Answer to referee's comments, on the manuscript «Monitoring snowpack SWE and temperature using RFID tags as wireless sensors»; 2023-01-09; Referee 1.

General comments:

1.1 In this manuscript, the authors propose and test a new method for SWE estimation: the use of passive (or semi active?) tags

There are still discussion on the denomination because “passive” and “battery” is usually opposed. The right denomination to us is “passive battery assisted” tag, because from the outside the tag works the same as passive tags, only internally it has a boost of energy. Active tags are totally different: they do not use the widely used standards of passive RFID, they generate their own wave, they consume much more energy, etc…. Our method works both with passive batteryless or passive battery-assisted tags (only with different performance in the read range), but would not work with active tags.

We have added a clarification on line 135–140.

1.2 An unexpected problem came up by large phase uncertainties due to interference by multipath propagation of the sensing waves. The use of independent measurements helped in reducing these uncertainties. In my opinion, the problem is still severe and should be improved. The questions:

- **what causes multipath effects?**
- **how can they be reduced?**

have not been addressed by the authors. Ways to tackle these questions are by numerical simulations using a forward model or by experimental work.

We agree that there is a need to better understand the multipathing effect on RFID systems in snow contexts. However, this is far beyond the scope of the present study (multipathing is a general issue in RFID, particularly for localization indoors where multipathing can be strong). We have a work in progress on this topic, for which we will dedicate a communication in itself. Two results are presented below in this document.

To reduce the multipathing in the present study, we then suggest to use an array of tags placed very close to the ground. It should help average the spread due to spatial diversity, and should also reduce the reflection between tags, and the reflection on the supporting material. Given that anyway we want to remove the vertical support to reduce the influence of the system on the snowpack.

What causes multipathing:

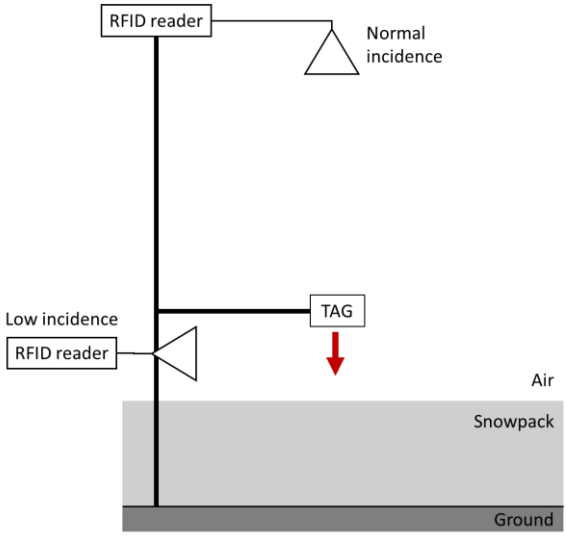
- The reflection on:
  - The tags
  - The snow surface
  - The soil surface
  - The different layers of snow
  - The light plastic supporting structure that holds the tags
  - The large metallic supporting structure that holds the reader

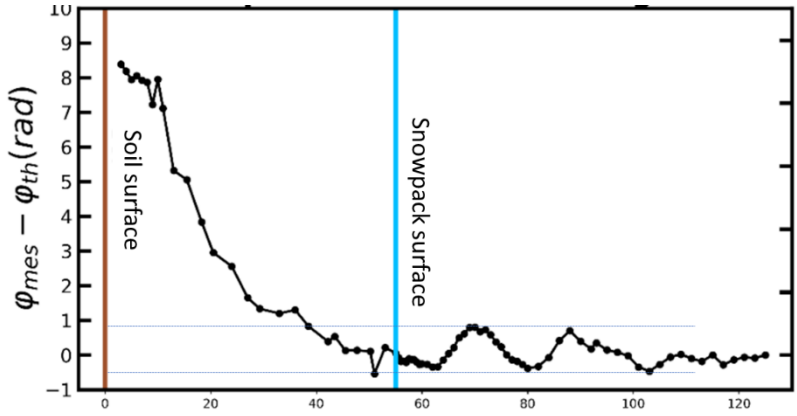
What causes variations of multipathing over time:

- Changes either in amplitude or in phase delay of the reflected paths, due to variations in height, density and moisture content of the snow.

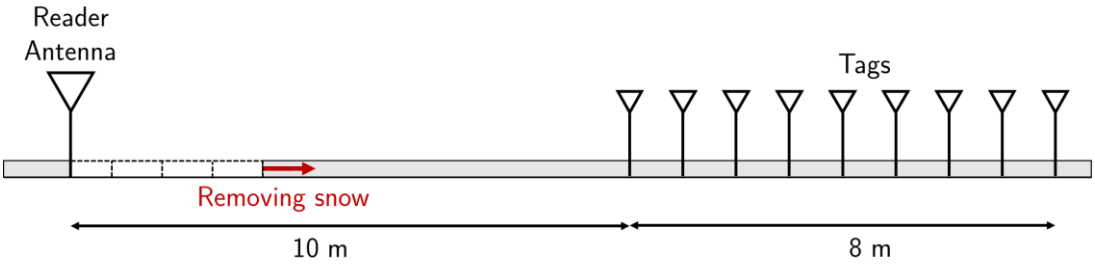
In the following experiment, we have moved a tag at different heights above and below the snowpack surface. We represent the difference between the measured phase and the phase expected if the tag moved in free space in the air.

