Reply on RC2:

The authors focus on the ground deformation along the Qinghai–Tibet Engineering Corridor, a key infrastructure zone that crosses extensive, climate-sensitive permafrost. Using multi-year Sentinel-1 InSAR observations, the authors separate long-term displacement trends from seasonal freeze–thaw cycles and infers deformation directions by combining ascending and descending satellite tracks. The results indicate widespread subsidence and pronounced seasonal deformation linked to frost heave and thaw settlement, with different timing patterns between valley floors and hillslopes that reflect contrasting hydro-thermal and mechanical controls. The seasonal deformation signal is then used to infer active layer thickness with constraints from in-situ measurements of active layer thickness, revealing broad regional differences along the corridor. The work also documents substantial thermokarst activities including thaw slumps and thaw lakes near major infrastructure. The paper is highly informative, which is a strength, but it can also be distracting. With all comments well addressed, the paper can be considered for publication.

We appreciate for your careful read and a thorough summary of our manuscript and constructive suggestions. We add subtitles for section 4.3, an illustrative figure about the geometry of ascending and descending InSAR satellite trajectories and imaging. We clarify that, theoretically, this approach can be used to infer ALT changes, but need to use with caution because the determination of seasonal deformation amplitude can be biased when the time window is less than a couple of years (Lines 228 and 416; track-changes version of our new submission). We also read through our text and updated some descriptions for clarity.

Please find our point-to-point response as below.

Detailed comments are outlined below:

The authors may consider adding InSAR in the title to highlight the technique and spatially continuous mapping.

Thank you for your suggestion. We update the title to be “Linking InSAR-derived Permafrost Deformation to Active Layer Freeze-thaw Dynamics in the Qinghai-Tibet Engineering Corridor”.

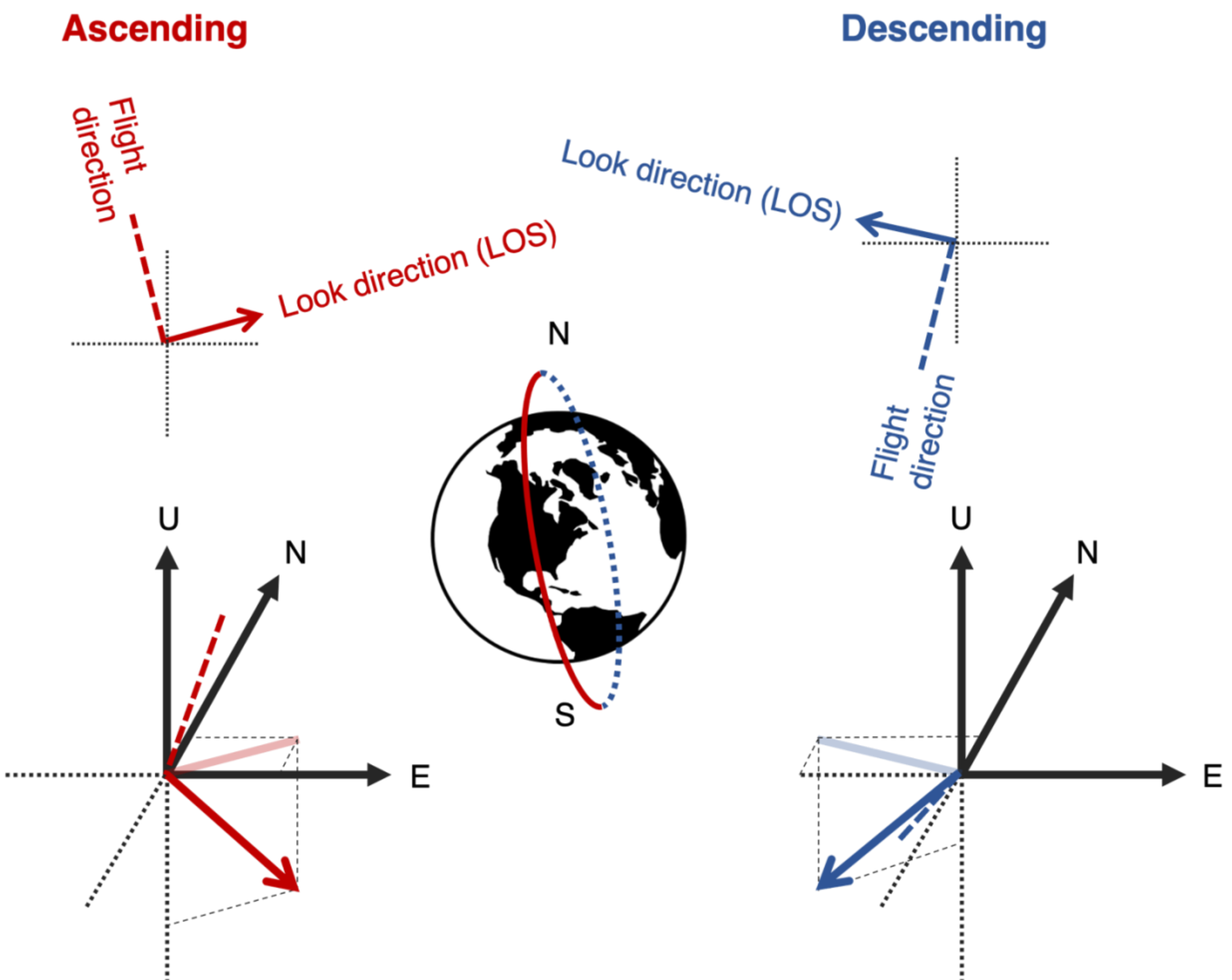
Line 54: “This situation presents substantial risks to the transportation safety of QTEC (Hjort et al., 2022; Yu et al., 2013).” Do both references talk about to the condition in QTEC?

