Response to referee report 1 for: “InSAR sensitivity to active layer ground ice content in Adventdalen, Svalbard”

In the following, we answer (shown in blue) the comments from the referee (shown in black). Changes to the manuscript are shown in italics.

Thank you for including the core cross sections, which have helped answer many of my questions. This manuscript was significantly improved by addressing the reviewers' questions, and revisions were made in accordance with their comments. I consider this work an important contribution to the remote sensing of frozen ground behavior, with field validation, which is rare.

However, I must still address an essential discussion for authors to consider in their future research, as follows. I defer to the authors' decision whether to respond to my comments and incorporate them into their manuscript or discuss them in their future works.

The key concern points of my major comments 1-3 were the contribution of volumetric loss to pore ice melt. Please note that I am in total agreement with the 100% contribution of excess ice melt to seasonal subsidence. Although we are on the same page in the fact that the primary contribution to the seasonal thaw settlement is due to the loss of excess ice (in other words, the primary cause of the frost heave is ice segregation/ice lens formation due to soil water redistribution), my concern is that the full contribution of 8 % pore ice to the thaw settlement must be a significant overestimate (I am aware that authors excluded very dry portions from this discussion).

For example, my major comment2 “...20% to total subsidence (as shown in Fig. 6) ...

“(AC2 in your response) is stating about the contribution % in the total subsidence, for example, about 20 % (20mm PIC contribution against 100mm total subsidence). for A1, about 50 % for E8, or 100 % for E10.

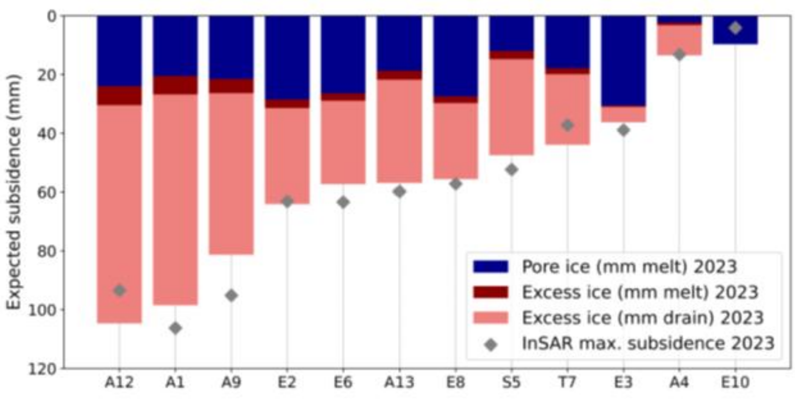
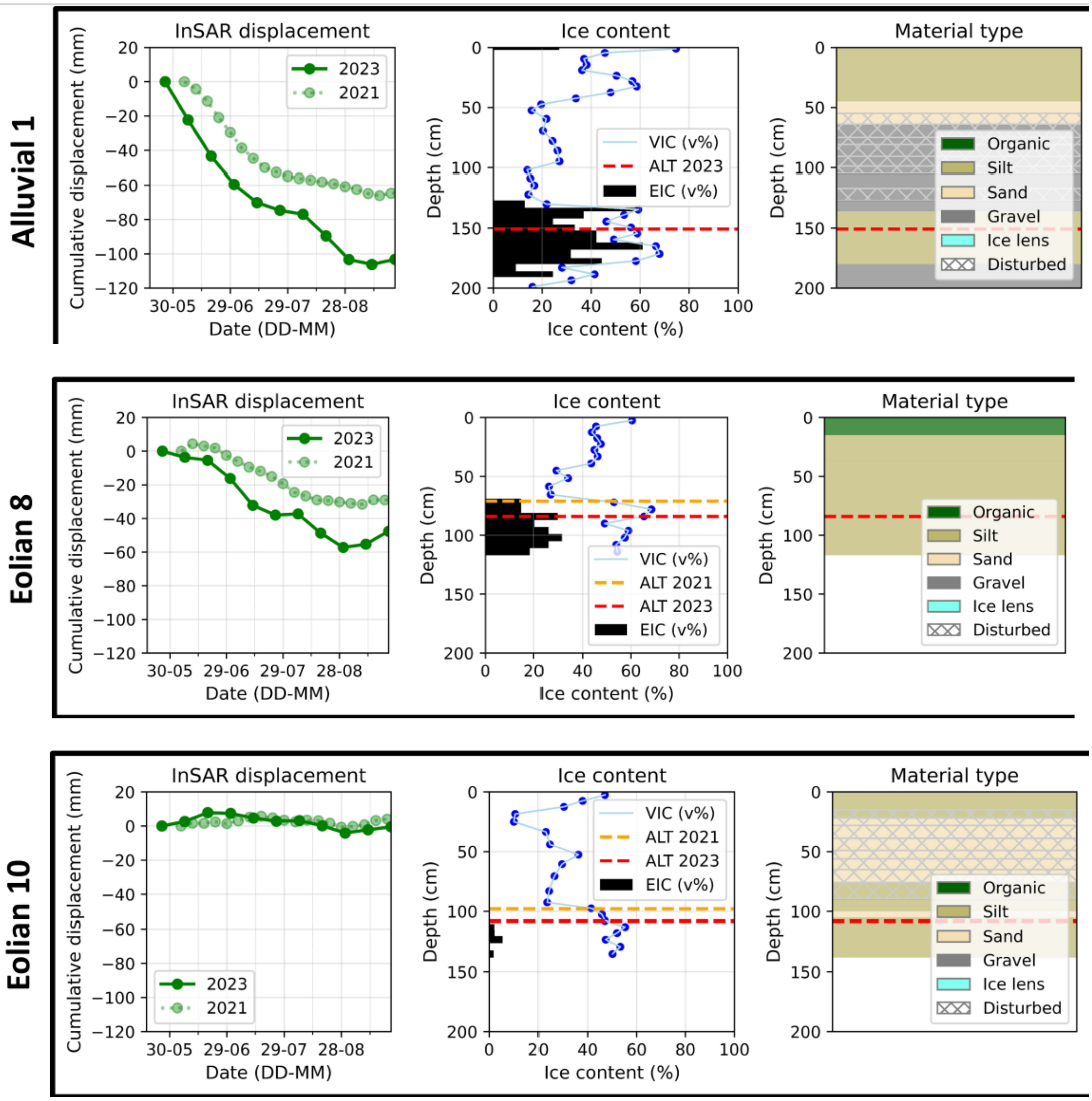


