Referee 1

General Comments:

This is an interesting manuscript that aims to illustrate how inexpensive lidar units developed for the automotive industry can be used for geoscience applications. The authors do a nice job at outlining the technical aspects of the lidar units they compare.

My general suggestions for improvements to the paper are to do a better job of setting up the problem in the introduction. In particular, can you better describe why users would want to use these systems versus techniques like photogrammetry. Your underground examples make it obvious as to why you need lidar, but I think you need to clearly explain that to readers. In addition, you should expand the intro to show the breadth of how people have been using lidar in the geosciences ranging from controlled outdoor studies (e.g., Rapstine et al. 2020; Rengers et al., 2021) to natural observations (e.g., Rosser et al. 2005) to damage assessments (Olsen and Kayen, 2013).

Another rather large suggestion is to try to gear the paper to seem relevant far into the future. Right now, there are references in euros and references to years when technology is expected to be developed, but those references will seem irrelevant 10 years from now. If you could re-frame the tone to have a long-view (at least a decade) I think it will seem more relevant.

In addition to these general suggestions, I have provided several line comments below.

Olsen, M. J., & Kayen, R. (2013). Post-earthquake and tsunami 3D laser scanning forensic investigations. In *Forensic Engineering 2012: Gateway to a Safer Tomorrow* (pp. 477-486).

Rapstine, T. D., Rengers, F. K., Allstadt, K. E., Iverson, R. M., Smith, J. B., Obryk, M. K., ... & Olsen, M. J. (2020). Reconstructing the velocity and deformation of a rapid landslide using multiview video. Journal of Geophysical Research: Earth Surface, 125(8), e2019JF005348.

Rengers, F. K., Rapstine, T. D., Olsen, M., Allstadt, K. E., Iverson, R. M., Leshchinsky, B., ... & Smith, J. B. (2021). Using High Sample Rate Lidar to Measure Debris-Flow Velocity and Surface Geometry. Environmental & Engineering Geoscience, 27(1), 113-126.

Rosser, N. J., Petley, D. N., Lim, M., Dunning, S. A., & Allison, R. J. (2005). Terrestrial laser scanning for monitoring the process of hard rock coastal cliff erosion. *Quarterly Journal of Engineering Geology and Hydrogeology*, *38*(4), 363-375.

Dear Editor, dear reviewers,

We are very grateful for two very detailed and constructive reviews and appreciate the valuable time put into this. We believe by incorporating the reviews we managed to achieve a much more mature manuscript which we hereby submit for your consideration.

In the following we mark black the comments given by the reviewers and the editor, give our answers and comments in blue and indicate how we addressed the amendments in the manuscript in green.

We wrote a new paragraph introducing TLS applications in geosciences, which includes the listed references and more.

„Non-automotive Terrestrial Laser Scanner (TLS) units have been used in many geoscientific applications such as spectral and structural geology, seismology, natural hazards, geomorphology, and glaciology as listed in the review Telling et al. (2017). Data products based on TLS are widely used and range from controlled outdoor studies (e.g., Rapstine et al., 2020; Rengers et al., 2021; Prokop et al., 2008) to natural observations (e.g., Rengers et al., 2021) and damage assessments (e.g., Olsen and Kayen). Typically, multi-temporal lidar studies deal with repeated measurements over years (e.g., O'Neal and Pizzuto, 2011; Neugirg et al., 2016) or months (e.g., Rabatel et al., 2008; Rengers and Tucker, 2015) in order to investigate deforming surfaces. Recently, permanently mounted TLS have been used to monitor rockfall at intervals of an hour (Williams et al., 2018, 2019) or to monitor a high mountain environment at daily or hourly intervals (Voordendag et al., 2021). Rengers et al. (2021) recorded a mass flow with speeds greater than $1\mathrm{m\ s}^{-1}$ for the first time. They used a modified VZ-400 TLS at a narrow field of view of $^{\circ\circ}44 \times 0.13$, which allowed a sampling rate of 60Hz.

Concerning the future proofness of the paper: We deleted speculative releases of lidar devices. Although, we kept current prices of units since we think it is relevant because lidar from the automotive industry are much cheaper than "conventional" TLS units. This enables new applications where the lidar unit is at risk of damage or loss.

