## Dear Editor, Associate Editor, and Reviewers,

We sincerely thank you for the time and effort invested in reviewing our manuscript, *"From Point Cloud to Digital Elevation Model: Airborne Topo-Bathymetric LiDAR Processing over the 28 km Ardèche River Gorges."* We greatly appreciate the constructive and insightful comments, which have helped us improve the quality and clarity of the manuscript.

In response to the reviewers' suggestions, we have carefully revised the manuscript and provide detailed point-by-point responses below. Reviewer comments are reproduced in light blue, followed by our responses. All modifications made to the manuscript are highlighted in the revised version.

We hope that the revisions satisfactorily address all concerns and that the manuscript is now suitable for publication.

Sincerely,
Ron Nativ et al.

## Response to reviewer #1

**Comment 1:** The workflow includes some manual steps (e.g., training, validation, and manual cleaning). Could the authors comment on whether this method would still work well for larger datasets or whether it could be further automated?

**Response:** We agree that scalability and automation are important considerations. While the workflow remains only partially automated, most processing stages, including waveform processing, point-cloud generation, OrthoFWF classification, and surface reconstruction, are already automated and can be readily applied to larger datasets. We have added a paragraph in section 5.3 of the Discussion section (lines 882-891) describing the scalability of the workflow, identifying the remaining manual steps, and highlighting opportunities for further automation, particularly in training-data generation and quality-control procedures.

**Comment 2:** The sonar data used for validation were acquired several years after the LiDAR survey. Could temporal changes in river morphology affect the reliability of this comparison?

**Response:** We thank the reviewer for raising this important point. Temporal changes in river morphology are almost certain given the 3.5-year interval between the surveys and the occurrence of several large floods. This is why we do not consider this dataset an independent validation of the LiDAR survey, but rather use it as a complementary source of information to constrain the interpolation of the deepest parts of the channel. We have clarified this limitation by adding a new paragraph to Section 2 explaining why we could not obtain a validation dataset, as well as its implications in Section 3.5.2, where we explicitly discuss the temporal offset between the two surveys and its potential impact on the comparison.

**Comment 3:** It would be useful to discuss how well this workflow would perform in more turbid or optically complex river systems, where signal attenuation and noise may significantly affect depth estimation.

**Response:** We thank the reviewer for this suggestion. The primary limitation is expected to affect the detection of weak bed echoes. We have expanded Section 5.2.1 of the Discussion to address the expected influence of increased optical attenuation. In short, although the orthoFWF approach should still improve the signal-to-noise ratio, increased water-column backscatter may alter the waveform such that the channel bed return no longer appears as a distinct peak, but only as a shoulder in the FWF signal. In such cases, the simple peak detection approach used in this study would not reliably identify the bed return. While more advanced waveform analysis methods are not yet implemented in the qFWF plugin, its open-source nature would allow them to be incorporated in future developments.

## Response to reviewer #2

**Comment: Lack of validation**

**Response:** We thank the reviewer for this thoughtful assessment. We agree that independent validation would strengthen the evaluation of the proposed methods. However, we now explain more clearly that we were unable to acquire such a dataset because a very large flood (with a decadal return period) occurred three days after the LiDAR survey, significantly altering the channel bed (Section 2). As noted by the reviewer, the primary objective of this study is to present and evaluate a scalable processing workflow. We have also expanded the Discussion (Section 5.1; lines 837-846) to explicitly address this limitation.

**Comment: Unsupervised noise filtering for the deep OrthoFWF classification -** This is a very interesting and exciting approach. However, I am interested in how the method handles depths at which green light attenuation in turbid or deep water causes the riverbed return amplitude to drop down to the (sensor) noise level. Since the amplitude of sensor induced noise peaks is depth-independent while the riverbed signal decreases with depth. Do you define a depth threshold beyond which riverbed peaks can no longer be reliably distinguished from noise peaks, thereby preventing noise peaks from being misclassified as riverbed returns? Additionally, in Figure 6, I seem to observe a consistent noise amplitude floor beginning at approximately 3.25 m depth — could you confirm this?

**Response:** Our approach does not rely on a predefined depth threshold. Instead, all detected peaks are retained above a minimum intensity that is twice the noise level of the orthoFWF signal. We now better explain this in section 3.4.1, 3.4.2 and shows the noise level that is used in fig. 5 (D).

The apparent consistent noise floor amplitude is an artefact of the 2D KDE approach which tends to 0 on the borders of the 2D space. We added a sentence in the figure 6 legend.

**Comment:** "Ensure the correct formatting of numerical values and units, such as 'between 0.0 m and 0.7 m,' to maintain precision and consistency."

**Response:** We reviewed the manuscript and corrected the formatting of numerical values and units where necessary to ensure consistency throughout the text.

**Comment:** "Consider adding details about the typical length of an FWF (Full Waveform) and whether the length or number of samples per FWF is dynamic or constant. Including a visualization of a typical raw individual FWF would also be beneficial."

**Response:** We have added information in section 2 (lines 221-237). Individual FWF data are visible in Fig. (5B), and we refer to this figure where needed.

**Comment:** "For completeness, please include the values for boresight alignment and lever-arm, along with their respective accuracies."

