# Response to Referees and Community Comments

*Title*: Characterizing Near-Surface Permafrost in Utqiaġvik, Alaska, using Electrical Resistivity Tomography and Ground Penetrating Radar.

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*Date*: 11/28/2025

## RC1: 'Comment on egusphere-2025-4702', Anonymous Referee #1, 05 Nov 2025

**Comment:** I believe this should be accepted with minor corrections, those corrections solely being the formatting of the manuscript. Some of the figures, particularly the GPR B Scans are small and are not easy to read. Additionally the formatting is such that the figure captions are on different pages to the figures in some locations. The application of methods is appropriate for the setting and there is a clear justification for the purpose and necessity for this research.

**Authors' Response:** Thank you very much for your positive assessment and helpful comments. We have increased the size of all figures, with special attention to GPR profiles, and adjusted the font size of all associated labels to improve readability. We have also revised the manuscript layout to ensure that, wherever possible, each figure now appears on the same page as its corresponding caption. Changes were made to Figures 2–6 (pages 8, 11, 14, 18, 22).

## RC2: 'Comment on egusphere-2025-4702', Anonymous Referee #2, 06 Nov 2025

**Comment #1:** Paper presents an interesting analysis of several sites in Alaska examined via ERT, GPR and thaw probing. Revision of the figures is necessary to make the results clearer to the reader as they are difficult to read with the current size and text sizes. Additional images of the sites without the scans overlaid would also aid in the interpretation of the results and understanding of the sites.

**Authors' Response to comment #1:** Thank you very much for your comment. We increased the size of Figures 2–6 and the font size of all labels, colorbars, and annotations to them (pages 8, 11, 14, 18, 22). In addition, we added several photographs of the study sites to aid interpretation of the geophysical results (figure 2 on page 8, figure 3 on page 11, figure 4 on page 14) with additional clarification in the text:

Page 7, line 178–179: clarification to the reference of the figure in the text was added because a new picture was added.
Original: '…Figure 2a…'.
Revised: '…Figure 2a, top…'.

Page 7, lines 182–183: text added to reference the new site photo – 'The building is elevated on pillars to reduce the structure's thermal impact on the underlying permafrost (Figure 3a, left).'

Page 8, lines 191–193: text was added in the figure caption to clarify the new site photo: 'Top – Survey layout showing the ERT profile (blue) and the GPR profile (green) overlaid on an ESRI basemap (QGIS). Bottom – Photograph of a >3 m snow pile at the TNHA site, located along the W–E transect during winter–spring (May 2025). Photo: Hannah Bradley;'

Page 9, line 224: clarification to the reference of the figure in the text was added because a new picture was added.
Original: '…(Figure 3a)…'.
Revised: '…(Figure 3a, right)…'.

Page 11, line 250: text was added in the figure caption to clarify the new site photo:
Original: '…(a) Surface elevation beneath the building at the TNHA site, outlined by the red line, indicating possible frost heave features (28 June 2024)'.
Revised: '…(a) Left – Photograph of the TNHA building (June 2024). Photo: MacKenzie Nelson. Right – Surface elevation beneath the building at the TNHA site, outlined by the red line, indicating possible frost heave features (28 June 2024)…'.

Page 12, line 280: clarification to the reference of the figure in the text was added because a new picture was added:
Original: '…The building is elevated ~1.5 m on wood piles…'.
Revised: '…The building is elevated ~1.5 m on wood piles (Figure 3a, left)…'.

Page 14, line 311–313: text was added in the figure caption to clarify the new site photo:
Original: '…(a) Location of ERT (blue, SE–NW) and GPR (green) profiles near the old section of Cakeeater Road, shown on ESRI satellite imagery (QGIS). …'.
Revised: '…(a) Left - Location of ERT (blue, SE–NW) and GPR (green) profiles near the old section of Cakeeater Road, shown on ESRI satellite imagery (QGIS). Right – Photo of the similar site with snow accumulation and melt water ponding along the Imaiqsaun Road (photo by Valentina Ekimova, May 2025);…'.

