**Review of: A comprehensive TLS-based framework for cave ice monitoring under adverse surface conditions: application at Scărișoara Ice Cave**

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The manuscript by Šupinský et al aims is to present a comprehensive and transferable TLS data-processing framework for monitoring and quantifying volumetric change of ice caves, using two different terrestrial laser scanning sensors. The proposed framework is demonstrated at a Romanian ice cave.

The manuscript is interesting and well-written and huge efforts have been made to do the data acquisition. However, I am not sure about the novelty of the research and if the research fits the scope of The Cryosphere. I'll list the shortcomings and points that can strengthen the manuscript before I give specific comments.

First, the novelty of the research is not clear to me. As presented here, the result of the 3-year measurement campaign is the decrease of ice volume in the ice cave. This result is given the present-day climate not surprising, but the authors do not relate their results to the processes driving the changes in the ice cave. If the processes behind the ice cave changes are assessed with, for example meteorological records, I can see that the manuscript fits the scope of The Cryosphere. Also, how is this research different from previous work of the authors in this ice cave?

Second, the presented manuscript has a lot of technical details on the data processing, which is according to what is aimed at with this paper. However, the decisions taken on for example scanner parameters and resulting point spacing cannot be generalized to other ice caves. As presented here, the research is not directly transferable to other icy environments. I would recommend to provide a clearer guideline for other researchers that want to assess ice cave changes with TLS. If the authors manage to give this guidelines, the manuscript would be very well suitable for a remote sensing/geodesy related journal, but as presented here, the manuscript is neither suitable for a cryospheric nor a geodetic journal.

Third, what bothers me is that technical jargon is not used appropriately. For example, the word surface glacier was invented, in order to distinguish between an ice cave and mountain glaciers. Other examples: cold air avalanches (?), ice cliff (wrong context) and accumulation (wrong context). Furthermore, DoD stands in a geographical context for DEM of difference, and is therefore not recommended to be used as 'differences of distances'. Other inappropriate use of technical jargon will be highlighted in the specific comments.

**Specific comments:**

1. Title: consider adding Romania after Ice Cave.
2. L10: consider removing the first sentence and directly focus on the monitoring of ice caves.
3. L14: from should be including.
4. L26: this sentence is too generic. Of course, omitting processing steps would affect the results.
5. L30: Marzeion et al is about the global sensitivity of glaciers to climate change and the other two references are the author's work on ice caves. Either use more recent references

for other cryospheric components or only focus directly on ice caves. Those references should be not only the author's own work.

6. L33 and L43: surface glaciers is an invented word. Just focus on ice caves in these contexts.
7. L42: replace however by thus.
8. L50: constrain should be constrains.
9. L51: I do not agree with the arguments for the unsuitability of MLS for cave mapping. With recent developments, MLS would also be a great and cost-worthy alternative for the data acquisition presented here. Please also read into the work of Goelles et al, 2022 and consider referencing.
10. L53: define what is meant by lowest spatial resolution and precision.
11. L59: be consequent in the use of technical jargon. With caves, ice caves are meant here. Please check this throughout the paper.
12. L63: add wavelength after 1550 nm. In the context of the different wavelengths of scanners, 1064 nm should also be mentioned, as this wavelength is also suitable for snow and ice. See research done with a Riegl VZ6000.
13. L71: laser scanning systemS
14. L83: consider ending the sentence after conditions and make the text more readable.
15. L93: cave glaciers? Please use appropriate jargon.
16. L95: replace the semicolon by a comma.
17. L97: clarify which methods are used to acquire the recent observations.
18. L100-L127: I got lost in the description of the ice cave. Please rewrite this section and describe all the labels from Fig. 1 in the text. For example, what is Rimaye? Is it possible to add pictures? Or place some of the pictures of Fig. 7 earlier in the manuscript?
19. L101: underground glacier? Please replace by ice body or a similar term.
20. L104: ice cliff? What is that? And what do you mean by ice block. Reader gets easily lost here.
21. L105: breakdowns accumulation? Again, some invented jargon. Also remove resembling a moraine in this sentence.
22. L123: cold air avalanches? Idem.
23. Fig. 1: label plan and side view with a and b and indicate in the caption that the yellow dashed line indicates the AoI and that the blue area is the area where ice occurs. Right?
24. Sect. 3.1: for the non-experts on TLS equipment, explain the difference between time-of-flight and phase-shift scanners and elaborate a bit more on the use of these different scanners. Would it have been possible to use only one sensor?
25. L145: Gabbud et al used the Riegl VZ6000, which is not using a wavelength of 1550 nm. Please use references where research has been done with a Riegl VZ1000 in icy or snowy environments.
26. L146: what is the last calibration protocol?
27. L152: what is the full scan resolution?
28. L155: replace 1 by up, so it reads up to 40 million points.
29. L158: remove the placement of.
30. Data acquisition: I want to compliment the authors on the huge efforts the have done for the data acquisition! 200 scan positions is a lot. Can you also indicate the scanning time of each scan position?
31. L161: remove sub-.
32. L164: add information about the wooden tourist path in the description of the cave. Knowing that there is a path and seeing the pictures in Fig. 7 made it more clear to me.

