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Comment

## ***Interactive comment on “Lidar-based remote sensing of atmospheric boundary layer height over land and ocean” by T. Luo et al.***

**T. Luo et al.**

tluo@uwyo.edu

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Response to Anonymous Referee #1 General Reply: The authors thank the referee for his time helping to improve this manuscript and the English language. We greatly acknowledge your comments and suggestions. According to reviewer suggestions we modified the paper. Our replies to the comments are given below.

General comments:

(1) The authors investigate lidar measurements at two stations: one continental in the US and one marine in the Southern Pacific. However, the location of the stations are not really described as well as it is not discussed if these stations are representative for the whole globe as the authors also developed a global boundary layer top height data

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base. Especially the results from Nauru concerning the decoupling of the marine BL may not be representative for all marine locations worldwide. Thus, the authors should discuss a little bit more on this issue (see also minor comments).

Reply: The locations of these two sites are typical ocean and land sites. The main reason selecting these two sites is that they have long-term sonde and lidar measurements. This allows us to evaluate the lidar-based method with sonde measurements, and to provide consistent BLH determinations by lidar as the other methods based on thermo-dynamical properties. Then the lidar-based method was applied to the global ocean measurements and further evaluated with the marine stratiform cloud top, which is capped by the boundary layer top temperature inversion. Results showed good agreements between those two. To deal with decoupling MBL, our results are from both ground-based lidar observations at Nauru site and CALIPSO global ocean observations (see also the reply to comment 32).

(2) Beside that, for a certain reason the locations are named as SGP\_C1 and TWP\_C2. I personally felt a little bit disturbed by these names as one has always to think which is which. Therefore, I would prefer (just a recommendation) to name the stations to their name (Nauru and . . .) or just to marine and continental.

Reply: Changed to marine site and continental site.

(3) Please clearly define once in your manuscript how you use the term mixing layer and atmospheric boundary layer and what the differences in terms of properties.

Reply: The mixing layer we use here is the well-mixed layer with nearly constant potential temperature and mixing ratio (see at 8318, line 17, the statement there was rephrased).

(4) Could you please state the vertical resolution and maximum height of the MPL?

Reply: 15m or 30m and 18km respectively. Detailed descriptions were added into Section 2.1.1 Ground-based data.

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Specific comments:

(5) 8312, line 10: cite->site (also found somewhere else in the manuscript)

Reply: Corrected them in the manuscript.

(6) 8313 different definitions by Seidel – which one do you use? (see general comment)

Reply: Seidel et al. (2010) recommended either the parcel method or the Richardson number (RI) method. In our study, we use Richardson number method to identify the BLH.

(7) 8313, 23ff. Please improve these lines, it is not made clear which message the authors want to give with their statements about the other publications.

Reply: Changed.

(8) 8314, line 13: There are certainly some more publications concerning ABL top measurements with backscatter lidar/ceilometer - also from long-term measurements. Some of them should be cited here as well. E.g.: a recent review of Haeffelin, 2012, Boundary-Layer Meteorology

Reply: The followings are referenced now: Flamant, et al., 1997; Menut, et al., 1999; Sicard, et al., 2006; Hooper and Eloranta., 1986; Lammert and Boil'senberg, 2006; Martucci, et al., 2007; Haeffelin, et al., 2012.

(9) 8314, line 18: The fact that ABL aerosol during nighttime is hard to distinguish by means of lidar has been found out long time before Ferrare 2013. So you may give a real citation here and not only a conference one. E.g. Martucci, 2007, JAOT, and Baars, 2008, ACP, already informed, that with backscatter lidar only the daytime convective ABL can be distinguished reliably.

Reply: Martucci, et al., 2007 and Baars, et al., 2008 were added.

(10) 8314, line 20. A careful evaluation is needed, and even more important, a clear

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definition which top height is detected with the lidar and what it stands for. The authors should state that and may write the definition they will use already down here.

Reply: Rephrase. In this study, we would like to identify the BLH by lidar consistent with the BLH based on thermo-dynamical properties (the RI method).

(11) 8314, Line 21ff. Here the authors write that they evaluate their lidar-based BLH to radio soundings. However at 8313, line 27ff they somehow criticize that previous work rely on in-situ measurements to evaluate global BLH climatology, but the authors do exactly the same in their paper. This should be rephrased.

