Comment on tc-2021-163

Craig D. Smith (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-RC1, 2021

Comments from the reviewer in blue
Answer in black
Text added in black and italic

The review article by Royer et al. provides some insight into the measurement principles, accuracy, and advantages/disadvantages of four instruments that employ electromagnetic waves to measure in situ snow water equivalent (SWE). Instruments reviewed are the Cosmic Ray Neutron Probe (CRNP) (deployed in two configurations: above and below the snowpack), Gamma Ray Monitoring (GMON) sensor, Frequency Modulated Continuous-Wave Radar (FMCW-Radar), and Global Navigation Satellite System (GNSS) receivers. The paper is a combination of reporting results from previous evaluation and intercomparison studies and the reporting of results from intercomparisons at two Canadian research sites: Foret Montmorency and the Site Interdisciplinaire de Recherche en ENvironnement Extérieur (SIRENE). The purpose is to inform the reader of the relative advantages and disadvantages of each of these systems in the context of employing them in operational monitoring networks.
I thought that the paper offered a complementing balance of previous assessment results and associated measurement issues with fresh results to build on the experience. SWE sensor evaluation is complex because advantages and disadvantages are only realized in differing measurement (snowpack) conditions which are impossible to assess at one, or even several, concurrent intercomparison sites. In this way, the paper is both interesting and contributes to the body of knowledge related to automated in situ SWE measurements.
Thank you for your comments

Having said that, there are several deficiencies in the paper that require revision before the paper can be published in TC.
These are incorporated into the attached annotated manuscript, but the major issues are as follow:

1)There are general wording and grammar issues and some terminology inconsistencies that need to be fixed. These are noted in the annotated manuscript.
Done.

2)The abstract is quite vague. It would benefit from some additional detail about each of the sensors assessed and perhaps a short overview of the offered recommendations.
Done. More details about the performance/recommendation of each instrument are given. But this makes the summary very long!

3)There are some redundancies and therefore readability to be gained in Sections 3/4/5. For example, by the time we get to Section 4 (in particular, lines 700-702), we shouldn't be reading more about instrument description, such as the field of view of the CRNP, as this should be outlined already in Section 3. I think that Section 4 can be organized a bit better to improve readability, perhaps by converting the bulleted list starting at line 637 to paragraphs using heading names organized by instrument.
Section 4 (Strengths and Weaknesses of Instruments) was re-organized to improve readability.

4) Similar to point #2, the Conclusions section contains redundant details, such as the bulleted list starting on line 740, that should only be briefly summarized at this point. Since your pros and cons are a bulleted list in Section 4, summarize these in a short paragraph in Section 5, followed by some brief recommendations to potential users.
Section Conclusion was briefly summarized.

Specific comments from the annotated manuscript.

L49 The techniques that you are about to describe are not an "automation" of a "manual survey" but rather (generally) a point measurement approximation. I would prefer that you stated this as "The automation of SWE measurement networks..."
Done

L100 "experimental setting" Maybe "measurement principle conceptualization" would be a better way to put this.
Done

L138 and 140 I think some of these details should be left out of the figure caption and discussed in the text of the section. The figure caption is quite desriptive, even without the details.
Shortened caption. Details reported in the text

L172. This sentence seems out of place here. I think flow would be better if you moved this someplace else, perhaps at the beginning of Section 2 or the end of Section 1.
Done

L208 "which is generally the case when soil remains frozen" You are right, this is very general, but far from universal. Infiltration into frozen soils is not uncommon, especially for sandy/silty soils and I think this can be a relatively large source of error with these measurement principles, especially during spring freshet and mid-season thaw cycles. I think that this should be addressed with a bit more detail. This also applies to the GMON discussion.
Gray, D.M., Granger, R.J., Dyck, G.E.: Overwinter soil moisture changes, Transactions of the ASAE, 28(2), 443-447, 1985.

Gray D.M., Toth, B., Zhao, L., Pomeroy, J.W., Granger, R.J.: Estimating areal snowmelt infiltration into frozen soils, Hydrological Processes 15(16), 3095–3111, 2001.
L256 Thanks for the citation :)
You can see in our results how the intercomparison with the snow scale at Sodankyla showed hysteresis during snow melt, which we felt was an indication of infiltration into the frozen sandy soils at this site. This didn't seem to happen at the site in the Alberta Rockies where the soils had more clay content.
I'm not saying that intra-seasonal change in soil moisture is a universal problem, but I think that it merits a note of caution, and as you (and we) point out, could be an advantageous measurement.
This aspect has been developed and put in a specific paragraph of Section 4 for the 2 sensors CRNP and GMON.
References added.

