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Interactive comment on "Cloud height measurement by a network of all-sky-imagers" *by* Niklas Benedikt Blum et al.

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0.0.1 Reviewer:

The Authors present and evaluate an approach to derive cloud-base height (CBH) from a network of seven upward looking all-sky imagers (ASIs). The analysis focusses on a region in NW Germany during summer and shoulder seasons. The authors demonstrate that a network approach outperforms individual pairs of ASIs. The manuscript is generally well-written, and the figures complement the main text appropriately. I recommend publication of this article after resolving several general and few minor comments.

0.0.2 Authors' response:

We would like to thank the reviewer a lot for the time and effort spent on providing feedback to our manuscript and for the insightful comments. We believe that these led to valuable improvements of our manuscript. We addressed all comments and have incorporated all of the suggestions made by the reviewer as good as it was possible to us.

In the following, we will address the reviewer's further comments point-by-point. Changes are extracted from the adapted manuscript within which changes were highlighted using latexdiff. Blue indicates insertions, red indicates deletions. Please note, that the order of Sect. 3.3 and Sect. 3.4 has been reversed as suggested by General Comment 5. This change has been excluded from the markup, as it would have obscured all other changes. Further, please note, that Sect. 3 and Sect. 4 have been reworked strongly, based on Reviewer Comment 2, Major Comments 1, 2.

We recommend viewing the PDF version of this response (supplement) which contains the changes to the manuscript. See bottom of this document. It was not possible to upload each change as figure.

0.0.3 Changes in manuscript:

See below.

1 General comments

1.1 General comment

1.1.1 Reviewer:

The Authors motivate their work as it allows to better nowcast downwelling solar fluxes (e.g., for photovoltaic power plants) and it is said that “accurate knowledge of CBH is required”. It is not perfectly obvious why better knowledge of CBH itself improves nowcasting. I’m assuming CBH is only one piece of information - apart from knowledge of each cloud’s horizontal extend, cloud-top height, and geolocation (derived from satellite?) as well as the wind vector in cloudy altitudes (from meteorological forecasts or from ASIs?). Section 1 (ll. 26-32, ll. 48-53) touches on this topic but leaves open questions of how exactly this work fits into a larger picture. It is also unclear to me if voxel carving (ll. 58-59) is a competing approach or if this work could be used for voxel carving efforts – the Authors should clarify this in Section 1.

1.1.2 Authors’ response:

We agree with the reviewer, that indeed nowcasting of solar irradiance is a complex task which includes a number of subtasks, which may all bring uncertainties to the method. Based on previous works, e.g. Nouri, B., S. Wilbert, P. Kuhn, N. Hanrieder, M. Schroedter-Homscheidt, A. Kazantzidis, L. Zarzalejo, P. Blanc, S. Kumar and N. Goswami (2019). "Real-Time Uncertainty Specification of All Sky Imager Derived Irradiance Nowcasts." Remote Sensing 11(9): 1059., knowledge of CBH was identified as critical, especially if the accurate position of cloud edges is of interest. We addressed this by a summary of the nowcasting procedure, pointing out the importance of cloud base height (CBH). We also added a short explanation on the relationship of stereoscopic and voxel carving approaches. From our perspective these approaches are in principle competing. However, previous works have shown that voxel carving approaches can be improved, if CBH is received from a stereoscopic approach.

1.1.3 Changes in manuscript:

p. 3, ll. 76-78

p.4 ll. 91-102

1.2 General comment

1.2.1 Reviewer:

When using a network of ASIs over an area of (100km)2 to obtain a single CBH, do the Authors inherently assume a cloud (or a field of clouds) of unique base height? The Authors should make this more explicit (perhaps in Section 3) and discuss the realism of this assumption (perhaps in Section 4.4)

1.2.2 Authors' response:

We share the reviewer's opinion that the use of CBH assessed in the urban area for the whole region of Eye2Sky measuring 100 km x 100 km is a strong simplification. We now tried to outline, which scope our method may fulfill and how the method can be enhanced for a broader scope in future. For this, we added an explanation to Sect. 3.2, as in this section the conditions at the studied site are analyzed. More precisely our expectation from the conditions on site is, that our method is suited to provide an estimation of CBH which is useful to nowcast solar irradiance in the urban area of

Oldenburg. For the task of providing nowcasts for the whole of Eye2Sky, we intend to classify the cloud conditions at larger distances from the urban area by a number of ASIs which are dispersed over the region and then to assign CBH from the urban area, by looking up which CBH was observed recently in the urban area for similar cloud conditions.

