Brief Communication : Monitoring active layer dynamic using a lightweight nimble Ground-Penetrating Radar system. A laboratory analog test case. Answer to reviewers

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Dear reviewers RC1,

Thanks for your review. Please find below our answers to your comments .

1 Originality (novelty): 2

In this contribution, the authors present a laboratory test using ground-penetrating radar to monitor the active layer dynamics. From the reviewer's understanding, the novelty of this contribution is that the authors used thermal and volumetric water content sensors as reference sensors in the experiment to understand the freezing/thawing process better.

The aim of the study is to present a novel low-cost monitoring GPR system prior to field deployment. We slightly changed the abstract by stating that the aim of the paper was to test a low-cost monitoring GPR, L.5 " The correspondence between the frozen front electromagnetic reflection and temperature allowed to test the ability of the system to closely monitor the frozen front/bottom of the active layer reflection.

We emphasize the aim of the study, as well, at the end of the introduction :

"Here we present a novel combination of low-cost/-energy nimble GPR mono-static ground-coupled antenna with a reflectometer in conjunction with a small array of thermal and volumetric water content sensors for monitoring active layer freezing and thawing during laboratory experiments. The study is thought as a first test case on a active layer laboratory analog before near future field deployments."

2 Scientific quality (rigour): 3

The experiment is well constructed under laboratory conditions. Section 2.1 is well written, except it is unclear whether three or four volumetric water content sensors are used.

We clarified that we used three sensors for VWC measurements. L 48 "Complementing these thermal measurements, 3 volumetric water content sensors (Decagon Terros 12) were set diametrically opposed to the thermistors string at 0, 10, 20 and 30 cm from the bottom of the sand layer". We modified as well the Figure 1-a)

The reviewer doubts if bedding the bowtie antenna by 30° can help to focus the energy.

We removed the sentence, since we are not presenting multiple antenna tests in this present study.

Equation (3) does not match its description (Line 91). The reviewer cannot understand why neither ϵ_w nor θ_i is given in equation (3). Further, in Section 3.2, the reviewer cannot understand how the dielectric permittivity distribution is derived from equation (3).

It has been corrected, this was, as you pointed out as well, typos. We added as well, Line 91 : "A transition zone was assumed between these two types of media (frozen/ unfrozen) were coexistence between frozen and thawed media was derived using the measured freezing curve without considering any change in porosity through the freezing process."

3 Significance (impact): 3

Since the main result is poorly presented, the reviewer cannot judge the significance of the contribution.

We tried to clarified the result presentation. Figures 1, 2 and 3 have been changed according to your remarks and better legend have been written. Paragraph 3.2 have been edited and we simplified Figure 3. As the paper has to be kept as short as possible, we were not mentioning all necessary information as you pointed out, we hope it is now clearer and you will be able to judge.

4 Presentation quality: 4

Poor writing style with many typos. The notations are not consistent, for example, S11 and zero-isotherm.

Has been changed according to your remarks.

Mistakes, e.g., line 103: "the depth of the zero-isotherm reaching the ground surface after 125h from the start..." does not match figure 2c).

Has been changed according to your remark.

Line 145: "efficiency ...is...less than a centimeter". What does this mean?

has been change to L 155 :" For the laboratory conditions encountered in the study, the M-GPR method was able to monitor a moving interface with an uncertainty being less than a centimeter [...]"

The quality of the figures is poor. Every figure has another font size.
We tried to correct this, in this new version.

The axis label of Figure 3(b) is even half covered. The reviewer cannot understand Figure 3(b). If we look at the t=0 curve, does it mean at the beginning of the experiment, the height of the sand is only about 0.1 m?
We modified the figure 3b to have the axis labels visible. The figure 3b represents relative permittivity profiles at different simulated times, corresponding to a freezing front going upward. The frozen saturated sand has a relative permitivity of about 4, while the saturated sand reaches 23. As the frozen front is moving upward the permittivity is dropping from 23 to 4, following a sigmoidal shape (Soif Freezing Curve). This is the same kind of profile you would obtain during a capillary rise.

Figure 3(d) should be an important result of the contribution. However, it is very poorly described. What are the black dots in the plot? Why are they not been used for calculating the linear regression?

The figure has been re-drawn, the black dots were corresponding to the beginning of the experiment and thawing phase. We now keep only the freezing phase points. We plot the 0-degree isotherm height as a function of the two-way travel times between the bottom of the sand and the freezing front. As such, we obtain the time needed for the EM wave to propagate thought the frozen media and then its bulk permittivity. We changed and added a sentence on Line 143-145 : "[...] gives the time needed for the electromagnetic wave to propagate thought the frozen media as a function of its thickness. Figure 2-d) shows that the points (TWTs as a fonction of frozen front height) align in a linear relationship inversely [...]". We do hope and do believe it will help you understand.

Thanks for your relevant comments,
Best regards
Emmanuel Léger