Use of lidar backscatter to determine the PBL heights in New York City, NY

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1. Introduction

Lidar (Light Detection And Ranging) systems measure the intensity of backscattered light as a function of distance from the instrument. The primary contribution to the backscatter signal is from aerosol particles suspended in the atmosphere. The atmospheric boundary layer usually has a much higher aerosol concentration than the free troposphere above and thus provides a stronger backscatter signal. The significant change in the backscatter across the top of the boundary layer provides a convenient means of determining the local boundary layer height.

Previous studies using lidar for determining the planetary boundary layer (PBL) height utilized subjective visual estimation of the boundary layer top. Automated approaches included the use of simple signal threshold values, and identification of the maximum gradient of the lidar backscatter vertical profile. However, both of these methods suffer from the significant noise in the lidar measured signal. Several recent studies utilized a wavelet-based technique to provide a scale-dependent approach to determine the PBL height and also retained the original lidar backscatter information. The key of the wavelet analysis was the selection of an appropriate dilation (vertical scale). The methods had been applied in several airborne lidar datasets to determine the boundary heights and entrainment zone (Cohn and Angevine, 2000; Davis, et al, 2000).

The ground based lidar backscatter intensity provides fine resolution of time-height data that is very useful in revealing the daily cycle of convective boundary layer (CBL) growth and collapse. Wavelet technique is applied to analyze the backscatter data obtained from the 1064nm NdYAG lidar backscatter measurements conducted by City College of New York (CCNY) to determine the PBL height in the urban core of New York City. These estimated PBL heights are then used to assess the PBL heights predicted by the WRF/CMAQ air quality forecast system operated at NYSDEC. In addition, the vertical profile of

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lidar backscatter is used to compare with the CMAQ simulated vertical distribution of extinction coefficients.

2. Method

The analysis method is the wavelet covariance transform of the lidar backscatter profile. A local maximum in the covariance transform profile identifies a step change in the lidar backscatter signal as the top of boundary layer. Figure 1 shows the behavior of the lidar backscatter covariance transform as a function of dilation. The covariance transform at small dilation is dominated by uncorrelated noise in the lidar backscatter profile and as the dilation scale increase, the physical gradients are more pronounced. The key of the wavelet analysis is the selection of an appropriate dilation (Brooks, 2003; Cohn and Angevine, 2000; Davis, et al, 2000). For an ideal clear sky well mixed convective condition, the mean backscatter is near constant both within and above the boundary layer, the method works well provided a sufficiently large enough dilation to distinguish the transition zone from small-scale variability in the lidar signal.

The method would overestimate the boundary height during the morning hours when boundary layer was shallow and overlaid by a residual layer of high aerosol concentration from the previous day. The wavelet method may recognize the upper boundary of the residual layer as the top of CBL because it represents the largest decrease in the backscatter data. The wavelet analysis could be improved to reveal the multiple layer structure of the boundary layer by identifying the local maxima higher than a threshold value in the wavelet transform of the backscatter.

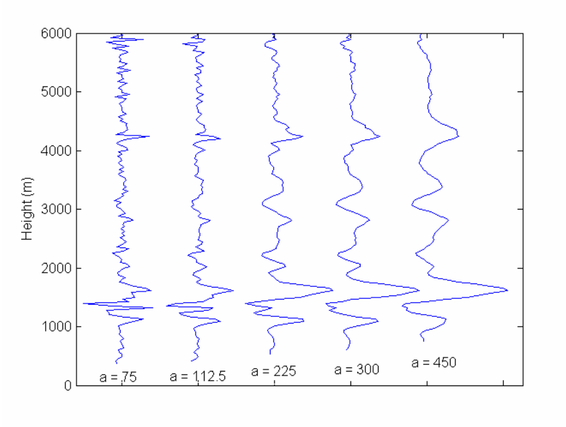

Figure 1: The wavelet covariance transform at various values of the dilation.

3. Data

In order to assess the WRF/CMAQ forecast system predictions regarding both PBL heights and aerosol profiles within the PBL, we have made comparisons between the vertical aerosol profiles obtained from the

Transmitter			Receiver	
Laser	Q-Switched Nd: YAG Infinity 40-100		Telescope Aperture	Newtonian telescope 20 " (50.8 mm)
Wavelength	1064, 532, 355 nm		Focal length	70 " (1778 mm)
Energy/pulse	500 mJ at 1064 nm 250 mJ at 532 nm 200 mJ at 355 nm		Detectors 532 nm 355 nm 1064 nm	Hamamatsu PMT: R758-10 PMT: R758-10 APD
Pulse Duration	3.5 ns at 1064 nm 3 ns at 532, 352 nm		Data acquisition	LICEL TR 40-160
Repetition rate	0.1 – 50 Hz		Photon Counter	LICEL TR 40-160
Harmonic Generators	Quanta_Ray HG-1			

Table 1. Lab Based Lidar Specifications

CMAQ model and the multiwavelength Lidar system at CCNY which provides aerosol vertical backscatter profiles. The basic details of the lidar transmitter and receiver systems are presented in Table 1 and can provide aerosol backscatter profiles at the laser wavelengths of 355nm, 532nm and 1064nm. To eliminate the difficulties in separating the molecular contribution from the aerosol contribution, the 1064 nm channel is optimal. The resultant backscatter profiles are given with temporal resolution of 1 minute and vertical scale of 37.5 meter.

The detail setup of the WRF/CMAQ air quality forecast system was in (Hogrefe, et al., in press). Briefly, the forecast system domain covered the east of the US and operated at 12 km horizontal grid and 22 vertical layers. PBL heights were directly calculated from WRF model. The extinction coefficient was calculated based on the CMAQ prediction of $PM_{2.5}$ concentrations and WRF prediction of relative humidity (Malm et al, 1994).