L333 This sentence doesn't read correctly. Try re-wording.
Done
Over the Arctic, snow cover can generally be characterized by a two-layer snowpack structure, composed by with a dense wind slab layer overlaying less-dense depth hoar (Rutter et al., 2019; Royer et al., 2021). Thus, assumptions can be made on the mean refractive index of each of these layers, thereby allowing bulk SWE to be estimated (Kramer et al., 2021).

L360 This sentence is a bit confusing and should be re-worded.
Description of different retrieval algorithms was presented, including a new reference added (Steiner et al., 2018).

L382 Why not just say "Evaluations of these sensors are available in the literature and a comprehensive review is presented, including estimates and a discussion of their respective accuracies."
Done

L440 I think for flow, this statement should be incorporated where you introduce fig 3 above.
Paragraph restructured.

L447 Was this ice layer able to be included in the manual measurement? If not, this could also explain why GMON is high compared to the manual measurement.
Rewritten sentence.
As this ice layer was not present in snowpits (the amount of water in an ice crust being otherwise difficult to measure), this could possibly explain the difference between GMON and manual measurements.

L469 This wording makes it sound like you stopped monitoring after 120 cm. This would read better as "A maximum snow depth of 120 cm was measured during the season, ..."
Done

L489 It would be helpful to revise this to include the air temperature threshold that you use.
Rewritten sentence.
…wet snow conditions (open black squares, Fig. 4) which correspond to melting periods with measured air temperature above 0° C,…

L493 ok, I see what you are trying to say here, but it comes across as a bit awkward. Suggestion: During the accumulation period, the GMON shows a relatively smooth and consistent evolution in SWE leading to a maximum of 465 mm on 19 April 2018 while the FMCW-Radar time series is more erratic and requires filtering to remove low SWE outliers.
Good suggestion. Rewritten sentence.

L504: "remains always close to in situ observations. " This is a vague term. You should quantify it.
Quantification added. This was indicated in Table 2.
(RMSE compared to snowpit for the GMON and GNSSR are respectively of 34 mm and 32 mm, Table 2)

L558 I think bridging woud be considered an error more so than an uncertainty.
I agree

L559 This sentence is a bit awkward and should be re-worked.
Modified sentence
… leading to disconnection of the weighing mechanism of the overlying snowpack and the surrounding snowpack.

L577 "(0 – 1 000 mm) "I assume that this is SWE and not depth, but you should probably indicate this.
Yes :
mm w.e.

L590 can you elaborate on this a bit?
Rewritten sentence.
The uncertainty in wet SWE retrieval could result from approximations in the retrieval algorithm used. For example, the wet snow refractive index varies linearly with LWC, with a slope significantly dependent of the snow density (see appendix in Pomerleau et al., 2020).

L628 "footprint of the sensor" footprint or response area? I think response area is more appropriate since footprint more likely describes the area taken up by the installed instrument, rather than the area that it is sampling.
The definition of the "footprint" was defined:
i.e. taken here in the sense of the area from which emanates the measured radiation having interacted with the snow

L634 and after: I'm wondering if this bulleted paragraph can be organized better, perhaps under individual instrument headings, since you seem to more or less discuss the instruments individually anyways. I think it would make it easier to read, and complement your bulleted list below.
Done

L699 I feel that these details should be covered in the desciptions in above sections and that this section should just be used for listing pros and cons. For example, this should just state that CRNP above snow has a relatively large (give area) response area compared to other sensors.
All the paragraph was restructured

L718 You should convert all currency to CAD or USD for comparison.
In the text, the prices are given in both money : US$ and in the money of country where the instrument is manufactured, and in the Table 2, they are all put in US$.

L721Doesn't this sensor also need ancillary measurements (snow depth)? That should be mentioned here as well.
Yes. Added.
This approach requires to measure the snow depth to be able to retrieve SWE.

L740 I feel that there is too much redundancy between this section of the conclusions and the previous discussion. The paper would have better flow if your conclusions only included a very brief summary and your recommendations.
The conclusion was rewritten.

Table 3 I'm not sure if it's a pro or a con, but one thing that I would like to see documented for these instrument suites are the communications/logging protocols. For example, I know that the CS725 uses SDI12 communication protocols. Some are probably RS482 (as an example). Can they be connected to data loggers or do they require onsite computers?
This technical specification can be found related papers.

Also, you mention in the text that each of these instruments can be operated with DC/Solar power. Stating the max power consumption would also be useful for many readers, considering the objective of informing decisions for network operation.
We added a line given the exact power consumption. Good suggestion.