P1.14 APPLICATION OF CCNY LIDAR AND CEILOMETERS TO THE STUDY OF AEROSOL TRANSPORT AND PM2.5 MONITORING

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1. INTRODUCTION

Between 1900 and 1970, the emission of principal pollutants such as particulate matter, increased significantly across the globe. Particulate Matter less than 2.5 microns in diameter have been shown to have health effects, not only to human health, but also to the entire global environment. Air pollution caused by such particulates has been a major problem since the beginning of the industrial revolution, and have the greatest influence on our activities due to a reduction in visibility because of their ability to scatter light. An increased PM2.5 concentration also causes concerns for the stability of our global environment due to "Greenhouse effects", Hidy (1998).

In an effort to improve Air Quality Forecasting, the EPA together with NASA and NOAA, implemented an ambient air quality-monitoring program to determine the composition of airborne PM2.5 in urban air, in an effort to assimilate satellite measurements of aerosol column optical depth into air quality transport models. However, current satellite based aerosol measurements cannot assess the distribution of aerosols in the atmosphere, so transport models based on vertical layering are not suitable.

However, with the advent of Calipso, the possibility of assessing and correcting the errors made in transport due to the vertical variability of the aerosols and the existence of plumes which may advect down into the Planetary Boundary Layer (PBL) can begin.

Finally, to complete the loop and connect the optical scattering data to PM2.5, it is important to assess the correlation between near surface optical backscatter and PM2.5. In particular, we see that for optical backscatter data obtained with heights under 100 meters, an excellent correlation is seen but for heights above 200 meters, a significant degradation in the regression is seen for high PM2.5 concentrations. These results provide us with the necessary spatial resolution needed to track PM2.5 from space using Calipso.

2. Plume Identification

To assess the need for lidar measurements to predict PM2.5, we first examine the cases where large plumes were predicted to affect air quality in New York City. A large-scale event of free tropospheric transport of dust particles that occurred in April of 2006 provided an excellent opportunity to gain new insight on the influence of such lofted dust plume layers. In support of this prediction, the CCNY lidar system observed some heavy transport activity over its location, which contributed to large aerosol loadings in the troposphere. Fig. 1 represents a 48-hour aerosol trajectory forecast with modeled winds and precipitation, showing that those large aerosol loadings were also captured by the MODIS derived AOD (Aerosol Optical Depth) across the northeast.

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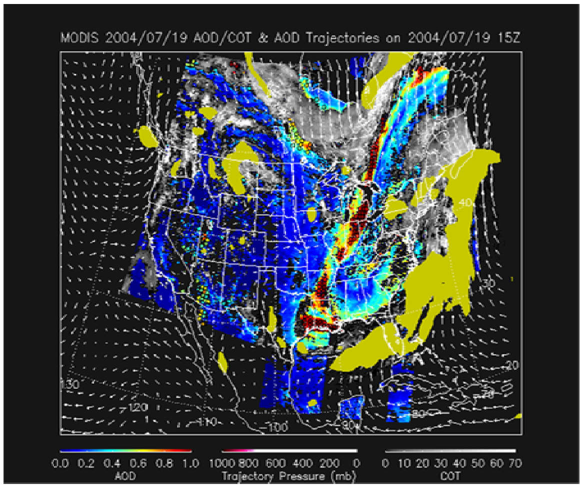

Fig.1. 48 hour Trajectory Forecast for high MODIS aerosol optical depth, τ_a>0.4 (April 19, 2006)

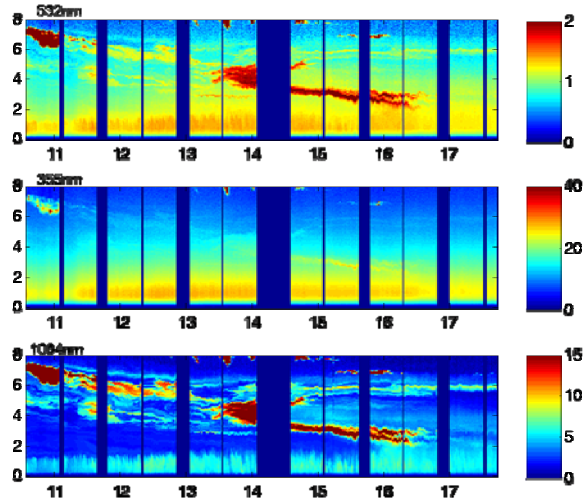

Fig.2. Range corrected three wavelengths Lidar signal on April 19, 2006 at CCNY (a) Visible at 532nm, (b) UV at 355nm, and (c) IR at 532nm

On April 19, 2006, a high-pressure system with aerosol optical thickness greater than 0.4 advected from the north (Quebec, Canada) towards NYC, as indicated in the IDEA forecast trajectory.

