Comment on tc-2021-163

Review from Yves Choquette (CC2)
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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-CC2, 2021

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

L 29 (Abstract). It should be mentioned that this accuracy is determined inside this study and from other papers and not the accuracy reported by the manufacturers. This means distinguishing equipment accuracy (calibration in the manufacturer process) and accuracy of the instrument at the field (considering the field variation of the snowpack).
The distinction in the accuracy between the field experiment and the calibration by the manufacturer has been made in the text. (good point).
At the beginning of the Sect.3.4 Accuracy analysis, we added the sentence:
Note that we only consider here the differences between instruments in the field and do not address errors derived from the calibration by the manufacturer.

L438. The GMON is calibrated by the manufacturer. It should be mentioned that the calibration is for the site where the GMON is installed. If no additional information is described for calibration parameters of all sensors, the reader should assume the best parameters set was selected but without describing the way parameters are selected weaks this study. I would like to see more about this subject (site calibration). Oftently, this is a key process to get reliable and accurate data.
We have to distinguish between “calibration”- site issue due to soil moisture (inherent to this sensor and also for the CRNP), and the calibration instrument from the manufacturer, that can be found in references relative to each instrument. In order to avoid any confusion, the term "calibration" was removed when it came to correcting (adjusting) the signal for differences in soil water storage before snowfall or during the winter.

L452. This paper did not talk about terms and semantic but a ice sheet under the GMON is associated to a SWE number and not to an overestimation of the SWE. We do not ascribe crystal ice inside the snow cover to an overestimation so an ice sheet should not too.
When there is ice under the snow, we can talk about “ice water equivalent” and not about “snow water equivalent”. In our case, there was no more snow on the ground! For the total amount of water, there is no overestimation, you are right.
The sentence was corrected:
… leading to a significant GMON overestimation in terms of snow w.e. but not in terms of total water.

L457 (Figure 3). Important to mention how the GMON parameter 9 (soil humidity) was determined because it can explain some of the difference vs manual SWE mm.
The GMON was adjusted to take into account the soil moisture prior to snowfall accumulation, but not after, during the winter.

Figure 4 This site is an "easy" site for the site parameters of the GMON because the soil is highly drained meaning a relative constant for the soil humidity so the results should be more accurate than other sites (more organic at surface) for SWE data.
This is indeed the case at the Foret-FM site and it was specified.

L597. Table 2 do not reflect the accuracy obtained by HQ. We have sites that are very accurate (less than 5 mm vs SC and SP) and others in the range of 20-30mm.
and
L600 It is true. At HQ, we got better results than 15 mm accuracy for SWE < 300 mm (however not for all sites but a pretty much significative number of sites). We do not have a lot of data for accuracy determination for SWE > 300 mm but the 15% is really in very bad situation where K counts are weaks.
For sites having high K counts level, it is < 15%.
For Table 2, we did not find statistical analysis performed by Hydro-Quebec. But, we specified that:
If SWE reference data and site adjustment process are well done, the GMON is able to report SWE inside an error as low as 5% (Wright, 2011; Choquette et al., 2013; Wright et al., 2013).

L661 “is not continuous” Again, I believe also here that it is a question of definition and semantic. A continuous monitoring for example of temperature is surely defined at a minute frequency but for the SWE data, what frequency is defined as "CONTINUOUS"? Being historically manually done at the best at week frequency, a data reported at each hour or 2 hours could be considered as "CONTINUOUS". Regarding an hydrological model operating 2 to 4 times per day surely deliver "CONTINUOUS" information so again this is a question of semantic.
Note (a) in Table 3: Not at ease with the "discontinuous" term regarding the need (water forecast for hydraulic power generation, model simulation, etc..)
Yes, this point about the time sampling rate has be defined:
- the temporal sampling rate, i.e., whether they were capable of quasi continuous SWE measurement capability, although the notion of continuous SWE measurements is relative to the application, such as for seasonal SWE monitoring, for hydrological model validation or to follow an event of a short winter storm

L665. The drawback (until more R&D investigations that are on going at ULaval) of this approach is the lost of the soil humidity variation information from the top ground surface monitored by the GMON. This soil humidity variation is also helpful in the hydrological model for off-snow water forecast.
Yes, but the objective here is to be able to monitor the SWE. To strengthen the gamma ray emission by such a process is an interesting hint that can counteract this limitation and make the use of GMON more universal (e.g. measurement on glacier).

