Dear Editors and reviewers:

We appreciate the constructive feedback we received, and here we provide detailed explanations of how we revised the paper to address one reviewer's questions. The reviewer comments are in blue, our responses are in black, and relevant text edited or found in the manuscript file is italicized. We thank the reviewers for their insightful comments, which substantially improved the quality of the paper.

Reviewer 1

Reviewer 1 did not provide any comments/questions in this round of review.

Reviewer 2

Comment 1 - Line 6: Maybe consider specifying it is the "equivalent thickness" of soil water that experiences the annual freeze-thaw cycles that ranges from 0 to 75 cm?

Response: We followed the reviewer's suggestion and changed Line 6 to: *"... the equivalent thickness of the soil water..."*.

Comment 2 - Line 22-25: It is not clear to me how the fate of carbon will depend on wetness or dryness. In your analysis, there is no net loss of soil water (line 94: the amount of water that experienced the annual freeze-thaw cycle does not change much – net water drainage ~ 0), no matter whether it is wet or dry. If the water is staying still and just freezing and thawing locally, the link from the soil water storage to the carbon cycle that seems to motivate the entire manuscript from the abstract and the introduction is not apparent to me. I would have thought that soil water is an important topic on its own because it sustains the ecology, and permafrost thaw could bring hydrological or geo – hazards etc.

Response: Water saturated soils can deplete oxygen and become anaerobic, which alters the balance of CO2 versus CH4 produced. We clarified this at Line 22-25:

"*Whether the carbon held by… depends largely on the wetness or dryness … of the active layer, which controls the redox status of the soil that influences the balance of CO2 and CH4 production (Bond-Lamberty et al., 2016; Taylor et al., 2021)*".

References:

Bond-Lamberty, B., Smith, A. P., & Bailey, V. (2016). Temperature and moisture effects on greenhouse gas emissions from deep active-layer boreal soils. Biogeosciences, 13(24), 6669–6681. https://doi.org/10.5194/bg-13-6669-2016

Taylor, M. A., Celis, G., Ledman, J. D., Mauritz, M., Natali, S. M., Pegoraro, E. -F., Schädel, C., & Schuur, E. A. (2021). Experimental soil warming and permafrost thaw increase CH_4 emissions in an upland tundra ecosystem. Journal of Geophysical Research: Biogeosciences, 126(11). https://doi.org/10.1029/2021jg006376

Comment 3 - Figure 2: The newly added cartoon does a good job in illustrating the conceptual model. Column A and column B are rather repetitive and can be combined into one. Column C looks like there is an additional layer of sediment in the frozen layer and overall, which is inaccurate. Could you decide in your model, whether the water will fill in the pore space of a thicker sediment column when frozen, or will expand the pore space of the original saturated sediment column? In either case, the total number of bubble layers should stay constant.

Response: We combined columns A and B as suggested, and we edited Column C so that the total number of soil layers remains unchanged in both unfrozen and frozen cases. In our model, water in the unsaturated zone can expand to fill the empty pore space (soil atmosphere) during freezing without contributing to surface deformation. Water in the saturated active layer leads to uplift during freezing.

NEW FIGURE 2:

