Response to Reviewer #1

Overall Comments

The authors used InSAR technique to map and characterize rock glacier movement in a region where previous knowledge of rock glaciers is limited. It produces a new dataset that sheds light on the kinematic behavior of those permafrost landforms and provides interesting insights as to how the rock glaciers respond to the climatic conditions and their potential local hydrological importance in the future. Hopefully, this paper will be published and help generate more interest in studying rock glaciers in North America.

It is a well-written paper in general. However, I would raise a few issues mostly regarding the necessary details of the InSAR method adopted in this work. Accuracy in terminology and clarity in the argument can be further improved in a few places. Please see my comments below.

No.	Comment	Response
1	*Line 21: the definition of rock glaciers here is inaccurate because they are not entirely "perennially frozen bodies", the upper part of which is seasonally frozen ground or the so-called active layer.*	Concur. Sentence will be simplified to read: "Rock glaciers are bodies of ice and rock debris that creep downslope due to deformation of their internal ice-rock mixture."
2	*Line 32–34, it might be inappropriate to draw an analogy between rock glaciers and ice glaciers here, because some of the enumerated drivers (e.g., liquid water, pore water pressure) influence the motion of the two types of landforms in ways that can hardly be regarded as similar.*	Here we are only referring the first-order relationships between changes in pore pressure and deformation of ice glaciers, faults, and landslides. We added some additional references to help clarify: "As with ice glaciers (e.g., Bartholomew et al., 2010; Iverson, 2010; Minchew and Meyer (2020) tectonic faults (e.g., Bürgmann, 2018) and landslides (e.g., Bayer et al,. 2018 Handwerger et al., 2019), liquid water, and pore-water pressure are also important drivers of short-term rock glacier motion (Ikeda et al., 2008; Moore, 2014; Kenner et al., 2017; Eriksen et al., 2016; Cicoira, 2019; Fey and Krainer, 2020)."
3	*Line 46, shear horizon is NOT "at the base of the rock glacier". Borehole investigations have revealed that sediments exist below the shear horizon, though the motion of which is negligible. The authors may refer to the two papers cited in the caption of Figure 1(i.e., Arenson et al., 2002; Kenner et al., 2017) and modify Figure 1b and 1d accordingly.*	Concur. Arenson et al. (2002) states that shear horizons can be located at different depths within a rock glacier. Sentence will be made more general to read: "Recent work suggests that spring acceleration is driven by water infiltrating shear horizons within rock glaciers, increasing pore-water pressure and reducing frictional strength (Kenner et al., 2017; Cocoira et al., 2019; Fey and Krainer, 2020)." Figure 1 will be modified, moving the shear horizon up slightly to reflect that the shear

		zone is not necessarily located near the base of the rock glacier
4	*Line 69–70, what are the "significant patterns"?*	The sentence refers to significant patterns in rock glacier kinematics across the Uintas revealed by InSAR. The sentence will be made more explicit as follows: "Many of these can be mitigated by careful study design, however, and at the scale of range-wide analysis, significant patterns in rock glacier kinematics can still be identified."
5	*Line 124–125, why do the authors use the 10-m resolution DEM for selected one-year pairs only, instead of applying it to all data?*	Computational limitations prevented us from processing all interferograms with the 10 m DEM. Instead, we used a 30 m DEM initially, then reprocessed our best interferograms with the 10-m DEM. Section will be revised to read: "To improve spatial resolution, selected one-year interferogram pairs were reprocessed with a USGS 3DEP DEM with 10 m pixel spacing. Computational limitations prevented us from processing all interferograms with the 10 m DEM."
6	*Line 138–139, the description "LOS velocity signal consistent with the downslope direction" is confusing, because a LOS signal is obviously always in the LOS direction, which is from the ground to the satellite, and thus cannot be consistent with downslope direction.*	The LOS velocity signal can be negative or positive, indicating displacement toward or away from the satellite. For us to classify a rock glacier as active, the direction of the LOS signal indicated by the sign must suggest significant downslope movement. For clarity, the sentence will be revised to read: "Rock glaciers displaying a clear and relatively high LOS velocity signal with a sign suggesting downslope movement were considered active (Fig. 2)."
7	*Line 147, which one-year interferograms do the authors use for calculating annual velocities? Here the authors mention both ascending and descending stacks of interferograms, however, Figure 2 only shows results derived from one descending track.*	Our ascending stack included interferograms: 20160921-20170922 20160921-20170910 20160927-20170922 20170805-20180731 20180731-20190807 Our descending stack included interferograms: 20160902-20170828 20160902-20170909 20160926-20170921 20170804-20180730 20180730-20190806

