Atmos. Meas. Tech. Discuss., 7, C2005–C2018, 2014
www.atmos-meas-tech-discuss.net/7/C2005/2014/

Atmospheric Measurement Techniques Discussions

Interactive comment on "Mixing layer height retrieval with ceilometer and Doppler lidar: from case studies to long-term assessment" *by* J. H. Schween

J. H. Schween

jschween@uni-koeln.de

Received and published: 1 August 2014

[draft, final]copernicus

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Reply to reviewers

1 August 2014

1 general

We thank both reviewers for reading and commenting the manuscript.

Both reviewers state that the limitations of mixing layer height (MLH) retrieval based on aerosol backscatter are well known. We believe that this is not really the case especially as there are meanwhile some studies on the diurnal evolution of the mixing layer (ML) (e.g. Baars et al., 2008; Korhonen et al., 2014) which do not investigate the uncertainty for long data sets and all, not just ideal cases. We therefore think that a quantification of the average uncertainty of an aerosol based MLH as we present it is needed for the community.

We emphasize this by adding the following text to the last paragraph of the introduction:

There exist studies (e.g. Eresmaa et al., 2012; Träumner et al., 2011) which show that MLH detection based on aerosol backscatter is only fully reliable during noon hours when the convective boundary layer is fully developed and topped by the clean, free troposphere. Recently some studies investigated the climatology of e.g. the maximum MLH or the ML growth rate (e.g. Baars et al., 2008; Korhonen et al., 2014). Especially

evaluating the growth rate between some hours after sunrise and maximum MLH assumes that there are no limitations of the MLH retrieval during this time. Therefore a quantification of the errors of aerosol based MLH retrievals is necessary. MLH retrieval based on doppler wind lidar gives the opportunity to evaluate this on high temporal resolution and over a long time period, if an automated system is used.

Reviewer 1 as well reviewer 3 suggest to investigate statistics of the derived mixed laxer heights. We added a section in which we investigate maximum MLH, hour of its occurrence as well as morning growth rate based on MLH derived from both methods. To make room for this we reduce the discussion about cases under broken clouds (section 3.2.2) and remove especially figures 7 and 9. Main findings of this new analysis are: maximum MLH from the aerosol based method is 300 m higher, the maximum occurs 1-2 hours later and the growth rate is by 30 m/h lower.

2 Reviewer 1

Reviewer 1 has six general comments :

(reviewer statments in **bold**)

1 There are already many papers around reporting on the detection of the ML-top ... and their limitations. ... The authors confirm this finding with their long term statistic, but in my opinion it makes no sense to quantify the general "overestimation" of the ceilometer retrieved ML since this is a methodological problem when the retrievals simply detect the wrong aerosol layer boundary. Therefore, I recommend to leave out some of the statistics purely comparing the differences of the ML height of the two instruments with known limitations.

We do not fully agree. Of course the problem is a methodological one: the retrieved MLH is sometimes just wrong. But beside this qualitative information the average difference and quantiles give a quantitative measure of how large the error due to the miss attribution is. And as our quantitative analysis over one year is new, we think that the difference analysis should be kept.

2 ... The really new and interesting issue of this paper is the use of a continuous measuring wind lidar for the ML detection. ... However, I miss clear statements on the potential of a wind lidar to monitor the ML for 24/7. Is this possible? Was there a possibility to compare to radio soundings as well? ...

We add a paragraph in the conclusions about the potential and shortcomings of the wind lidar based retrieval:

To our experience a doppler wind lidar based MLH retrieval can provide under more circumstances a reliable estimate of the MLH compared to an aerosol based. During situations with precipitation both methods fail in general: The standard deviation of vertical velocity is biased by the fall speed of the hydrometeors and aerosol backscatter shows large variability in backscatter which is not related to vertical mixing. In case of presence of cumulus clouds capping the ML, a wind lidar provides information until cloud base, where the signal vanishes due to strong extinction. In contrast hereto aerosol based methods, which search a distinct decrease in backscatter, cannot detect a MLH. During times with low aerosol content the capability of both mehtods to retrieve a MLH depends strongly on the sensitivity of the instrument. In our case the attenuated backscatter retrieval of the ceilometer typically failed before backscatter was too low for the wind lidar. During night the wind lidar gives clear information whether vertical movements take place whereas aerosol backscatter based methods frequently identify aerosol layers in the stable surface layer or the residual layer.

We were in the lucky position that we could make use a set of 225 radio soundings from

the HOPE campaign of the HDCP^2 project for an intercomparison. We add a section to evaluate the performance of the wind based retrieval and addressed the points asked by the reviewer.

3. The conclusion of the limitations by using STRAT-2d to detect the ML should be more stressed ...

We added the following sentences at the end of the conclusions:

MLH detection based on aerosol backscatter and any gradient method can provide reliable values only during noon hours when the convective boundary is fully developed i.e. bounded by the clear air of the free troposphere and as long as convection is active. An alternative when using lidar or ceilometer could be the three layer model described by Eresmaa et al. (2012) or the use of a vertical pointing doppler lidar and a retrieval as described here.

4. The meteorological statistics of the one-year data set are very interesting but have much more potential. Therefore it would be more useful to do some further investigation on the MLH behavior ...

As mentioned above we added a section with an analysis of the MLH statistics.

5. Fig. 8 and 9. and the concerning text can easily be left out as it gives no new information to the reader.

We do not think so: the joint histograms of both retrievals give additional information compared to the difference plots before.

6. [line] 4292: I do not really get the idea why one should exclude cloudy cases. Is it possible to derive the MLH with wind lidar during cloudy cases while it is not

possible for the ceilometer? What is your definition of the ML during cloud occurrence? Why should this cases be excluded? I anyway do not see significant difference between Fig. 6 and 7.

Arguments for the exclusions of cloudy cases were given originally in the last paragraph of section 3.2.1 before:

Because spring, summer and autumn statistics also include many different weather situations, the retrievals might be biased by other atmospheric phenomena such as precipitation, layers within stable stratification or clouds. As the classical definition of 25 MLH development mostly applies during fair weather conditions, the following analysis is restricted to cases where cloud cover is low. A threshold of 4 octa for clouds with base height lower than 3 km is arbitrarily chosen. The amount of cloud cover was determined from the ceilometer data as the relative occurrence of cloud base height below 3km during a period of 30 min.

We move this paragraph to this section and will reduce the section about broken cloud cases. Accordingly the text will change strongly.

Specific comments:

Page 4281, line 17: Sentence not clear: What variable is provided by the software?

To clarify the sentence we dropped the 'or for short ...'. the sentence reads now:

The instrument software provides profiles of the attenuated backscatter coefficient (β) which are subsequently input to STRAT-2D.

Fig 3: An additional panel with the vertical wind speed only would be great for understanding and discussion.

We orignally thought that a vertical velocity plot for the whole day can not be visualized:

a single plume is typically for some minutes visible in the data (see 12UTC plots in our quicklook browser http://gop.meteo.uni-koeln.de/~hatpro/dataBrowser/dataBrowser1.html?site=JOYCE&date=-1&UpperLeft=Windlidar_w_12UTC). In a whole day plot a single plume will thus take about one thousandth of the full plot width i.e. it will be in the order of one pixel on a computer screen. Nevertheless we added the vertical wind speed in the figure. The plot is made with vector graphics and you can zoom into until your displaying device resolves the temporal resolution of 1 minute. The original temporal resolution of 1.67 sec was not feasible without large drawbacks (13MB size as compressed pdf and several seconds until it is drawn in an pdf document). The figure caption has been adapted.

3 reviewer 1 Specific comments:

4281, line 6: STRAT-2D is first time introduced without citation

done.

4281, 18ff: I cannot believe that valid data is available at the range gate of 0 m as stated. Even if the full overlap is already at 0 m, there is still the problem of receiver efficiency and imaging on the detector etc. What is the authors' experience? Down to which height level the retrieved backscatter signal can be used, i.e. what is the real minimum height for the data analysis?

That overlap is achieved from the very first range gate is a statement from Vaisala for all their ceilometers from the CT25K to the CL51, it is stressed in Münkel et al. (2007) which is a 'Vaisala' paper. But of course one can critically question it. We adapted the sentence:

The manufacturer states that the first range gate starts at 0 m, because a full overlap is achieved by using the same telescope for transmitting and receiving (Münkel et al., 2007). To our experience there are no hints that the backscatter profile can not be used at the very first range gates.

4283, 18. What is meant by relative vertical backscatter difference? Please explain more exactly. With my interpretation, I do not understand how the chosen threshold avoids the misinterpretation in clouds.

This is a detail deep inside STRAT-2D, spread over several routines. But of course it is essential part of the candidate selection. To make it clearer the respective text has been changed:

During daytime STRAT-2D tries to avoid that the decay of β in clouds is misinterpreted as MLH. Therefore the relative difference of β from 60 m above and 60 m below the respective candidate is determined. If this relative difference is larger than 0.9 the candidate is rejected. Finally the first valid candidate from the list MLH_{large}, MLH_{second}, MLH_{low} is returned as MLH. If no candidate is found, STRAT-2D returns the lowest valid range gate as MLH.

4283, 21: This statement is very critical: If no candidate is found, the lowest valid range-gate is returned as MLH: Do you use this values? These values should be clearly flagged and not used for the statistics (as later mentioned), since they are completely arbitrary.

Of course they are not used - it is mentioned later in the text. But you are right it should be mentioned here. We therefore added a sentence:

As these are not real MLH retrievals we do not use them in our further anlysis.

Fig. 1 : In my opinion the statistic would be much more valuable if it would show absolute values and not relative ones. 5% could be 5 m or 500 m.

Fig. 2 same as Fig. 1. Please absolute values.

We provide now both plots with absolute and relative values.

4286: A conclusion is missing for the threshold sensitivity test.

The conclusion was in the middle of the paragraph. Following a suggestion of reviewer 3 we restructured the whole paragraph. The conclusion is now at the end.

4228, 9: Are you referring to Figure 4? Please do so!

We added a reference to the figure.

4289,7-9: Advection could also be one reason for the observed features ...

Could be in some cases. But advection could also invert or increase the backscatter gradient. As we observe rather frequently a vanishing backscatter gradient between developing ML and RL above we believe that our explanation is the more probable.

4289: It would be good to describe the general climatological characteristics of the observed year. Was it a usual year? Was there an exceptional hot summer? Lot of westerly winds or high-pressure dominance etc.? This would be very helpful for the interpretation of the presented data.

A short summary will be included in the manuscript.

4290, 12-13: Can you explain, why in wintertime often a nighttime ML is detected above the minimum height while during the other season it is not? I.e. come up

with an interpretation.

We added a sentence:

This is due to a rather large number of storm passages in the dataset. The observed large mixed layer heights are thus not convective but wind shear driven.

4290,13-14: I cannot see the switch between night time and day time mode. Can you describe in more detail?

We added an explanation in the sentence:

The switch of the STRAT-2D algorithm between the day mode (beginning 3 h after sunrise) and the night mode (beginning with sunset) is in Winter clearly visible as a sudden increase in average MLH.

4290, 15-17: This topic is really interesting! Do you have one case study which could be shown and discussed? This would be of high interest for me (and possible other readers). And it would also increase the scientific value of the paper.

This was a somehow misleading formulated sentence. It tried to explain what the effect of day/night switch of STRAT-2D is. We reformulated to:

In contrast hereto MLH_{wind} does not show a diurnal course and it must thus concluded that the switch of STRAT-2D between night and daytime works not properly at least in winter.

4291, 512: Please come up with a conclusion concerning the threshold selection and/or other methods for the wind lidar.

We added a sentence about MLH_{aero}:

As this difference can not be removed by changing the threshold σ_{wts} within the large range investigated in Sect. "Threshold sensitivity" it must be concluded that MLH$_{aero}$ is systematically overestimated.

4292, 7: I guess you mean Fig. 6 instead of Fig. 5?

no, we meant figure 5, but we admit that it is not clearly formulated. As we drop the figures with broken cloud cases, this section will change entirely.

4292, 25: I think concerning this analysis one cannot apply the word "hysteresis" with respect to its physical meaning.

We intended to say "hysteresis like effect". But reconsidering it, it becomes clear that it is a hysteresis in terms of that MLH$_{\mathrm{aero}}$ is influenced by the past state of the ABL: During morning hours aerosol layers in the RL, which developed during night, are detected. In the late afternoon the top of the RL is detected which is determined by the ML in the hours before. Nevertheless we changed the words to

hysteresis like effect

Section 3.4.: The first sentence is confusing, because I guess you are not always detecting cumulus clouds. You should motivate a little bit more that you do this analysis to show that in some seasons the detected clouds are strongly linked to MLH.

We added some sentences in the first paragraph:

To investigate this further we compare here cloud bases as detected by the ceilometer with the MLH found by the two methods. We use the data set with cloud cover below 3 km lower than 4 octa. Allthough this does not fully gurantee that the observed clouds are cumulus clouds, we regard it as a first attempt to restrict to this cloud class.

4295:4-6: This statement is too strong. You only can use it as a proxy if you know that it is a convectively driven cloud. Usually you do not know this without any ancillary parameter/measurements.

We agree. The statement was changed to:

As the determination of cloud base height is simpler than the determination of mixed layer height it could be used as a good proxy for MLH. Nevertheless it is necessary to ensure that the observed clouds are convective e.g. by investigating the surface sensible heat flux H_s. A strategy could e.g. to check in situations with sufficient large H_s whether MLH$_{aero}$ lies close to or above CBH.

4295, 23: You should also report here that you confirm previous findings that a ceilometer cannot follow the ML evolution in the morning and afternoon instead of solo referring to sec 3.2.

we added the following sentence:

This confirms earlier findings for aerosol based MLH retreival of the growing ML in the morning (Eresmaa et al., 2012) and its evening decay Träumner et al. (2011). We could quantify the average differences between the two methods.

4295: 26ff: I do not understand! How do you conclude that the differences are connected to convective situation?

The arguments were described in detail in section 3.2.2 (discussion of the joint histogram for broken cloud cases). As we changed this section it will become difficult to keep it. Therefore we drop it.

4297, 23: Conclusion needed. It depends strongly on threshold, ok, but what can we conclude from that finding?

We added the following sentence:

In summary it can be said that it is principally not always possible to determine the time of the end of convective mixing exactly. A different σ_w threshold may shift the moment of detection, but as there is no universal definition of 'convective mixing' there is also no universal value for the threshold. Nevertheless a change of the σ_w threshold by -25% is not sufficient to explain the difference between aerosol and wind derived MLH and it must be concluded that MLH_{aero} is in average in the order of 500 m too large.

4298, 11ff: Make a strong statement: Ceilometers can only be used for ML detection at daytime under certain conditions.

We added some sentences at the end of the conclusions - they were already cited in reply to your point three.

Caption Table 2: More explanation needed, caption must be self-explaining. E.g.: On what did you apply the linear regression? How can I interpret the slope?

We adapted the caption.

Caption Figure 1: What does it mean: During times when less than 20% of data was available? Synoptic situations, instrument failures, what time interval did you use for your selection?

We changed the respective part of the caption:

After removing all MLH values below the overlap region 9173 data points could be analysed most of them during daytime, in average 80 % of the original data per half hour interval. During times when less than 20 % of the original data were available median and quartiles are not displayed.

References

Baars, H., Ansmann, A., Engelmann, R., and Althausen, D.: Continuous monitoring of the boundary-layer top with lidar, Atmospheric Chemistry and Physics, 8, 7281–7296, doi:10.5194/acp-8-7281-2008, 2008.

Eresmaa, N., Härkönen, J., Joffre, S., Schultz, D., Karppinen, A., and Kukkonen, J.: A Three-Step Method for Estimating the Mixing Height Using Ceilometer Data from the Helsinki Testbed, Journal of Applied Meteorology and Climatology, 51, 2172–2187, doi:10.1175/JAMC-D-12-058.1, 2012.

Korhonen, K., Giannakaki, E., Mielonen, T., Pfüller, A., Laakso, L., Vakkari, V., Baars, H., Engelmann, R., Beukes, J. P., Van Zyl, P. G., Ramandh, A., Ntsangwane, L., Josipovic, M., Tiitta, P., Fourie, G., Ngwana, I., Chiloane, K., and Komppula, M.: Atmospheric boundary layer top height in South Africa: measurements with lidar and radiosonde compared to three atmospheric models, Atmospheric Chemistry and Physics, 14, 4263–4278, doi:10.5194/acp-14-4263-2014, 2014.

Münkel, C., Eresmaa, N., Räsänen, J., and Karppinen, A.: Retrieval of mixing height and dust concentration with lidar ceilometer, Boundary-Layer Meteorology, 124, 117–128, doi:10.1007/s10546-006-9103-3, 2007.

Träumner, K., Kottmeier, C., Corsmeier, U., and Wieser, A.: Convective Boundary-Layer Entrainment: Short Review and Progress using Doppler Lidar, Boundary-Layer Meteorology, 141, 369–391, doi:10.1007/s10546-011-9657-6, 2011.