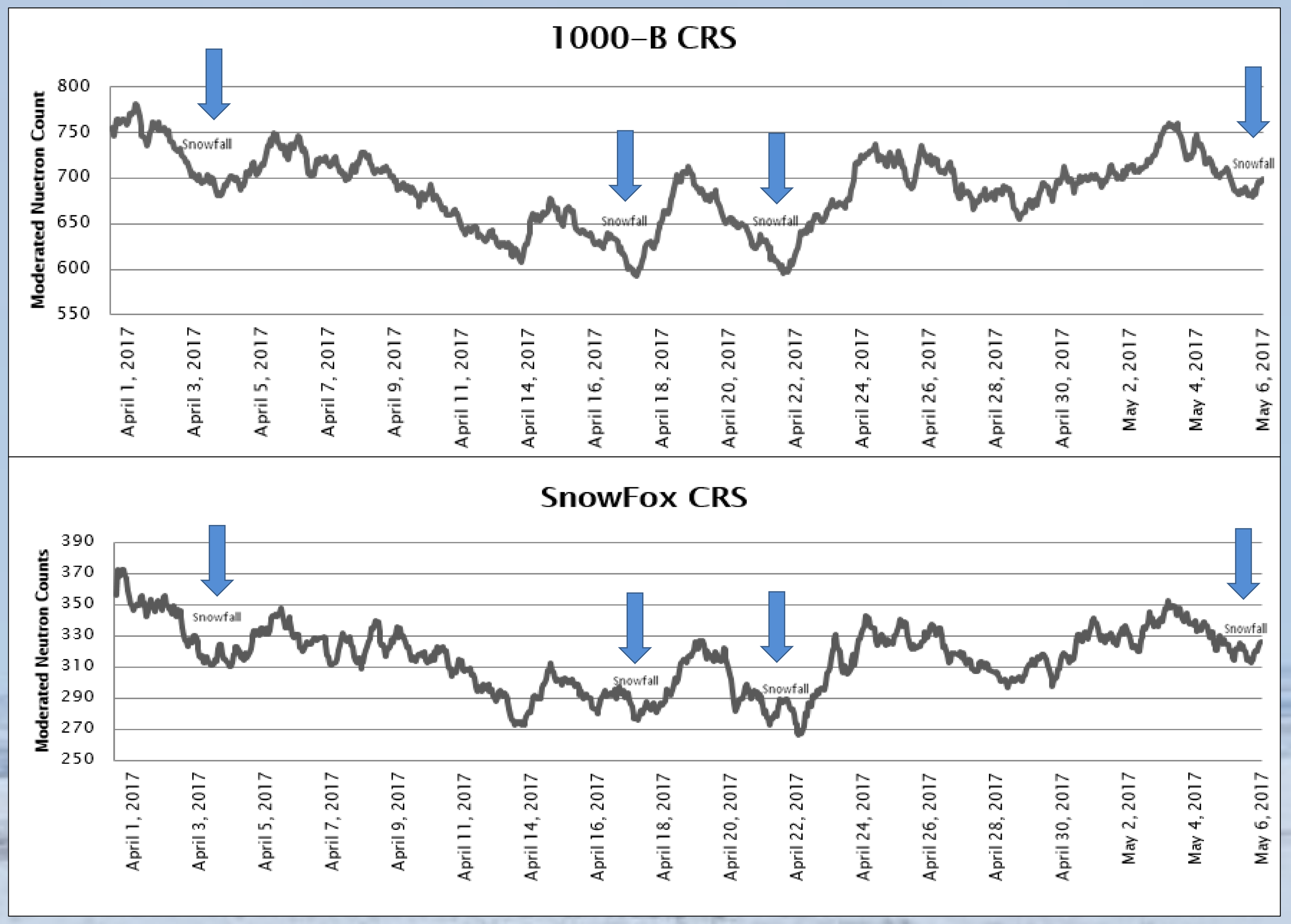

Figure 4. During precipitation events (when SWE increases) the moderated neutron count experiences a rapid decline in both the CRS 1000-B (top) and the SnowFox (bottom). A natural rebound then occurs. Both types of CRS are at nearby sites, ~300m apart.