4. Results

4.1 Boundary Layer Height

The lidar backscatter and the boundary layer height as derived from each single lidar backscatter signal for July 31, 2006 are shown in Figure 2. The boundary layer is outlined clearly with a decrease in intensity at the top of the CBL. The darkest regions at the top of CBL in the afternoon hours are strong backscatter from clouds. Based on the analysis, the data shows two separate aerosol layers from 11:00 to 13:00 (Figure 2b). The upper layer (residual layer from previous day) descended from about 2000 m at 11:00 to about 1200 m at 13:00, while the lower layer expanded from 500 m at 11:00 until both layers merged at 13:00. The WRF predicted PBL heights (black ?) showed steady increased from 500 m at 11:00 and reached about 1500 m as the CBL fully developed. From 11:00 to 13:00 when lidar signal showed two separated layers, the WRF predictions tended to match the lower boundary layer from lidar data that should be considered more representative of the mixing layer height in the morning. In this July 31, 2006 case, the WRF predicted PBL heights matched the lidar backscatter measurements pretty well.

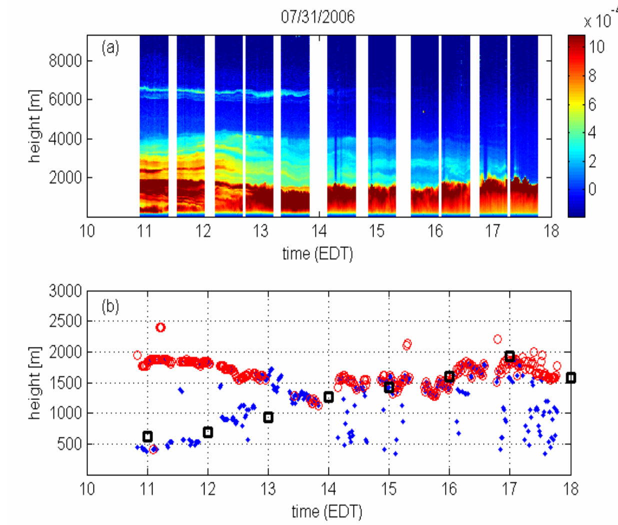

Figure 2: (a) Lidar backscatter image of July 31, 2006 at CCNY; (b) Temporal development of the boundary structure derived from lidar backscatter data and PBL heights predicted by WRF model (black ?).

4.2 Lidar Backscatter and CMAQ extinction coefficient comparison

The high temporal and vertical resolution of the lidar backscatter data has a potential to provide the measurement of the development of the boundary layer structure. In this study, we performed a comparison between the vertical profiles of extinction coefficient by the CMAQ simulation and the lidar backscatter to demonstrate the CMAQ in simulating the evolution of the boundary layer.

The Lidar backscatter data were one minute in temporal and 37.5 meter in vertical resolution. The CMAQ were setup with 22 vertical layers from 20 meter to about 15 km with hourly data of extinction coefficients. To make the comparison, hourly lidar backscatter data were calculated by averaging the signals that fall within the same hour. The missing data were ignored that each hour may contain different number of lidar signals. The hourly averaged lidar data were then averaged vertically according to the CMAQ vertical layers. It must be emphasized that this is a qualitative comparison, since the extinction coefficient is not exact the same as the measurement of lidar backscatter. The similarity is that both extinction coefficient and lidar backscatter reflect the aerosol and humidity loading in the atmosphere.

Figure 3 shows the scatter plot comparison of the averaging lidar backscatter and the CMAQ extinction coefficient for July 31, 2006 from 10:00 to 17:00 (EDT) for data within the range of about 300 m to 5 km only. The correlation coefficients ranged form 0.08 at hour 17:00 to 0.96 at hour 15:00. The low correlation coefficient of hour 14:00, 16:00 and 17:00 were due to high lidar backscatter value from cloud contamination.

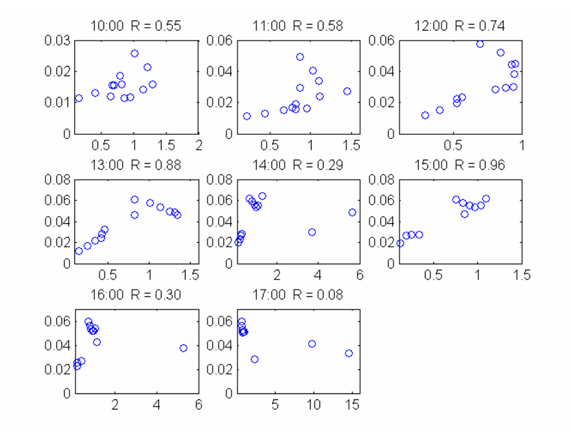

Figure 3: Comparison of the vertical profile of lidar backscatter (H-axis) and CMAQ calculated extinction coefficients (V-axis) for July 31, 2006.

5. Conclusions

We applied the wavelet transform technique to the lidar backscatter data measured in the New York City for analyzing the depth of the convective boundary layer. The aerosol residual layer was also clearly delineated using this method. The observed PBL heights by lidar data were used to assess the predicted PBL heights from the WRF/CMAQ air quality forecast system. The results indicated that the model predicted the development of the PBL heights pretty well in comparing with the observed data.

The lack of vertical information of aerosol makes it difficult to assess the performance of PM model simulations. The high temporal and vertical resolution of lidar data may have the potential to provide the data for model assessment. It is important to develop mutual parameters of the lidar measurements and model outputs that can be used for quantitative comparisons.

6. REFERENCE

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