Reply to comments by T. Strozzi on "Mapping and inventorying active rock glaciers in the Northern Tien Shan (China) using satellite SAR interferometry"

1. General comments

The manuscript by Wang et al. nicely describes the application of SAR interferometry and Google Earth optical images to the mapping of active rock glaciers in the Northern Tien Shan. The structure of the paper is solid, the objectives of the work are clearly stated, the employed technology is well explained, the results are nicely described and illustrated, and the conclusions are well formulated. Although not completely novel, the approach of mapping and inventorying active rock glaciers from SAR interferometry and optical images is here throughout applied for the first time in the high mountains of western China, revealing new insights into rock glaciers as proxies of permafrost. The same approach presented by Wang et al. can be used for the systematic investigations of rock glaciers, and thus permafrost, over other remote mountainous locations. Considering the excellent work done by the authors in the redaction of the manuscript, I only have a few specific comments.

We thank Dr. T. Strozzi for his thoughtful consideration and helpful comments on our manuscript. We have addressed all the comments below. Our replies are highlighted in blue.

2. Specific comments

1. The short description about error sources in SAR interferograms at line 138 could be expanded a little bit to avoid the impression that their effects are not well considered or underestimated. In particular, the use of a coarse resolution DEM as SRTM results in uncompensated phase signals that scale up with the baseline of the interferograms. The authors state that maximum baselines considered in their studies are 600 m, but I would expect here a quantitative estimate of the phase disturbances that may occur in high mountains as a consequence of typical SRTM height errors or artefacts.

Authors: We have added a sentence copied below to demonstrate the contribution of topographic error to the interferometric phase (please see Lines 151–156):

"The contribution of the topographic error to the interferometric phase is proportional to the perpendicular baseline, the radar slant range, and the radar look angle (Rosen et al., 2000). The maximum perpendicular baseline of the interferograms produced in this study is about 600 m. Adopting the vertical accuracy of the digital elevation model as its nominal value of 16 m (Farr et al., 2004), we estimate that the residual topographic phase in the InSAR measurements would be about 0.92 radians, corresponding to 1.7 cm.

In addition, a statement about the different distortions that occur with respect to the slope

and orientation of the rock glaciers and the satellite line-of-sight direction should be included.

Authors: We have rewritten the relevant part in Section 4 (copied below) to include the influences of geometric distortions to the identification of ARGs (Please see Lines 259–268):

"The number of ARGs we compiled is a conservative estimation of all the ARGs in the NTS due to the following three reasons. First, we may have missed some ARGs due to the geometric distortions such as shadows and layovers in the SAR images. For the PALSAR images used in this study, the rock glaciers facing east with the slope angles larger than 51.3 ° are in the radar shadows, and the rock glaciers facing west with slope angles larger than 38.7 °are in the layover regions. These distortions would result in significantly phase de-correlation and make it difficult to identify rock glaciers in these regions. Second, ARGs facing nearly north or south might also have been missed, as InSAR (using images from all space missions, including ALOS) is not sensitive to ground motions along these directions. Finally, some small ARGs could not be identified as the interferogram maps have a moderate resolution of about 15 m."

Then, on the same paragraph, a short comment on the typical atmospheric disturbances at L-band with respect to the size of the active rock glaciers would be beneficial to strengthen the potential of the technology.

Authors: We have added two sentences (copied below) to describe the atmosphere disturbance on the L-band SAR interferometry, with concerning the size of the active rock glaciers, please see Lines 156–159.

"The atmospheric (including tropospheric and ionospheric) effects are generally manifest themselves as long wavelength signals on the order of 1–10 km in interferogram maps (Hanssen, 2001), thus can be assumed nearly constant over a specific rock glacier. By using a local reference point just outside each rock glacier (see section 3.2), we effectively removed these large-scale atmospheric errors."

Finally, Barboux et al. (2015) found out that phase unwrapping is the major limiting factor to the use of SAR interferometry for monitoring active rock glaciers in the Swiss Alps. In their paper, Wang et al. are not discussing at all possible phase unwrapping errors. I did some rapid calculations with the active rock glaciers velocities reported by the authors in the Northern Tien Shan. If maximum down-slope velocities of active rock glaciers in this region are about 114 cm yr^{-1}, then the maximum line-of-sight velocities should be about 2/3 of the down-slope direction, i.e. about 76 cm yr^{-1}. Over a time period of 46 days this would correspond to about 10 cm or less than one fringe an L-band. Indeed, in the Northern Tien

Shan phase unwrapping is not a relevant issue, but this is not the case in many other mountain regions. Therefore, a short comment on phase unwrapping with respect to the velocities of the active rock glaciers should be included in the manuscript.

Authors: We have added some words to demonstrate the unwrapping issues for addressing the surface velocities of rock glaciers using InSAR (Please see Lines 205–210). We also carefully examined unwrapped interferograms and confirmed no unwrapping errors over the rock glaciers we mapped.

"Previous studies indicated that phase unwrapping is the major limiting factor to the use of SAR interferometry for monitoring active rock glaciers (Barboux et al., 2015). Phase unwrapping may fail in the areas where phase gradients are large due to fast slope movements. To minimize the phase unwrapping errors, we applied the phase filtering with a window of 8 ×8 pixels and masked out the decorrelated areas with a coherence threshold of 0.3 before phase unwrapping."

2. At line 63, the paper by Strozzi et al. (2010) is about landslides, not rock glaciers. Use instead Strozzi et al. (2004): Strozzi T., A. Käab and R. Frauenfelder, Detecting and quantifying mountain permafrost creep from in situ inventory, space-borne radar interferometry and airborne digital photogrammetry, Int. J. Remote Sensing, Vol. 25, No. 15, pp. 2919-2931, doi: 10.1080/0143116042000192330 2004.

Authors: We have changed the reference "Strozzi et al. (2010)" to "Strozzi et al. (2004)" in Line 65.

3. Figure 9a is nearly impossible to interpret, there is too much information and there are too many colors and symbols. An alternative representation of this image should be proposed by the authors.

Authors: We have broken Figure 9a into two sub-figures to improve interpretation. We also changed Figures 9(c–d) as a new Figure 10.