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Interactive comment on "Vulnerable top-of-permafrost ground ice indicated by remotely sensed late-season subsidence" *by* Simon Zwieback and Franz J. Meyer

Anonymous Referee #3

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Review of "Vulnerable top-of-permafrost ground ice indicated by remotely sensed late-season subsidence" by Simon Zwieback and Franz Meyer

This work proposed the use of late-thaw-season subsidence occurring in an extremely warm year to indicate the presence of ground ice at the top of permafrost. The study builds on a simple idea that if ice-rich ground thaws at the end of a warm summer, the resulted surface subsidence should be larger than in other normal or cooler summers. The authors presented InSAR observations in their study area that soundly support this idea and further backed up using independent ground ice mapping as obtained based on borehole data and manual interpretation from optical imagery. Overall, this

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Discussion paper

is an innovative way to utilize InSAR data for studying permafrost. Despite that the current work only provides a new indicator for the presence of excess ground ice at near surface, it may lead to more quantitative estimates of ice content or even temporal changes of ice content using observations alike.

I would like to raise a few points, hoping to improve the clarity and rigor of the paper.

1. Excess ground ice

For TC readership, it would be better to first define what excess ground ice is, e.g., referring to the Glossary of permafrost and related ground-ice terms as ‘the volume of ice in the ground which exceeds the total pore volume that the ground would have under natural unfrozen conditions’. A clear definition would help to interpret the schematics as shown in Figure 1 and equation 1. Since the excess is relative to pore volume, it is more rigorous to include the contribution of pore ice. The authors’ strategy is clever as the use of late-thaw-season subsidence in a warm summer implicitly removes the contribution from melting of pore ice (which happen in all summers, manifesting in the ‘early-mid-season’ results shown in Figs 6 and 10). The validity of equation 1 also builds on the fact that subsidence due to the melting of pore ice is negligible in late summer.

Figure 1 is confusing at first sight. The ice content profiles imply excess ice in the active layer, even in the ice poor case (or the authors mean pore ice instead of excess ice in the active layer?). And a minor note is that the label ‘heave - subsidence’ unnecessarily implies heave. The figure caption is already clear.

2. Top of permafrost

The classic two-layer model, active layer on top of permafrost, is adopted and well suits the nature of this work. In the discussion section, the authors did introduce the more complete four-layer structure: active layer, transient layer, intermediate layer, and permafrost. As the time scale of concern is an extremely warm summer within a few years (three, in this case), it is very likely that the excess subsidence is due to melting of ice-rich intermediate layer or transient layer (later of which is possibly ice rich, yet the authors claimed to be ice poor, L248), instead of the permafrost below. Then, is it justifiable to claim that excess ground ice is present at the top of permafrost (part of permafrost)? I would be more comfortable to use 'near permafrost table' or alike to allow some leeway. Quantitively, excess subsidence of 5 cm may correspond to an ice-rich layer of 5-10 cm, roughly the same order of magnitude as the thickness of transition zone (transient layer + intermediate layer).

3. Extremely warm summer

I have no doubt that 2019 was an extremely warm summer in Kivalina (it was the warmest according to Fig. 2b). Without a statistical or meteorological perspective, I would also regard 2018 as very warm (2nd warmest in the Fig 2b time series); yet the late-summer subsidence in 2018 was normal. Then I was wondering how 'exceptional' the warming must be to cause the excess subsidence. Is it ever possible that the excess subsidence in 2019 resulted from the decadal warming in the region, esp. considering that it typically takes decades or longer to thaw permafrost in continuous permafrost zones?

4. Timings of late thaw season

The choices of the beginning and end of late season (namely, t1 and t2) make sense. I was just wondering if these are backed up by temperature data and do you need to adjust them when applying this method in different areas (I suppose you need). The authored mentioned 'diurnal frost heave', were there any signs of heave in September? Then how about late-summer heave (Mackay 1983 10.1139/e83-012)?

5. Overall, I think larger-than-usual late-season subsidence is an indirect, instead of direct, indicator of "vulnerable excess ground ice" near the permafrost table.

Minor comments

3.1.4 The authors may provide more details of the spline fitting and help us to understand Fig 3b.

L167: $ should be &

L209: Delete the extra for

L228: indicate should be indicates

L251: Its should be It

L312: an should be and

L316: includes should be include

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