Review of:

Layer-optimized SAR processing with a mobile phase-sensitive radar for detecting the deep englacial stratigraphy of Colle Gnifetti, Switzerland/Italy

Submitted to: *The Cryosphere*
Reviewer: Benjamin Hills

Summary.

Oraschewski et al. describe a novel setup and implementation of the popular ApRES instrument, specifically for SAR profiling in alpine environments. Overall, I believe that this work could be highly impactful, particularly for alpine glaciology studies. As I describe in detail below, I believe that some additions to the engineering discussion as well as some organizational changes could elevate the impact of this article. It is well written and a great fit for *The Cryosphere* after these minor revisions.

General Comments.

I love this, neat design and I learned a lot. My largest high-level comment is that the article, as written, feels like it is in between a science narrative and an engineering narrative. I believe that you are intending for this to be read as an engineering article with a scientific proof of concept, and I think that some very minor organizational changes could help make that clearer. I would completely segregate the engineering language from the site-specific scientific proof of concept, preferably loading the engineering up front. I would also generalize the engineering discussion as I describe in paragraphs below. Ideally, anyone who is thinking about using a pRES to do profiling in future studies will be coming back to this article to figure out how to optimize their setup.

One plausible organization scheme could be:

1. Introduction
2. Hardware design & Data Acquisition
    - Continuous acquisition vs stop-and-go
    - MIMO (might be too much for this article?)
3. Data Processing
    - Standard FMCW
    - LoSAR
    - Multipass (might be too much for this article?)
    - Polarimetry (might be too much for this article?)
4. Proof of Concept at Colle Gnifetti
    - Site Description
    - Radar Dataset
    - Comparison to ice core (I would put *all* the chemistry background, results, and discussion in this one section, it is interesting but not the focus of your manuscript and confusing when it comes up in three separate places)

5. Discussion
    - Mainly covers the nuance of your proof of concept (which is what you are already doing with the Discussion).
6. Conclusion

As you see in my outline above, I added a few sections which you do not currently cover (e.g. MIMO, multipass, and polarimetry, I expand on each in the following paragraphs). Here, I am encouraging you to consider broader use cases for this instrument rather than limiting the conversation to what you end up doing in the example, that way you can have a bit broader impact with this article. You could also consider adding a section (possible between Discussion and Conclusion?) on "Future Directions" where you would put some of this multipass and polarimetry language.
Sections 2 and 3 obviously have a lot of overlap and may need some consideration in how they are folded together or not.

ApRES specificity
I believe you are currently too specific to particular ApRES settings. In my opinion, the engineering language would be more useful if you generalized the numbers for center frequency, bandwidth, and chirp time (all of which can be changed in software as far as I know). Then, in your proof of concept section you give the specifics for that particular case and use those specifics as justification for your survey design (e.g. the stop and go surveying mode).

MIMO and Polarimetry
I know that this team has already been thinking about multi-input-multi-output designs, so I am eager to know what they think that might look like for this alpine setting? Is that infeasible here? Too heavy to carry by ski? My tendency would be to include this, even if it is presented as a possible next direction, then go more specific to your single-channel design in the proof-of-concept section.
If you include MIMO in the hardware section you would want to at least mention how the multiple channels helps you, whether that be variable offset (for velocity inversions) or mult-polarization for polarimetry.

Multipass
This is the other obvious use case for your design which would not need any hardware changes. If you left out MIIMO and polarimetry that seems fine to me, but I think this should be included because in my mind it is an obvious use case for your instrument. Specifically, what I mean is resurveying the same profile between two different times to measure vertical velocities.

Specific Comments.

Title – I would say it is a proof-of-concept at Colle Gnifetti. The current title makes it sound like this instrument is only useful at one site.

Abstract – I believe that "(pRES)" and "(LO-SAR)" don't need the acronym in parentheses since you only use them once in the abstract and you redefine in the text.

L10 – "down to the base…" you could be more specific. "Improved from 50% depth with pulsed radar to 80% depth with lo-sar"?
Coming back to this since in the discussion you mention the ages that you resolve (78 yr vs 288 yr) I think those are useful numbers to have in the abstrace if it is something you want to emphasize.

L25 – Instead of the in press article, there are many alternatives you could cite (Arcone et al., 2005; Medley et al., 2013).