Reply: In our study, the limited ground base observations were just used to evaluate lidar-based methods, not for the evaluation of the global BLH. After the lidar-based methods were applied to satellite observations and the global marine BLH were evaluated with the lidar measured boundary layer stratiform cloud top heights, as we stated later, at 8314, line 25ff. The statement here was rephrased to address this point.

(12) 8315, line 8. Please give coordinates of the two sites and a description. I.e. discuss why Nauru is perfect to study tropical marine conditions.

Reply: Changed.

(13) 8315, line 13: First sentence is confusing, because you speak of cloud-free signals and in the next sentence you state how “the cloud” is detected. This should be rephrased, e.g.: Because only cloud-free ABL shall be studied, clouds need to be screened out of the long-term MPL set. This is done the following way. . . :

Reply: Changed.

(14) 8315, Line 23: What happens in the rare case of aerosol between 5 and 6 km, can you automatically sort out these cases?

Reply: Yes, this kind of case was removed in the data processing by using the slope of returned signals between 5 and 6km, which should be close to the slope of molecular

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backscattering.

(15) 8317, line 21: What is a no-negative BLH. How is this possible?

Reply: The statement is cited from Seidel, et al. (2012). We removed this statement because it is not necessary here.

(16) 8318, line 1-6: Either refer Emeis, 2008 for all methods, because all are described there or refer for each method the original one. E.g., the variance method was much earlier introduced, than by Jordan, 2010 (by Hooper and Eloranta, JCAM, 1985 or Piironen and Eloranta, JGR, 1995).

Reply: Changed.

(17) 8318, line 10: Earlier you write that you would like to define the BLH in such a way that it fits to the thermodynamic structure of the atmosphere and therefore fit to radio soundings. However, this is in contrast to the definition you made here, i.e. up to which height surface influence concerning aerosol is detectable. You nicely demonstrate this by yourself in Fig.1. So please adapt this paragraph.

Reply: Changed.

(18) 8318,15: What is shown in Fig. 2, that's not clear? Is this one land, one shallow and one deep ocean case, or are these mean values plus standard deviation? Please clarify and state how you have selected the profiles, how many, which period etc.) Please also state explicitly that the y-Axis is the normalized (by BLH) height!!!!

Reply: Changed.

(19) 8318, 25 ff. I do not see any sharp gradient at the top of the ABL for Shallow Ocean. What do you mean?

Reply: Changed to "There are no sharp gradients in humidity, temperature or TAB at the ABL top as those over land." This is what we mean.

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(20) 8319, line 5: two times ocean Line 8: rephrase: the aerosol content has more concentration. Line 16-22. Please improve English.

Reply: Changed.

(21) Fig. 4 and Fig. 5. What is shown? Is this one characteristic profile or a mean of many cases? Please clarify! This is essential because of these figures you justify why you use the different methods, but these methods may fail for a different case...so please give evidence that the methods you have chosen are appropriate for “all” oceanic and “land” cases.

Reply: The lidar based methods for oceanic and land cases were chosen according to the mean ABL thermal and aerosol structure shown in figure 2 and figure 3. Figure 4 and Figure 5 are typical cases to illustrate the lidar based methods. The further evaluation of the lidar methods is given in figure 6 in the section 3.1. As shown in figure 6, the lidar derived BLH agrees well with the Sonde derived BLH. Therefore, The lidar methods we have chosen should be appropriate for the most of the cases.

(22) 8320, 5ff:It is still unclear how you remove elevated layers. Please use a better formulation of the paragraph. I could not understand when a layer will be identified as BLH and when it is identified as elevated layer.

Reply: Rephrased as following 4) Final check with elevated layer. In most of the cases, multi-layer aerosol structure can be identified with gaps between layers in an aerosol extinction profile. When multi-layer aerosol case is identified, only the lowest layer is regarded as the boundary layer aerosol. Although this approach can remove most elevated layers, there are still a few cases that elevated layer connected with the boundary layer aerosol. Therefore, additional tests are needed. If the initial identified BLH is higher than 2.5km and the extinction profile has a strong peak closed to the initially identified BLH, the elevated layer exists. Then, the elevated layer base (where the gradient of extinction change its sign) is used as the BLH.

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(23) 8321, 11: What does it mean: “assuming layer top at 8 km”. You set the calibration interval to this height? And what happens if there are lofted aerosol layers at this height?