SWE ↑, Neutron Count ↓

TVC - SnowFox

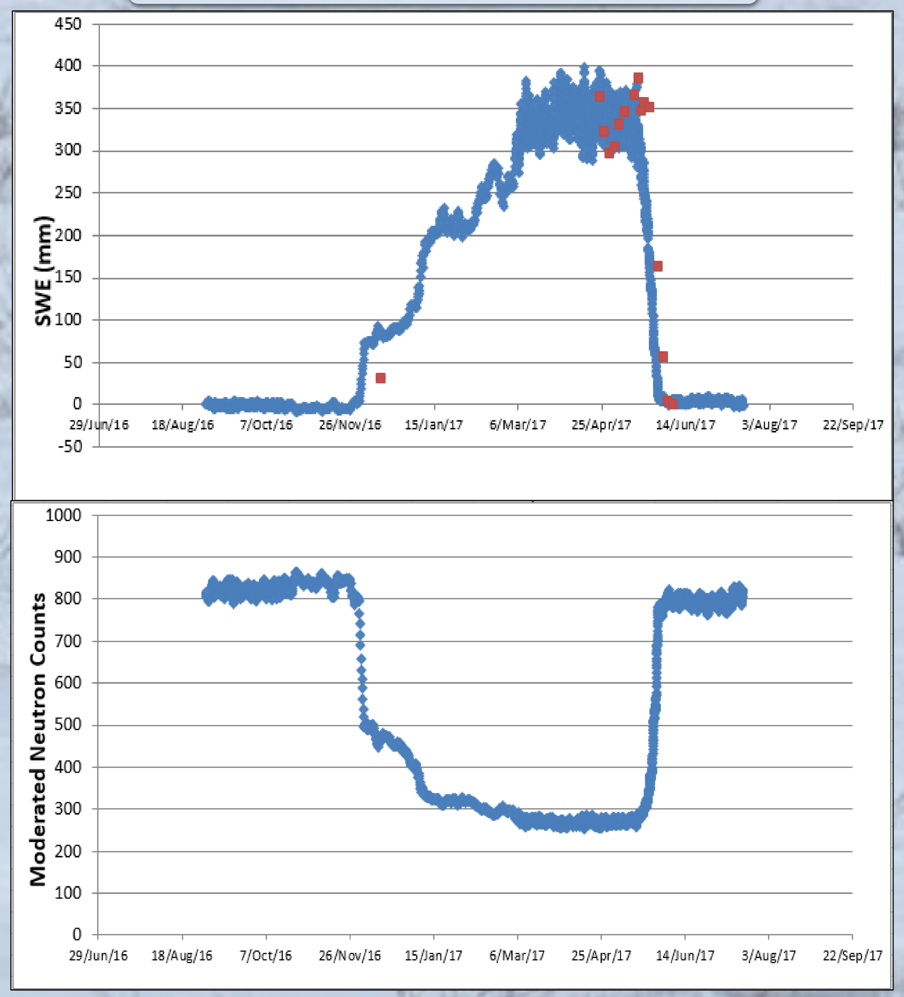

Figure 5. SnowFox at a deep shrub patch in Trail Valley Creek. Blue line represents the CRS calculated SWE, red dots are manual snow survey measurements. As SWE increases (top), moderated neutron counts decrease (bottom).

Elora - SnowFox

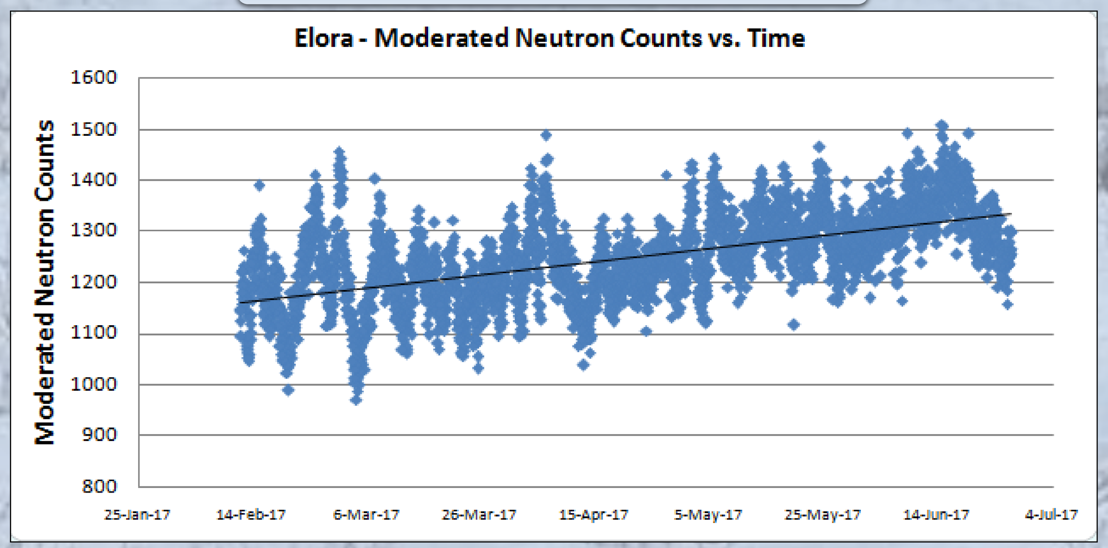

Figure 6. SnowFox at a rural field in Elora. As SWE decreases, moderated neutron counts increase (indicated by the trend line).