		These selected one-year pairs showed the lowest level of atmospheric effects. We calculated 75th percentile LOS velocity for each rock glacier using both stacks. The larger of the ascending and descending values is used to represent rock glacier velocity in our data analysis (line 153-154). We will highlight these interferograms (red for ascending, blue for descending) in Table A1 to indicate that they were used to construct our interferogram stacks.
8	*Line 149, why do the authors remove negative LOS values? The motion towards the satellite is possible and Figure 2a does include negative values.*	We apologize as our language here is confusing. We didn't remove negative values- we took their magnitude in order to make all displacement values positive. This made it more straightforward to determine average LOS velocities over the surface of each rock glacier without negative and positive values cancelling each other out, leading to average LOS velocities with erroneously low magnitudes. The sentence that reads: "We use the velocity magnitude to remove negative LOS values that are caused by motion towards the satellite." will be removed, as the prior sentence states: "Average LOS velocity magnitudes were calculated by taking the mean of the absolute value of velocity values over the surface of each rock glacier."
9	*In Figure 2a, Line 715–716, the authors should specify the time span they used to calculate the average velocity, instead of just providing satellite orbital information. Also, the legend shows the unit of the velocity map in distance unit (cm) which may confuse the readers. Is Figure 2a a displacement map or a velocity map?*	Concur. In the caption we will mention that Figure 2a shows our average descending one-year pair stack. The figure is a velocity map, and the legend should be changed to read: "velocity, (cm/yr)"
10	*In Figure 2a, Line 715, the legend shows the unit of the velocity map is in centimeters which may confuse the readers. And the period of the observation should be specified.*	Concur. See response to comment #9.

11	*Line 163–172, this part is not under the topic of "InSAR analysis". The authors may consider reorganizing the structure of this section. Please also refer to the first technical correction below.*	Concur. We will add a new subsection header above line 163 titled, "2.3 Climate Data."
12	*Line 236–239 and Figure 2, Line 716, the previous inventory (Munroe, 2018) didn't classify the mapped rock glaciers based on their activities. How do the authors identify the inactive rock glaciers from the previously published dataset? If the inactive rock glaciers are landforms that do not show displacement in the interferograms, is it possible that some of those landforms are actually active, but their activity is not detected by InSAR, due to limitations of the technique, such as decorrelation, shadow, overlay, or the flow direction of landform is insensitive to the LOS direction?*	That's correct, we classified rock glaciers from the previous inventory that don't show displacement in the interferograms as inactive (line 204-205). We will edit the second sentence beginning on line 716 to read: "Black polygons represent rock glaciers identified in the previous inventory (Munroe, 2018) which are inactive (i.e., show no active deformation) in our InSAR velocity maps." In addition, we will add a sentence to our methods section beginning on Line 140 that states: "Rock glaciers identified in the previous inventory that showed no deformation in our InSAR velocity maps were classified as inactive." It is possible that some rock glaciers are active, but their activity was hidden by 1) decorrelation, 2) InSAR geometry, 3) the flow direction of the landform being insensitive to the LOS direction, or 4) motion at rates less than a few mm per year. I'll address each possibility. 1) In general, decorrelation over the rock glacier surface was very infrequent in our one-year stack velocity maps. 2) There were some instances where rock glaciers were partially or mostly hidden by InSAR geometry, but this was uncommon. 3) Rock glaciers tended to have multiple directions of flow, and we used interferograms derived from two tracks with different look directions. It's possible that rock glaciers flowing directly orthogonal to the satellite look direction, could have appeared inactive. 4) Rock glaciers moving slower than a few mm per year may be considered essentially inactive. It's certainly possible that an active rock glacier appeared inactive in our velocity maps, however, it seems unlikely that this would be a widespread issue for 155 rock glaciers. We should acknowledge that this is a possibility.

