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Reply on RC3

Gina Jozef et al.

Author comment on "Testing the efficacy of atmospheric boundary layer height detection algorithms using uncrewed aircraft system data from MOSAiC" by Gina Jozef et al., Atmos. Meas. Tech. Discuss., https://doi.org/10.5194/amt-2021-383-AC3, 2022

The authors thank anonymous referee 3 for taking the time to review our manuscript and for their helpful comments, which have improved the manuscript. Each referee comment is given below in ***bold italics*** followed by our response to the comment. The line numbers provided in our responses refer to line numbers in the revised manuscript.

Review of « Testing the efficacy of atmospheric boundary layer height detection algorithms using uncrewed aircraft system data from MOSAiC" by Jozef et al.

This study compares different methods to determine the ABL height from uncrewed aircraft system and radio-sounding from an icebreaker in the central Arctic Ocean during the MOSAiC expedition. "Subjective" visual detection methods are compared to four "objective" methods for both the UAS and RS profiles. The difficulties of ABLH estimation largely depends on the peculiarities of ABLH in Arctic, which are shallow ABLH and a high percentage of NBL cases (and a low percentage of CBL cases).

Major comments:

- ***The methodology sections (§2.3-2-5) is very long and contains many redundancies. I encourage the authors to structure the paper with greater caution. For example,***
  - ***1 describes the DH2 UAS data. § L152-162 relates however to the ABL identification methods.***

The authors have moved this information to a new section titled "Preparing the DataHawk2 data for analysis" (beginning on line 187) where it better belongs so that it is not conflicting or distracting from the purposes of the section, which is to describe the DH2 UAS data.

- ***the four objective methods are cited four times (L23, L89, L156 and L300) before to be described under §2.4.***

The authors have changed the text so that the objective methods are only cited twice before described under section 2.4 – once in the abstract (lines 24-25) and once in the introduction (lines 120-122). We hope this change helps the text to not be as redundant.

- ***Part of the subjective method refers to some objective method, so that I would first describe the objective methods and then refer to similarity of the subjective method. For example the bulk Richardson method is to some extent describes at several places***

The authors think it is important to first explain the subjective methods, since subjective ABL height is included in the figures which demonstrate the application of objective methods (Fig. 3 and the Supplementary Figures S3-S6 of the revised manuscript), to show how the two compare. If we had not yet explained subjective ABL height identification, the figures could then be confusing. However, we have worked to not repeat the underlying physics guiding ABL height identification in the objective section that are already described in the subjective section.

- ***The description of the ABL structure and the corresponding profiles -with Stull as reference (30 mentions)- is dispatched in the whole paper. A clear description of the ABL structure in the Arctic ocean would benefit the comprehension of the reader***

The authors have added a paragraph to the introduction which summarizes the primary features of the Arctic ABL structure: stability regime, turbulence, and capping by a theta_v inversion (lines 61-73). We have thus removed this information from where it is stated later in the text. We do leave some of the description of ABL structure in the subjective methods section, as it is immediately relevant to methods described.

- ***The term "subjective" and "objective" methods seem to be inappropriate. The "subjective method" relates to "manually" or "visual inspection" performed by a person. The objective method relates to automatic algorithms performed by computers. Moreover, the subjective method contains to some extent elements of the objective method (e.g. the use of the Rib profile, but with a threshold described as 0.25, CBLH is the parcel method, the use of RH gradient,…).***

The terms 'subjective' and 'objective' were chosen to simplify what they really mean (visual/manual identification vs. automated algorithms performed by computers.) The authors choose not to change the use of these words throughout the paper, but have better specified their true meaning near the beginning (lines 111-114 and 220-224). Additionally, though the subjective methods do look at the Rib profile, we subjectively decide where Rib increases significantly rather than using a fixed threshold as in the objective method. Thus, just because we use Rib doesn't mean the method isn't subjective. The authors have adjusted the text describing the subjective methods to clarify this (lines 272-285 and Table 3 of the revised manuscript).

- ***The subjective method is considered as the best ABLH estimate. It is however also prone to error and several experiences have shown a clear ABLH uncertainty if several persons were estimating the ABLH. Were all the ABLH estimated by a unique person? A comparison between several subjective estimation could be performed? Second the criteria/profiles mostly used for the subjective SBL and NBL heights estimation are not mentioned. For example, the best correlation between the subjective method and the bulk Richardson number method found (Figs 9-10) is perhaps due to large weight of the Rib profiles in the subjective method. The subjective method is then a mixing of several criteria, a mixing that could also be applied to the objective methods. Since this exercise can be quite difficult, why not comparing visual and automatic detection with the same criteria/profiles (e.g. only with the***

potential temperature or the Rib profiles?)

