Responses to RC1

(Reviewer's comments in black; authors' responses in blue)

This manuscript presents an important study on a comprehensive inventory of retrogressive thaw slumps (RTSs) along the Qinghai-Tibet Engineering Corridor (QTEC). An iteratively semi-automatic method with manual inspection were utilized to ensure the reliability of results, which should be very difficult to validate due to the lack of field evidence. The manuscript is well prepared, I suggest it should be a good study after addressing the following comments. Links between RTSs and geographic environment and environmental changes require further analysis to help reader understand mechanisms behind the distribution characteristics.

Thank you for the insightful and detailed comments. We addressed all the comments carefully with our point-by-point responses given below.

(1) It is suggested to provide a table list of the data and the purpose.

Response: Following your suggestion, we have added a table as shown below to list the data used.

Table 1 List of the data used for mapping RTSs and analyzing their spatial distribution

	Acquisition time	Spatial coverage	Spectral bands	Spatial resolution	Purpose	Source/Reference
PlanetScope Scenes	July, August 2019 July and August during the years 2016 to 2020	QTEC	red, green, blue	3–5 m	Automatically delineating Manual inspection	Planet Team, 2017
LandSat-8	2013–2016	RTS locations and the surrounding areas within 1 km	Panchromatic band	15 m	Manual inspection	Google Earth Engine
			red, green, blue	30 m		
LandSat-5	2009–2016		red, green, blue	30 m		
Sentinel-2	2015–2016		red, green, blue	10 m		
UAV images	August 2020; July 2021	16 selected sites along the Qinghai-Tibet Highway	red, green, blue	~ 15 cm	Manual inspection	Field surveys
ESRI World Imagery	Since 2010	QTEC	/	< 1 m	Manual inspection	Esri Inc., 2018

SRTM DEM	2000	QTEC	/	30 m	Manual inspection and analyzing RTS distribution patterns	Farr et al., 2007
Vegetation type	/	QTEC	/	1 km	Analyzing RTS distribution patterns	Wang et al., 2016
Soil textures	2010	QTEC	/	1 km	Analyzing RTS distribution patterns	Food and Agriculture Organization of the United Nations, 2019

(2) It is better to add place names such as Wudaoliang, Beiluhe in Figure 5. It is found that most RTSs are distributed over the region between Chumar River and Beilu River. Is that related to the initial training data (300 RTSs in the Beilu River basin) (10.1016/j.rse.2011.04.022)? Since it is very difficult to do a validation, is that possible to do another experiment with sparsely distributed training samples along the QTEC?

Response: We have added the location names: "Wudaoliang" and "Beiluhe" in Figure 5 as follows,

