Improved mixing height estimates from atmospheric LiDAR measurements

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Abstract. In this study, an improvement in the estimation of the mixing height is carried out by introducing a time-dependent maximum and minimum analysis altitude (TDMMAA) in the Haar wavelet covariance transform (WCT) technique applied to atmospheric light detection and ranging (LiDAR) measurements generally used in mixing height estimations. Results showed that the standard method usually overestimates the mixing height and that the proposed algorithm is more robust against clouds and residual layers in the boundary layer that generally occur in the nighttime and early morning. The TDMMAA method does have a bit of subjectivity especially in defining the analysis periods as well as the top and bottom of the analysis altitudes as it needs user experience and guidance. Moreover, the algorithm needs to be further objectively refined for automation and operational use, validated with in-situ profile measurements, and tested during different atmospheric conditions.

1. Introduction

The exchange between the surface of the Earth and its atmosphere is primarily driven via turbulence, and this turbulent domain of the atmosphere adjacent to the ground surface is specifically referred to as the mixing layer. Within this layer, air pollutants, such as particulate matter, are assumed to be well-mixed [1]. The top of the mixing layer is often referred to as the mixing height (MH), which generally undergoes distinct diurnal variations with higher daytime altitudes and lower nighttime altitudes. Assuming constant emissions throughout the day, as well as calm and cloud-free weather conditions, the mixing height significantly controls the diurnal variation of air pollutants, especially particulate matter. This causes the concentrations of particulate matter to be generally high during the nighttime when the mixing height is low, and low during the daytime when the mixing height is high [2]. Its accurate estimation is therefore necessary.

In this study, an improved algorithm for estimating the mixing height is investigated and compared to the standard method using atmospheric light detection and ranging (LiDAR) measurements performed over the Fang district of Chiang Mai province in northern Thailand (near the border with

Myanmar observed to have very high air pollution episodes during the dry season) from March 4-31, 2019 as part of the Profiling with LiDAR and UAV Multi-scale Experiment (PLUME) of the Seven Southeast Asian Studies (7SEAS) Spring 2019 measurement campaign.

2. Methodology

The mixing height can be estimated using atmospheric light detection and ranging (LiDAR) measurements. This technique uses an Nd:YAG laser, usually having a visible wavelength (532 nm) and energies of 4 μJ, that is normally shot vertically into the atmosphere reaching altitudes up to 20 km. As the laser encounters particulates, the radiation is scattered back towards the receiver (telescope and detector) of the system. The measured signal is called the LiDAR backscatter profile and after removing the effect of the system characteristics, the resulting signal is called the normalized relative backscatter profile. This signal is proportional to the number concentration of particulates in the atmosphere and is used to estimate the mixing height.

The mixing height is estimated by finding the maximum change or gradient in the normalized relative backscatter profile. This is done by using a basis function, in this case the Haar wavelet, to perform a pattern search of sudden signal jumps. The pattern search in done by using the wavelet covariance transform (WCT) with translated and dilated versions of the basis function analyzed through a certain altitude range (analysis altitudes). Using various dilation values of the Haar wavelet, the noise in the signal is reduced at higher dilation values. From this, the mixing height is estimated from the altitude of the peak wavelet covariance transform coefficient [3].

The standard algorithm normally has a fixed analysis altitude range, usually from 0 to 4 km from the ground. In this study, we introduce a time-dependent maximum and minimum analysis altitude (TDMMAA) to make the mixing height estimate more robust against atmospheric phenomena (e.g. clouds, nighttime and early morning residual layers) and instrumentation features (e.g. noise, condensation due to enclosure air conditioning). These features also help identify analysis time periods when the standard algorithm is sensitive to. These sensitive analysis periods are the maximum mixing height period, the morning transition period, the afternoon transition period, and the minimum mixing height period.

3. Discussion

Putting all the normalized backscatter profiles together in a time-height-intensity plot as shown in figure 1, atmospheric (clouds on March 8, 2019; residual layers in the boundary layer every early morning and during the nighttime) and instrumentation (noise and condensation in the early morning of March 9 and 10, 2019) features caused an overestimate in the mixing height calculated using the standard algorithm as shown in the red line in figure 1. The black line in figure 1 is the estimated mixing height calculated using a time-dependent minimum and maximum analysis altitude (TDMMAA) as outlined in table 1. As can be seen in figure 1, the TDMMAA did not overestimate the effect of clouds, residual layers, noise and condensation. This algorithm was then applied to the entire dataset from March 4 – 31, 2019 as shown in figure 2.