One of the references (Hjort et al., 2024 <it should be 2024 not 2022 in our original text>) is about the risks to transportation safety in permafrost environment across the Earth.

We update the text as “This situation presents substantial risks to the transportation safety in permafrost environment (Hjort et al., 2024; Yu et al., 2013).”

Table 1: The authors can add an illustrative figure about the geometry of satellite InSAR.

Thank you for your suggestion. We add an illustrative figure about the geometry of satellites InSAR trajectories and imaging.



Line 180: “we identify and tally the peaks and troughs of the seasonal deformation. Typically, one calendar year holds one peak and one trough. This allows us to compile a collection of pixels with an anticipated number of peaks and troughs.” The authors should emphasize that this approach only favors for multiple years of observations.

We add the limitations. “This approach favors for multiple years of observations. The more the years the less fraction of the uncertain peaks and troughs among the total number.”

Figure 2: add label “not to scale”.

Added in the figure.

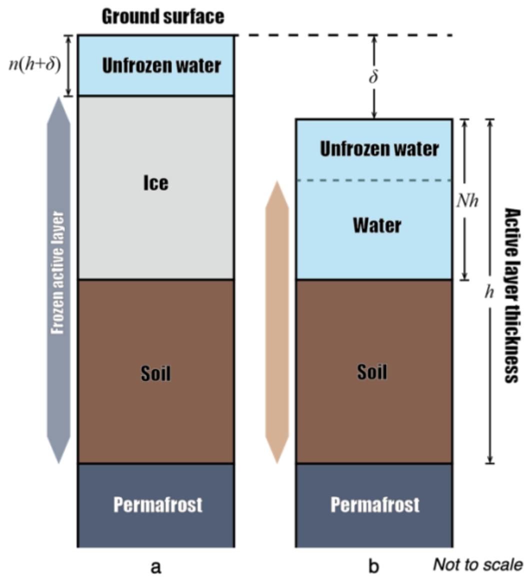


Figure 2: Schematic view of frost-heave to thaw-settlement transition in the active layer (not to scale). a, freeze season. b, thaw season. Water, ice, and soil blocks are separated to facilitate the math derivation. Vertical gray bars represent the frozen parts of the active layer during the freeze time epoch, and vertical brown bars represent the thaw parts of the active layer during the thaw time epoch. We refer to Liu et al. (2012) and Li et al. (2023) on the design of this schematic view with modifications.

Figures 5 and 6: The authors used displacement in the figure captions and legends but deformation in the text. The authors should use consistent wording to avoid confusion. The authors should rewrite the captions. What are the white polygons in the figures?

Thank you for noting this. We update and use “deformation” consistently through the text, including those in the figures.

The white polygons in the figures are glaciers. We add in the figure caption “The hollow (white) polygons represent glaciers.”

Line 252: change “permafrost dynamics” to “subsurface environment”.

Changed.

Line 260: “On consolidated hillslopes, elastic unloading peaks in late summer when substantial meltwater drainage occurs, thereby leading to the peak surface position.”

This is only a plausible reason. Can it be related to different arrival time of the lowest ground temperature at different altitude?

We cannot conclude that the timing differences in ground deformation are driven by altitude. As the other reviewer noted, surficial geology, ground-ice content, and vegetation conditions may also contribute. Given the lack of high-resolution data and because this is beyond the scope of this study, we prefer not to overinterpret altitude here.

Line 272: what is the meaning of "spaceborne line-of-sight measurements represent real movements"?

It is important to note that spaceborne InSAR measures only the projection of true ground deformation onto the satellite's line of sight; therefore, line-of-sight observations alone cannot determine the actual deformation direction. We update this sentence for clarity.

Line 275: what are the traditional and non-traditional interpretations of secular and seasonal displacement directions?

Thank you for your comment. We realize that the term "non-traditional" can lead to confusion.

Traditionally, determining the true direction of ground motion requires at least three independent InSAR line-of-sight viewing geometries. This is difficult to achieve with SAR satellites because they operate in near-polar orbits and image to the side, producing look directions that are predominantly downward to the east–west with only a limited north–south component. As a result, sensitivity to north–south motion is intrinsically constrained by the orbital geometry.

We therefore describe our approach as "non-traditional." Rather than estimating motion direction as an azimuth (degrees clockwise from north)—given the fundamental limitations of InSAR viewing geometry—we use the consistency between ascending and descending line-of-sight measurements to qualitatively infer the dominant deformation mode (e.g., primarily vertical or primarily horizontal). When motion is primarily horizontal, we can sometimes further distinguish whether the east–west or north–south component is dominant.