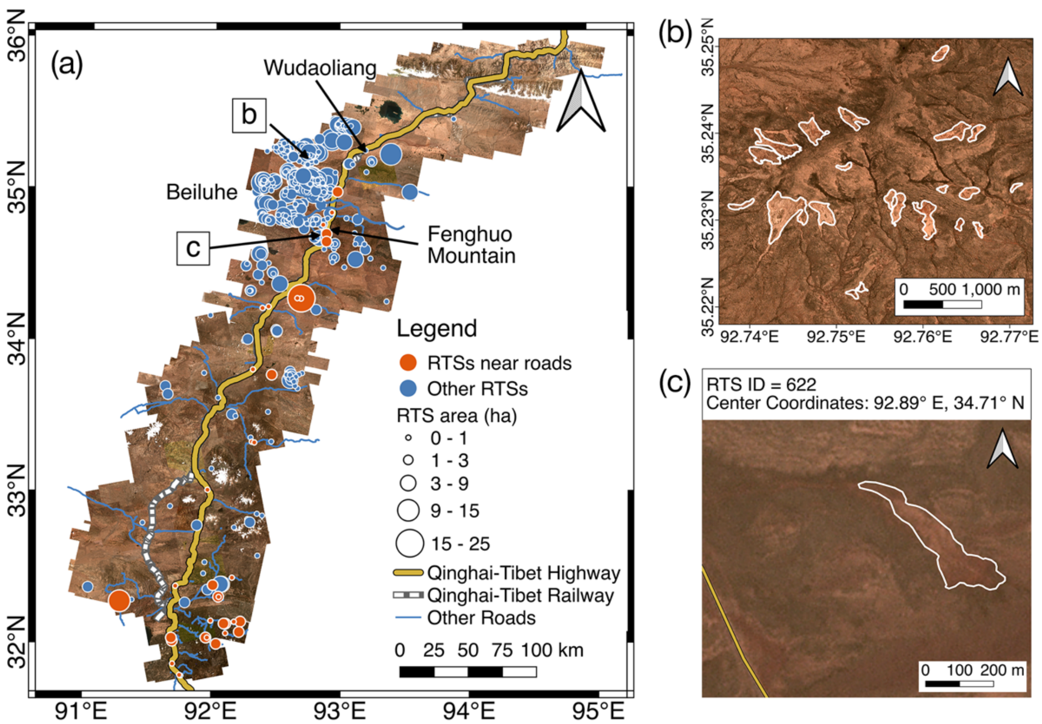

Figure 5. (a) Permafrost distribution map (Zou et al., 2017) with 875 delineated RTSs. The circle sizes indicate the RTSs' area. Orange circles are RTSs close to roads, while blue circles show other RTSs. (b) Examples of the delineated RTSs in the Beiluhe region, with the white polygons representing the boundaries of RTSs. (c) An example of an RTS adjacent to the Qinghai-Tibet Highway (yellow line). Basemap images © Planet Labs Inc.

The clustering phenomenon is not related to the initial training data. The outputs of the very first iteration (among the total nine iterations documented in the manuscript) contain thousands of polygons distributed across the Qinghai Tibet Engineering Corridor, with no prominent cluster in the Beiluhe region (Figure R1a).

Regarding the second comment, 'Since it is very difficult to do a validation, is that possible to do another experiment with sparsely distributed training samples along the QTEC', we conducted a new experiment with training data sparsely distributed along the QTEC, containing 434 randomly selected RTSs and 45 negative polygons. The network output 9192 mapped polygons (Figure R1b), among which 3777 polygons have already been inspected in our previous nine iterations, as documented in the manuscript. We manually inspected 5415 polygons and found no more RTSs. We chose not to add this new experiment to our revised manuscript because (1) the new experiment did not improve our mapping results, and (2) the experiment results of the first iteration have already proved that the RTS clusters are not related to the initial training data as we have addressed above.

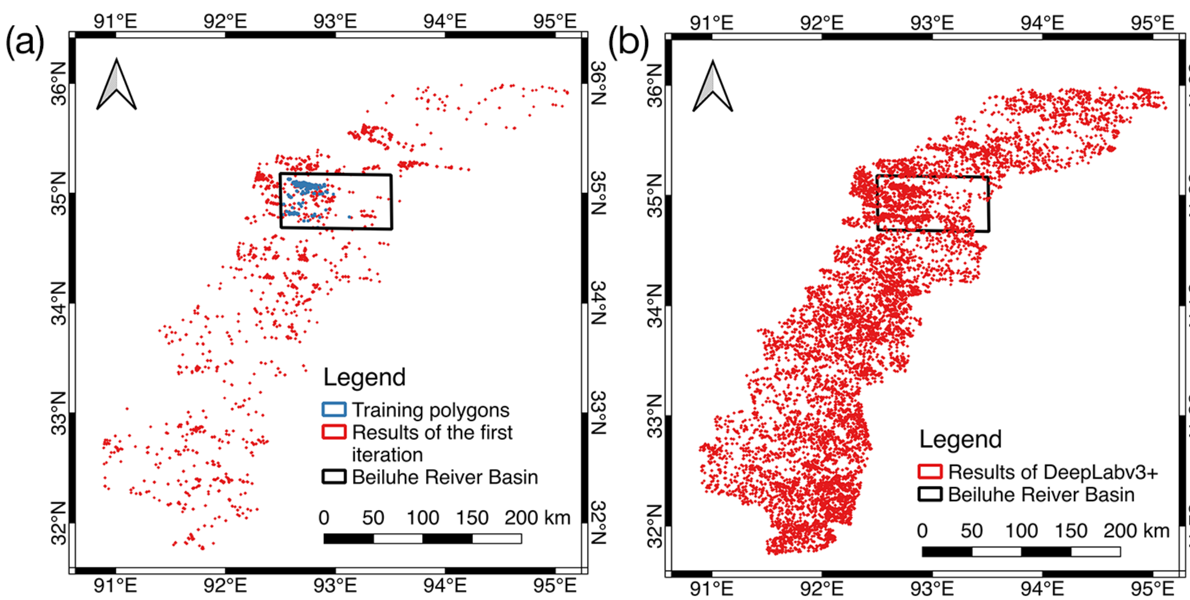

Figure R1. (a) The results of the first iteration, in which we only used data in the Beiluhe region to train DeepLabv3+. (b) The results of the new experiment with sparsely distributed mapped polygons along the QTEC.

