Responses to the Comments from Reviewer #1

General Comments:

The authors propose a combination of InSAR time-series data from one viewing direction with one ML approach (Random Forest Method) to map the permafrost deformation in the Tibetan Plateau, emphasizing the area where radar visibility problems take place. As InSAR delivers ground displacements along the slant-looking direction, visibility problems such as layover and shadow often arise in mountainous areas; it occurs in the descending track in this study. In such a case, InSAR users will usually take advantage of other data imaged from another direction that is the ascending track in this study. However, instead of using the ascending InSAR data, the authors employ the ML method to infer a permafrost stability map even at unmeasured areas. In other words, it appears as if the authors derived some signals from virtually nothing. In terms of the overall design of research work, I am not willing to recommend the authors' approach to my friends.

Response: Thank you for the reading and comments. We agree with the reviewer that the combination of ascending and descending datasets could improve the monitoring ability of ground deformation; however, in regions where the datasets are strongly affected by terrain visibility, the ground deformation could not be monitored by the combination of ascending and descending datasets. According to the previous studies (Michaelides et al., 2019; Chen et al., 2020; Li et al., 2022), the permafrost stability, which could be captured by the ground deformation rate, is closely correlated with environmental factors. Thus, the machine learning method was adopted in our study for mapping the relationship between the environmental factors and the permafrost stability. With the aid of the established mapping relationship, the permafrost stability in areas where the visibility of SAR images is poor or InSAR results are not available could be mapped. We believe that the combination of InSAR and machine learning method is a topic worthy of investigation. To avoid the confusion of the reviewer, a clarification will be added in our revision.

Chen, J., Wu, Y., O'Connor, M., Cardenas, M. B., Schaefer, K., Michaelides, R., Kling, G., 2020. Active layer freeze-thaw and water storage dynamics in permafrost environments inferred from InSAR. Remote Sensing of Environment, 248, 112007.

Li, R., Zhang, M., Konstantinov, P., Pei, W., Tregubov, O., Li, G., 2022. Permafrost degradation induced thaw settlement susceptibility research and potential risk analysis in the Qinghai-Tibet Plateau. CATENA, 214, 106239.

Michaelides, R. J., Schaefer, K., Zebker, H. A., Parsekian, A., Liu, L., Chen, J., Schaefer, S. R., 2019. Inference of the impact of wildfire on permafrost and active layer thickness in a discontinuous permafrost region using the remotely sensed active layer thickness (ReSALT) algorithm. Environmental Research Letters, 14(3), 035007.

Furthermore, there are a couple of serious issues in the authors' interpretation of InSAR data and time-series analysis. They do not mention anything about the corrections of the tropospheric errors/artifacts. Even if they employ the time-series analysis approach with plenty of SAR images, it is impossible to ignore the tropospheric errors particularly when they use the entire image frame; the larger the imaged area, the larger the tropospheric errors. Although the authors attribute the apparent seasonal signals to the subsidence and uplift due to the freeze-thaw cycle of the active layer, we should first eliminate or minimize the tropospheric errors.

Response: Thank you for the reading and comment. Indeed, a tropospheric correction was conducted through spatial-temporal filtering (Garthwaite et al., 2013; Li et al., 2021) in our InSAR processing, even though this correction was not mentioned in our manuscript, as we believed that this kind of processing is routine in InSAR analyses. The adopted spatial-temporal filtering, which has been shown effective in minimizing the tropospheric error on the Tibetan Plateau (Garthwaite et al., 2013; Li et al., 2021), assumes that the atmospheric phase delay signal is spatially correlated but temporally uncorrelated. In addition, the verifications of the ground deformations obtained with InSAR analysis further confirmed the accuracy of our time-series InSAR processing. To avoid this confusion, a clarification will be added in our revision.

Garthwaite, M. C., Wang, H., Wright, T. J., 2013. Broadscale interseismic deformation and fault slip rates in the central Tibetan Plateau observed using InSAR. Journal of Geophysical Research: Solid Earth, 118(9), 5071-5083.
Li, R., Li, Z., Han, J., Lu, P., Qiao, G., Meng, X., Zhou, F., 2021. Monitoring surface deformation of permafrost in Wudaoliang Region, Qinghai-Tibet Plateau with ENVISAT ASAR data. International Journal of Applied Earth Observation and Geoinformation, 104, 102527.

Secondly, while it is related to the previous comment, Figure 14 derived from ascending track clearly indicates that the "deformation rates" are closely correlated with the local topography. Those are called topography (elevation)-correlated noise, which is again caused by tropospheric delays. They can be corrected, by fitting with the DEM.

Response: Thank you for the reading and comment. Indeed, the topography-correlated noise was simulated and reduced using the external DEM in our InSAR processing, and the same procedures were adopted for processing ascending and descending SAR images. To avoid this confusion, a clarification will be added in our revision.

Thirdly, while InSAR tells us the surface displacements relative to non-deformed point(s), it is not clear where the reference pixels are located; the reference pixels should be stable not only in one InSAR image but also over the entire observation period. I, therefore, recommend reanalyzing the InSAR time-series data based on the ascending track, considering the points above.

Response: Thank you for the reading and comment. In our InSAR processing, the reference pixels (i.e., Ground Control Points) were selected in the flat terrain with minimal ground deformation, and they were stable not only in one InSAR image but also over the entire observation period. To avoid this confusion, a clarification will be added in our revision.

It is not clear why they must use the Random Forest Method; permafrost stability and landslide susceptibility follow totally different physical mechanisms. The authors should show both descending and ascending data over flat areas as verification of deformation signals as they are mostly vertical.