We simplified our writing by removing "non-traditional" to avoid misleading the readers.

What is the purpose of section 3.2 Disentanglement of ground deformation? It doesn't seem to show any regulations in Figures 5 and 6.

Thank you for your notes. We intend to look for regulations in the direction of ground deformation in section 3.2. We agree that Figures 5 and 6 do not show a strong regulatory signal. As an overview, for secular deformation, 31% of pixels show similar ascending/descending magnitudes (vertical), 19% show similar magnitudes with opposite signs (east–west; mainly near lakes and seasonally frozen ground around Lhasa and north of Golmud), and 50% are indeterminate. For seasonal deformation, 40% show similar amplitudes and in-phase timing (vertical; common in permafrost near Chumaerhe and south of Fenghuoshan), <1% indicate east–west motion (similar amplitudes, 180° out of phase), and the remaining 60% are indeterminate (9% similar amplitudes with other phase offsets; 51% different amplitudes). We anticipate that our movement-direction inference approach can be applied across broader permafrost regions to produce more robust statistics.

Line 315: elaborate “hydro-thermal alterations”

The temperature variation at greater soil depths typically responds to changes in air and shallow ground temperatures with a time delay, depending on the thermal diffusivity. In-situ measurements from the TGL permafrost station indicate that minimum temperatures at shallow depths occur in January, when surface freezing may already begin, whereas deeper layers continue cooling and do not reach their minimum temperature until March (Zhao et al., 2022).

Line 321: “coupling” is too vague.

We change it to “correlation”.

Line 336: “at a limited number of isolated locations” and “the monitoring stations are clustered”. It sounds contrasting.

Thank you for your notes. Now it reads:

These methods measure frozen-soil deformation and active-layer thickness at only a limited number of sites and are often limited by accessibility. On the QTP, monitoring stations are concentrated along the highway because access is easier there, whereas the vast lands with low population density to the west of QTEC have a notable scarcity of stations (Ni et al., 2021).

Line 338: “assumption-based numerical models and limited-data-driven machine learning approaches”. This should be rewritten.

Thank you for pointing it out. Now it reads:

To estimate large-scale, continuous ALT, numerical models and machine-learning approaches are widely used, but both have clear limitations. Models such as GIPL2 rely on simplifying assumptions (e.g., no water movement and no heat sources or sinks; Debolskiy et al., 2020), while machine-learning methods are data-driven and lack explicit physical derivation, particularly, the data in QTP are often limited as well.

Line 358: what is the meaning of "soil texture" here?

Sorry for the confusion. We update it to "vegetated". Now it reads:

The relationship between seasonal deformation and ALT varies with the vegetated and moisture conditions.

Figure 8: What is the meaning of "SeaAmpVel" in the right panels?

It means the seasonal amplitude of vertical deformation. We update the abbreviation to be "SeaAmpVer" and added the description in the figure caption.

Section 4.2 Implications for quantifying the active layer thickness. This section is a critical part of the manuscript, but it is too crowded. The author can provide subtitles to make the context flow better.

Thanks for your suggestion. We provide subtitles:

4.2.1 ALT estimates on the QTP

4.2.2 Relationship between ALT and seasonal deformation

4.2.3 Derivation of ALT from InSAR-derived ground deformation

4.2.4 Comparison of ALT estimates

The authors can move the last but two paragraph on ALT in the Introduction to Section 4.2.

Thank you for your suggestion. We move this paragraph to section 4.2.2.

The "wiggle" in ALT peaks in the frequency histograms in the past through the future can be used as indicators for evolution of permafrost degradation. Please elaborate.

Sorry for the confusion. We mean the ALT peaks in the frequency histograms over QTEC may change through time. For example, the ALT is mostly between 4 and 6 meters for one decade but may change to 3-5 or 5-7 meters in the next decade. The overall thickening or thinning of ALT may infer the stage of permafrost degradation or recovery. It might not be appropriate to demonstrate this casual example. We update the text and now it reads:

The “wiggle” pattern of ALT modes (peaks) in the frequency histograms from past to future can be interpreted as an indicator of evolving permafrost conditions. In other words, the modal ALT over QTEC is expected to shift through time, reflecting changes in the most common active-layer thickness. A systematic shift of the distribution toward thicker ALT, or a broadening and migration of its dominant peak(s), may indicate progression in permafrost degradation, whereas a shift toward thinner ALT may be consistent with stabilization or recovery.

Sections 4.3 Thermokarst disasters over the QTEC and 4.4 Risks mitigation due to permafrost thaw seem to be disconnected with the previous sections. Some connecting context should be added.

Thank you for your comment. We update the beginning sentences of these two sections to make it flow better.

4.3 Thermokarst processes over the QTEC

Thermokarst processes poses direct risks to the engineering integrity of infrastructures constructed on permafrost along QTEC (Niu et al., 2011; Xia et al., 2022; Zhou et al., 2024).

4.4 Risks mitigation due to permafrost thaw

Mitigating permafrost-thaw–induced damage has become a key priority for the government.