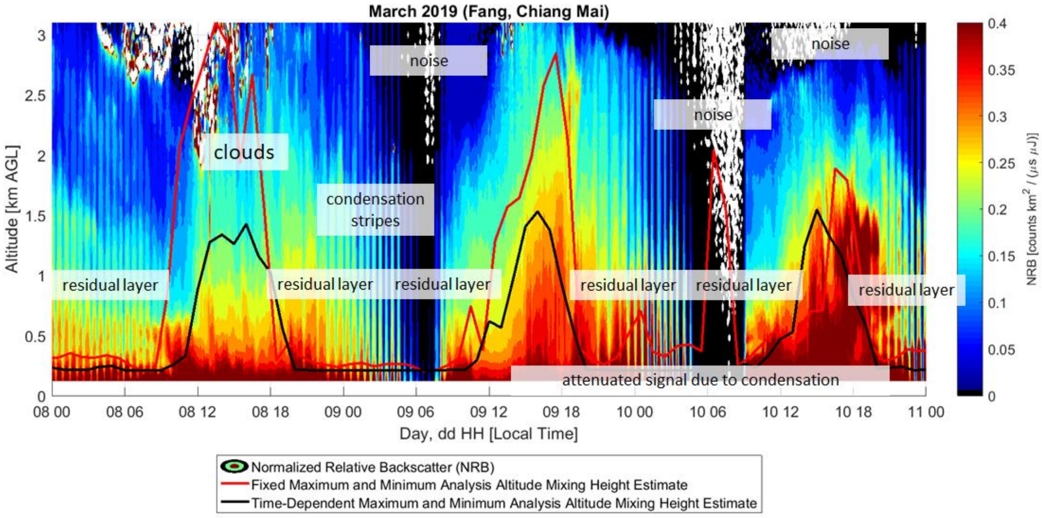

Figure 1. Atmospheric and instrumentation features detection and algorithm testing from March 8 – 10, 2019 over Fang district in Chiang Mai province in northern Thailand.

Table 1. TDMMA Parameters. Defined analysis periods (in local time, LT) and time-dependent maximum (top) and minimum (bottom) analysis altitudes (in meters above ground level, mAGL). The red font depicts changes from the parameters of the previous day.

Date	Period	Start Time (LT)	End Time (LT)	Top (mAGL)	Bottom (mAGL)
March 8, 2019	Maximum MH	1300	1800	2000	1000
	Morning Transition	1200	1300	2000	200
	Afternoon Transition	1800	2000	2000	500
	Minimum MH			400	119.9
March 9, 2019	Maximum MH	1500	1800	2000	1000
	Morning Transition	1200	1500	1500	200
	Afternoon Transition	1800	2000	2000	500
	Minimum MH			400	119.9
March 10, 2019	Maximum MH	1500	1800	2000	1000
	Morning Transition	1200	1500	1500	200
	Afternoon Transition	1800	2000	1500	500
	Minimum MH			400	119.9

The success of the TDMMAA algorithm greatly depends in the proper definition of the analysis periods as well as the maximum (top) and minimum (bottom) analysis altitudes. This introduces subjectivity in the algorithm and needs an experienced or a well-guided user. Future work entails making the algorithm more objective by coming up with monthly TDMMAA parameters or by using machine learning in defining these variables. Validation with in-situ profile measurements using unmanned aerial vehicles that were also deployed nearby the atmospheric LiDAR site during the same study period needs to be also performed to gain better confidence in the algorithm. Further testing of the algorithm in various atmospheric conditions and deployment locations of the atmospheric LiDAR in Chiang Mai province will also be done as a next step.

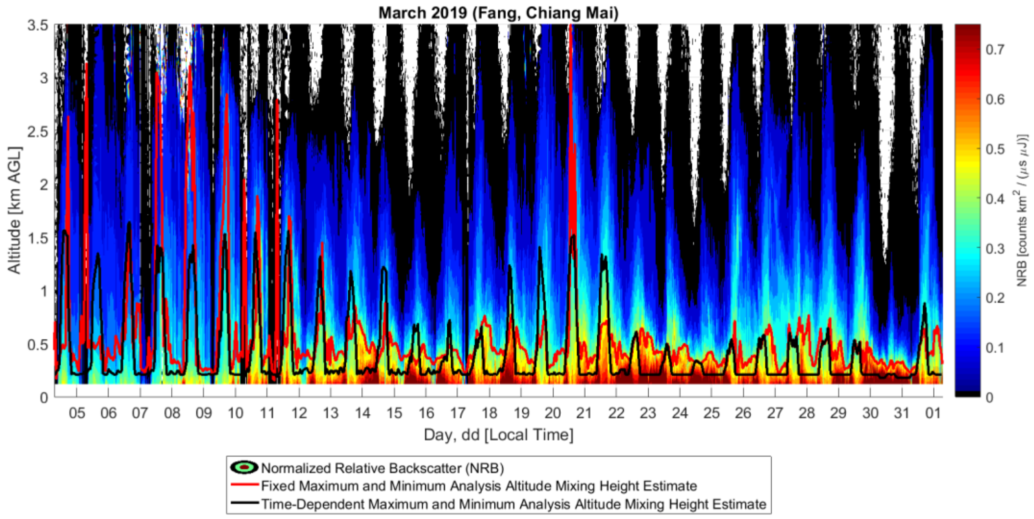

Figure 2. Applying the algorithm for the entire dataset from March 4 – 31, 2019.

4. Conclusion

A time-dependent maximum and minimum analysis altitude (TDMMAA) has been incorporated to the standard Haar wavelet covariance transform (WCT) method used in estimating the mixing height from atmospheric LiDAR observations over Fang, Chiang Mai in northern Thailand during the 2019 dry season. This method proved more robust against atmospheric and instrumentation features that the standard Haar WCT method tend to overestimate the mixing height estimate. However, there is some subjectivity in the TDMMAA method that needs to be further investigated in order to produce a more objective algorithm.

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