However, we see in figure 2, backscatter measurements made by the CCNY lidar system on April 19, 2006 clearly illustrates a complex vertical structure of the observed atmosphere over CCNY which is consistent with upper air meteorological soundings (figure 2d: complement of NOAA Air Resources Laboratory HYSPLIT model), and with the majority of the optical depth carried in aloft plumes. In addition, we observe a well-mixed PBL layer in the CCNY Lidar image, indicating a PBL height of approximately 1 km in the morning with a gradual increase to about 2 km during the afternoon, allowing for an interaction between the PBL and the aloft plume. Upper air soundings provide a means to confirm the detailed vertical structure of the atmosphere as observed by the CCNY Lidar system. Shortly after 14:00 EDT, the dust cloud separated into an aloft plume, and a descending plume which advected into the boundary layer. The incursion of the transported aerosol plume into the boundary layer was clearly a cause for air quality concerns.

3. Plume Properties

Since a plume incursion into the PBL was evident, it would be appropriate to examine the influence of these incursions on near surface air quality. Interestingly, when we examined the levels of particulate matter, a very small increase was seen in the PM2.5 mass loading but as indicated in figure 3, the small PM2.5 loading occurred simultaneously with a distinctively large increase in the PM10 mass loadings during the incursion period, which is consistent with the PBL. This finding is consistent with the hypothesis that the plume is comprised mainly of large dust particulates undergoing large-scale transport from remote sources. Furthermore, we have analyzed coincident data obtained from the CCNY Mobil Lidar stationed at Princeton University in New Jersey, which is downwind from New York City, and indeed, captured the same transport event seen over NYC.

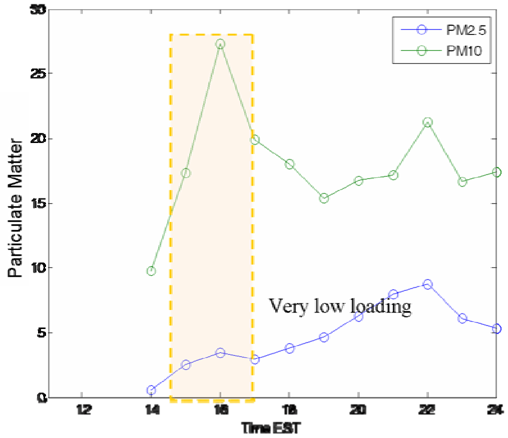

Fig.3 PM2.5 and PM10 Surface Loadings

To test the dust particulate hypothesis, we have processed our lidar signals at both the 532nm and 1064nm channels in order to derive the wavelength dependence of the backscatter within the plume. To obtain the absolute backscatter on the 532nm channel, we use the traditional Frenauld processing scheme, where the far end calibration is determined by the molecular profile while the 1064nm channel is calibrated using a cirrus cloud feature within the scene. This approach is similar to that described in Schneider (2002) where it is assumed that the cloud backscatter from cirrus clouds between the 532nm and 1064 nm channels is to a good approximation a white scatterer independent of wavelength so that the backscatter color ratio is near unity. In this case, an accurate measurement of the backscatter below cloud base at the 532nm channel can be used to obtain the callibration of the 1064 channel. While the main idea is the same, the approach in Schneider (2002) is somewhat different technically, than our approach and does not discuss the uncertainties inherent in the calibration scheme, due to uncertainties in the 532nm channel; therefore, we briefly describe it below

1. To begin, a reference height is chosen, which is sufficiently clear, based on match-ups with the molecular only signal obtained from radiosondes (see Figure 2).