Figure 6: Contribution of pore ice melt, excess ice melt, and excess ice meltwater drainage to the total expected subsidence for each coring site. The maximum InSAR subsidence in 2023 is displayed as grey diamonds. The x-label denotes the site names (sediment deposit type and unique core number, see also Table 1).

According to the authors' estimation model of thaw subsidence from core analysis, most of the upper AL at their sites frost-heaved 100% due to water phase expansion, as they contained no excess ice (see the examples of A1/E8/E10 below).

Although I agree that this happens in a close-system of fully saturated soil, it is unlikely in unsaturated soils or even in fully saturated soil in an open-system (in the case of our argument, the freezing front goes top down, and the water expansion pressure can escape to the air space in the unsaturated zone beneath (or 3-dimensionally/laterally). In your study sites, E3 may have had a condition of waterlogged (saturated) bog, where 9 % volume expansion of pore water could fully contribute to the frost heave amount. However, other sites seem to have unsaturated conditions, where I cannot imagine a closed system in the AL.



The no-EIC zone in AL is fully saturated or unsaturated (not over-saturated). Judging from the soil texture and VIC of the above three examples (A1, E8, and E10), the AL of most locations appears to be largely unsaturated (I am aware that the authors have already excluded highly unsaturated and disturbed soil layers from the subsidence estimation). Even though the AL was saturated just before freezing and the soil water was redistributed, producing frost heave, the middle layers of the frozen AL tend to have a desiccated zone due to cryosuction and water redistribution. And the pore waters in those unsaturated zones should not be regarded as contribution sources to the subsidence.

My understanding and knowledge from previous studies on frost heave were that there was a negligible contribution from pore-water expansion upon freezing to the amount of frost heave in the most natural ground surface layers.

Therefore, accounting for all PIC in the AL to contribute to frost heave/thaw settlement can be a significant overestimate in this study, although the volume reduction is only 8% of them, and although the absolute subsidence calculated is relatively small. This argument may considerably influence the validation assessment between InSAR and expected subsidence, especially when the contribution of pore ice melt is significant enough.

We thank the reviewer for highlighting this uncertainty. We agree that the contribution of pore ice melt may be overestimated in partially unsaturated soils that act as open systems. In our analysis, visibly unsaturated or disturbed core sections were not included in the expected subsidence calculation to avoid this bias. The 8% volumetric contribution was only applied to intact core sections, which were classified as pore-ice saturated after visual examination. Nevertheless, we acknowledge that open-system behaviour cannot be ruled out where lateral or vertical escape of expansion pressure would reduce frost heave and subsequently lead to less pore-ice-melt-induced subsidence than the theoretical 8% volumetric reduction assumed here. We have clarified this in the discussion of the limitations and highlighted it as a priority for future field validation as follows (L. 517 in revised manuscript):

> *"Lastly, pore ice melt from core sections that were retrieved intact and appeared saturated was considered to contribute to the expected subsidence in this study. However, open-system behaviour of the active layer could have allowed lateral or vertical escape and expansion pressure from phase change to dissipate, leading to less pore-ice-melt-induced subsidence than the theoretical 8% volumetric reduction. This may have caused an overestimation of the expected subsidence from pore ice melt and could have affected the validation assessment between InSAR and expected subsidence. Future research should aim to better quantify the role of pore ice in heave-subsidence soil mechanics under natural freezing and thawing conditions."*