Responds to Anonymous Referee #3:

General comments:

The manuscript "A novel Mie lidar gradient cluster analysis method of nocturnal boundary layer detection during air pollution episodes" presented a new algorithm to retrieve the nocturnal boundary layer height (NBLH), based on cluster analysis of gradient method, using 39 days lidar observations. The radiosonde data were used to evaluate its performance of NBLH retrieval, and results show that the presented algorithm had a better agreement than the other 3 methods (GM, WCT, CRGM). A comparison of this new methods with the other 3 methods were also analyzed and discussed, using a 256 hours data set. The presented method is promising for improving the NBLH retrieval, and results look interesting. However, I don't think the current form can clearly deliver the information, and a number of point must be clarified. Major changes are needed, and the writing of the paper must be improved, before the manuscript can be considered for publication. Please see my comments below.

Response:

Thanks a lot for your reviews on our manuscript entitled "A novel Mie lidar gradient cluster analysis method of nocturnal boundary layer detection during air pollution episodes (ID: amt-2020-167). We have revised the manuscript according to the comments, the language has been polished by Elsevier Language Editing Services. Moreover, the comprehensive reference and the discussion of the results, and the limitation and the uncertainty of the algorithm have been added. The details are shown as follows.

Specific comments:

1.The presented method can only be applied for the BIT-lidar or can be used for other elastic lidars? Why you used "Mie lidar" in the title? I think this method is not only valid for Mie lidar. The conditions/constraints of using such method should be discussed.

Response:

1) In my opinion, this method can be used in other elastic lidar systems. The implement of the algorithm is needed a dataset of the RCS gradient with height more than 30 min collection within an hour. I think it can be used for other elastic lidar. Therefore, we have changed the title as a n*ovel lidar gradient cluster analysis method of nocturnal boundary layer detection during air pollution episodes*.

2) The reason why I used "Mie lidar" is that our lidar system (BIT-lidar) system is the Rotation Raman Mie system, and I use the Mie channel signal to detect the atmospheric boundary layer.

3) The condition/constraints are added to the discussion.

'The limitation of the CA-GM is based on the nocturnal boundary layer is stable, hence, we can calculate the distribution of the minima gradients of the RCS in an hour interval to use weighted k-means clustering to work as height restriction to the

layers. Secondly, based on the limitation of the lidar system. The lower limit of the BIT-lidar is around 300 m. Too shallow of nocturnal boundary layer height (NBLH) are not be detectable. Thirdly, the method should be used in the high SNR condition, such as night-time and air pollution.'

In this study, the raw data resolution is used to get a high time & vertical resolution, any comparison with other methods? Have you used any vertical smoothing? What is the final time & vertical resolution? If reader want to apply this method to another lidar system, what's the limitation? Some discussions are need.

Responds:

1)The raw data time resolution of lidar system is 50 s and the vertical resolution is 2.5 m. It is a relative high time and vertical resolution. Other research using 2 min average signal (Su and Patrick McCormick, 2019),15 min time-averaged signal (Martucci et al., 2010) or even 30 min time-average(Tsaknakis et al., 2011) for elastic lidar system tracing the aerosol distribution.

2) In our algorithm, we use the Savitzky-Golay smooth method at the preprocess of RCS. The final time & vertical is the raw resolution, but the effective time resolution is 30 min. In order to implement the algorithm, we should collect at least 30 min of the dataset for the RCS gradient with height within an hour. Therefore, we have enough dataset for cluster analysis (CA).The CA determines the NBL by taking into account the overall set of observations of a given profile, which can be considering as the effective time resolution.

3) The limitation of the implement of the method are added at the discussions part. P17 332-335.

2. No uncertainty/error study is presented. Such information should be added.

Responds:

Thank you for your suggestion. The testing with the real signal are shown below, and can be added at the Supplement.

1)The testing with the real signal are shown below.

Use the $\mathrm{RCS}(z)$ signal, and randomly noised $\mathrm{RCS}^{noised}(z)$ by the expression:

$$\mathrm{RCS}^{noised}(z) = \mathrm{RCS}(z) + [\alpha \times \chi(z)] \quad \text{(R3-1)}$$

Where $\chi(z)$ is the random noise function taking values between 0 and 1, z is the height, and α is a varying parameter as introduced in Eq (R3-1) to produces different levels of noise.