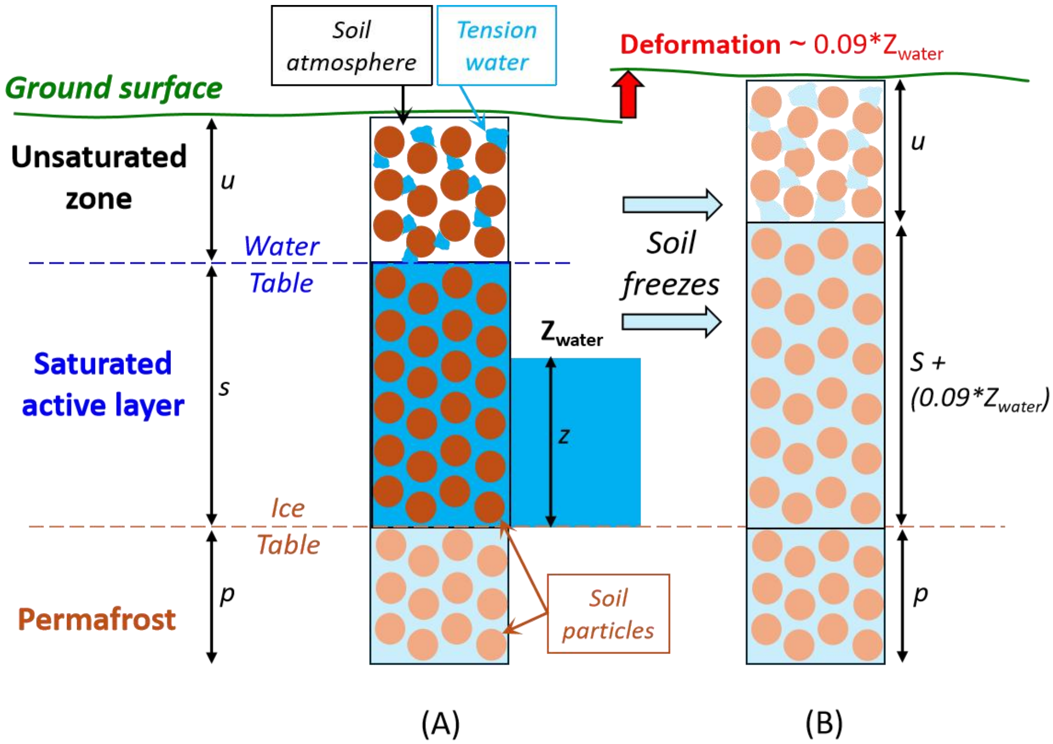


Figure 2. Conceptual diagram of how the depth of saturated water (Z_{water}) affects soil surface deformation. (A) The summer case when the entire active layer is thawed. Here the soil is divided into three zones: (1) the active layer unsaturated zone (thickness of u), which contains soil particles (dark circles) and soil atmosphere (white open space). It may also contain tension (capillary) water (shown in light blue); (2) the water-saturated active layer (thickness of s). The upper surface defines the water table, and the lower surface defines the ice table that separates the thawed active layer from frozen ground (or the permafrost layer at maximum annual thaw depth); and (3) the frozen permafrost (thickness of p). (B) The winter case when the entire active layer is frozen. Water stored in the saturated active layer leads to frost heave ($0.09*Z_{water}$) during freezing. By contrast, water in the unsaturated zone can expand to fill the empty pore space (soil atmosphere) during freezing without contributing to surface deformation (thickness u does not change).

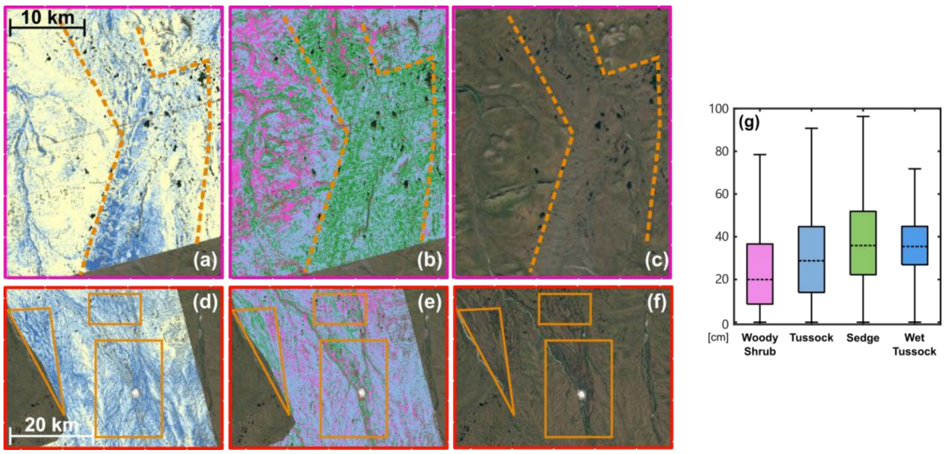
Comment 4 - Figure 5: The land cover map is labelled with 3 land cover classes, but in your data analysis in Table 1 and Figure 7, you added a 4th "Wet Tussock" class. In Figure B4, you show three field photos including a wet sedge instead of wet Tussock. It would be nice to be more consistent. Could you also label Fig 7 against the red and purple polygons in panel c, as it is not described in the caption, only mentioned in the capture of Figure 7.