The authors recognize that even a subjective ABL height identification is prone to error, and have added some text discussing this at the beginning of section 2.3 (lines 251-255). Since one best subjective ABL height identification criteria is not found amongst the literature (since there is much disagreement) the best way to get around this is for us to take into account some of the most commonly used methods in the literature and remain consistent in our ABL height criteria across all profiles, which was agreed upon amongst the authors. Discussion of this has also been added to the beginning of section 2.3 (lines 251-255). To ultimately settle on the subjective ABL height for each case, the lead author and the second other author reviewed all the cases together, and based on the patterns in all cases, discussed and refined the criteria and ABL depth, based on both of our analysis of the profiles. The other authors, as well as some non-co-author colleagues, also provided input for especially difficult cases. Next, you say that the best correlation between the subjective method and the bulk Richardson number method found (Figs 9-10 of the original manuscript, or Figs 5-6 of the revised manuscript) is perhaps due to large weight of the Rib profiles in the subjective method, but really the most weight in the subjective methods is given to theta_v profiles, and secondarily to the humidity profiles - Rib is only used heavily in few difficult cases. The authors have clarified this in the subjective methods section (lines 288-290). Lastly, you are correct that the subjective method is a mixing of several criteria, which would be difficult to apply objectively, which is precisely the point of the paper – to find which single objective method estimates an ABL height most similar to that found when mixing several criteria manually. Only comparing a single subjective criteria to a single objective criteria would not provide as useful of results as are already given. Therefore, the authors do not perform this analysis, but do add a sentence clarifying this point in the beginning of section 3.1 (lines 433-436).

- ***Similarly, the subjective method uses RH profiles, why not applying an objective gradient detection to the RH profiles?***

This was not done as there is very little literature on applying an objective method to the RH profile. Most weight in literature is given to the methods currently discussed in the paper, which is why we choose these 4 to focus on.

- ***This comparison of the objective methods between themselves would also be of high interest and is really lacking.***

The efficacy of the different objective methods can be seen in the bar plot (Fig. 10 of the original manuscript, or Fig. 6 of the revised manuscript). If you are suggesting similar comparisons using each objective method as the basis for figures like Fig. 6, we feel that this would add significant length to the manuscript without much benefit. Since all of the objective ABL heights for each profile are listed on the figures in the Supplementary Figures document (S4-S69), it is possible for someone reading this manuscript to compare one particular objective method to all of the others. Since the purpose of this paper is to compare the objective with the subjective ABL heights, the authors think this amount of comparison of the objective methods between themselves is sufficient. Please let us know if this does not address what you were looking for, and please provide more input on what you were intending.

- ***The stability regime could also be further used to explain the differences between the applied ABLH detection. For example, the symbols of Fig. 9 (apart from the blue and red colors for UAS and RS) could be differentiated as a function of the stability regime, allowing to identify potential systematic causes for the observed differences. Some similar uses could also be thought for Fig. 10.***

The authors like this idea, and have addressed this by creating identical figures which are shown in the Supplementary Figures document, which contain only SBL datapoints (S70 and S72) and only NBL datapoint (S71 and S73). We chose this instead of using different symbols for SBLs and NBLs as these plots are easier to interpret than if we use different symbols in one plot. We discuss the main takeaways of these figures in section 3.1 (lines 491-496 and 531-536) by highlighting which methods have the highest efficacy for each stability regime. In section 3.2, we recommend which objective method(s) to use if one were to choose a different method based on stability regime (lines 592-600).

- ***To avoid confusion, I would use the term "inversion layer" instead of only "inversion" to describe the atmospheric layer with temperature or humidity increase with altitude.***

This change has been made.

Minor comments:

- ***L63-64 and Table 1: I think that Table 1 mixes measured profiles, computed variables and, to some extent, detection methods. E.g. the virtual potential temperature is a variable that is used alone in the Parcel Method (PM) but it is also the main component of the bulk Richardson number (Rib) method. In that sense, I think that the name of the method and the used profile data are much more useful than the "variables" given in Table 1. The potential temperature is also used for the PM, Rib and gradient method. The difference between "component-wise wind speed perturbations" and "wind shear" are not directly understandable. Moreover, this list of "variables previously used to identify ABLH" is not complete (e.g. all the methods based on aerosol concentration are not mentioned).***

The authors have added some text introducing Table 1 to clarify that we list only some of the atmospheric variables used for ABL height identification (lines 85-90). We also clarify that we list only thermodynamic and kinematic processes, as these are the focus of the paper. Since not all of the variables (or used profiles) listed have a specific 'method name', we don't add this column to the table, but we do change the heading 'Variable' to say 'Quantity Used.' We have also merged "component-wise wind speed perturbations" with "wind shear" into one common quantity labelled as "wind shear," as these two quantities are essentially the same thing.