		We will add a sentence to that effect into the paragraph in the discussion addressing limitations of our methods, which begins on line 307.
13	*Line 279–280, the references here do not fully fit. Delaloye et al. (2010) focus on the Swiss Alps which is a regional study and cannot represent rock glaciers "around the world".*	Concur. We will edit this sentence to read: "This range of mean velocities is lower than velocities reported for other rock glaciers in the western US and the Alps (Janke et al. 2005, Delaloye et al., 2010)."
14	*Line 283–285, Janke et al. (2005) reported average velocities of 7.3, 6.3, and 9.5 cm/yr for three rock glaciers in the Front Range, which are not notably faster than the LOS rates between 0.88 and 5.26 cm/yr presented in this paper in my opinion, especially when accounting for the underestimation in LOS values, as the authors discussed in the last paragraph of Section 4.2. Besides, the three rock glaciers in Janke et al. (2005) cannot represent "most other North American rock glaciers". The authors may consider changing their conclusions or drawing different comparisons.*	It is correct that the average velocities of the three rock glaciers reported by Janke are not notably faster than the rock glaciers in the Uintas. However, Table 1 in Janke et al. (2005) compiles velocity measurements of other North American rock glaciers, most of which have velocities above 10 cm/yr, and several of which have velocities above 50 cm/yr. For clarity, the reference in line 283-285 will be changed to read, "(Table 1 in Janke et al., 2005)"
15	*Line 295–296, are there any references supporting this alternative explanation proposed here? Some studies suggest a contrasting point of view that the rock glacier accelerates when ice content decreases (Arenson et al., 2002), or a non-linear relationship between ice content and surface velocity (Cicoira et al., 2019).* *Arenson, L., Hoelzle, M., & Springman, S. (2002, Apr-Jun). Borehole deformation measurements and internal structure of some rock glaciers in Switzerland. Permafrost and Periglacial Processes, 13(2), 117-135. https://doi.org/10.1002/ppp.414* *Cicoira, A., Beutel, J., Faillettaz, J., Gartner-Roer, I., & Vieli, A. (2019, Mar). Resolving the influence of temperature forcing through heat conduction on rock glacier dynamics: a numerical modeling approach. Cryosphere, 13(3), 927-942. https://doi.org/10.5194/tc-13-927-2019*	To our knowledge, there are no references supporting this alternative explanation. We agree that rock glaciers could theoretically accelerate with decreased ice content, and/or there could be a non-linear relationship between velocity and ice content. However, as evinced by the presence of relict rock glaciers, at some critically small ice/debris ratio, rock glaciers must decelerate. We suggest that many of the rock glaciers in the Uintas may have a small enough quantity of ice to cause deceleration. This threshold may be higher in the Uintas than other places due to dryer conditions and increasing aridity, minimizing liquid water in the rock glacier body.
16	*Line 308–316, this part is not discussing rock glacier velocity. Please consider restructuring this section.*	Concur. We will create a new subsection called "Limitations of InSAR"

17	*Figure 8, Line 758–759, this sentence is unclear to me. Please explain how to scale the ascending and descending LOS and the purpose of that.*	The time series results provide cumulative displacement in the LOS direction. As such, cumulative displacement can be negative and decreasing or positive and increasing (motion towards or away from the satellite). In this figure, we took the absolute value of displacement so to make all displacement positive and increasing for ease of comparison between rock glaciers.
18	*Line 418–421, I would suggest the authors specify those rock glacier velocities are InSAR-derived LOS velocities, otherwise the readers may misinterpret them as 3D creep velocities.*	Concur. We will revise the caption accordingly.

Technical Corrections

1	*Line 81 and 106, these two parts are better to be numbered as 2 and 3, as there is no Section 2 in this manuscript, and I don't see clear relations between the two subsections "Study area" and "InSAR analysis".*	Concur. We'll number these sections 2 and 3.

Thank you very much for providing comments!