Response: Thank you for the reading and comments. We agree with the reviewer that permafrost stability and landslide can follow different physical mechanisms; however, both permafrost stability and landslide occurrence can be correlated to environmental factors. Note that although the random forest method was adopted in our study to map the relationship between the permafrost stability and the environmental factors, other machine learning methods could also be adopted for building such a relationship. In addition, the adopted random forest method has been shown effective in mapping the permafrost degradation-induced thaw settlement susceptibility on the Tibetan Plateau (Li et al., 2022). To avoid potential confusion, more clarification will be added in our revision.

We also agree with the comment that the comparison of ground deformation over flat areas obtained from both descending and ascending data may be adopted for verifying the deformation signals. Figure R1 depicts the comparison of the ground deformation rate obtained from the ascending and descending SAR images, which confirms the accuracy of the ground deformation results obtained from our InSAR analyses. This kind of comparison will be added in our revision.

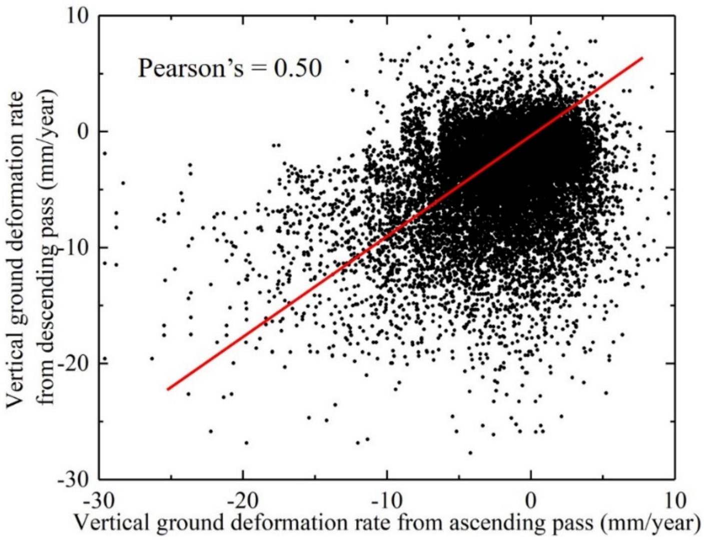

Figure R1. Comparision of the ground deformation rate derived from the ascending and descending observations

Li, R., Zhang, M., Konstantinov, P., Pei, W., Tregubov, O., Li, G., 2022. Permafrost degradation induced thaw settlement susceptibility research and potential risk analysis in the Qinghai-Tibet Plateau. CATENA, 214, 106239.

Specific and technical comments:

L30: As the focus is now on Tibet, those papers outside Tibet and/or Global should be removed.

Response: Thank you for the suggestion. References that are not related to the Tibetan Plateau will be deleted in our revision.

L48: Delete "that"

Response: Thank you for the suggestion. The revision will be made accordingly.

L51: Unclear sentence

Response: Thank you for the comment. To avoid this confusion, this sentence will be modified as follows in our revision. "The permafrost stability is often manifested by the variation of the permafrost thickness, and which could be captured by the ground deformation; thus, the permafrost stability can be captured through the monitoring of the ground deformation."

L58: The two references are not related to permafrost.

Response: Thank you for the comment. Related references will be modified.

L109: Delete "in which"

Response: Thank you for the comment. The revision will be made accordingly.

L135: Replace "spatial" with "temporal"

Response: Thank you for the comment. The revision will be made accordingly.

L176: "relatively flat and homogeneous" conflicts with L115, "mountainous terrain"

Response: Thank you for the comment. Note that the study area is relatively flat, and variations of the ground elevations in the mountainous terrain are relatively small. To avoid this confusion, related sentences will be modified in our revision.

L276: Is 0.8 true? There is a big deviation near the end.

Response: Thank you for the comment. Note that although the deviation near the end of the line was large, the value of 0.80 was correct and the overall performance of the fitting was satisfactory.

Figure 6: When are the periods in the four years? Show month and date.

Response: Thank you for the comment. The thawing periods in these four years were 1 April 2015 to 23 August 2015, 26 April 2017 to 24 August 2017, 21 April 2018 to 31 August 2018, and 28 April 2019 to 26 August 2019, respectively. This information will be provided in our revision.

L319: Disagree with "in general agreement"

Response: Thank you for the comment. Plotted in Figure 7(c) are the variations of the seasonal thaw subsidence and the ground elevation along profile AB; as can be seen, a larger elevation tends to yield smaller thaw subsidence but there are exceptions. The related expressions will be modified in our revision.

L333: Michaelides et al (2019) examined the post-fire area, where there occurred a big change in surface vegetation. But the authors are now examining unburned areas. If we follow the suggestion by Michaelides et al (2019), we expect significant deformation signals over “Bare lands” as there would be no insulation effects. The authors should check if there exist such signals.

Response: Thank you for the comment. Figures 8(b-c) depicted that a smaller NDVI value tends to result in larger thaw subsidence, and the bare lands with smaller NDVI have larger thaw subsidence; however, the thaw subsidence can be affected by various factors (e.g., elevation, slope, ice content), which caused the relationship between the thaw subsidence and the NDVI not significant. As such, the bare lands do not always yield significant deformations. To avoid potential confusion, more clarifications will be added in our revision; meanwhile, the related reference will be modified.

Figure 12: Leveling route by Wu et al (2018) should be clarified, whereas only one leveling data was shown.

Response: Thank you for the comment. In the studies of Wu et al. (2018), only one leveling site was located in the study area, thus, only one leveling data was provided in our study. More clarifications of the leveling data will be added in our revision.

Wu, Z., Zhao, L., Liu, L., Zhu, R., Gao, Z., Qiao, Y., Xie, M., 2018. Surface-deformation monitoring in the permafrost regions over the Tibetan Plateau, using Sentinel-1 data. Sci. Cold Arid Reg. 10(2), 114-125.