We thank the reviewer for this suggestion. We agree that the lever-arm and boresight calibration parameters may be of interest to readers familiar with airborne LiDAR processing. However, our objective is to keep the manuscript accessible to a broad readership, particularly geomorphologists who are likely end users of topo-bathymetric LiDAR data. We therefore chose to focus on the overall geometric performance of the processing chain, which we assess through comparison with the LiDARHD reference dataset (Fig. S1). We believe this provides a more meaningful evaluation of the geometric calibration and point-cloud generation workflow than reporting the individual calibration parameters, at least for the topographic component given the lack of an independent bathymetric validation dataset. Since the geometric calibration procedure follows standard practice and is not a methodological contribution of this study, we prefer not to expand the manuscript with a detailed discussion of these parameters. For completeness, the lever-arm accuracy is on the order of 5 mm, and the estimated boresight angles are −0.004°, +0.005°, and +0.0191° (roll, pitch, and yaw), with typical uncertainties of approximately 0.002° for roll and pitch and 0.01° for yaw.

**Comment:** "The refractive index in water (nW) significantly impacts the accuracy of bathymetric points. Could you briefly explain how this value was determined and provide a reference to a formula or guideline? Could you also clarify whether this value can be adjusted in the CloudCompare plugin?"

**Response:** Indeed, the choice of the refractive index is particularly important in deep coastal environments (>10 m), where it can have a significant impact on bathymetric accuracy. Its influence is much smaller in shallow fluvial environments such as the one investigated here. We have added a reference for the refractive index value used in this study and quantified the sensitivity of the refraction correction by varying $n$ between 1.333 (the refractive index of freshwater) and 1.335 (representative of the water conditions in our study area). This results in a maximum vertical difference of approximately 4 mm at a depth of 4 m (Section 3.3.1). We also clarified that the refraction correction is performed in a Python script rather than in CloudCompare.

**Comment:** "Can you provide more details on how misclassified bathymetric points are identified? Please describe the criteria or visual patterns used for reclassification, especially if this process is based on manual filtering."

**Response:** We have expanded the description of the manual validation procedure. Misclassified bathymetric points were identified through visual inspection of the bathymetric depth maps and cloud-to-cloud distance maps. Candidate points were typically characterized by anomalous depths relative to the surrounding channel bed or by local discontinuities in the bathymetric surface. These areas were then inspected in cross-sectional view, where misclassified volume echoes could often be recognized as points located above the surrounding bed surface and subsequently reclassified.

**Comment:** line 451: "The sentence in this line seems out of place to me and doesn't have a clear connection to the preceding section. Consider rephrasing it or integrating it more effectively into the text."

**Response:** We agree that the sentence was insufficiently connected to the surrounding text. It has been moved and integrated into the introduction of Section 3.4.2 to better motivate the subsequent deep-return noise classification procedure.

**Comment:** "The stated height accuracy of 63.1 cm seems relatively high. Could you elaborate on why this value is so large?"

**Response:** The reported value of 63.1 cm does not represent the intrinsic precision of the sonar instrument. Rather, it corresponds to the standard deviation of the elevation differences between the sonar-derived bathymetry and the LiDAR bathymetry after vertical alignment. This value incorporates multiple sources of uncertainty, including temporal changes in channel morphology between the October 2021 LiDAR survey and the May 2024 sonar survey, differences in discharge conditions, horizontal positioning uncertainty of the kayak-based sonar system, and interpolation effects. We have clarified this point in the revised manuscript.

**Comment:** "The depth range of 5–8 m is mentioned, but the scale in Figure 7B-C ends at 4.5 m. Please clarify where these depths are shown or adjust the figure accordingly."

**Response:** We thank the reviewer for noticing this ambiguity. The depth range of 5–8 m refers to channel depths constrained by the complementary sonar survey, whereas Figure 7B-C only shows depths directly observed by topo-bathymetric LiDAR. The maximum depth reached by the LiDAR dataset is 4.46 m ($D_{99}$; Table 1). We have revised the text and figure caption to clarify this distinction.

**Comment:** "The statement that sonar should be viewed as a supplementary tool rather than a primary data source sounds too generalized to me..."

**Response:** We agree that the original statement was overly broad. The text has been revised to clarify that topo-bathymetric LiDAR and sonar are complementary techniques. While sonar remains the primary method for bathymetric measurements in deeper waters, topo-bathymetric LiDAR offers important advantages in shallow-water environments.

**Comment:** "Ensure the completeness and accuracy of the references in both the text and the bibliography."

**Response:** We reviewed the references throughout the manuscript and corrected the inconsistencies identified by the reviewer, as well as additional issues found during this review.

**Comment:** "Please check whether the signal strength of an FWF sample is referred to as 'amplitude' or 'intensity.' I guess these terms are not the same."

**Response:** We thank the reviewer for this observation. While the manuscript text consistently uses the term *intensity*, we identified two occurrences of *amplitude* in figures 2 and 5. These have now been revised to ensure consistent terminology throughout the manuscript.

**Comment:** "Clarify what 'LiDAR HD' stands for, as this term may not be immediately clear to all readers."

**Response:** LiDAR HD is described in the manuscript as the national airborne topographic LiDAR dataset provided by the IGN. We believe this information adequately defines the term for readers unfamiliar with the program.