2. Given this reference layer, we then "forward" integrate the Frenauld equation from the reference layer through the cloud base using a large range of viable parameter values for both the reference aerosol lidar ratio (eqn. 1) and aerosol S ratio (eqn. 2) values.

$$1 \le R_{532}(z_{ref}) \le 1.2 \qquad (1)$$

$$(30 \le S_{532} \le 70) \qquad (2)$$

3. Since it is well known that the forward integration method may become unstable for sufficiently large optical depths, we utilize an iterative scheme for the integration of the Frenauld equation, which allows us to ensure stability by calculating the solution at different iteration orders and only penetrating into the cloud when the 10th iterate is the convergent solution.

4. For all convergent solutions, we then calculate the mean and standard deviation of the backscatter retrieval over all lidar parameter sets, to identify the optimal depth into the cloud that maximizes the backscatter retrieval, while maintaining a sufficiently small retrieval uncertainty.

5. Once the optimal altitude is determined, we may easily obtain the calibration constant as

$$C_{1064} = \frac{\overline{P}(z_c)}{A+B} \qquad (3)$$

where:

A = $\beta_a(z_c\lambda(532))$

B = $\beta_m(z_c\lambda(1064))T_a^2(R,\lambda(1064))T_m^2(R,\lambda(1064))$

$\overline{P}(z)$ **:** received backscatter signal (1064) from altitude z.

Once the 1064nm calibratation is performed, and the backscatter signal is constructed, the vertical estimate of the cloud plume angstrom coefficient can be obtained, as shown in figure 4 for the 16:00 EDT time slot. The Angstrom exponent was calculated from the backscatter coefficients at 532nm and 1064 nm wavelengths, with the only assumption of the wavelength dependence of the backscatter coefficients (Schneider 2002) and the results are displayed in figure 4.

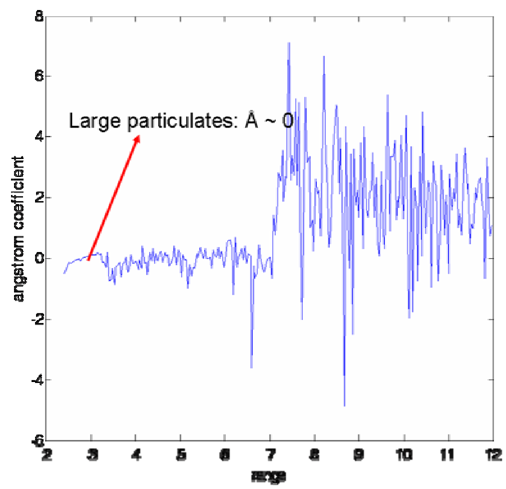

Fig. 4. Vertical estimate of angstrom coefficients for April 19, 2006 at 16:00 EDT

The small values of the angstrom coefficient insure that the particles in the plume are consistent with dust.

Finally, once we have identified the altitude of the observed plumes, further analysis based on extended HYSPLIT backwards trajectories (13 days) confirmed that the observed dust plume seen by CCNY Lidar on April 19 was in fact transported from dust storms originating from the Gobi Desert in Asia and the trajectory is also consistent with the wind patterns on that day in question, and no rainfall was reported along the trajectory path.

4. Correlation of Lidar Backscatter to PM2.5

These observations show an apparent need for accurate measurements of optical data within the PBL. However, often the PBL is not well mixed but undergoes significant dynamic flux as seen in figure 6. Unfortunately, conventional Lidars have problems seeing near the surface; consequently, not much structure is seen in the PBL of the CCNY Lidar image. To compensate for such drawbacks, we have in operation, a Continuous Eye Safe Ceilometer (single wavelength ~905nm) which acts as a lidar for near surface distances, and its precision makes it ideal for vertical information on near surface (low altitude) aerosols.

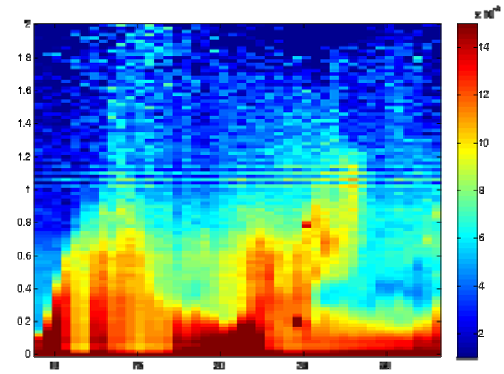

Fig.6. CCNY Eye Safe Ceilometer backscatter April 19, 2006.

