Introduction

- From the introduction, it is not clear why ice caves or their dynamics are important. Although authors identify the need to quantify changes in ice accumulations and appropriate techniques by which to achieve this, no case is made for why the changes in ice volume are important. Furthermore, the aims need clarification and to reflect the contents of the paper. Currently, they outline that the paper will further develop the methods of detecting ice change. The paper does do this, but by using TLS, the methods that are used in the paper are already well established and are not further developed in this paper. Deriving complex 3d models using meshing is not novel and has been used in caves previously (eg. Silvestre et al 2015, Fabbri et al 2017, Gallay et al 2016).
- Cave ice formation is briefly mentioned in page 1, line 20. This is unclear and could be expanded upon to provide the reader with an understanding of how ice-coating in caves forms and the factors controlling this.
- Page 2, lines 7 –10 seem unnecessary – unnecessary detail in point density and number of points.
- Page 2, lines 11 – 15. List of TLS applications in non-ice caves. This information does not really add to the argument for using TLS, as it simply informs the reader that TLS has been used elsewhere. Perhaps re-organising this paragraph to show what TLS is, how it has been used, and the difficulties of scanning ice and use of TLS in ice coated caves would read better. Eg. Line 26 – 30 outlines the issues with tachymetric surveying. This needs to be presented up front, before presenting the argument that TLS provides an improvement on this, and then the applications of TLS elsewhere can be summarised.
- Page 2, line 15 – use of 'etc.' to end sentence is not acceptable – unprofessional use of language and assumes reader knowledge of other uses of TLS.
- Page 2, line 16 – re-write 'reflectance of ice absorbing much of the laser energy'. This suggests that the ice is reflecting the laser beam and absorbing it at the same time – the paper cited for this shows the difficulties in scanning ice, as ice can absorb red laser beam wavelengths.
- Page 2, line 16-18 – this is not a full sentence, just a phrase.
- Page 2, line 21 – what are the open questions not addressed by Avian et al 2018? Be specific, this assumes that all readers have read Avian et al 2018's paper. If these questions are addressed by the manuscript, this must be made clear.

Area of Interest

- Figure 1 – This map does not provide much information. The text on the map is too small and blurry, particularly in the inset map showing the location of the cave in Slovakia. Providing a map that demonstrates the important geomorphological features surrounding the cave would be more useful – eg. addition of contours may add to show if cave is located in depression/high elevation, addition of notable features such as the debris cone mentioned on page 4, line 11. It would be good to overlay the planform of the cave onto

the map to show it in geographical space given that no overview of the scanned cave is given. The figure caption also needs to be more explanatory – what exactly is the figure showing us?

- Figure 2 – The figure caption needs to be more explanatory – is this the same view in each panel? Is the view of the cave entrance from inside the cave? Say in the caption that the figure shows decreasing ice coverage. Presumably, an object in the centre of the 2018 picture provides scale – this needs to be highlighted in the caption and readers need to know what this object is.
- Page 3, line 13 – no need for repetition of information from introduction.
- Page 4, line 3 - the description of the cave shape is not clear. What does an obliquely falling bag look like?
- Page 4, lines 11 – 15. Description of cave is unclear and does not correspond with Figure 3. Where is the debris cone? What is meant by the bottom of the iced part of the cave? It would help the reader to see these features on a map.
- Figure 3 – This figure is too small, and the writing needs to be larger. What is meant by the mapping line and mapping points? These are difficult to see on top of the background colouring. It would be good to know how deep the cave floor is from ground level, and where the cave entrance is. Is it necessary to show rock blocks, clay, gravel and debris on this map? Where is the icefall mentioned on page 5, line 8? I think knowing the location of ice coverage is important, but the composition of the rest of the cave does not seem to add any information/contribute to the reader's understanding of the paper – at least the importance of knowing this is not highlighted. A further thought – is the cave below ground, or above ground? Is it completely sealed off, are there any water inputs to the cave/how big are these, is there any flowing water through the cave, what is the height of the cave, what is the ambient temperature and moisture, is air circulation within the cave known/are there any openings to the outside? These sorts of information, and the locations of such detail, are useful for understanding potential causes of ice accumulation/decreases.
- Page 4, line 6 – 7 – 'large portion of floor ice situated beneath layers of sediment' - does this mean that sediment is lying on top of layers of ice, or that water has percolated downwards through the sediment and frozen in place? Ie, are these actual layers of horizontal ice, or frozen within the spaces between sediment?
- Page 6, line 3 – ice forms identified are hoar frost in the upper parts, ice coatings on the cave walls and 'others'. Surely these 'other' ice forms are important? Don't assume that the reader knows what these ice forms are. Are the authors referring to ice stalacmites and stalactites here? Or other morphological features?
- Figure 4 – the picture of the icefall is not particularly clear – is that a person at the top of the ice fall to show scale? This needs to be pointed out in the caption if so. Could the rock surface be labeled to make it clearer where the ice fall is coming from? In panel A, does the cave extend at the bottom left of the photo where a head torch can be seen? Again, there is no acknowledgement of where this ice fall is within the cave. Is this at the entrance? The caption for this figure is better than the preceding figures – gives more detail. Scale would be good.