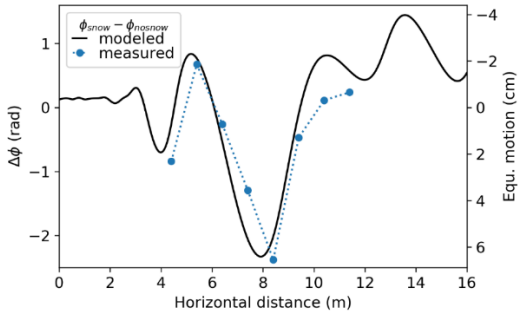
We can see clearly the effect of multipathing when the tag is above the snowpack, with variations of 1.4 rad amplitude, that correspond to the spread observed in the present study (up to 1.2 rad).





In another experiment, we have removed a thin layer of snow from the ground, with tags placed at different locations. As a consequence, the phase varied between +1 to -2 rad (3 rad of amplitude). It is coherent with the changes expected from a simple 3-ray model.





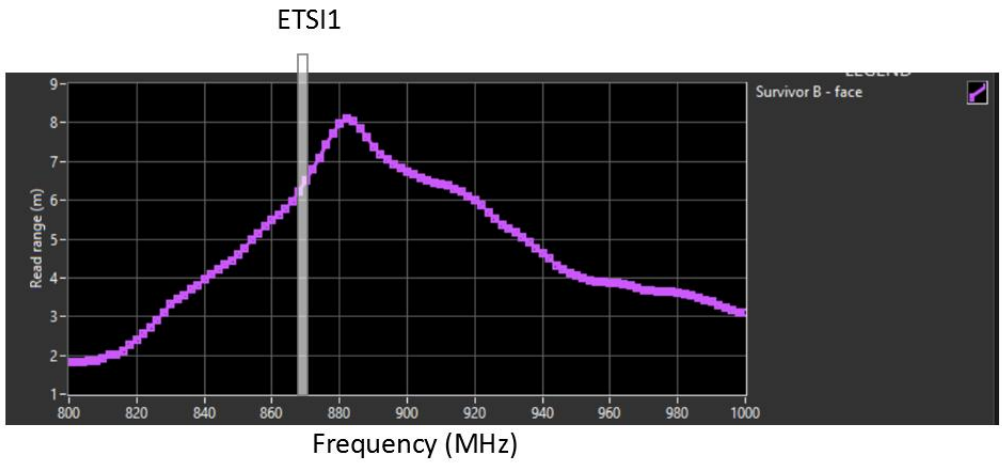
1.3 No information is given on the properties of the antennas used.

We have added the exact model number which allows to find the data sheet. We corrected the gain, and added the beam width, polarization, and protection indice (Line 130–135).

1.4 No information is given on the scattering and absorption cross sections of the tags used, nor of the supporting structures.

We are not sure of what it would bring in the experiment's context. I could see two goals, either for tag designing, or for characterization of the multipathing.

Concerning the tag design and behavior: the principle of this experiment is independent of the tag used (at the contrary to the RSSI for example, but we did not want to display or discuss RSSI data in this article, in order to stay focused). We can display the tag's response depending on the frequency (see figure below for example), but again, this study is not about the tag's design.



Concerning the multipathing: as we suggest in 1.2, multipathing is one of the major issue in RFID in general, particularly for the localization methods from which our approach originates. If we wanted to model the multipathing, we would need the cross-sections. But then, it relates to comment 1.1, and understanding the multipathing is also out of this study's scope.

We have added a picture of the tag without its casing.

1.5 No information is given on the method used to discriminate the responses and the backscattered signals from different tags, and how this discrimination may be linked with the phase determination.

Indeed, it needs explanation. The tag being interrogated by the reader modulates its reflection between two states, while the other reflections (environment and tags) are static. The phase difference of arrival is calculated from the IQ difference between the two states, which relates only to the interrogated tag (given a static environment).

I have explained on lines 140–145, and added a reference to Nikitin 2010 for further understanding.

1.6 Information is also missing on how the temperature measurement of the tags is working.

The temperature sensor in included in the tag's microcircuit, that we use as it is.

We have added a picture of the tag, in order to see the location of the microcircuit that measure its temperature.

We have also added a reference to the integrated microcircuit model datasheet.

1.7 An alternative to the vertical stack of tags would be tags close to the ground surface in a type of (phased?) array. The tags close to the ground are the ones that gave most of the information.

Absolutely! We are planning this update in our next installation.

→I have added this suggestion more clearly on line 257 and 267.

Details:

1.8 English language should be improved.

We are working on it.

1.9 Improve the final part of the Introduction, sentence on lines 74–75, and "Section 0", lines 85 to 88.

corrected

1.10 After Equation (1): “in-phase and quadrature” are generally used to describe the complex electrical field of electromagnetic waves. Don’t use it here for the complex dielectric constant.

Ok, modified.

1.11 Section 2.1 Theory: from phase delay to SWE to be improved and simplified as a whole.

We are simplifying it.

1.12 Section 2.2 Instrumentation does not present the instruments and their properties. I missed this description, see general comments above. The subsection describes experiments and sites.

We have increased the description of the instruments.