(3) Microwave remote sensing has complementary information to the optical images and is sensitive to the water content in soils (10.1016/j.rse.2020.111680). Sentinel-1, which is a C-band SAR since 2014, can be a good data source to identify RTSs (10.1002/2015JF003599). It is suggested to use this kind of microwave data or include them in the future work.

Response: We agreed that microwave remote sensing could provide complementary information to optical images and will consider including them in our future work. The relatively low spatial resolutions and the speckle noise make it is extremely challenging, if ever possible, to visualize RTSs on images. Firstly, the raw spatial resolutions of 2.7x22 m to 3.5x22 m are insufficient for identifying RTSs, as half of the RTSs have areas smaller than 100x100 m. Secondly, the Sentinel-1 data are adversely affected by speckle noise, making the RTS in the image not distinguishable from the surroundings (Figure R2). The access to very high-resolution (<5 m) SAR imagery is still limited. The similar microwave data to those in 10.1016/j.rse.2020.111680 are not sufficient to identify RTS due to their low resolution, but the derived products such as soil moisture can be used to analyze RTS distribution and controlling factors. The second paper that you mentioned (10.1002/2015JF003599) used the InSAR technique to measure thermokarst subsidence. However, InSAR observables alone cannot differentiate RTSs from other disturbances, for instance, constructions, landslides, periglacial mass movements, wildfires and other thermokarst landforms. Nonetheless, it is still meaningful to explore how to utilize SAR data in the future due to its availability and complementary information.

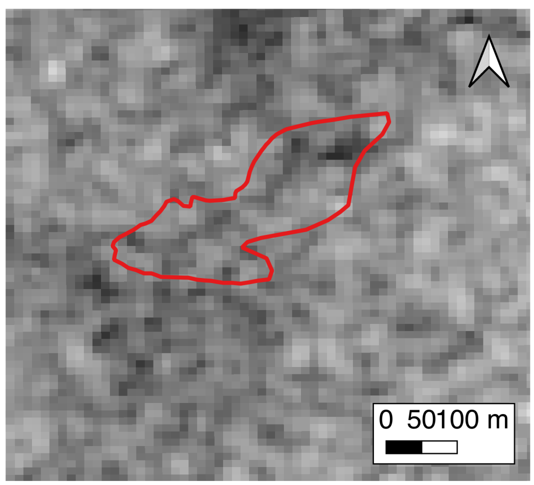

Figure R2. An example of an RTS in a typical SAR image. The background is the IW product of the Sentinel-1A image, with the red polygon representing the boundary of one RTS we obtained in this study.

(4) It is very interesting to further discuss why the RTSs are concentrated in the Beilu River region. The authors have mentioned several influencing factors including topography, hydrology, soil properties, vegetation cover and human activities. It is suggested to number these outlined contents. The RTSs are one of the major components of freeze-thaw erosion and should be related to the water and heat dynamics of permafrost (10.1002/2013JF002930). Therefore, its occurrence might be correlated with the number of freeze-thaw cycles (10.1002/hyp.7930) and the phase changed water content (10.1109/TGRS.2010.2051158). From your discussions, it is still not very clear why the RTSs are concentrated in the Beilu River region. A deeper analysis with controlling factors might be needed rather than a documentation presented here.

Response: We have numbered the contents according to your suggestion and merged two paragraphs explaining terrain and human-induced factors into one.

The excellent papers you shared may refer to the hydrological and thermal processes of the active layer. However, RTS development is mainly caused by the abrupt thawing of ice-rich permafrost, which lies below the active layer (typically, more than two meters below the surface on the Tibetan Plateau). To the best of our understanding, although most RTSs initiation is related to the accumulation of liquid water under the active layer during the thawing season, the hydrological and thermal dynamics of the active layer derived from microwave data have limited direct impacts on the RTS distribution.

To provide geographical analyses of the distribution patterns of RTSs, we collected topo-climatic, hydrological, vegetation, and soil datasets to analyze the factors that control the distribution of RTSs, as documented in the manuscript (section 6.1). The reasons for the presence of the cluster in the Beiluhe region are worth investigating but beyond the scope of this study. We plan to obtain an RTS inventory over a larger area in the future. A larger and more comprehensive RTS inventory will enable robust and meaningful factor analyses.