

## Comment on tc-2021-163

Charles Fierz, SLF, Davos (Referee)

Referee comment on "Review article: Performance assessment of electromagnetic wave-based field sensors for SWE monitoring" by Alain Royer et al., The Cryosphere Discuss., <https://doi.org/10.5194/tc-2021-163-RC2>, 2021

### Comments from the reviewer in blue

Answer in black

*Text added in black and italic*

#### General comments

This paper presents an assessment of methods to measure autonomously and continuously the water equivalent of snow cover. The presented data (one winter each on two sites) are augmented by a wealth of already published data, including own ones. This allows for a thorough analysis of pros and cons of these instruments that are increasingly used worldwide. Furthermore, an emerging, truly low-cost method based on FMCW radar is presented. These two last points form the major strength of the paper while I cannot really call it a 'review'.

Thank you for your comments. This paper first includes a review of all field sensors based on radiation measurements, and then, a large part of the analysis is based on a review of their performance with a comparison between them. We combine in this analysis our own measurements to complement the comparison. Our manuscript thus meets the requirements for a "review paper".

On the other hand, it is sometimes difficult to find out whether the authors speak about their own data or data taken from the literature. This ambiguity is one of the major drawback of this contribution, that also reflects itself in a poor structure of Section 3 (see comments below).

Section 3 has been restructured and the distinction between the literature review and our own experiences has been clarified. See also answer below

Another major problem is the 'classification' of the Cosmic Ray Neutron Probe as an 'electromagnetic wave-based field sensor'. With that respect the authors are required to make necessary corrections throughout the text.

Yes, you right, this is a mistake. Cosmic radiation consists of high-energy charged particles flux, particles that have a mass! They thus cannot be classified as EM. We thus modified the text where appropriate to use the term "radiation-based field sensor" (see further as well).

Furthermore, the author should eliminate quite a number of weaknesses I address below and in the manuscript. This to make the paper less ambiguous and easier to read, thereby increasing its value for the community.

The modifications suggested by the authors were made.

In summary I recommend accepting the paper after the authors addressed the issues below and consider the revisions as suggested in the annotated manuscript.

#### Specific comments

Title:

In view of my general comments and because CRNP is not based on EM waves, I would suggest to change the title to, "**Performance of autonomous field sensors for continuously monitoring the water equivalent of snow cover (SWE)**"

Thank you for your suggestion, but "autonomous field sensors for continuously monitoring SWE" can include a lot of instruments that are not considered here, such as those based on pressure and load cell sensors (snow pillow), or on snowmelt lysimeters, or on dielectric sensor (e.g. the SNOWPOWER system, commercially available as the Snowpack Analyzer) or acoustic sensors (see Kinar and Pomeroy, 2015). All

these listed sensors do not meet the targeted criteria of ease of installation, or consumption (autonomy), or non-invasive or non-operational. This remark has been added in the introduction

We thus suggest a title more specific to the scope of this paper:

***“Performance assessment of radiation-based field sensors for monitoring the water equivalent of snow cover (SWE)”***

The cosmic ray neutron probe can be considered as a radiation-based sensor.

Line 25: *‘relatively low cost’*

In Table 3, cost is named as a drawback for at least three instruments! I would also argue it is a matter of appreciation whether one considers USD 10 000.- to be *‘low-cost’*. I would thus propose to drop this argument, at least in the abstract, the introduction, and the conclusions.

This is a delicate but important aspect of the comparison of instruments. The instrument’s price is also a very relative argument depending on the purchasers (Hydro-Quebec equips its SWE measurement network with about a hundred GMONs!). This criterion can also influence the choice of decision makers or researchers.

This said, we agree that the term *‘low-cost’* can be more contextualized, therefore we modified the text and Table-3 such that:

Modified text and Table 3:

*- the price of the instrument itself, knowing that the cost of the system may vary in cases where additional instruments are required for the SWE measurements. Also, the cost that is associated with on-site maintenance during winter should be considered here, but in our case, the 4 instruments are considered on the same basis, i.e., autonomous, with no need for intervention; - and the possibility of other applications.*

*The cost criterion is somewhat subjective, which can influence the choice of decision-makers or researchers, depending upon the intended application (e.g., large network, in remote areas, among others) and also on the purchasers.*

Line 40: *‘kg m<sup>-2</sup>, or in mm’*

You nicely define water equivalent of snow cover as *‘its mass per unit area’*. Why then use mm as a unit? I would prefer by much seeing only kg m<sup>-2</sup> throughout the paper.

In theory, I agree with this remark in accordance with the SI unit system (kg m<sup>-2</sup>). However, it is also a common practice to consider SWE in mm (sometimes in cm).