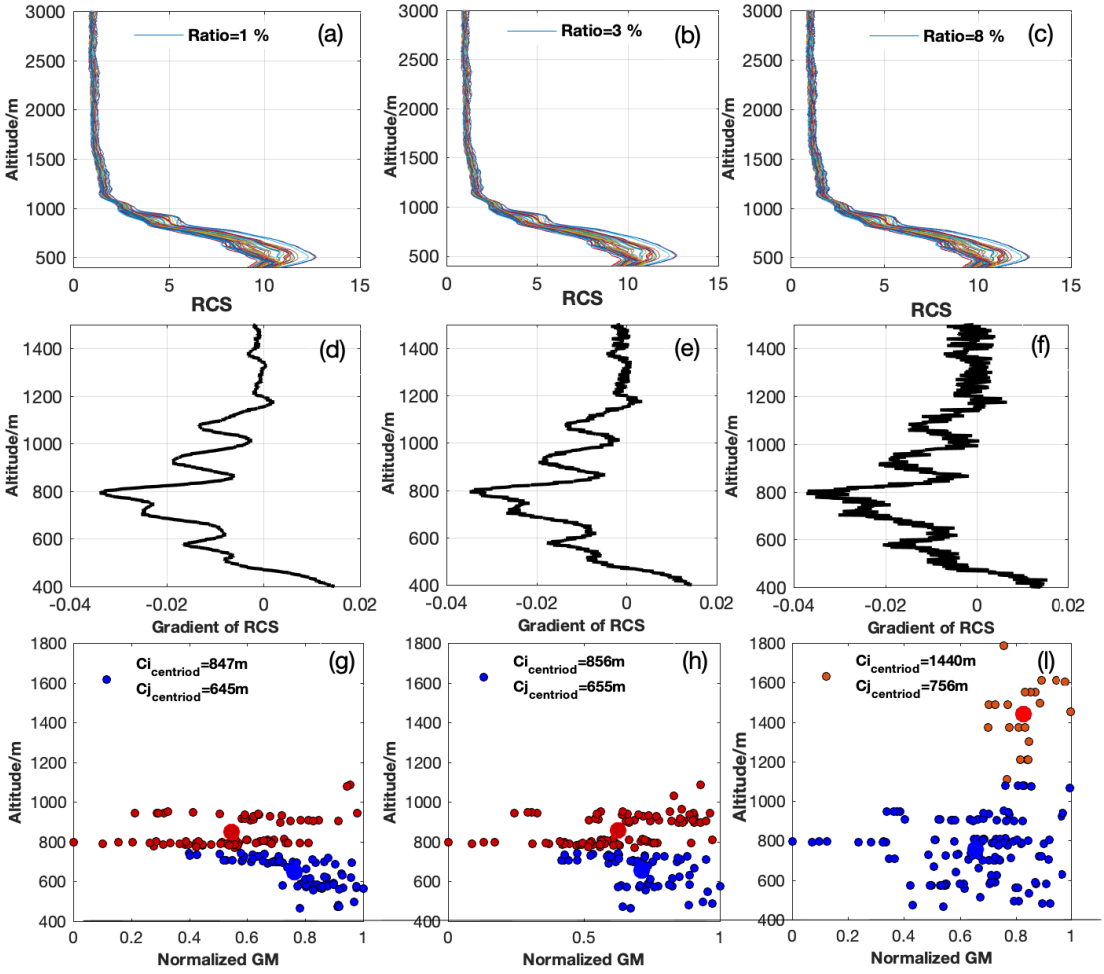


Figure R3-1. The real lidar RCS for the heavily polluted case (17 Dec 2016 20:00-21:00 LST).
(a-c) three noise level cases, (d-f) with the gradient of RCS, and (g-i) the first weighted k-means clustering.