We added a paragraph motivating the development of MOLISENS. This and the new paragraphs about TLS and structure from motion address the question: "better describe why users would want to use these systems versus techniques like photogrammetry"

Structure from motion (SfM) especially from Unmanned Aerial Vehicle (UAV), is another tool to derive 3-dimensional (3D) point clouds for geoscientific applications. For example, Lague (2020) compared SfM to TLS for fluvial geomorphology and Wilkinson et al. (2016) for digital outcrop acquisition. Its main advantages are low-cost, uniform point density, high resolution RGB information with the limitations of no penetration through vegetation, requirement of good Global Navigation Satellite System (GNSS) signal, and UAV flight regulations. In addition, SfM is problematic for surfaces with homogenous textures like snow and is limited to well-lit environments. In caves SfM has been used with digital close-range photogrammetry by a digital single-lens reflex camera mounted on a tripod in the study of Pukanská et al. (2020), where they also compared it to TLS data. Their conclusion was that both methods have their specific requirements, advantages, and disadvantages. Therefore, they recommended a combination of both methods for mapping complex cave spaces. „

For details please also see the attached latex diff which shows all the changes.

Once again, many thanks for the valuable input and all the best – on behalf of the author team,

Thomas Gölles

Specific Comments:

Line 19: Explain why you used such a long-range lidar for such confined areas?

We used the long-range TLS as a reference since it is a state-of-the-art TLS with high accuracy and high precision. The VZ6000 has a minimum rang of 5 meter and is therefore suitable for static compression in section 3.2.

We added "high accuracy and high precision" to the text for further reasoning.

24: This is a minor comment, but I don't see how you get the "LI" in MOLISENS. Don't you need to put "Lidar" in there, for example, Mobile Lidar Sensor system.

This was a typo. The sentence now includes lidar.

28: Here and elsewhere, when you say automotive lidar, it is a little unclear. What you mean is that you are using small lidar sensors that were originally designed for the automotive industry. But it is a little confusing because people might think you mean lidar mounted on an automobile. So try using a more descriptive term like lidar developed for the automotive industry.

This is a very valid point and we added it specifically in the title:

This is now also reflected in the improved title: "MOLISENS: A MObile LIdar SENsor System to exploit the potential of small industrial lidar devices for geoscientific applications "

The vehicle independence is also mentioned in the first paragraph of the introduction and the abstract. Therefore, it should now be clear that it is a lidar sensor from the automotive industry which does not require a vehicle in our setup. Therefore, we kept the terms automotive lidar throughout the text to distinguish between to Ouster lidar and "conventional" TLS such as the Riegl VZ6000.

43-44: I think you should avoid things like prices and saying when an instrument is expected to be out. Here you write "late 2022", but what if your paper isn't out in 2022? What if the instrument isn't ever released.

Yes that's true, it is speculative and hence we deleted the sentence.

145: Can you explain how the GPS works in a cave?

It does not. The system does not depend on continuous GNSS data, as mentioned in line 242 in the original version of the manuscript.

Since the section deals with the software stack and MOLISENS is for multiple applications, and not just caves, we think it is appropriate to leave this information further down the line in the SLAM algorithm section.

206: The sentences here: “We found that…” should be in the results.

We moved the sentence to section 6.1

218: Where you have written (etc) what are the other things that you are measuring? I’m more interested in that, than the information in Table 1. Consider putting those measurements in a table.

We now list all attributes which are stored by the Ouster sensor.

„In addition to the x-,y-, and z- coordinates, also range, intensity, reflectivity, ambient near infrared, azimuth angle, and time stamp for each point are stored“

226: where you say “How many clusters of points in a 0.5m radius exist between 5 and 10 in THE x direction …” What are the units you are refering to when you say between 5 and 10?

Added: „between 5 and 10 m”

345-361 Add this information to the intro.

Done.

Figure 1. Add labels (a, b, and c) for the sub-figures here. Also in (b) consider adding something for scale, such as a pen.

Done. In addition, the caption was adapted and the presentation of the battery was made consistent with the rest of the image.

Figure 5. Add a colorbar in 5d.

Done.

Figure 6. Use a more complete sentence and be more descriptive in the caption for (a). (b) Add a colorbar, label the hand-rail, and try using something like the EDL filter to make the point cloud more visible in the figure.

We added the color bar, hand-rail label, and increase the readability of the point cloud image.

The new caption reads as follows: „Panel (a) shows karst shapes, concrete, and metal structures in the Lurgrotte cave (image by Christian Bauer). Panel (b) shows a detailed image of the cave section including the walking path and handrail (created with CloudCompare)”

Figure 7: Show location map of where the glacier is located (similar to inset in 5a). Add a colorbar to all figures.

We added a detailed map and completely reformatted the figure. All point clouds now use the same color bar.

Table 1: Is this table necessary? The specs feel somewhat out-of-step with a journal article.

The second reviewer was interested in the specs, and we think that it is of importance for users, since they enable many new applications which are otherwise impossible with a heavy and bulky instrument. Therefore, we deleted Table 1 but mentioned the key specs in the caption of Figure 1.