Page 16, line 377–378: text was added to make a reference for the new photo of the site and clarification of the connection with analysis: 'Photo from another site near showing the snow accumulation and ponding of the melt water at Imaqsaun Road in May 2025 (Figure 4a, right). '

**Comment #2:** Paper's aims would be aided by a discussion section linking the results and a discussion of the results of the different monitoring methods/a more robust analysis of how they compare/can be aided by one another. And an explanation of where they differ.

**Authors' Response to comment #2:** Thank you for the comment. We added a short comparative discussion at the end of each section (regarding each site) of the different methods' results on permafrost investigation (ERT, GPR, and thaw probing), highlighting where they provide consistent results and where they differ.

The text was added in the following places of the manuscript:

Page 13, line 291–295 (for TNHA site): 'The comparison of ERT, GPR, and thaw-probe results at the TNHA site shows strong overall agreement in the spatial pattern of thaw, yet each method contributes unique detail. ERT delineates subsurface features and active layer thickness, including the area beneath the building where the active layer is shallower directly under the structure and deeper along its sides; deeper thaw is also identified in the GPR data, and thaw depths from both geophysical methods are confirmed by the thaw-probe survey.'

Page 17, line 394–397 (for the old spur of Cakeeater Road site): 'Taken together, thaw depth estimates at the Cakeeater spur site derived from ERT, GPR, and thaw-probe measurements are in good agreement and show a consistent pattern of deeper thaw beneath and adjacent to the road and shallower thaw in tundra with undisturbed vegetation. GPR helps to distinguish ice wedges, while ERT resolves deeper subsurface features in the area.'

Page 21, line 493–497 (for the snow fence site): 'Overall, thaw depths inferred from ERT and GPR broadly agree with probe measurements, especially in the undisturbed tundra (with natural vegetation cover and water flow) and east of the fence, but ERT indicates somewhat greater depths in the thaw ponds, where elevated moisture content affects resistivity values. Taken together, ERT, GPR, and thaw probing provide a coherent picture of spatial thaw variability, with ERT also resolving deeper ice-rich zones and GPR capturing near-surface thaw and the locations of ice wedges.'

Page 23, lines 552–556 (for BEO site): 'Overall, thaw depths inferred from ERT and GPR broadly agree with probe measurements across both the polygonal and frost-heave segments, with the greatest depths consistently associated with ponded and degraded polygon areas near the road. Taken together, ERT, GPR, and thaw probing provide a coherent picture of thaw variability at the BEO site, with ERT resolving deeper ice-rich zones, GPR highlighting near-surface thaw and ice-wedges location, and probing providing point-scale ground truth for thaw depth.'

Page 24, lines 590–594 (in conclusion part): 'Across all sites, thaw depths inferred from ERT and GPR generally agreed with ground truth thaw-probe measurements, with the largest differences in water-saturated thaw ponds and dry gravel pads where geophysical sensitivity is reduced. Taken together, these methods provide a consistent yet complementary view of near-surface permafrost, where ERT constrains subsurface features, GPR resolves the geometry of thaw and ice wedge location, and thaw probing supplies point-scale ground truth for thaw depth.'

**Comment #3:** Additionally for Figure 1: the naming scheme for sites could be clarified between figures and the text.

**Authors' Response to comment #3:** Thank you for the comment. The naming logic was adjusted to align with the caption of Fig. 1, with changes on page 4, in lines 111–114:
Original: 'Surveys were conducted at four sites (Fig. 1): (1) a Taġiuġmiullu Nunamiullu Housing Authority (TNHA) residential area with localized thermokarst; (2) the old section of Cakeeater Road that crosses an ice-wedge polygonal landscape; (3) a snow fence with delayed melt and frost heave (Hinkel and Hurd, 2006); and (4) the Barrow Environmental

Observatory (BEO)…'
Revised: 'Surveys were conducted at four sites (Fig. 1): (a) a Taġiuġmiullu Nunamiullu Housing Authority (TNHA) residential area with localized thermokarst; (b) the old section of Cakeeater Road that crosses an ice-wedge polygonal landscape; (c) a snow fence with delayed melt and frost heave (Hinkel and Hurd, 2006); and (d) the Barrow Environmental Observatory (BEO)…'