Response: In this study, we mainly focused on three land covers: "Heath", "Tussock", and "Sedge". We found that the active layer tends to be wetter as the terrain becomes flatter in the northern part of the study area (Path 255 Frame 1380). Thus, we refer to the "tussocks" pixels in regions highlighted in Figure 7 (d)-(f) as "wet tussock".

We clarified at Line 316-320: "*Figure 7 (d)-(f) shows another zoomed-in area from frame 1380 (with the location outlined in a red dashed line in Figure 5(c)), where the terrain transitions from rolling hills to coastal plains. Here, tussocks are the dominant land-cover type, and water-loving shrubs and sedges are distributed along the water tracks (visible in the optical image). Because this region is wetter than the Toolik Lake area, we refer to the tussock pixels in Figure 7 (d)-(f) as "wet tussock" in Figure 7 (g) and Table 1"*. We also changed the caption of Figure B4 to *"... (c) sedge land cover..."*.

In Figure 7, we added purple outlines to panel (a)-(c) and red outlines to panel (d)-(f) to better illustrate the image locations in Figure 5. We have changed the red solid and dashed outlines to orange to avoid confusion and updated the figure caption accordingly.

NEW FIGURE 7:

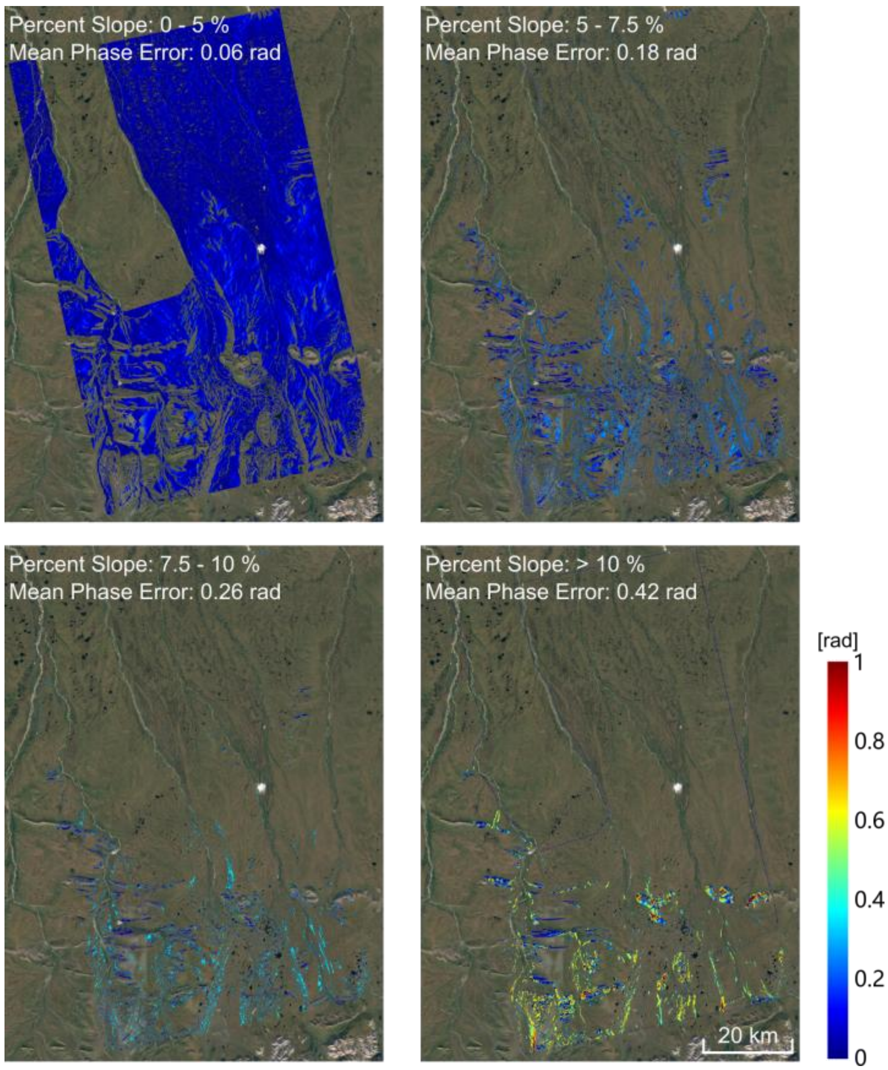


Comment 5 - Figure 14: The caption says the locations of these pixels are shown in Figure 10. I see one location of Pw and one location of Pe and if we are looking at all interferograms with phase difference extracted from these two locations and from the Pf pixel, why should there be a range of slopes?
Response: As shown in Figure 10-11, InSAR phase measurements around point P_W and P_E are noisy, and the slope shows relatively large spatial variations. To generate Figure 14, we calculated the average phase difference across a ridge line (P_E-P_W) and across a flat area (around point P_f) to estimate the LOS errors at these two locations. Here phase averaging around a point of interest serves as a spatial box filter, which reduces random phase noises associated with surface vegetation.
We rephrased the caption of Figure 14 to: *"... perpendicular baseline (in m) at P_E-P_W with an average percent slope of 10.4% (blue dots) and around P_f with an average percent slope of 1.9% (orange dots)"*. In this updated caption, we reported the average slope of all pixels used for estimating the LOS errors..

Comment 6 - Line 449: In various places in text, you concluded that 95% of Z_{water} estimates range from 0 to 62 cm (and I assume the whole range is 0-75 cm). This can only result from a subsidence map that is strictly negative, as shown in Figure 5a. I wonder whether there is any positive value detected in the InSAR thaw subsidence map due to the misregistration of DEM pixels, given how the offsets should produce both positive and negative errors rather symmetrically. If not, is it a lucky event? Or is it expected as it is the valleys that are wetter and subside faster and experience more of an error with pixel corregistration? Or maybe could we have a Z_{water} map against an estimated error map to show the uncertainties in map new? Figure 5 and Figure 13 currently do not have the same extent.