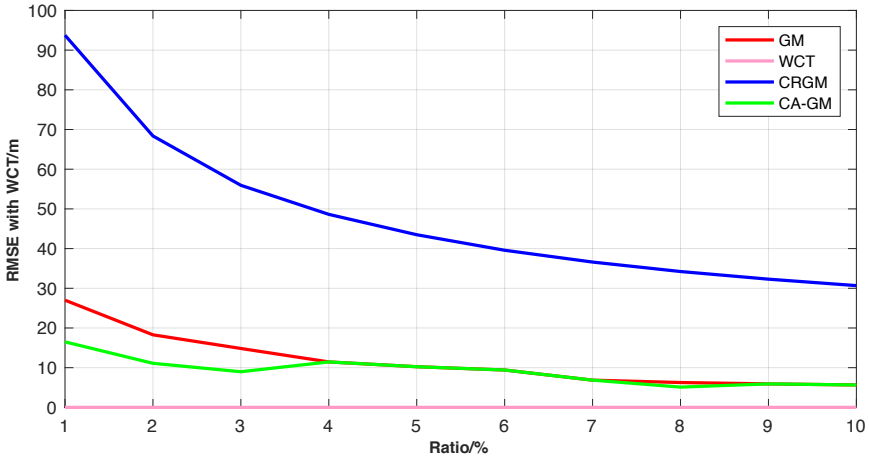


Figure R3-2 RMSE between the WCT and the other three algorithms (GM,CRGM and CA-GM)

As a result of the figure R3-2 shows, the CA-GM has less RMSE than GM at the ratio of 1%-4%. The figure R3-1 (g-h) shows similar groups in different range of noise affection. However, the clustering changes at the results of R3-1(i). Due to the noise distribution of the signal, the centriod of the cluster will get higher and lose the ability to restrict the changes of GM. The difference in the NBL top is found with the noise level 4% case, they are lower than 1% in respect to the estimate for the case with raw signal.