- ***L69-71: rephrase, grammatical problem.***

The authors see no grammatical problem with this sentence, but have added a comma to make it flow more smoothly (line 96-99).

- ***L 74: "to either decrease or increase more above the ABL": does this correspond to an increase/decrease of the gradient of the humidity?***

This does refer to an increase/decrease of the vertical gradient of humidity. We now write it this way (line 101).

- ***L86-95: (see also main comments) I wonder if the use of subjective/objective methods is the right one or if it corresponds to an opposition between "manual" (=performed by a person) and automatic/operational detection method. I suppose that a person estimate the ABL heights "visually identified through combined evaluation of θv, humidity (both relative humidity (RH) and mixing ratio), and Rib profiles" via the same criteria as the objective methods.'***

We now clarify that the 'subjective' method refers to a manual process, while the 'objective' methods refer to automated processes, when we introduce these two terms (lines 111-112). One could manually apply the objective methods as well, however combining aspects of the different objective methods into the subjective method we have developed provide the best estimate of ABL height based on taking into account all of the relevant physical processes at play, and considering them in conjunction which is not possible with an automated method in the same way as is possible with the human brain. We now point this out as well (lines 251-255 and 306).

- ***L154-159: This information has already be given.***

This sentence has been removed in the process of restructuring the Data and Methods section to add a subsection titled "Preparing the DataHawk2 data for analysis." Thus, we no longer repeat this information.

- ***L164-167: Before to compare ABL height from radiosondes and UAS measurements, a comparison of the measured T, wind and humidity profiles should be performed. However, this is perhaps already included in other joined papers on the MOSAiC expedition.***

We did visually compare the T, wind, and humidity profiles between the DH2 and corresponding radiosonde to make sure the measurements were similar, before proceeding with the analysis. We add a sentence which states this when we introduce the radiosonde (lines 384-386). The theta_v and wind speed profiles from the corresponding DH2 and radiosondes are shown in Figure 7 of the original manuscript (Figure 3 of the revised manuscript) and in the Supplementary Figures to demonstrate the similarity between the DH2 and radiosonde profile. Usually, the closer in time of the DH2 and radiosonde launch, the more similar the profiles are (they agree well in the revised supplementary figure S23 but poorly in S40). Additionally, the UAS and radiosonde profiles for a few case studies are shown together in the MOSAiC atmosphere overview paper (Shupe et al., 2022) which can be found at https://doi.org/10.1525/elementa.2021.00060.

- ***L 191: "in either direction" means in increasing/decreasing direction? I think it should be rephrased.***

We have rephased this sentence to be more clear. It now reads: "If this minimum is not either negatively (in the case of a CBL) or positively (in the case of an SBL) reached, the ABL is identified as an NBL" (lines 239-240).

- ***L 193: does this number also depends on the uncertainties/noise of the measurements?***

Yes, it does. We have added some text to state that this number also depends on inherent uncertainties or noise in the measurements (lines 241-243).

- ***L197: "between a SBL, NBL or CBL" in arctic (I suppose).***

This change has been made (line 245-246).

- ***L194-203: this could be more efficiently explained and, consequently, shortened.***

This paragraph has been significantly condensed and now only contains the vital information (lines 244-247).

- ***L215-216: what is meant by " the θv inversion is at its strongest"? does it mean that the positive θv gradient is at its strongest ?***

Yes, it means the gradient of theta_v is greatest at the surface. We now clarify this (line 260).

- ***L236: delta represent the difference between the elevation z (at which Rib is computed) and the ground level.***

The way we calculate Rib, this is not true. To calculate Rib throughout the profile, the delta is always 30 m, but refers to a different altitude range. As we explain (and in the updated draft we try to explain more clearly), Rib is calculated over an altitude range (delta) of 30 m, with a 5 m resolution, starting at 30 m. Therefore, the lowest Rib value is calculated between measurements at 30 m and 60 m. The next Rib value is calculated between measurements at 35 m and 65 m, and so on. This information can now be found in lines 212-214.