Response: As shown in Figure 5(a), InSAR suggested a majority of pixels experienced centimeter-level thaw subsidence between early June and late July. There are positive values below the noise level (<1cm) detected at a small number of InSAR pixels, mostly around the reference point (a dry highland area with relatively flat terrain; marked in Figure B1) where the minimum seasonal deformation is expected. The positive values were due to noise (e.g., residual decorrelation noise and residual tropospheric noise) added to ~ 0 cm of deformation signal. We also want to note that up to 75 cm Z_{water} was observed in the wettest riparian zone after removing less than 3% of outliers. We clarified this in the first paragraph of Section 3.1.

We have updated Figure 13 to cover the same area as Figure 5, and our conclusion remains the same: the pixel misregistration artifacts are mostly observed in a small subset of pixels with relatively large slope angles (located in the southernmost portion of the study area). As shown in Figure 10, while we observed a phase difference across the ridge line (P_E-P_W) in early June to late July interferograms, the LOS phase observations are ≥ 0 radians on both east and west sides of the ridge (Here pink indicates positive LOS or subsidence and blue indicates minimum deformation) with respect to the reference point (marked in Figure B1). We also presented additional interferograms in the zoom-in region in Figure 11. As noted in Figure 11 caption, all interferograms here were referenced to a local reference point near P_E (not the reference point marked in Figure B1). This is why, we see both positive and negative phases in Figure 11.

NEW FIGURE 13:



In addition, could we have some statistics on the subsidence magnitude (or Z_{water}) vs slope (scatter or box-and-whisker) to understand whether the 14 cm of error are associated with the high-end of the Z_{water} values or not?

Response: As we discussed in Section 2.3. the <1cm error in LOS measurement (equivalent to <14 cm error in Z_{water}) could be due to residual tropospheric turbulence noise. Topographic artifacts related to DEM-SAR pixel misregistration are most noticeable in areas with a slope larger than 10% (Figure 13). We emphasize that the DEM error δ is determined by both the slope angle and the amount of pixel misregistration. When there is no pixel misregistration, DEM error equals 0 regardless of the slope angles. Furthermore, while topography influences soil water distribution (Z_{water}), there are many other factors that can play a role. Therefore, we cannot identify any clear relationship between subsidence magnitude vs slope in a scatter plot.