- From Figure 4, it seems that the upper parts of the cave are separated from the lower parts by access down the ice fall. Is this correct? Does the map in Figures 3 and 6 just represent the lower level?
- Page 6, lines 7 – 18. Most of this information regarding the cave history is redundant and does not add to the reader's understanding. However, the connection of the cave with the Archaelogical Dome is important – this needs to be kept but an explanation of what this dome is is needed, as well as demonstrating where this link is with the Silicka l'adnica cave on a map. How did this link change the microclimate within the cave and lead to negative effects on cave ice?
- Capitalisation of the cave name needs to be consistent throughout the manuscript– sometimes l'adnica has a capital L and sometimes it does not.

Data and Methods

- It is not clear why authors collected data over 2 years, nor is the time interval at which the cave was scanned given. This information is fundamental, given that the results show ice changes from season to season. How did the authors come to the conclusion that ice volume may have changed at an intra-annual scale?
- Were scans positioned around the cave to record the entirety of the ice floored section, or just parts of interest?
- The surveying technique could be presented in more detail/more clearly and concisely, with omission of principles such as those on page 8, lines 10-16. The Panorama mode 40 used could be summarised more succinctly.
- Where were ground control points taken around the cave? Just at the entrance? Why were further scan missions after the initial scan mission only completed in areas of ice accumulation? This will skew the results and only present data on increasing ice volumes rather than presenting an overview of the whole cave. Is this due to the wording?
- Page 9, lines 1-5. Information on scan times not necessary, unless trying to prove the point that TLS enables faster data acquisition than other survey techniques, which allows repeat scanning at increased time intervals.
- Table 1 – columns 4 and 5. Does 'no. of p.' refer to the number of points within the point clouds? This information does not add to the paper, as the decimation/clipping of point clouds is explained elsewhere. Column 3 – why are differing scanner modes used? This needs to be explained.
- Page 9, line 9-10. Is the noise identified here the noise that was present in the laser scans, or is this comment more general about the different types of noise?
- Page 9, line 19 – the points that are used are within the deviation value range of 0-20. Is this the same range as described in lines 16-18? Why have only this range of points been used? Is 20 a known threshold in the dimensionless number range of $0 – 65,535$?
- Page 10, line 5 –7- this sentence is confusing, please clarify.
- Page 10, line 10 – clarify what 'scratches' are.