**Comment #4:** For the methods, an discussion of soil conditions in the region would aid in the analysis.

**Authors' Response to comment #4:** Thank you for the comment. Some additional information on soil conditions was added in the text on page 4 in lines 101–103:
Original: 'The area is underlain by Quaternary nearshore marine, alluvial, and eolian sediments forming the Gubik Formation, divided into the Barrow Unit (organic-rich sands, silts, and gravels) and the Skull Cliff Unit (marine, clay-to-cobble materials). The Barrow Unit forming a roughly 8–15 m thick surficial veneer that overlies finer grained Skull Cliff sediments and Cretaceous bedrock at about 15–30 m depth (Black, 1964; Sellmann and Brown, 1973). Ice-rich permafrost is common, with segregated ice reaching 40–80% by volume and massive ice wedges several meters deep'
Revised: 'The area is underlain by Quaternary nearshore marine, alluvial, and eolian sediments forming the Gubik Formation, divided into the Barrow Unit (organic-rich sands, silts, and gravels) and the Skull Cliff Unit (marine, clay-to-cobble materials) (Black, 1964; Sellmann and Brown, 1973). Ice-rich permafrost is common, with segregated ice reaching 40–80% by volume and massive ice wedges several meters deep'

## CC1: 'Comment on egusphere-2025-4702', Rachel Harris, 14 Nov 2025

**Comment #1:** It is not clear what the guiding scientific question is for this work, which makes it difficult to assess how effectively the study design and results address the intended objectives. A definitive scientific question that is stated in the introduction, reiterated in the conclusion, and answered in the discussion, would aid reviewers' ability to judge the scientific results.

**Authors' Response to comment #1:** Thank you for the comment. We added an explicit statement of the guiding scientific question in the Introduction and the Conclusion. The corresponding text was added on page 3, lines 87–89: 'Our guiding question is how common infrastructure types in Utqiaġvik modify near-surface permafrost features and active layer thickness relative to a local tundra reference with unchanged vegetation and drainage, and whether combined ERT, GPR, and thaw probing can reliably resolve these differences for site assessment.' And the conclusion was revised on page 24, lines 573–575:
Original: 'This study provides an integrated geophysical assessment of near-surface permafrost characteristics within an Arctic city.'
Revised: 'This study provides an integrated geophysical assessment of near-surface permafrost characteristics within an Arctic city and examines how contrasting land use types (residential buildings, gravel roads, snow fences, and a local tundra reference site) alter near-surface permafrost structure and active layer thickness.'

**Comment #2:** For the GPR profiles where the author interprets ice wedges and labels them with dashed red lines on the profiles, the annotation lines extend to the surface, which is contrary to the understanding of ice wedge processes detailed in the published literature (e.g., Shur et al., 2025). The interpretation of the ice wedges within the active layer, as presented in the GPR results, also appears inconsistent with both the expected thermal regime of the permafrost and the corresponding ERT resistivity values for massive ice presence. Ice wedges typically occur below the active layer, within the perennially frozen zone, and their identification at shallower depths within the active layer should be carefully reconsidered. The authors could revisit their GPR interpretation and clarify whether the observed reflections may instead represent other features. Alternatively, if the authors have additional field observation, or ground truthing to support the presence of ice wedges within the active layer, this evidence should be explicitly presented or discussed.

**Authors' Response to comment #2:** Thank you a lot for this important comment. We revisited our GPR interpretation and the way ice-wedge–related features are shown. In the revised figures, the dashed lines no longer extend through the entire active layer up to the surface. Instead, we restrict them to the deeper, perennially frozen zone. Changes were made in figure 4 on page 14, figure 5 on page 18, figure 6 on page 22.

**Comment #3** The manuscript would benefit from revisions to improve figure quality and consistency. At present, the figures are too small to be easily read and interpreted; larger, higher resolution versions with larger text/label size are recommended. Review figure axes, color scales, and labelling so that they are consistent throughout each figure and the paper overall. For Figure 6, subfigure labels are incorrectly referenced in the text.