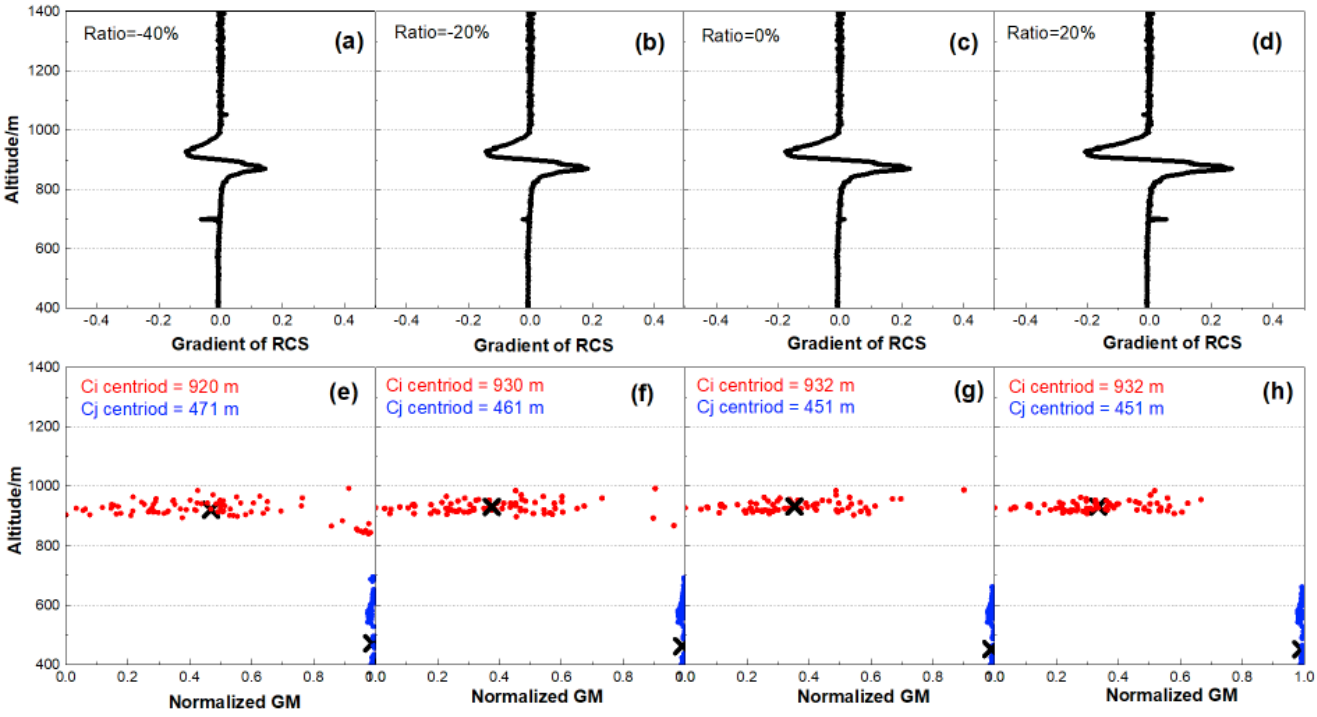


Figure R3-3. The real lidar RCS for the cloud case (5 Jan 2016 00:00-1:00 LST).

(a-d) the different ratio of strength of the cloud layer intensity. (e-h) the first weighted-means clustering

Add the signal of the cloud layer on the raw data, the ratio of the intensity for cloud layer changes from -40% to 40%. As the figure shown the first k-means clustering in figure R3-3(e-h),the intensity of the cloud layer will not influence the CA-GM.

In summary, these results indicate that the degree of estimation of the NBL top by applying CA is weakly affected by the signal noise. In fact, a few NBLH depending on the value of the RCS gradient in a discrete point. CA determines the NBL by taking into account the overall set of observations of a given point, thus decreases the dependence of the method on the RCS values in single moment. The intensity of the CLs changes ±40% and will not affect the cluster of the CA-GM, it can be significant stratified due to the relative significantly signal difference on the backscatter signal. As for the EALs, the strict threshold will defined the EALs accurately. Therefore, the CA-GM approach is able to accurately obtain the NBLH with the effect of noise, cloud layers and elevated aerosol layers.

We add the uncertainty analysis in the discussion in P17 Line 336-341.

3. The description of methodology is not clear, please revise it.

L88, explain more about the assumption.

Responds:

The content has been added in P4 Line 102-105.

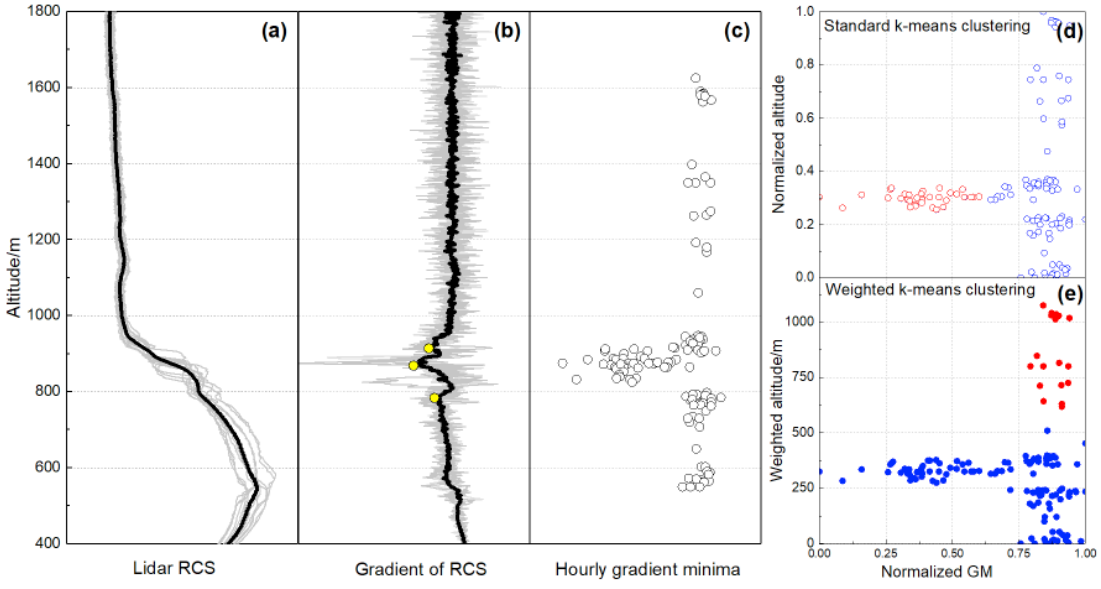
'The NBL shows more complex internal structure at night, the particulate can be used as an important indicator of atmospheric layering because its vertical distribution is strongly affected by the thermal structure of the atmosphere (Neff and Coulter, 1986).The assumption of the NBL at which the aerosol concentration and turbulence intensity are significantly higher in the NBL than in the free atmosphere (FA)(Dang et al., 2019; Wang et al., 2020).'