- Page 10, lines 13-23. This paragraph on the principles of cloud to cloud registration is confusing, including un-defined terms such as 'cube size' and 'search radius', which do not mean anything to the reader unless they have used the software. Brief explanation of what these are would benefit the explanation. This paragraph would perhaps be better suited to Section 3.2. It is appreciated that authors are trying to make results repeatable – but readers do not necessarily need to know the working of the algorithms used.
- Page 10, line 27 – 29. Do the areas of the cave with stable geometry have ice covering them? Are they areas of bare rock? This needs to be clarified in the area of interest section in the cave description.
- Page 11, line 1 – the authors propose that the sC2C approach is more suitable, however, it is not clear which other approach this is an improvement on. Is this a wording issue and is it perhaps meant to say that this approach is the most suitable?
- Page 11, line 5-7 – the last sentence of this paragraph is unclear.
- Figure 7 – Panel C could be interpreted as a planform map, highlight which view of the cave this is in the figure caption. Check figure for spelling. Why have only scans from 23/06/2016 and 02/10/2018 been presented? Is this figure purely to demonstrate the improved registration provided by sC2C?
- Page 11, line 22 – both points explaining why a heterogeneous distribution of points occurs in TLS point clouds need to be clarified. The explanations of high densities of points in some areas and low densities in others on page 12 could be clearer.
- Page 12, line 8 – this sentence does not make sense.
- Figure 8 – this figure is not needed. It shows that the point cloud spacing has been homogenised; the reader does not need to see this to understand the explanation given in the text. Although this figure demonstrates where cave geometry is possibly more intricate, requiring more scans to be conducted around these features, this does not add to the reader's understanding of the paper.
- Page 12, line 14-15 – the authors introduce a result of the paper here. As this section should just outline the methods used, this sentence would be better placed as part of an introduction to the results section.
- Page 12, line 16 – this sentence does not fit here and is unnecessary.
- Page 12, line 20 - 'classical bivariate functions' needs to be explained or defined. It is unclear whether this means that certain parts of the cave have not been modelled.
- Page 12, line 21 – equation for modelling terrain needs components to be defined.
- Page 12, line 22 – page 13, line 2 - bivariate functions needs to be defined – currently this does not make sense despite the example of using a cube with a defined side length.
- Page 13, line 6 – 19 – the authors provide an explanation of PSR principles. An explanation of why this interpolation method was selected would be more useful than the detailed principles, together with maybe one or two sentences on how this interpolation method works.
- Page 13, line 21 – authors say that ice is expected to occur on the floor of the cave – previously, they have inferred that ice covers the floor of the cave. Is this an issue with wording? This suggests that the ice coating the walls of the cave and features extending

between the floor and ceiling have not been included in the analysis of ice volume change.

- Page 13, line 29 – the authors need to clarify what is meant by 'gradual' change. Quantify. What is the 'difference of distance' approach? Is this finding the difference in floor height between each scan mission?
- Page 13, 28 – 30 – again, this sentence should not be in the methods section but would be better situated in the results section.

Results and discussion

- Page 14, line 5 – authors should be careful in using the word 'significant'. This should be used only to refer to statistical testing, and the relevant test and significance values should be presented, otherwise, the word 'considerable' may be better. Significant is also used on page 17, line 7.
- Section 4.1 - how was the cross-section location decided upon? Was only one cross-section assessed and why? Although the cross-section encompasses three areas of different cave floor types, it cannot be concluded from this that ice accumulations are decreasing (as indicated by page 15, line 14) as changes in ice surface are also governed by local factors. More cross-sections demonstrative of these three floor types are needed to reach these conclusions.
- Page 14, lines 11-12, 18 – these sentences explaining what each panel shows are repeating information from the caption of Figure 9.
- Figure 9, line 14 - 'vertical' cross-sections imply that a cross-section was taken from the cave ceiling to the floor.
- Figure 9, line 15 – the cross-sections show the floor surface morphology, not the dynamics. The dynamics of the ice typically imply ice motion/change and the processes causing this, and can be inferred from looking at changes in ice volume/morphology.
- Figure 9, line 16, (b) – see previous comment with regard to ice dynamics. This panel seems to show the greatest change in elevation rather than the most visible dynamics.
- Page 14, line 21 – page 15, line 1 – this sentence does not make sense. Cross-section 'convergence' is also a confusing term – does this mean areas where the lines become closer together (ie little change in floor elevation)?
- Section 4.2 and Figure 10 – it is unclear what the differences of distance method shows – in the figure, it appears that the panels show areas of increasing/decreasing ice elevation, representing literally the difference in height elevation between each survey, as shown from the scale bar unit of 'm'. However, the authors then talk about the figure showing changes in volume in the figure caption. Does this figure show changes in volume or changes in elevation?
- It may make more sense to present the DEMs of difference (figure 10) first, and then use the cross-sections to examine the changes in areas of transitions between floor materials. The cross-sections basically demonstrate the same data as the DEMs of difference, but using a different viewpoint (ie long profile of the floor across the ice fall, rather than the