Elora - SnowFox

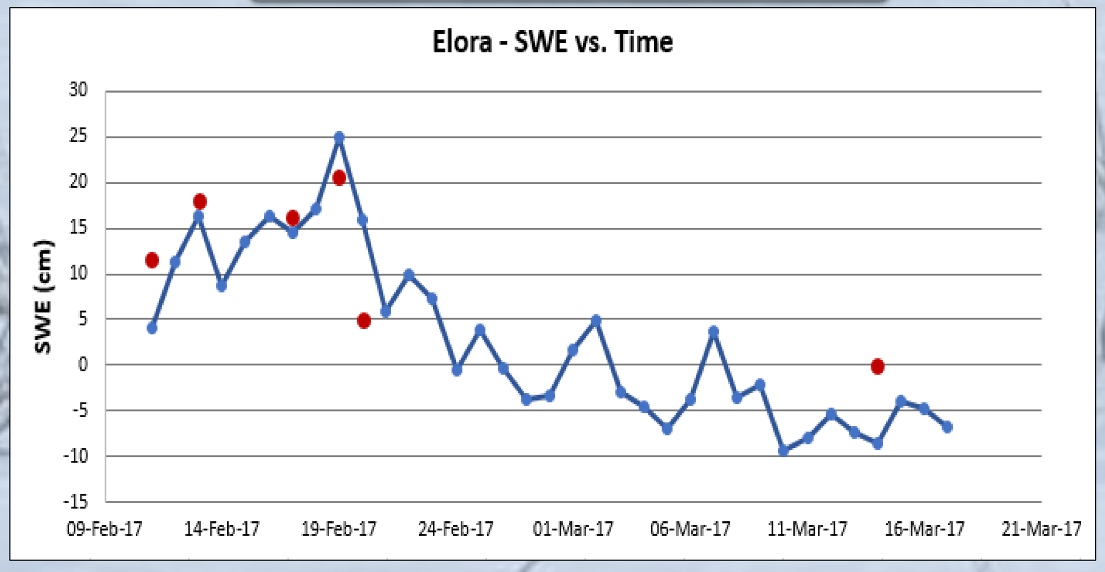

Figure 7. SnowFox results at the Elora site representing end of winter SWE, Feb 11 to March 14. Blue line represents the CRS calculated SWE, red dots are manual snow survey measurements.

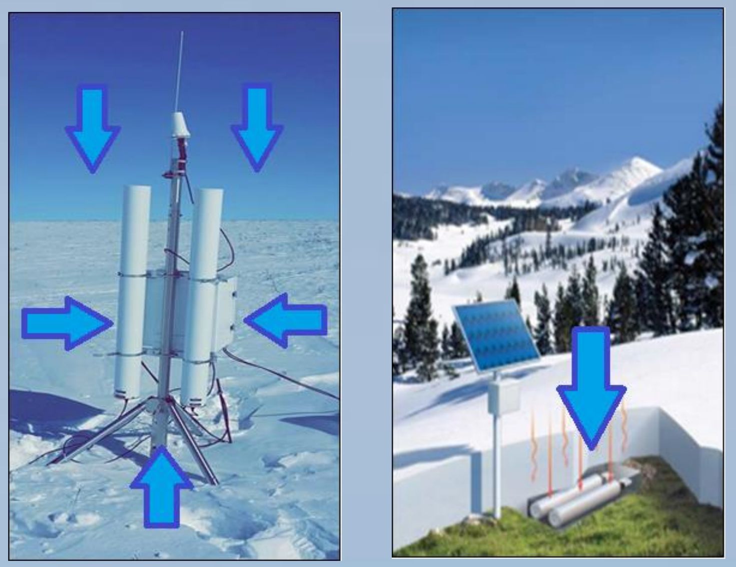

Figure 8. Cosmic ray sensor 1000-B (left). Cosmic ray sensor SnowFox (right) (Hydroinnova, NM, USA). Blue arrows represent incoming secondary cosmic rays.

Discussion

Unlike other studies, this research takes place at sites located in the Arctic and therefore possesses a unique set of environmental and topographic characteristics. In addition, this study uses a rural site that is easily accessible allowing the results between sites to be compared.

The maximum calculated SWE depth in this research is found to be ~38 cm in a deep shrub patch while a study by Schattan et al. (2017) was able to measure SWE up to 60 cm in the Austrian Alps. Earlier works calculated SWE to be between 7 and 12 cm (Desilets et al., 2010; Siguoin and Si, 2016). Other studies using the cosmic ray sensors are almost exclusively related to soil moisture measurements (Zreda et al., 2008; Chrisman and Zreda, 2013; Coopersmith et al., 2014; Wrona, 2016). Wrona (2016) is the only other study set in the Arctic, however, her soil moisture measurement results were inconclusive. Chrisman and Zreda (2013) used the 1000-B model in an attempt to measure soil moisture at a landscape scale in a moving vehicle, however, due to an extremely short pre-set time interval the results were flawed and soil moisture measurements were inconclusive.

Preliminary results indicate that both types of cosmic ray sensors are sensitive to SWE and exhibit the expected trends. Currently, due to the unique characteristics of the Trail Valley Creek sites, reformulations are necessary to the calibration equation in order to account for an extremely porous, organic, and high water content soil. Interestingly, this type of soil corresponds closer with standard glacier parameters than it does to a standard silica-type soil in the calibration formulation.

This approach allows for the continuous & remote monitoring of SWE on an intermediate scale and in deep snow packs.

Acknowledgements

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