Fig2, add legend for red line, grey lines, colour circles etc. are GM peaks from the red line? More description needed.

Responds:

Thank you for your suggestion.

These contents have been added to the article in P6.line 138-142.



'Figure 2. The theoretical schematic of the weighted-k means clustering. (a)The real profile of a lidar RCS(light gray line) and the hour averaged RCS (black line). (b) The gradient of RCS (light gray line), the hour averaged gradient RCS (black line), and the three minima in the profile (yellow points). (c) The distribution of the gradient minima within an hour. (d-e) The results obtained by standard k-means and weighted k-means clustering, where two clusters are differentiated, as shown by red and blue hollow and solid points, respectively.'

L122, "three minima peaks", and L145 "three gradient minima", do they refer to the same information? Please clarify which minima criterion you used, the 3 minima gradient values of RCS? Or the peaks with minima values? You can also add these minima by the markers in figure 2.

Responds:

The content has been add in P6 Line 144-146

Yes, the three minima peaks and the three gradient minima are both the same information. The method of finding the three minima of RCS gradient is collecting the minimum points by a window of 25 m, and sort the top three minimum points.

L144, describe more about the reference height.

Responds:

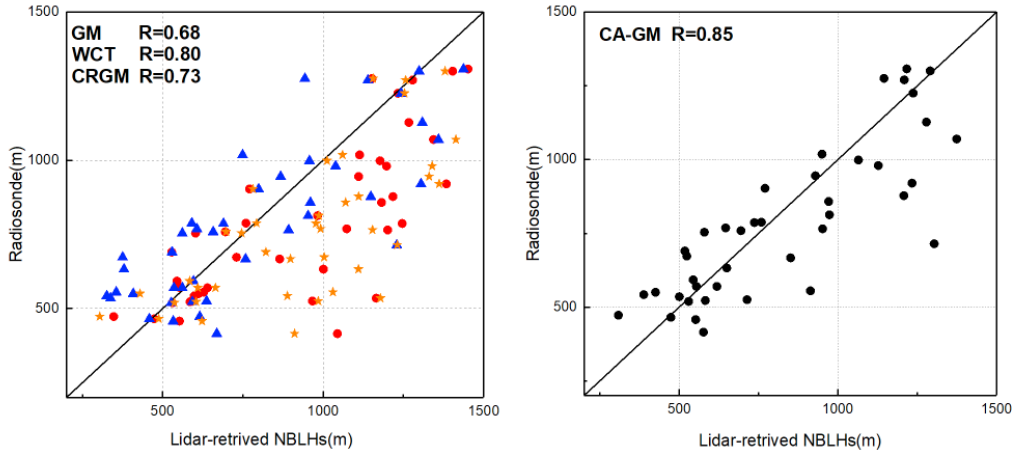
We are choosing as in the Fernald algorithm by choosing a molecular reference so that ${\beta_m}^{aero} \ll {\beta_m}^{mol}$.

The reference has been added in P7 Line 167.

Fig4, you can put all other methods using different colour/marker.

Responds:

The Figure4 has been changed in P9 Line 200.



'Figure 4. Comparison between the radiosonde-determined and lidar-retrieved measurement of NBLH in gradient method (GM) (red circle), Wavelet covariance transform transition method (WCT)(blue triangle), cubic root gradient method (CRGM) (orange star) and cluster analysis of gradient method (CA-GM) (black circle). The correlation coefficients is represented by R. The black solid line is the 1:1 line.'