planform view of the entire cave floor), and therefore it cannot be said that these two methods of analysis are difference – they are presented as such in the manuscript.

- Page 15, line 20 and 24 – the term 'glacier' has a very specific definition and is not what the authors are suggesting here; this seems to be a misunderstanding in translation which has implications for the content that are not necessarily correct.
- Page 15, line 24 – although the collapse of an ice stalactite does not change the ice volume of the cave, the authors have only examined the changes in cave **floor** volume and, thus, this collapse does contribute to this change.
- Page 15, line 25 – sentence needs to be revised to make it clear when melting occurs and when seasonal minimums are observed.
- Page 15, line 27 – it is not clear what the 'increment of the stalagmite on the icefall' refers to, and whether the volume of the ice fall has increased over the whole period, or the volume of the stalagmite.
- Page 17, line 1-6 – it would be nice to see the authors' interpretation of events causing the loss of ice using the data sets mentioned (temperature, precipitation). Without this, the manuscript is just a report of ice change and does not present any concepts or ideas for this. If the manuscript presented a novel technique for obtaining such a great dataset, and explored its potential uses, this would be more acceptable. However, the techniques used have already been established.
- Figure 10 – this is a good figure and is perhaps the only figure of appropriate size in the manuscript. The scale bar text could be larger. A scale with more than two colours could be used to show more subtle differences in elevation, as currently the changes from light to dark blue/red are hard to correlate with the scale bar. Also, the labelling of 'gradual' and 'seasonal' is incorrect – it appears that the 'gradual' column reflects seasonal change (change from one season to another), and the 'seasonal' column reflects annual change (change from one summer/spring etc to the summer/spring of the following year). However, caution must be taken in that the top panel of this column shows summer change over 2 years (2016 – 2018).
- Page 17 – ice accumulation means addition of ice. Authors should alter wording to reflect whether ice has increased/decreased. For example, 'the loss of ice accumulations' in line 1 suggests that there is no further increase in ice, whereas I think that the authors mean that ice is decreasing.
- Page 18, lines 1-2 – the volumetric error calculation appears to be derived by multiplying the total error by the area of observation – I am unsure that this is correct. Furthermore, errors for each DEM should be reported.

Conclusion

- Page 18, line 14 – the content of this sentence should also be in the introduction and expanded upon to explain why ice caves are important and what they can tell us about changes in the landscape. Furthermore, the whole point of the paper seems to be on detecting changes in ice volume – if these changes are dependent on the surrounding

landscape/climate, the decreasing ice volumes can infer changes to these factors and should be discussed in the manuscript.

- The conclusion implies that using sC2C has not been accomplished in caves before and presents the advantages of this. These advantages could be made clearer within the rest of the paper.
- The dynamics of ice cave changes have not been explored fully in this paper with only brief suggestions for causes of change. If only the datasets and basic analysis are to be presented, the paper needs to acknowledge the uses of such a dataset and present the paper in such a way as to show that this dataset is available for further use. This style of data presentation would be expected if the manuscript was improving a method or ascertaining its applicability.
- Without the inclusion of temperature or rainfall datasets, it is impossible to conclude that ice losses are related to dry years, and even more difficult to determine whether these ice losses are related to climate warming.