Reply: It means the maximum retrieved aerosol layer top is 8km. We only retrieve aerosol extinctions below 8km. The case with lofted aerosol layers at this height could happen. But this kind of case was removed by the same slope method as we used in ground-base data processing.

(24) 8321, 16: 3 points of what? 3 range bins?

Reply: Changed to “3 range bins”.

(25) 8321,18: Please rephrase with improved English. I do not understand. Do you set it to 1 if one of the channels detect aerosol or must both channels detect aerosol?

Reply: Changed. We set it to 1 if one of the channels detect aerosol.

(26) 8321, 24: screen or remove, decide for one!

Reply: The descriptions were rephrased. This statement was removed.

(27) 8322, 1: Strong peak of what? Please write scientific correctly!

Reply: Changed to “strong peak of extinction”.

(28) 8322, 9: Please state period for the recorded profiles!

Reply: Corrected.

(29) 8322,16: Why can you detect a MPL BLH much lower than SONDE due to the overlap issue? Can you explain?

Reply: We re-checked this kind of cases again. The reason for much lower lidar-derived BLH is the instrument artificial signals under low cloud or fog conditions. Under these conditions, the returned signals at low levels are strongly attenuated and low-level strong signals result in strong after-pulse signal in MPL data (a known MPL issue).

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This kind of cases are now identified and removed from the analyses. The figures are reproduced.

(30) 8322, last line: I think that the positive bias in the cold season is due to the overlap effect. Especially at very continental places under stable conditions in wintertime almost no convective ABL development can be expected. Possibly very shallow ABL are not “seen” and thus lofted layer tops are detected as BLH, which are higher than the SONDE BLH. Is this possible? Can you discuss this? Thus, it can be the same reason as for nighttime measurements and thus not be further improved.

Reply: Added. The possible overlap effect for nighttime condition was discussed at 8322, line 4. It’s also possible for cold season cases.

(31) 8323, 13: Why do you only consider cases with cloud fractions of 0.1 and 0.7. Please explain!

Reply: The reason is to spatially close cloud top height and BLH. The CALIPSO level 1b data were collocated into Cloudsat data (~1km resolution) to identify the cloud information. Then cloud-free CALIPSO profiles were averaged and collocated into 25km grid box. Data with partially cloudy in 25km grid box were used to evaluate the global BLH. With partially cloudy cases, we could determine both BLH and cloud top within the grid. Larger than 0.1 cloud fractions make sure to have at least 2 cloudy profiles for cloud top calculations. Cases with cloud fraction larger than 0.7 were not included in the evaluation because there is not enough cloud-free CALIPSO profiles within the 25km grid box to be averaged to achieve needed signal-to-noise ratio.

(32) 8324, line 12: Figure 8d not 9d. Line 18: It is not evident for me why these results show that decoupling frequently occurs under cloud free conditions. Can you give evidence for this statement and explain more detailed?

Reply: Changed to figure 8d. The decoupling in terms of aerosol loading frequently occurs under cloud free conditions over ocean, which could be observed by both ground

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and satellite measurements. Here, we defined the case with BLH 200m higher than MLH as the decoupling cases. The mean occurrence of decoupling as observed at Nauru site is 67.8%, and that as observed by CALIPSO over the global ocean is 56.8%.

(33) 8324, line 24: Not only temperature profiles, I thought the thermodynamic state of the atmosphere is considered with the RI method.

Reply: Changed to “In this study, lidar-based methods are developed to provide consistent BLH and MLH determinations as those based on the thermo-dynamical properties”.

(34) 8325, 3: Over the specific Ocean site of Nauru the decoupled structure was found, please discuss if this is valid for all maritime sites-> see comment before – same for the continental station.

Reply: Referring to the answer to comment (32). And discussions were added into 8324, line 19.

(35) 8325, 5-10. The aerosol structure “can” be complicated not “is” 8325, 22: “was” instead of “were”

Reply: Corrected.

(36) Fig.2, Caption: Please state explicitly which profiles are shown (mean profiles or a case study etc.) see comment before.

Reply: Changed.

(37) Fig 3, Caption: It’s not a black dot but a black cross.

Reply: Corrected.

(38) Fig. 4 and 5: Are these illustrations one specific case study? If yes, please write down date. Reply: Corrected.

(39) Fig 8a: White circles would be better; I hardly can see the black circles in my

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printed version. Caption: “site” instead of “cite”

Reply: Corrected.

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