L225, Are you sure it is a cloud layer? RCS looks very weak for this layer. It could be a lofted aerosol layer. If it is not a cloud layer, another case should be presented in this section.

Responds:

Thank you for your suggestion. It is really hard to use single wavelength lidar to layer the classification of the aerosol and

cloud layers. According to the (Zhao et al., 2014), The maximum and the minima of the F(z) are donated as T and D, respectively. When z is below 3 km, layers are classified as clouds when T>3 or D<-7; As the following figure shows, the T just overpass the threshold. Therefore, it cloud be a weak cloud layer. If you think it is still not reasonable, I can change for another example.

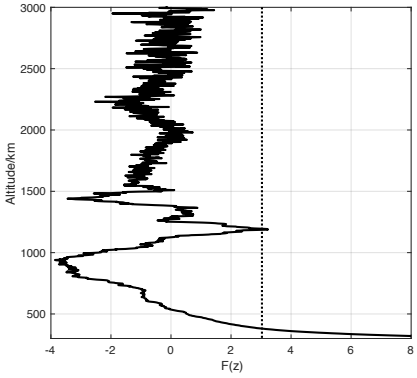


Figure R3-3. The gradient of logarithmic ranged correction signal

Technical corrections:

L12, 39 days is not a “long-term”, maybe another expression.

Responds:

The long-term have been changed as 39-d in P1 Line12.

L32-33, rephrase the sentence.

Responds:

The sentence have change in P9 Line 49-54.

‘Some graph theory methods like extend Kalman filter (Banks et al., 2014), Pathfinder and PathfinderTURB (de Bruine et al., 2017; Poltera et al., 2017)*, and k-means clusters* (Liu et al., 2018; Toledo et al., 2014) *are proposed to promising results using an automated method which reduces incorrect detection of the ABLH. However, all these methods will higher cause uncertainty in ABLH identification when encountering a multiple layer vertical structure. However, those techniques depend strongly on the vertical distribution of particle layers (aerosols and clouds) and are not suitable for dealing with complicated multiple-layer conditions* (Granados-Muñoz et al., 2012)*.’*

L67, provide the vertical resolution of radiosonde.

Responds:

The L-band radiosonde provided fine-resolution profile of temperature, pressure, relative humidity, wind speed and direction twice a day at 08:00 and 20:00 local standard time (LST) (Guo et al., 2016).The sample time resolution is 1.2 seconds. The vertical resolution varies from site to site.

Th content has been added in P3 Line 79.

'The vertical temporal resolution was 1.2 s, and the vertical resolution is less than 20 m.'

L73, add "gradient" for PTG

Responds:

Thank you for your suggestion, the word has been add at P2.Line 86.

L76, is BIT-lidar rotational Raman–Mie lidar, but in this study you only use the elastic channel?

Responds:

Yes. We use the Mie signal only.

L79, after the overlap correction, what's the lower limit for BIT-lidar?

Responds:

The lower limit of BIT-lidar is 300 m. The content has been added at discussion.

L89, NBL top. Add "top" here.

Responds:

The word has been added in P5. Line 105.

L115, change hw to hnor

Responds:

The words has been changed in P5. Line 132.

L127, "the noise . . . be affected" do you mean the accuracy can be affected. L130, add "layers" for EALs.

Responds:

Yes, the sentence has been changed in P6.Line 150. And the word has been added at P6. Line 60.

L170, what do you means here "with all algorithm"? L206, any value for this "low SNR condition"?

Responds:

With the other three algorithm (GM,WCT and CRGM).The sentence has been changed in P8 Line 193-194.

The Brooks not mentioned the specific value for the low SNR condition for WCT method(Brooks, 2003).

L208, please specify which "improvement".

Responds:

The improvement has been express in P11 Line 233-235.

L282, “was automatics developed”?

Responds:

Thank you for your suggestion. I delete the words.

L283, “high time resolution”, please specify it. is it equal to the lidar vertical resolution?

Responds:

The inaccurate expression has been changed as the lidar raw resolution.P17 Line 312.

Thank you so much for your reviewing! We deeply appreciate your recognition of our research work.

Reference

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