**Authors' Response to comment #3:** Thank you very much for your comment. We increased the size of Figures 2–6 and the font size of all labels, colorbars, and annotations to them (pages 8, 11, 14, 18, 22). In addition, for Figure 6 the inconsistency in the GPR ice-wedge interpretation was fixed on lines 507–509:
Original: 'Figure 6: (a) Location of SW–NE ERT (blue) and GPR (green) profiles at the BEO site in Utqiaġvik, Alaska (ESRI satellite imagery); (b) Thaw probe measurements along the ERT profile. SW–NE ERT profile: (c) Coarse-scale view (~0–40 m depth along the entire profile); (d) Fine-scale view (~0–2 m depth, from 0 to 82 m distance along the profile); (e) SW–NE GPR profile showing thaw depths (solid red line) and hyperbolic reflections was interpreted as ice wedges (red dashed lines).'
Revised: 'Figure 6: (a) Location of SW–NE ERT (blue) and GPR (green) profiles at the BEO site in Utqiaġvik, Alaska (ESRI satellite imagery); SW–NE ERT profile: (b) Coarse-scale view (~0–40 m depth along the entire profile); (c) Fine-scale view (~0–2 m depth, from 0 to 82 m distance along the profile); (d) SW–NE GPR profile showing thaw depths (solid red line) and hyperbolic reflections was interpreted as ice wedges (red dashed lines).;(e) Thaw probe measurements along the ERT profile.'

And correction of the figure references was done on lines 511–525:
Original: 'The SW–NE ERT inversion profile (Figure 6c–d) includes a coarse-scale view (~40 m depth, Figure 6c) and a small-scale view (~3 m from 0 to 82 m, Figure 6d). In the coarse-scale cross-section, the upper 5 m shows consistently high resistivity values (1,000–

10,000 Ω·m), with localized zones exceeding 10,000 Ω·m—interpreted as ice-rich permafrost (Zone D) and excess ice features such as ice lenses (Zone E).'
Revised: 'The SW–NE ERT inversion profile (Figure 6b–c) includes a coarse-scale view (~40 m depth, Figure 6b) and a small-scale view (~3 m from 0 to 82 m, Figure 6c). In the coarse-scale cross-section, the upper 5 m shows consistently high resistivity values (1,000–10,000 Ω·m), with localized zones exceeding 10,000 Ω·m—interpreted as ice-rich permafrost (Zone D) and excess ice features such as ice lenses (Zone E).'

And in line 537 (original: '(Figure 6e)'; revised: '(Figure 6d)'), 543 (original: 'Physical thaw probing (Figure 6b)…'; revised: 'Physical thaw probing (Figure 6e)…'), 547 (original: '…GPR observations (Figure 6c–e).'; revised: '…GPR observations (Figure 6c–d).'), 551 (original: '…GPR profile (Figure 6e)…; revised: '…GPR profile (Figure 6d)…'

**Comment #4:** The range on the color bar and the color bar label make it unclear if the resistivity values shown in the tomograms are on a log or linear scale. This may be related to a plotting bug in ResIPy.

**Authors' Response to comment #4:** Thank you for the comment. We checked and corrected the consistency among all figures and the text. The ERT resistivity values are displayed on a linear scale and are now clearly labeled as resistivity in Ω·m for Figures 2–6 (pages 8, 11, 14, 18, 22).

**Comment #5:** The color bar scales should be identical within the same figure since the entire cross-section and the zoomed in cross-section are showing the same data.

**Authors' Response to comment #5:** Thank you for the comment. The color bar is different on the large scale and the coarse scale, because the large scale demonstrates subsurface ice-rich features, while the coarse scale mainly aims to show active layer depth.

**Comment #6:** The ERT tomograms show elevation above sea level while the GPR radargrams show depth. The y-axis should be consistent between ERT and GPR images to facilitate direct comparisons between the two results.

**Authors' Response to comment #6:** Thank you for the comment. We corrected the y-axis for the ERT profiles to be in depth values, as in the GPR profiles, for Figures 2–6 (pages 8, 11, 14, 18, 22).