While these units are well defined at the beginning, there is no possible confusion.

Line 50: *‘reliable and automatic instrument alternatives exist’*

This is questionable. At least I could not find corresponding evidences in the references provided.

Sentence changed as:

*“The automation of SWE measurement networks is an essential medium-term prospect, especially since reliable and automatic instrument alternatives exist (Dong, 2018; this study).”*

Section 4:

Consider shortening the last paragraph (lines 367-376) or moving it to the introduction as it is not further considered in the paper.

Other sensors based on a similar principle are mentioned in each of the four instruments presented (here the GNSS). We think this complements and adds interesting value to the literature review.

Lines 533-534: *‘winter period, uncertainty can be introduced by well-known local SWE spatial variability that can occur at fine scales around the sensors.’*

I would argue this variability is less present in bulk snow density. Thus a comparison of SWE recomputed with regard to one reference snow depth may have been beneficial.

Yes we agree. Snow depth is significantly more variable than bulk density.

However, bulk density can also spatially vary, as showed for example by Rutter et al. (JGR, 119, doi:10.1002/2013JF003017, 2014) in the Arctic.

Line 653: clearly, in your own words, CRNP is NOT EM wave!

Corrected

Comments on structure

Section 3 is quite difficult to follow and not free of ambiguities. I'd suggest the following to improve its readability:

Rename Section 3 as '*Results*' and start with a description of both sites (Sub-section 3.1). Adding a figure showing the location of the instruments at each site as well as a summarizing table would extremely helpful.

Then Section 3.2 would become '*Validation of measurements*' with separate sub-sections on SIRENE and Neige-FM.

3.3 '*Uncertainty of measurements*' would end Section 3.

This section was restructured as suggested.

Comments on terminology

'*snow water equivalent*':

Consider switching to "**water equivalent of snow cover**" as defined by WMO (for example, see WMO 2018): Guide to instruments and methods of observation: Volume II - Measurement of Cryospheric Variables, 2018th ed., edited by: WMO, World Meteorological Organization, Geneva, Switzerland, 52 pp., 2018.)

The SWE acronym is used in the paper to define « **water equivalent of snow cover** »

'*accuracy*':

Consider switching to "**uncertainty**", see the VIM <https://jcgmm.bipm.org/vim/en/index.html> or <https://jcgmm.bipm.org/vim/fr/index.html> 'CNRP' (see line 23):

Corrected. Yes "uncertainty" relates to the characterization of the dispersion of measurements compared to a reference (expressed by the standard deviation or root mean square difference, regression analysis, or statistical distribution of the quantity values from series of measurements, or probability density functions ...), while the accuracy is defined as the closeness of agreement between a measured quantity value and a "true" quantity value (accepted reference value).

Please correct to "**CRNP**" throughout the text.

Corrected

'GNSS' (used 16 times) vs 'GNSSR' (used 34 times):

The distinction between 'GNSS', that is the satellite system, and 'GNSSR', that is the instrument used, is sometimes misleading in the text. Also note that GNSSR can easily be misunderstood as GNSS reflectometry. Thus I'd suggest the following: on lines 24-25 and 67 write, "**Global Navigation Satellite System receiver(s) (GNSSr)**". Using GNSS alone later should then be clear too.

Corrected. Good suggestion!

Please also note the supplement to this comment:

<https://tc.copernicus.org/preprints/tc-2021-163/tc-2021-163-RC2-supplement.pdf>

All annotations were taken into account. Except for (Line numbers refer to the annotated pdf document):

Fig.2 comments: For the sake of clarity, I would separate set-up illustrations (Figs. 2a-c) and pictures of your sites in two Figures. Also, a picture of the CRNP set-up at SIRENE would be great!

These photos are only illustrative. To separate this figure will make the article longer. This maybe would be interesting to add a photo of the CRNP and GMON at SIRENE. Unfortunately, we can't find such a photo (the CRNP and GMON are no longer in operation at SIRENE). Instead we changed the photo (a) where the CRNP is more visible than previous photo, and we add, in insert, a close-up of the probe we had in Sherbrooke, that is exactly the same than the EDF NRC sensor.

L 294 “precision” : Degree of internal agreement among independent measurements made under specific conditions (ISO Publications, ISO 3534-1, Statistics - Vocabulary and symbols - Part1: Probability and general statistical terms, International Organization for Standardization (Geneva, Switzerland), 1993).

L 391 and elsewhere : We give here the station coordinates in order to situate them in the world. Five digits do not appear necessary. The exact locations can be found in the cited references.