Interactive comment on “Aircraft based Stereographic Reconstruction of 3D Cloud Geometry” by Tobias Kölling et al.

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Introduction

We thank referee #1 for his/her careful reading, comments and suggestions which we address in the following. The authors’ answers are printed in italics.

Remark: The figure numbers in the referee comments and the page numbers in the authors’ answers are corresponding to the original manuscript. If not stated otherwise, figure and equation numbers in the authors’ answers are referring to the revised, marked-up manuscript version (showing the changes made) which can be found at the end of this text.
General comments

- The submitted manuscript deals with the 3-D reconstruction of clouds via the structure-from-motion technique using image data obtained from a downward-looking camera installed at a research aircraft. The goal is to provide 3-D cloud top geometry information and geolocation that can be used to improve retrievals by other remote sensing methods, e.g. derivation of cloud droplet radii from spaceborne hyper-spectral imagery. While airborne observation of clouds is a costly enterprise and delivers data only for the flight period, it provides a quite complete and still rare view on the cloud top geometry.

The article describes in detail the methodology and evaluation of the proposed airborne reconstruction, including camera calibration, feature tracking and 3-D reconstruction. Besides an empirical evaluation with an onboard lidar system, the article discusses related challenges of such an approach, such as synchronization with the aircrafts navigation system or the effect of cloud evolution and motion during the sequence of photographs. The article proves that the structure-from-motion technique can be successfully applied to obtain the 3-D cloud top geometry of clouds and should be published after dealing with the following remarks.

→ Thank you for your helpful and supportive review. We generally agree with your comments and are confident that we could improve the manuscript quite a bit with your support. At the end of this text you will find a diff for the revised manuscript.

Specific comments

- For the purpose of evaluation, the article yields a case study of tracked features (Fig.2) and an illustration of the retrieved data (Fig.3). While Fig.3 shows that the
method allows to detect cloud evolution (arrows), the missing spatial reference, height information and the large dataset makes a proper interpretation difficult. It would be helpful if the reader would be able to connect the shown 3-D data with the cloud scene shown in in Fig.2. Maybe it is possible to exclude the more distant 3-D data and introduce some regions of interest, such as individual cloud turrets, that could be marked in Fig.2 and then used in Fig.3 to provide a direct connection. Also, the shown arrows could encode the mean height by an appropriate color code, as done in Fig. 5. This might have the advantage that the reader can estimate the cloud geometry directly.

→ Indeed, it is difficult to connect the 3-D data with 2-D images. While it is possible to draw a 2-D image into the 3-D plot, this does not yield much benefit. Showing this data from a different perspective than the camera perspective is almost as hard to understand as the figures presented in the discussion manuscript. Thus we chose to present only a single figure showing the camera’s perspective as in the previous figure 2 but added color coded height information as well as cloud movement vectors as you suggested. This way, the reader can estimate the cloud geometry more easily and relate it to the actual image. Additionally, we marked the location of this image in figure 7, which shows the wind field in the larger area.

• Fig.5 gives a nice overview of the techniques capabilities on a large scale. Two points of critique here: First, the figure encodes the height as color, but lacks a legend. Second, the figure shows the dataset over a quite large extent. It might help to add a detail view of a specific region of interest contained in the large-scale view, such as a local two-layer situation.

→ We have added a legend and a magnification of the central part of the scene. It highlights two cloud layers and a small cloud patch above both of them.
• Fig 6 and 7 may be combined into one figure as both intend to show (among others) the challenge of a proper comparison between lidar and stereo data.

→ We have combined the figures and added an arrow to mark the relevant region of the comparison plot.

Technical Corrections / Suggestions

• P1, 5: "...relatively simple installation on an aircraft...“
Maybe simple in case of a dedicated research aircraft, but most probably not in general.

→ We’ve added "(research)" before "aircraft". We agree that it is certainly easier to install the system on research aircraft. On general purpose aircraft, the lack of apertures might prevent an easy installation but still, the discussed single camera system requires very little space and the only additional requirement is an accurate navigation system, which should be available on most bigger aircraft anyways. If that is not available, such a navigation system mostly consists of a box to be attached statically somewhere on the airframe and connected to a GPS antenna. So compared to other, especially bigger or active sensors, this system is indeed simpler to install on a general aircraft as well.

• P1, 7: "However we will show that to some extent usable wind information can also be recovered.“
More precise (“to some extent”).

→ We now refer to the filtering of outliers.
• **P2, 21:** "...a big advantage when observing moving and changing clouds."
  Maybe better: "...., so that cloud evolution and motion does not affect the 3-D reconstruction."
  → Changed accordingly.

• **P3, 16:** "For geometric calibration of the camera we use a common approach."
  → Has been changed to "For geometric calibration of the camera we use a common approach of analyzing multiple images of a known chessboard pattern to resolve unknown parameters of an analytic distortion model." For further details, the reader is referred to the appendix.

• **P8, 6:** "After all filtering..."
  Delete "all".
  → Changed accordingly.

• **P8, 8:** "Such a point cloud is shown in figure 5."
  Maybe just put the figure reference at the end of the previous sentence and delete this sentence ("... relative to a point on the earth’s surface (figure 5).")
  → Changed accordingly.

• **P8, 8-10:** "This point cloud can then be used as a starting point..."
  Maybe better: "The point cloud can then serve as reference for other distance measurement techniques..." (Which?) "...or allow for a 3-D surface reconstruction."
→ Changed to "This point cloud can be used on its own, serve as a reference for other distance measurement techniques (e.g. oxygen absorption methods (Zinner et al., 2018) distances derived by a method according to Barker et al. (2011)) or allow for a 3D surface reconstruction."

• **P9/10, 20/1**: "Generally, there is a good agreement...“

Maybe better: "The measured distances between the aircraft and clouds as obtained from the WALES lidar and the stereo method show a good agreement...“ (typical errors?) "... .The automated comparison between lidar and the stereo method, however, typically includes a significant number of outliers in multi-layer cloud situations."

→ *We reviewed the data for this comparison in order to better quantify the typical errors. Still, we were not able to find a sensible method of removing clear outliers due to comparing different clouds without manual filtering. We prefer not to introduce an artificial bias into the comparison by adding subjective criteria. Therefore we added a reference to Stevens et al. (accepted) and additional explanation about the difficulties in comparing the sensors (different sensors see different clouds). We decided that out of this reasons, quantitative comparison with lidar data is only useful for bias, not for spread. On the other hand, for homogeneous cloud decks, as investigated in the across track stability section, the internal spread of the stereo method can be quantified (17.3 m standard deviation in this case). We swapped the order of sections 4.1 and 4.2 to support this argument.*

• **P10, 27**: "...have been binned in 1 min bins...“

Maybe better: "....have been binned in time intervals of 1 minute...“

→ *Changed accordingly.*
References


Please also note the supplement to this comment: