Integrated System for Atmospheric Boundary Layer Height Estimation (ISABLE) using a Ceilometer and Microwave Radiometer. By Min et al.

General comments:

This manuscript presents a method (ISABLE) for determining the atmospheric boundary layer (ABL) height using ceilometer profiles with stated improvement compared to previously well-established methodologies. The approach uses four existing methods (time-variance VAR, gradient GM, wavelet covariance WAV, and cluster analysis CLST methods) to identify multiple boundary layer candidates. It then uses a second cluster analysis approach to select the final ABL height. Microwave radiometer retrievals are then used to support stable nocturnal boundary layers. The ISABLE approach is then used in a long-term data set.

The manuscript's current structure and organization are adequate with some room for improvement. However, the text is often unclear with grammar oversights and language faults making it at times, difficult to follow. The most unique aspect of this methodology is the application of a cluster analysis that will select the ABL from initial results using multiple methodologies. Results show slight improvement in the ABLH using ISABLE when compared to the initial methodologies used. The manuscript does not provide discussions into the possible benefits from using the ISABLE approach, nor does it improve or expand on extensively studied challenges in ABLH detection using ceilometers.

The ISABLE methodology presented in this study should be further discussed and contrasted to previously published results as this is a field of extensive analysis. The results using the individual methods (VAR, GM, WAV, CLST) should be contrasted against published results using the same methodologies as the validation results of the individual methodologies in this manuscript are significantly lower than those in previously published studies (e.g. Cohn and Angevine, 2000; Morille et al., 2007; Münkel et al., 2007; Uzan et al., 2016; Caicedo et al., 2017). This invites questions about the application of the methodologies in this study.

Further, as ISABLE merges existing methodologies, it should be contrasted to similar algorithms which also merge various methodologies such as Lammert and Bösenberg (2006), Martucci et al. (2007), Morille et al. (2007), Di Giuseppe et al. (2012), Pal et al. (2013), Hicks et al. (2015), Geiß (2016), Peng et al. (2017), and Poltera et al. (2017). Similarly, although ISABLE in this case, slightly outperformed the individual methodologies in this study, it does not show improvements in the known challenges across all ABL ceilometer retrievals (ABL layer attribution, precipitation, lofted aerosol layers, low aerosol conditions, clouds, etc.). These challenges have been addressed in more recent methodologies which improve retrievals through various tracking tools (e.g. Lewis et al., 2013; Geiß, 2016; Poltera et al., 2017). Properly addressing the literature, would give further insight into the benefits or challenges of using ISABLE for ABLHs and may justify the suggested use of ISABLE.

The manuscript states improved results using ISABLE in comparison to VAR, GM, WAV, CLST methodologies. However, improvements in correlations when compared to sondes are slight and RMSE (above 300m) are substantial. These results and bias should be further discussed as a RMSE of 300m+ can be quite significant in the ABL.

For these reasons, the current state of the manuscript does not present substantial conclusions or new results that further our efforts in ceilometer ABL detection and should be considered for publication in AMT after major revisions.

Specific comments:

Section 2. Please provide references for ceilometer and MWR instrumentation. Additionally, the net radiometer is overlooked and left without description

Section 3.3. Please provide references to the entire methodology in this section.

Section 4.2.4: Was the cluster analysis applied to averaged $\bar{}(z)$ or $\sigma_{\beta\,SNR}$ profiles or else?

Section 4.3: MWR have also gone through extensive ABL retrieval evaluations and these should be discussed. The selection of the methodology should also be supported with further literature discussion. Additionally, is there a reason why MWR are only used for SBLH retrievals and not ML and RL heights?

Table 2 and 3: The difference between these two tables is not explained. Table 3 hints at a removal of “major error factors”, how is this defined?

L23-24: Definitions of the ABL are unclear in this sentence. This reads as both the stable and residual layers are nighttime lofted layers. Please clarify.

L24: “By convection and turbulence” implies separate mechanisms independent of each other. Please review

L26: “Besides” is incorrectly used here.

L26-27: the reduced dilution volume of the SBL should also be noted as this can increase surface pollutant concentrations

L28-30: Although the ABL can influence pollutant concentration, it cannot be used to determine air pollutant concentrations as stated. The interactions between pollutant concentration and the ABL height are not the only drivers in air pollutant concentrations. Emission sources, transport, photochemistry etc. may have large impact in pollutant concentrations and must not be neglected.

L45: “back into the atmospheric aerosol” implies that the laser originated in atmospheric aerosol and returns back to its origin. Please revise

Equation (1): the variable N is not defined in the text

L126-130: Can you comment on how much of the improvement of h_{SNR} may be due to the applied averaging?

L162-164: It is unclear if residual layer heights are not being identified in radiosondes as the current text seems to imply aerosol profiles are sufficient for residual layer identification. Is the ‘final ABLH’ alternating between SBLs and RLs? Please clarify

L165-167: It is unclear what method was used in the final ABLH attributed to the SBL.

L177: Please describe how $\sigma_{\beta\,SNR}$ profiles were smoothed

L193-195: How is this consistent with Emeis et al. (2008), please specify.

L207-208: How were these settings chosen?

L223-224: Please define what 'distribution' is divided

L284: Is this an artificial gap or a threshold marking?

L296-297: A follow up to the previous comment, does the final ABLH average include the added 150m or was this removed at some point? Please comment on how averaging the final cluster group can affect the ABLH, uncertainty, and validation.

L313-316: How was the 500m limit defined and what artifacts were observed? Please expand.

L333: This reads as the surface will only cool under clean air. Please review.

L335: the 'nocturnal heat island' effect is mentioned but not clearly connected to the results. Please expand on this effect and how at times (yet not always) it is responsible for high altitude outliers during nighttime.

L340-342: why was this time period chosen?

L369-390: No need to list all results already clearly presented in tables 2&3. Instead, insight into the possible culprits or conditions leading to the major findings should be presented and discussed.

L369-375: The clear and cloudy sky results (Figure 9b) shows very similar results across all methodologies (excluding WAV1&3) with a very small improvement in the ISABLE results. Can the benefits of ISABLE be expanded upon?

L388-390: This implies ABLHs were higher in altitude than other methodologies, yet Figure 9 refers to R, please review.

L392: It is unclear what 'merely 3(5) times higher' means. If SBL heights are a factor of 3-5 times higher than MWR, it is not a mere difference.

L 447: please specify these results correspond to daytime

L449: this is the first instance that R2 is used. Please revise for consistency and define all variables.

L452: This explains now the difference between Table 2 and 3. The removal of these "error" retrievals should be specified and described in the results section. Additionally, these should be clarified as manual removal of retrievals deemed inadequate and are not representative of the overall performance of ISABLE itself.

L458-460: The impact of ISABLE retrievals as "great potential in parameterizing vertical diffusion" and to "understand severe haze/smog events fumigated from the upper layer" is unsupported. Such statements require further discussion and supporting evidence.

Technical:
L72: repeated 'and' should be removed

L171: Should this be 'equation (7)'?

L439-440: "and compared to and verified". Should this be "are compared and verified against…"?

References:

Di Giuseppe, F., Riccio, A., Caporaso, L., Bonafé, G., Gobbi, G. P., and Angelini, F.: Automatic detection of atmospheric boundary layer height using ceilometer backscatter data assisted by a boundary layer model. Q. J. R. Meteorol. Soc.138:649–663. DOI:10.1002/qj.964, 2012

Geiß, A., Wiegner, M., Bonn, B., Schäfer, K., Forkel, R., von Schneidemesser, E., Münkel, C., Chan, K. L., and Nothard, R.: Mixing layer height as an indicator for urban air quality? Atmos. Meas. Tech. 10:2969–2988. DOI:10.5194/amt-10-2969-2017, 2017.

Hicks, M., Sakai, R., and Joseph, E.: The evaluation of a new method to detect mixing layer heights using Lidar observations. J. Atmos. Ocean. Technol., 32, 2041–2051, 2015.

Lewis, J. R., Welton, E. J., Molod, A. M., and Joseph, E.: Improved boundary layer depth retrievals from MPLNET, J. Geophys. Res. Atmos., 118, 9870-9879, doi:10.1002/jgrd.50570, 2013.

Martucci, G., Matthey, R., Mitev, V., and Richner, H. 2007. Comparison between Backscatter Lidar and Radiosonde Measurements of the Diurnal and Nocturnal Stratification in the Lower Troposphere, J. Atmos. Ocean. Technol. 24: 1231–1244, DOI:10.1175/JTECH2036.1

Morille, Y., Haeffelin, M., Drobinski, P., and Pelon, J.: STRAT: An Automated Algorithm to Retrieve the Vertical Structure of the Atmosphere from Single-Channel Lidar Data. J. Atmos. Ocean. Technol. 24:761–775. DOI:10.1175/JTECH2008.1, 2007.

Lammert, A. and Bösenberg, J.: Determination of the convective boundary-layer height with laser remote sensing. Boundary-Layer Meteorol. 119: 159–170. DOI:10.1007/s10546-005-9020-x, 2006.

Pal, S., Haeffelin, M., and Batchvarova, E.: Exploring a geophysical process based attribution technique for the determination of the atmospheric boundary layer depth using aerosol lidar and near-surface meteorological measurements. J. Geophys. Res. Atmos. 118: 9277–9295. DOI:10.1002/jgrd.50710, 2013.

Peng, J., Grimmond, C. S. B., Fu, X., Chang, Y., Zhang, G., Guo, J., Tang, C., Gao, J., Xu, X., and Tan, J.: Ceilometer based analysis of Shanghai's boundary layer height (under rain and fog free conditions). J. Atmos. Ocean. Technol. 34: 749- 764. DOI:10.1175/JTECH-D-16-0132.1, 2017.

Poltera, Y., Martucci, G., Collaud Coen, M., Hervo, M., Emmenegger, L., Henne, S., Brunner, D., and Haefele, A.: PathfinderTURB: an automatic boundary layer algorithm. Development, validation and application to study the impact on in situ measurements at the Jungfraujoch. Atmos. Chem. Phys. 17: 10051–10070. DOI:10.5194/acp-17-10051-2017, 2017.

Uzan, L., Egert, S., and Alpert, P.: Ceilometer evaluation of the eastern Mediterranean summer boundary layer height – first study of two Israeli sites, Atmos. Meas. Tech., 9, 4387–4398, doi:10.5194/amt-9-4387-2016, 2016.