TESTING AND COMPARING A NEW 1.4 GHZ COAXIAL SENSOR FOR LIQUID WATER CONTENT IN SNOW

Jean-Benoit Madore[1,*], Alex Mavrovic[1,1], Alexandre Langlois[1,2], Jacob Laliberté[1,2], Alain Royer[1,2]

[1] *Groupe de Recherhce Interdicsiplinaire sur les Milieux Polaires, GRIMP, Université de Sherbrooke, Sherbrooke, Qc, Canada*
[2] *Centre d'Étude Nordique, CEN, Québec, Qc, Canada*

ABSTRACT: Liquid water in snow is an important metric for the evaluation of the snowpack physical processes. The percolation of water from rain and melt can lead to instability through the additional weight of wet snow and the creation of ice layers/crusts. Numerous studies have established various ways to measure snow liquid water content (LWC) using microwave devices. Modern microwave sensors used for snow properties evaluation have wavelengths below L-band (1-2 GHz) and this study focuses on a new approach for LWC evaluation using a coaxial sensor at 1.4 GHz. A sensor initially developed in our group for tree and soil humidity is applied to snow LWC measurement. Calorimetric measurements of different snow types and a wide range of LWC were conducted in order to calibrate the device under controlled conditions. A field campaign took place in April-May 2018 at Glacier National Park, Canada, in the province of British Columbia under a high spring percolation environment. Multiple LWC measurement devices were compared to calorimetric field measurements. The results of the campaign are expected to be a comparison of different LWC devices performance and the development of a new instrument at 1.4 GHz.

Keywords: LWC, Microwave measurement, Water percolation, Instruments comparison

1. INTRODUCTION

Evaluation of the snow properties and state with precision has been constantly improved throughout the years. During the last decades, various devices were developed and tested to allow field observers and researchers to get fast and reliable data on snow structure and physical properties. More recently, remote sensing of the snowpack via fixed microwave devices has been put forward to evaluate the water liquid content (LWC), the snow water equivalent and state of the snowpack (e.g. Pérez Diaz et al. 2017, Schmid et al. 2016, Mitterer et al. 2011). With the recent integration of new percolation schemes in multi-layered snow model (Wever et al. 2014, D'Amboise et al. 2017) and the evaluations of modeled preferential flow (Wever et al. 2016) , precise measurements of the vertical variability and accumulation of LWC are needed for a validation and model implantation.

Instruments for the measurement of the vertical variability of LWC on the field has been developed since the 80's. Those instruments measure the dielectric component of the snow at various wavelengths between 0.1 GHZ to 1 GHZ. The Finnish snowfork (Sihvola and Tiuri, 1986) and the Denoth instrument (Denoth, 1994) are the devices commonly used for LWC measurements. Techel and Pielmeier (2011) made extended measurements with those instrument and showed a good correspondence (1%) between the two instruments. Nevertheless, developing new instruments and ways to measure LWC is crucial to increase the quality and amount of validating data available for models. A new 1.4 GHz sensor was developed by our group (Mavrovic et al. 2018) to measure the dielectric component of vegetation. This sensor was tested during a 2018 spring campaign in Glacier National Park (GNP), BC, Canada.

2. METHODOLOGY

2.1. Study sites

GNP is affected by 136 avalanche paths (Schleiss, 1990) and has been subjected to avalanche control from artillery since 1962. The transitional climate present there promote significant amount of snowfall. The annual average snowfall is around 13m at 1905m of altitude (Schweizer et al. 1998). Two main study plots are being exploited by the park avalanche safety group to evaluate snow structure and stability assessment. Those sites are equipped with meteorological instruments and the snow there is protected from any disturbances. One site is at the Roger's Pass compound at 1300m of altitude below treeline. This site is at the highest point of altitude of the highway crossing the park. The sec-

*Corresponding author address:
Jean-Benoit Madore, Université de Sherbrooke
2500 Boulevard de l'Université,
Sherbrooke, QC, Canada J1K 2R1
tel: 819-821-8000 62506
email: jean-benoit.madore@usherbrooke.ca

ond site is situated at the Fidelity study plot on Fidelity mountain at 1905m of altitude at treeline. The LWC measurement were performed on both sites between the 26th of April and the 2nd of May. Both sites had different state of snowpack. The Roger's Pass snowpack was isothermal and had a snow height of 144cm. The snowpack at Fidelity had a total height of 320cm and the presence of LWC was observed on the first meter and a half.

2.2. Coaxial probe description

The coaxial probe consisted of two coaxial conductivity cylinder of 65mm in length, the small one was 16.2 mm radius and the big one 30 mm. Those cylinders were separated by a dielectric material, polytetrafluoroethylene (PTFE) of 11.2mm thickness (see Figure 1) (Mavrovic et al. 2018). The probe was custom made (Atelier Pedro, Sherbrooke, QC, Canada) following Filali et al. (2006, 2008). The probe size was design to fit the L-band spectrum centered at 1.4GHz. The signal received by the probe is measured via a Planar R54 reflectometer attached with a coaxial cable. The measurement was displayed and recorded via a field computer. The instrument was calibrated before each set of measurement (i.e. one time before doing the vertical profile of the snow) with saline solutions that had known permittivity values. To make a measurement, the probe must be placed on a perfectly flat snow surface that has been freshly cut and thus not affected by the outside conditions. The measurement is almost instantaneous, the longest step being recording the readings on the computer.