**Comment #7:** The resistivity zones (A-E) are inconsistently labeled and referenced between all the figures and captions.

**Authors' Response to comment #7:** Thank you. We checked all ERT figures, captions, and the main text and corrected the labelling so that zones A–E are used consistently throughout the manuscript. Figure 2 on page 8 and figure 3 on page 11 were corrected in labels of zones.

**Comment #8:** The ERT tomograms appear to have abundant vertical artifacts present within the inversion (Figure 5 in particular). It is recommended that the authors assess if the artifacts are a color bar scale issue, a mesh issue, or an issue with the inversion settings.

**Authors' Response to comment #8:** Thank you for pointing this out. We examined the inversion settings and mesh, and we agree that some of the vertical streaks in Figure 5 likely represent inversion artifacts and local small-scale heterogeneity. In the text, we state that our estimates of active layer depth are based on broader, laterally coherent patterns in the tomograms. Therefore, these artifacts do not affect our main interpretation of active layer thickness.

**Comment #9:** The satellite maps currently include only a scale and a north arrow. It would improve spatial interpretation if a graticule or coordinate grid were added to provide more specific location information.

**Authors' Response to comment #9:** Thank you. We added a grid with coordinates for Figure 1, containing all sites, on page 5.

**Comment #10:** Providing a more detailed description of the thaw-probing methods would aid in the transparency and repeatability of the experiment.

**Authors' Response to comment #10:** Thank you. We expanded the description of the thaw-probing procedure on page 6, lines 150–154.
Original: Thaw probing served as the primary ground validation technique, involving the insertion of a metal probe into the ground until reaching the point of refusal, which corresponds to the depth of the permafrost table. This method is highly effective for identifying the depth to permafrost but is less reliable in rocky terrain due to probe obstruction (Boike et al., 2022).
Revised: Thaw probing served as the primary ground validation technique, involving the insertion of a metal probe into the ground until reaching the point of refusal, which corresponds to the depth of the permafrost table. At each measurement point, the metal rod (probe) was pushed vertically through the thawed active layer until a sharp increase in resistance of sediments was encountered, interpreted as contact with ice-bonded, compacted sediments (permafrost). The probe was then withdrawn, the position of the ground surface on the metal probe was marked, and the penetration depth was measured with a measuring tape to obtain local thaw depth. This method is highly effective for identifying the depth to permafrost but is less reliable in rocky terrain due to probe obstruction (Boike et al., 2022).

**Comment #11:** The description of the “undisturbed tundra” site (site D) requires further clarification. Given the close proximity to a gravel road and an observatory, it would be useful to justify more clearly why the site that is located along the same road as sites B and C and near the building is considered undisturbed and used as a natural reference, and/or to adjust the terminology accordingly.

**Authors’ Response to comment #11:** Thank you. We clarified that the “undisturbed tundra” site is characterized by intact vegetation and natural drainage.

Page 1, line 15:
Original: ‘…to characterize near-surface permafrost variability across four land use types in Utqiaġvik, Alaska: gravel road, snow fence, residential building and undisturbed tundra.’
Revised: ‘…to characterize near-surface permafrost variability across four land use types in Utqiaġvik, Alaska: gravel road, snow fence, residential building and undisturbed tundra (with intact vegetation cover and natural drainage).’

Page 3, line 91:
Original: ‘Our focus on residential buildings, raised gravel roads, and snow fences reflects the most widespread infrastructure types in the Arctic, with undisturbed tundra included as a natural reference.’
Revised: ‘Our focus on residential buildings, raised gravel roads, and snow fences reflects the most widespread infrastructure types in the Arctic, with undisturbed tundra (with intact vegetation and unchanged drainage) included as a natural reference.’

Page 4, line 114:
Original: ‘…(d) the Barrow Environmental Observatory (BEO), representing undisturbed tundra…’
Revised: ‘…(d) the Barrow Environmental Observatory (BEO), representing undisturbed tundra (with unchanged vegetation and drainage)…’