L34 – "neither of which are applicable…"

L57 – Instead of "invisible" I might say "unresolved"

L85 – I recently talked with Keith Nicholls about doing pRES profiling and he suggested that I shorten the chirp time. I didn't have a lot of luck with it, but my experience has me thinking about whether you want to change how this gets presented here. If you give some guidelines for how short a chirp you need to profile continuously the community may come back to this paper a lot more.
I am now seeing that you do talk through some of this in the discussion, but I think talking about it when it is introduced will be helpful (I am guessing that a lot of readers will be primarily interested in your hardware design and processing flow).

L102-103 – as I said before, it might be more broadly useful to the community to generalize some of the numbers here until you get to your proof-of-concept where you would give specifics.

L113-115 – I might add 'volumetric scattering' in line with my comment above on adding another adjustment.

L134-139 – This is fine to do here in my opinion, but I think it is not precisely correct since you are compressing information over the full bandwidth to get the range in eq. 1. I might just add a bit more nuance so people don't misuse this approximation.

L143-144 – I may be confused the "explicit sum", but I believe Castelletti et al. (2019) did something similar if not the same. They do a coherent sum in their eq. 3 and then "incoherent

averaging" as described in the subsequent paragraph. Maybe you are doing something different; if so, more explanation would be helpful.

L153-154 – This is interesting. I have actually had a lot of luck with the method from MacGregor et al. (2015) (it is much faster as you say), but that has been with MCoRDS data and I hadn't considered the phase uncertainty in this way. I am interested in seeing a comparison figure although I get that most readers are not me and this is not the emphasis of the article, so disregard unless you think it is useful.

L159-176 – I believe this is mostly the same as Castelletti et al. (2019), correct? Either way, I think it is important for you to write it out here (especially since the way you write it is a bit different). Still might be worth citing them and pointing out explicitly where you are (or are not) different.

L181 – comma feels like it is in a weird spot to me

L212 – I believe more details on "poorer data quality" could be exceedingly useful for future studies trying to do this type of thing.

L214-215 – save mention of the ice core for the next section

L230-231 – I believe this result is correct. You might add a citation to Greenland radar work and the Holocene-glacial contrast, longer time period but similar idea.

L248-249 – Nice. "should not be a more painstaking data collection using pulsed GPRs but rather aim at accelerating the profiling capabilities of FMCW radars". Very much agree with this.

L 274-278 – What is required to change the frequency band. I think you can change it in software, but I am guessing the skeleton slots are specifically designed for this band. Could someone design new antennas and use the same unit? As Jonathan has been doing for the HF ApRES but now to a higher frequency band? Could be some interesting additional notes here.

L307 – most likely "not"

L328-335 – Do you think there is also a lot of uncertainty in the density which causes thickness uncertainty? Or you are decently confident on the density?

L336 – I would add that it improves SNR specifically for specular reflectors, which the bed is not in most cases.

L349 – "promote" changes in the COF? Or "caused by" changes in the COF?

L368 – This group could probably convince me (so please do if I am wrong!) but I don't think it is the impurity layers which are causing changes in the COF. Rather that boundaries between two different COFs can cause a reflection.

Conclusion – Too focused on your site. I believe that this radar design will be highly useful to many groups all over the world, do not undersell yourself by making the reader thing it is only for this site!

L388 – Excited to see the processing scripts when you have them up! Please do be sure to post them.

Figures.

Figure 1. I am not very familiar with this area so an inset map showing where you are located in the alps and then where on the glacier, those would be helpful. As with my *general comments,* I think you should move this figure lower. Having Figure 1 be a map makes it feel like this is a scientific paper, whereas if you want it to feel more like an engineering paper starting with Figures 2 and 3 would be helpful.

Figure 3. If you decide to include language on MIMO and multipass then I would add more to this flowchart as well.
I was at first confused about the arrow labeled "power and phase of traces in synthetic aperture length". I didn't understand the direction. I would put little arrowheads along that line to help a reader out.

Figure 4. It is tough to see the layers with your red annotation lines over top of them. Either drop the lines and label with points/arrows (as you do in e and f) or make additional panels for interpretation as in Welch & Jacobel (2005) Figures 3a and 5b.

References

Arcone, S. A., Spikes, V. B., & Hamilton, G. S. (2005). Stratigraphic variation within polar firn caused by differential accumulation and ice flow: Interpretation of a 400 MHz short-pulse radar profile from West Antarctica. *Journal of Glaciology*, *51*(174), 407–422. https://doi.org/10.3189/172756505781829151

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