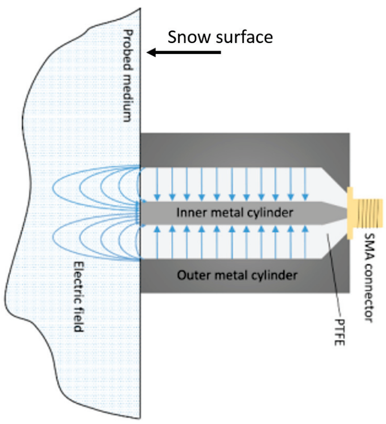

Figure 1: Transversal cut of the head of the coaxial probe taking a measurement

2.3. LWC Measurements

Two other LWC measurements were made at each site. First, melting calorimetric measurements were made. To perform this measurement, hot water of a known mass M_1 (g) and temperature T_1 (℃) was pour into a thermal insulated container. Then a sample of wet snow of mass M_2 (g) and temperature T_2 (℃) were mixed to the hot water until equilibrium temperature was achieved. Assuming heat loss was null, we can then use:

$$cM_1(T_1 - T_2) = cM_2T_2 + LI \qquad (1)$$

where c is the specific heat of water (4.18 J/gK), L is the latent heat of the melting of ice (333.6 J/g) and I is the Ice mass (g)(Akitaya, 1985). We can express LWC(%) with:

$$LWC = (1 - \frac{L}{M})x100 = 100 - \frac{1.25(M_1(T_1 - T_2) - M_2T_2)}{M_2}. \qquad (2)$$

The second serie of measurements was made with the Finnish snowfork (Sihvola and Tiuri, 1986). This device measures both parts of the permittivity and calculates the density directly to make LWC measures at 2cm vertical resolution. Measurements with this device were made every 3 cm.

3. PRILIMINARY AND EXPECTED RESULTS

Results from the field campaign look promising. Though density was calculated automatically by the snowfork, LWC from this device will be recalculated with in situ density measurements. At this point, the permettivities measured by the coaxial sensor have yet to be transposed to LWC. Nevertheless, first sights at the measurements indicate good potential for LWC retrieval.

ACKNOWLEDGEMENT

This work was funded with the Natural Sciences and Engineering Research Council of Canada (NSERC), the Canadian Founation for Innovation (CFI) and the Centre d'études nordiques (CEN). The authors would like to acknowledge significant contributions from Jeff Goodrich and the Glacier National Park avalanche safety for field support.

REFERENCES

Akitaya, E. (1985). A calorimeter for measuring free water content of wet snow. *Annals of Glaciology*, (4):246–247.

D'Amboise, C. J. L., Müller, K., Oxarango, L., Morin, S., and Schuler, T. V. (2017). Implementation of a physically based water percolation routine in the Crocus (V7) snowpack model. *Geoscientific Model Development Discussions*, pages 1–32.

Denoth, A. (1994). An electronic device for long-term snow wetness recording. *Annals of Glaciology*, 19:104–106.

Filali, B., Boone, F., Rhazi, J., and Ballivy, G. (2008). Design and calibration of a large open-ended coaxial probe for the measurement of the dielectric properties of concrete. *IEEE Transactions on Microwave Theory and Techniques*.

Filali, B., Rhazi, J.-E., and Ballivy, G. (2006). Mesure des propriétés diélectriques du béton par une large sonde coaxiale à terminaison ouverte. *Canadian Journal of Physics*, 84(5):365–379.

Mavrovic, A., Roy, A., Royer, A., Filali, B., Boone, F., Pappas, C., and Sonnentag, O. (2018). Dielectric characterization of vegetation at L band using an open-ended coaxial probe. *Geoscientific Instrumentation, Methods and Data Systems*, 7(3):195–208.

Mitterer, C., Hirashima, H., and Schweizer, J. (2011). Wet-snow instabilities: Comparison of measured and modelled liquid water content and snow stratigraphy. *Annals of Glaciology*, 52(58):201–208.

Pérez Díaz, C. L., Muñoz, J., Lakhankar, T., Khanbilvardi, R., and Romanov, P. (2017). Proof of concept: Development of snow liquid water content profiler using CS650 reflectometers at Caribou, ME, USA. *Sensors (Switzerland)*, 17(3).

Schleiss, V. (1990). Rogers Pass Snow Avalanche Control - A Summary, Glacier National Park, British Clumbia, Canada. Technical report, Canadian Parks Service, Revelstoke, B.C.

Schmid, L., Schweizer, J., Bradford, J., and Maurer, H. (2016). A synthetic study to assess the applicability of full-waveform inversion to infer snow stratigraphy from upward-looking ground-penetrating radar data. *Geophysics*, 81(1):WA213–WA223.

Schweizer, J., Jamieson, B., and David, S. (1998). Avalanche forecasting for transportation corridor and backcountry in Glacier National Park (BC, Canada). *25 Years of Snow Avalanche Research*, 203:238–244.

Sihvola, A. and Tiuri, M. (1986). Snow Fork for Field Determination of the Density and Wetness Profiles of a Snow Pack. *IEEE Transactions on Geoscience and Remote Sensing*, GE-24(5):717–721.

Techel, F. and Pielmeier, C. (2011). Point observations of liquid water content in wet snow – Investigating methodical, spatial and temporal aspects. *Cryosphere*, 5(2):405–418.

Tiuri, M., Sihvola, A., Nyfors, E., and Hallikaiken, M. (1984). The complex dielectric constant of snow at microwave frequencies. *IEEE Journal of Oceanic Engineering*, 9(5):377–382.

Wever, N., Fierz, C., Mitterer, C., Hirashima, H., and Lehning, M. (2014). Solving Richards Equation for snow improves snowpack meltwater runoff estimations in detailed multi-layer snowpack model. *Cryosphere*, 8(1):257–274.

Wever, N., Würzer, S., Fierz, C., and Lehning, M. (2016). Simulating ice layer formation under the presence of preferential flow in layered snowpacks. *The Cryosphere Discussions*, (August):1–24.