1.2.3 Changes in manuscript:

p. 12, ll. 305-310

1.3 General comment

1.3.1 Reviewer:

To obtain CBH probabilities (Section 3.3) the Authors use a subset of available datapoints. It is unclear what portion of the data was excluded. Did this selection mostly affect samples of high-altitude clouds? Perhaps the Authors could add a column to Table 1 that lists the fraction of data points excluded per altitude group?

1.3.2 Authors' response:

First of all, we would like to apologize as a statement in the manuscript was misleading. The filter excluding variable situations is applied in the modelling of conditional probabilities (now Sect. 3.4) and in Sect. 4.4 to compare performance metrics from ASI-pairs and ASI network. In Sect. 4.1-4.3 this filter is not applied. As suggested, we added a column to Table 1, indicating the excluded fraction of time stamps per interval of CBH and added a description, how the filter influences the distribution of CBH in the validation data set. The filter excludes observations from all ranges of CBH in a similar way. However, for the lowest range of CBH a larger fraction is excluded. As this range is still represented by a large number of observations in the filtered data set, this was accepted.

1.3.3 Changes in manuscript:

Description on filtering of validation data was corrected, moved; additional description of the filter effect added (Sect. 4.4):

pp. 20-21, ll. 531-535,

pp. 28-29, ll. 691-702,

p. 28, Table 1.

1.4 General comment

1.4.1 Reviewer:

The Authors measure accuracy of their approach by using a three-month dataset, shown in Fig. 9 and elaborated in Section 4.3. From a machine-learning stand point is would be important to know if these were “training samples” (i.e., used to prepare CBH probabilities, etc.) or whether these data points were withheld from algorithm preparation.

1.4.2 Authors’ response:

In the study we use two separate data sets: one for training/development of the method and one for the test/validation. The training period is 01 April 2019 to 29 June 2019.

The validation period is 30 June 2019 to 27 September 2019. We hope that this answers the reviewer's question satisfyingly. We revised passages, by which we intended to describe this split of the used dataset, as shown below, for more clarity.

1.4.3 Changes in manuscript:

p. 20, l. 530,

p. 7, ll. 160-162,

1.5 General comment

1.5.1 Reviewer:

The Authors introduce the Maximum Likelihood Estimation (MLE) approach in Section3.4 and – before in Section 3.3 – provide information on conditional CBH probability. This arrangement seems confusing to me and recommend that Section 3.3 follows 3.4(or is a subsection of 3.4).

1.5.2 Authors' response:

We changed the order of the sections accordingly. As this change would obscure the markup of other changes in the red-line version, we excluded this exchange from the markup (by applying the change before comparing with latexdiff). These sections have additionally been revised strongly based on Reviewer Comment 2, Major Comment 1.

1.5.3 Changes in manuscript:

Order of 3.3 and 3.4 is exchanged (p. 12-20, ll. 311-526).

1.6 General comment

1.6.1 Reviewer:

Section 3.3 lists a variety of filters that were applied (ll. 240ff). The Authors should revise Section 3.3 and reference the use of these filters - if applied in the past – and explain their intended effect.

1.6.2 Authors' response:

We revised Sect. 3.4 (in new order) strongly according to the reviewer's feedback but also based on the Reviewer Comment 2, Major Comment 1. We now pointed out, why a method to estimate the distributions of conditional probability from measurement data, was developed, which was new in our perspective at least to this application. Such distributions were so far not available for stereoscopic CBH measurements. We moved details on the implementation of the filters to the appendix and focused on the intended effects of the filters and motivated the value assigned to the parameters of the filters.

1.6.3 Changes in manuscript:

pp. 16-20, ll. 403-526,

Appendix A, pp. 35-37.

1.7 General comment

1.7.1 Reviewer:

The Authors list high temporal and spatial resolutions ("30 s or 5 m", l. 6) of state-of-the-art nowcasts. It is not obvious if chosen CBH intervals ("100m", l. 231) are fine enough to provide such high resolution. Perhaps the Authors could expand on this in Section 3.3 or in their discussion to address this question.