- ***L247: I don't understand what you mean by "over 30 m bins"?***

The authors realize that the word "bin" is inappropriate for what we are trying to describe. Instead, what we mean is that Rib is calculated over an altitude range of 30 m. We have changed the wording in the text to reflect this, and also provide an example so that this is more understandable. This reads: "Ri_b profiles are created by calculating Ri_b over a 30 m altitude range (Δ), at 5 m resolution (i.e., between 30 and 60 m, then between 35 and 65 m, and so on)" on lines 212-214.

- ***L251-252: this is the description of the parcel method and has nothing subjective. The simultaneous increase of Rib is obvious since the bulk Richardson method with a threshold=0 corresponds to the parcel method.***

We have changed the presentation of this information to be in the form of a table rather than paragraphs (Table 3 of the revised manuscript). In doing so, we highlight only the subjective aspects of this method, and have removed reference to the specific threshold of theta_v returning to its surface value, since this was not exactly implemented, but rather just visually estimated.

- ***L252 "this will not be the first altitude at which the virtual potential temperature increases with altitude": unnecessary, this is obvious.***

This has been removed with the presentation of this information in a table.

- ***L 334: why is Liu and Liang's threshold is inappropriate for the current case? Due to arctic condition? How did you identify that it is inappropriate?***

We found this threshold to be inappropriate because the ABLs heights found with the original threshold were far too low. This may be due to differences in the vertical resolution of our data versus that used by Liu and Liang (2010). We added some text on lines 321-323 to state this.

- ***L446-447: I do not see the use of this sentence***

This sentence has been removed.

- ***L467-469 should be rephrased.***

We have split this into a few sentences to be more understandable (lines 392-397).

- ***8: It's very nice to see the differences in ABL heights as a function of the time between launches. Other criteria such as the stability classes could also be used. Fig. 9 f) with ABLH from RS versus from DH2 also brings a nice overview of the comparison and should be discussed with Fig. 8. By the way, isn't Figure 8 already a result so that it should appears under §3?***

The purpose of this figure is simply as justification for using the radiosonde closest in time to each DH2 to test whether the methods also work well for the radiosonde data. The justification is that the radiosonde measured approximately the same ABL structure which is identified similarly by the different objective methods. Therefore, in this case we don't separate this analysis into stability regimes, however we do add stability-regime-separated analysis for Figures 9 and 10 of the original manuscript (Figures 5 and 6 of the revised manuscript). Additionally, we leave this in the methods section since the purpose of the results section is to compare the objective to subjective ABL height for each platform rather than compare the objective ABL heights from each platform to each other. As just mentioned, this figure only justifies the validity of the methods which is why it is included in the methods section. We have added a sentence to state this (lines 421-423).

- ***L549-551: is it due to the fact that RS cannot be used below 30 m? Or due to the interpolation if the RS go through icebreaker's plume?***

We do not think it is due to the fact that RS below 23 m cannot be used, or the interpolation through the plume, but rather because there are simply more samples of lower ABL heights, so we are likely to see more deviation. We have added some text on lines 480-481 to mention this.

- ***L565-570: The main point with the comparison with Liu-Liang method is 1) (as described in the manuscript) this method works well for ~40% (within 20%) of the cases and 2) in about 40% of the cases, Liu-Liang has more than 100% difference with the subjective method.***

We have added your observation that the Liu-Liang has a high % of cases that are more than 100% different than the subjective ABL height (lines 506-507). However, this number is about 20%, not 40%. This is determined by adding the 52% of cases with Liu-Liang ABL height within 100% of the subjective ABL height, and 23% of cases with no ABL height found by Liu-Liang.

- ***Liu-Liang method results in the largest differences with the subjective method: is it due to a bad classification of the stability leading to a false applied detection method? Which are the stability cases with the greatest differences?***

As mentioned in the text, the Liu-Liang method struggles with SBLs typically because the dtheta_v/dz criteria are not met anywhere in the profile, usually because a weak θ_v inversion persists throughout the whole profile, meaning that the method reverts to using the LLJ core height as the ABL height. However, the LLJ core was observed to usually be above the subjective ABL, so this predicts the ABL height to be too high. We have added discussion of this (lines 566-570). Likely the buoyancy thresholds set by Liu-Liang do not work well for a similar reason as why the Liu-Liang NBL threshold also doesn't work – due to differences in the resolution of the data they use to develop their methods.