33. L168: the points per position also depends on the number of returns per scan position, so giving these numbers here is not very useful.
34. L171/172: I do not see why the ice-free areas are excluded in later acquisitions, because they are the stable surface that help to register the data from year to year. Please elaborate.
35. L179: refer not only to Fig. 2 but also to Sect. 3.3.
36. Fig. 2: ice accumulations in the caption should be ice cave.
37. L186: what is the unit of the deviation threshold?
38. L193: Laser (..) spacing should be placed before the sentence about importing in RiSCAN Pro.
39. L194/195: I don't see why this C2C approach is necessary, because this is mainly depended on the point spacing of these very dense clouds.
40. L199: here a note is made about the reference surface, but no explanation has been given before that there is at stable cave ceiling. Is this enough surface area to use as reference surface?
41. L201: why is the latest scan used as reference and not the later scans relative to the first one (2023)?
42. Fig. 3b: in the legend, what is the unit of density?
43. L242: remove the reference to table 2, as it is first discussed in the results.
44. L246: is the Cloth Simulation Filter in CloudCompare? Please indicate.
45. Eq. 2: how are the variables in this equation derived? Do they come from the software or did you calculate them? Please elaborate. Also, this Etotal and Ev are not discussed in the results.
46. Eq. 3: where does this equation come from? Does it make sense mathematically?
47. L261: here is the first time that 2.5D volume change is mentioned. Please elaborate here in the difference between 2.5D and 3D volume change.
48. L280: only 2-3% of the data is kept. This is very surprising to me and also asks the question if the amount of data acquired was appropriate. Could it have worked with less scan positions? The amount of scan positions are very high for a relatively small area. Could you give the reader recommendations on how to do the data acquisition differently?
49. L295: the registration errors, are they given in the software? I also wonder if the ice cave is assumed to be stable during the two day acquisition period. If the ice cave is changing during those days, how is this affecting the registration errors?
50. Table 1: the processing error StdDev, is this the same as the registration error? And is it derived in the software?
51. Fig. 4: on the floor, is the yellow line, kind of shaped as a shoe, the footpath? Has the footpath been sinking? Can you give a magnitude of this, between 2023 and 2025 and between 2024 and 2025? Maybe it says something about your registration method.
52. L308: what is ice block?
53. L310: the points per m2 says something about the roughness of the surface. If the surface would be perfectly planar, there would be 10k point per m2. Is this true? Elaborate on the surface structure.
54. L313: was more filtering or subsampling done for the combined point cloud? As these numbers do not sum up from the two data sets.
55. L315: why are the results of the FARO scanner better on wet surfaces? The scanners work at the same wavelength, right?
56. L318: introduce the Rimaye passage in the introduction of the ice cave.
57. Fig. 5: in the combined point cloud, is the FARO data overlayed on the RIEGL data? Because the percentage of FARO data seems to be higher than indicated. Also, and

especially for 2023, there doesn't seem to be a lot of data gaps that have to be filled with FARO data. Is this a matter of visualization?

58. L327: how are the incidence angles derived?
59. Fig. 6d: What is meant with scan position? Is this the right legend?
60. L347: is ice fall a correct term in an ice cave?
61. Fig. 7: this figure is too small and almost unreadable. Maybe focus on 4 instead of 8 surfaces and make the labels bigger/better readable.
62. L354: ice fall, see above.
63. L376: what is high incidence angle degradation? Please rewrite this sentence.
64. Fig. 8b: in the FARO point cloud residual on the left, a cyclic pattern is visible with outliers every (approx.?) meter. Please explain where this comes from. This figure is also too small and barely readable.
65. Fig. 9: add a scalebar to the figure.
66. L417: ice accumulations monitoring? Use a different term than accumulations.
67. L418: the definition of 2.5D and 3D should have been given before.
68. L427: because of not uniform point cloud coverage within the AoI. Please rewrite this sentence.
69. Table 2: I don't understand why 2025 is reference. The DeltaV and Deltah are negative, relative to 2025. So does it mean that the volume of the ice increased over time?
70. Fig. 10: please add labels a, b, etc to the subplots. Is it correct that the combined point cloud C2C gives positive results and the other ones show negative results? Is it ice loss or gain? Also, the sum of volume change between 2023 to 2024 and 2024 to 2025 should be the volume change between 2023 and 2025. Especially for M3C2, this deviates a lot. Please elaborate.
71. L520: reference to the several published ice cave studies is missing.
72. L524-528: please reconsider this statement. With the gap filling, artificial surfaces are created and you can never be sure that volume change is happening here.
73. L571: I like the listing of recommendations, but please rephrase and refrain from using DoD evaluation.
74. L573: what is a well-characterized laser scanner? The choice of scanner should be elaborated better earlier in the manuscript.
75. Data availability: I was happy to see that there is a web interface, however this page is not working in different browsers. I can see the labels of the sections of the ice cave, but no point cloud is visible.
76. Author contributions: with investigation, is the data acquisition meant?
77. References: the doi or link to Buchroithner and Gaisecker is missing, but I found it here: https://www.zobodat.at/pdf/Hoehle_71_0062-0070.pdf

**References:**


- Goelles, T., Hammer, T., Muckenhuber, S., Schlager, B., Abermann, J., Bauer, C., Expósito Jiménez, V. J., Schöner, W., Schratter, M., Schrei, B., and Senger, K.: MOLISENS: MObile LIdar SENsor System to exploit the potential of small industrial lidar devices for geoscientific applications, Geosci. Instrum. Method. Data Syst., 11, 247–261, https://doi.org/10.5194/gi-11-247-2022, 2022.