L708 “…footprint (2-3 m)” How this number was determined?

Table 3 “footprint GMON” Not true, see the paper of Ducharme. Depend also on the snow layer thickness.

The foot print was defined by the diameter sensed within the IFOV: H x 2 x tg(IFOV/2), where H is the height of the sensor above the snow surface. But, attenuated gamma rays that emanate from the snowpack can effectively come from further away than this geometrical footprint by scattering. This was adjusted.

The size of the area effectively monitored by the GMON (“footprint”) extends to 10 m from the detector when there is no snow or water on the ground (Ducharme et al., 2015). The size of the sensed area exponentially decreases with increasing SWE and is estimated to be of the order of 5 m radius (50 – 100 m^2) for 150-300 mm w.e. (Martin et al., 2008; Ducharme et al., 2015). This relatively large foot print is an advantage of this sensor.

L710 “uncertainty of instrument”. It could be also semantic but a systematic error (called bias) comes from an under or over estimation of the soil moisture. So, at one site, it is not considered as "uncertainty" but more a "bias error". However, when more than one GMON site is considered (ex. in a hydrological model), then an uncertainty can be generated, which is a "spatial" uncertainty.

Corrected

Yet, it needs systematic site adjustment for soil moisture-induced error, which can increase the bias of measurements.

L710 “particularly at the end of the season “ Which one? Fall? or Spring?From our knowledge, a "typical fall" will generate a soil saturated. If the fall is higly dried and winter comes early with high freeze, soil humidity will not be saturated but with snowpack accumulation, the soil will get saturated.

We spoke here about the winter:

particularly at the end of the winter when the soil becomes potentially saturated during snowmelt.

L724 A brief snapshot about cost. First, authors should consider reporting the same base money (US$ or Euros or CND$). Second, the most significant data is the cost of ownership and maintenance because, by exemple, a cheaper instrument which need many maintenance will cost more after some time in operation especially for distant remote area which are oftenly the case for snow monitoring stations.

The price was noted in the money form the manufacturer in the text, and has been translated in USD in Table 3.

The cost of the maintenance has been mentioned.

L738 Rio Tinto did already use the GMON since more than 3 years for its entire meteo network.

Added

L754. Total cost should be considered, and also, the cost of the sensor vs the total cost of establishment of a meteo station. Ex. CNRP needs other equipement to estimate the SWE so increase the real total cost.

This was noted.

L768. This is well done with this paper but authors have already a major pro for the GNSSR when they write "strongest potential for a wide range of applications". I think that much more parameters must be included in the analysis before making a conclusion. The free maintenance (the real free maintenance) is of huge of importance for operational network and nothing is mentionned. The footprint and the area where the equipment could be deployed is another real big issue. Ex. it looks like GNSSR could not be deployed in forest area and this is a major drawback for south watershed in Quebec. So, to be more interesting for decision makers who want establishing a meteo network, this paper should be more explicative.

The potential of GNSSR mentioned here concerns its lightness and compactness for snow monitoring in the Arctic, as example.
The issue of the footprint of the GMON was detailed (see above)
As the GNSSR signals are normalized between the direct and snow-attenuated radiation in the processing, the effect of the forest is not a major drawback.
All instruments analyzed in this study are free of maintenance, they were thus considered as such.

Table 2 I didn't see how the calibration of the site (ex. for the GMON) was done which can influence the SWE data so this is a miss in this report. Same comment for other equipments.

The principle of the “calibration” for the GMON and the CRNP needed for soil moisture-induced bias correction was mentioned in the text. The detailed procedures on how to include this correction in processing data is well explained in given references (see Choquette et al., 2013, or Desilets et al., 2017).

Table 2 I think I did not see this in the text which is very important to mention: my understand is that the accuracy was evaluated at the highest SWE, which is just fine, but should be more explicit in the text.

The accuracy derived for the regression analysis was calculated for the whole range of SWE data