Using near field Ceilometer backscatter measurements, range confinements less than 80m consistently show correlations in the order of (70-90) percent agreement of backscatter to PM2.5. However, shifting this window to a higher altitude within the boundary layer (220-280m), we observe 20% degradation in the backscatter-PM2.5 correlation; particularly for high PM2.5 loadings (figure 7). This result provides an understanding of the vertical level and resolution to assess and validate PM2.5 from space borne lidars. Figure 8 shows the degrading of the near surface Ceilometer backscatter-PM2.5 correlation as we deviate from the surface.

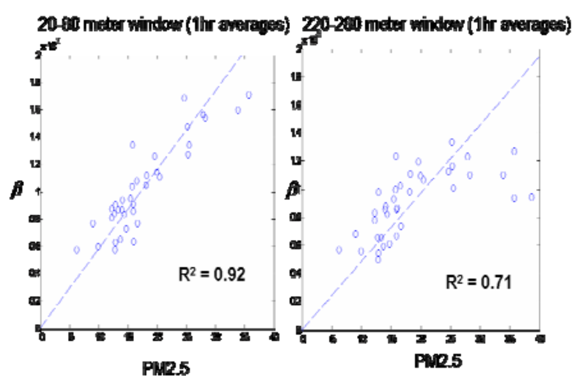

Fig.7. (a) 20-80m window (1hr average) Ceilometer near surface Backscatter-PM2.5 correlation, (b) 220-280m window (1hr average), Ceilometer Backscatter-PM2.5 correlation.

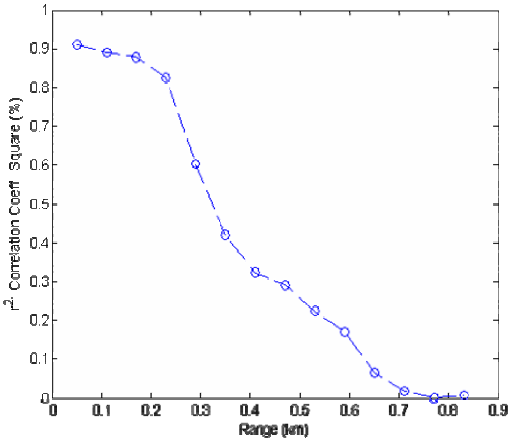

Fig.8. Variation of Ceilometer's near-surface backscatter-PM2.5 correlation coefficients with altitude

Although results show that the Ceilometer is a useful tool to investigate layers of the lower atmosphere, i.e. near surface, and its particulate matter contents (particularly PM2.5), there is still need to investigate whether such patterns are seasonal or weather dependent. There is also a need to evaluate the spatial distribution of particulate matter within the Planetary Boundary Layer.

3. CONCLUSIONS

Predicting air quality requires accurate satellite measurements of aerosols. However, column optical depth is not sufficient to predict PM2.5. In particular, passive satellites cannot determine the vertical location of aerosols and therefore the connection with air pollution is poor. Furthermore, the vertical structure of aerosols is very important in assessing transport events and how they mix with the PBL as demonstrated. These plumes were identifiable as dust plumes from their influence on the PM10 mass load in comparison to the almost unnoticeable change in the PM2.5 mass In particular; we see that incursions of the dust plumes into the planetary boundary layer coincide well with spikes in observed surface PM10.

The need for vertical information and plume detection has led to the launch of the CALIPSO space borne Lidar system, which can in principle obtain surface level aerosol backscatter; however, the relationship between the optical backscatter and the PM2.5 mass is not simple. To investigate this, we show using near field Ceilometer measurements that, unlike column aerosol measurements, near surface backscatter measurements within 100 meters of the surface accurately correlate to PM2.5 but by 300 meters we observe a significant degradation in the correlations. This result gives practical guidance on the vertical resolution needed to process CALIPSO data in support of surface aerosol loading.

6. REFERENCES

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