1.7.2 Authors' response:

We agree with the reviewer that indeed the specification of the used state-of-the-art ASI-pairs may appear contradictory to the accuracy of the CBH estimation attested in this study for all of the studied ASI-based CBH measurements. As suggested, we added a short discussion to give an explanation why ASI-based nowcasts may be provided at a resolution which is by far finer than the deviations of cloud shadow positions induced by deviations in the estimation of CBH. The source cited in this discussion was additionally added to the introduction. Note that Sect. 4.4 was also reworked based on Reviewer Comment 2, Major Comment 2.

1.7.3 Changes in manuscript:

p. 2, ll. 37-38,

p. 30, ll. 740-754.

1.8 General comment

1.8.1 Reviewer:

To help the reader appreciate the scientific advance in the work, the Authors should stress wherever (in Section 3.3 or 3.4) new techniques were developed or combined.

1.8.2 Authors' response:

To emphasize the novelty of the method used in the study we added a short introduction to the MLE-based method in 3.4. Our combination method allows to combine the CBH measurements from a large number of ASI-pairs. Additionally, the method takes account of the individual characteristics of the ASI-pairs by the use of conditional probabilities. Finally, the use of MLE is to the best of our knowledge not known to this application. Further we also pointed out that the required distributions of conditional probability were so far not available for CBH measurement by ASI-pairs.

1.8.3 Changes in manuscript:

pp. 12-13, ll. 312-321,

p. 17, ll. 409-410.

Printer-friendly version

Discussion paper

2 Minor comments

2.1 Minor comment

2.1.1 Reviewer:

Fig. 2: The plot seems to contain redundant information (by switching perspectives between two ASIs). The Authors could color code each perspective or exclude one redundant half.

2.1.2 Authors' response:

We adapted Fig 2 (left) and for consistency also Fig. 2 (right). As suggested, the plots now make it clearer which ASI-pairs' axes orientations and also distances were yielded by switching the used main camera.

2.1.3 Changes in manuscript:

p. 6, Fig. 2.

2.2 Minor comment

2.2.1 Reviewer:

ll. 140-144: Please provide the minimum optical thickness for ceilometer detection.

2.2.2 Authors' response:

We requested this information from the manufacturer but did not receive a response yet. As requested by Reviewer Comment 2, Specific Comment 4, 9, we added a more detailed description of the algorithm used by the ceilometer and extended the description of how this reference instrument was validated in previous studies. We hope that this may be helpful to a possible reader. Otherwise, we hope that we can add this information in a response to be handed in later.

2.2.3 Changes in manuscript:

p. 6, ll. 137-141,

pp. 7-9, ll. 174-203.

2.3 Minor comment

2.3.1 Reviewer:

ll. 145-151: Is there a maximum solar zenith angle that limits CBH retrieval?

2.3.2 Authors' response:

The measurement of CBH by the ASI-pairs is in principle only limited by the illuminance of the scene. In this study we included zenith angles smaller than 90 degree. We added a description on this. Note that a further addition was made here based on Reviewer Comment 2, Specific comment 6.

2.3.3 Changes in manuscript:

p. 7, ll. 157-158.

2.4 Minor comment

2.4.1 Reviewer:

l. 171-173: Please substitute “most dominant in features, driven by area and optical thickness” instead of “most dominant in the sense of area and optical thickness”.

2.4.2 Authors’ response:

We appreciate the reviewer’s suggestion and replaced the term accordingly.

2.4.3 Changes in manuscript:

p. 11, ll. 270-271.

2.5 Minor comment

2.5.1 Reviewer:

l. 193-195: Please link to reference or plot(s) or else put “not shown”.

2.5.2 Authors' response:

We added this note as suggested.

2.5.3 Changes in manuscript:

p.12, l. 292.

2.6 Minor comment

2.6.1 Reviewer:

Equ. 1: What is “j”?

2.6.2 Authors' response:

We would like to apologize for the mistake, the letter was indeed not intended. We corrected the equation.

2.6.3 Changes in manuscript:

Appendix, p. 36, l. 895.

2.7 Minor comment

2.7.1 Reviewer:

Fig. 8: Please provide performance metrics (e.g., correlation coefficient, bias, and RMSD) to each panel.

2.7.2 Authors' response:

We added performance metrics to all scatter-density plots shown in the publication. We further adapted the scatter-density plots as Sect. 4 was reworked based on Reviewer Comment 2, Major Comment 2.

2.7.3 Changes in manuscript:

p. 24, Fig. 8.

Please also note the supplement to this comment:
https://amt.copernicus.org/preprints/amt-2020-430/amt-2020-430-AC1-supplement.pdf

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