SMOKE AND DUST PLUME OBSERVATIONS BY A MIE-RAMAN LIDAR, SUNPHOTOMETER AND SATELLITE IN THE NORTHEAST US

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ABSTRACT

In this presentation, we analyze the smoke and dust plumes optical characteristics and long-distance transport with a ground-based multi-wavelength Mie-Raman lidar, sunphotometer and satellite observations in New York City (NYC, 40.821ºN, 73.949ºW). Vertical profiles of aerosol plume extinction coefficients and ångstrom exponents are derived from the combination of multi-wavelength lidar and sunphotometer measurements. Aloft smoke plumes from Idaho/Montana forest fires were measured at 2~8 km altitude on August 14~15, 2007 with aerosol optical depths (AOD) of 0.6~0.8 at 500 nm and high Angstrom exponents (~1.8). On Mar.19, 2010, the aloft Asian-dust plumes appeared at 3~9 km altitude with the small ångstrom exponent (<1.0) and AOD of 0.1~0.4 at 500nm. Their sources and transport pathways to the US east coast are illustrated by the satellite MODIS and CALIOP/CALIPSO imageries as well as the air backward trajectory analysis. We further illustrate the potential influences of these aloft plumes on the local air quality and aerosol optical characteristics.

1. INTRODUCTION

Forest-fires and dust storms often inject large amount of aerosol particles into atmosphere affecting climate radiation, air quality and visibility in the regional or continental scale via long-distance transport [1, 2]. The occurrence, transport and column optical properties of smoke/dust plumes have been extensively investigated by satellite-borne radiometers. In particular, range-resolved lidar observations can reveal the temporal-spatial structures of aerosol plumes and their mixing down into PBL [3]. In this study, profiling vertical distribution and characterizing optical properties of smoke and Asian dust plumes are performed with complementary measurements from a multiple-wavelength lidar, AERONET-sunphotometer and satellite sensors in NYC located in the eastern US to obtain accurate classification and to assess their dynamics with regard to surface air quality.

2. INSTRUMENTS AND METHODOLOGY

A ground-based multi-wavelength elastic-Raman scattering lidar has been operating in New York City (NYC) since March, 2006 [4]. A Nd:YAG laser (Spectra-physics Quanta-Ray 320) emits the laser beams at 1064-, 532-, and 355-nm with a repetition rate of 30 Hz. Three elastic-scattering and two Raman-scattering returns by nitrogen and water vapor molecules excited by 355-nm are collected by a receiver telescope (Ø50.8 cm). A Si-APD (Perkin-Elmer C30956E) is used to detect the 1064-nm signal while the Hamamatsu PMTs are used at the 355~532 nm wavelength. The signals are acquired by a LICEL transient recorder (TR40-160, 12-bit 40-MHz ADC), and full return signals are detected with the starting altitude 0.5 km. In addition, an AERONET Cimel sun/sky radiometer is deployed at the lidar site to measure aerosol optical depths, microphysics parameters (volume size distribution and refractive index), fine- and coarse-mode-AOD [5]. With the spheroid-shape assumption on the dust aerosol, the linear depolarization ratio of lidar can be calculated with the above microphysical parameters [6]. Meanwhile, a standard surface air quality monitoring station is deployed for $PM_{2.5}$ mass concentration nearby the lidar site (~100 m away) by New York State Department of Environment Conservation. Due to general SNR limit of Raman-channel in the daytime, we derive aerosol extinction profiles from the elastic lidar returns by using sunphotometer-measured AOD to constrain lidar-ratio, and then ångstrom exponent profile is derived to discriminate aerosol types within the plume [7]. The aerosol contribution in the lidar overlap region (<0.5-km) is corrected by using the ceilometer-measured backscatter profile near the surface when available or by extending a constant aerosol extinction at 0.5 km to the surface.

3. OBSERVATION RESULTS

3.1 Forest-fire smoke plumes on Aug.14-15, 2007

A heavy smoke intrusion was observed by the CCNY-lidar on Aug. 14-15, 2007. Figure 1 (a) shows the time-height cross section of the range-corrected lidar backscatter returns at 1064-nm on Aug. 14, 2007. The colorbar indicates the returns intensities with the warm color (yellow and red) representing aerosol plume layer, blue for the clean air, and dark red for cloud. The Lidar imagery shows a dense aerosol plume layer at 6~8 km altitude arriving at ~16:00 pm (local time, LT) along with some light aerosol layers before 16:00 LT. Then on Aug.15, 2007 in Fig.1 (b), two separate dense plume layers were located at 2~4 km and 4.5~6.5 km altitude, respectively. By the afternoon of August 15, the lower aloft smoke plumes appeared to be mixing down into the planetary boundary layer (PBL) and even into the surface layer, possibly contributing to significant increase in the surface $PM_{2.5}$ loadings. To quantitatively analyze and characterize the event, we first plot the vertical distribution of aerosol extinction coefficients and Angstrom exponents at 1064-532 nm on Aug.14-15. In Fig.1(c) on Aug.14, large Angstrom exponents of 1.7~2.0 in the aerosol plume layer at 6.0-8.0 km indicate that the plumes are fine mode dominated. The column averaged lidar-ratios were then obtained with values of 69±9 sr, 42±2 sr, and 63±1 sr at 532-, 1064- and 355-nm, respectively. On Aug.15 in Fig.1 (d), the upper layer of smoke at 4.0~6 km has the extinction peak value of 0.3 km^{-1} at 532-nm with Angstrom exponent close to 2.0. Aerosol multi-layer structure can be identified but the stability of the Angstrom exponent implies homogeneous particle properties

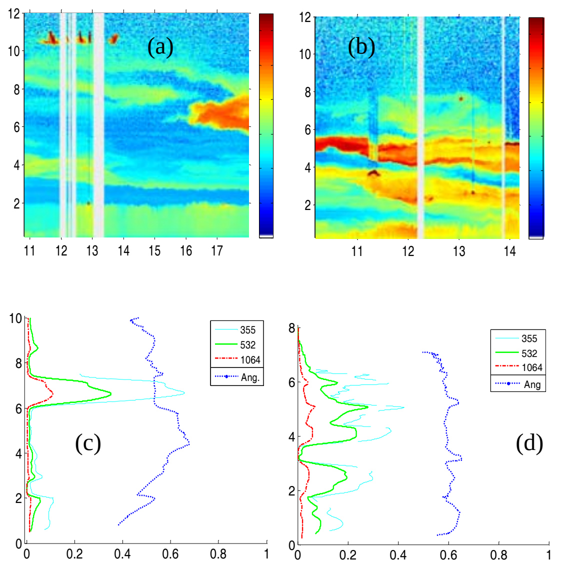

Figure 1. Time-height cross section of range-corrected lidar returns at 1064-nm on (a) Aug. 14, (b) Aug. 15, 2007; aerosol extinction and Angstrom exponent profiles at (c) 16:30-16:45, Aug.14, (d) 13:35-13:50, Aug.15, 2007.

Figure 2 shows the aerosol volume size distribution from AERONET-sunphotometer inversions on Aug.14, 2007. Clearly, the aerosols become fine-mode dominated after 16:00 LT, which is quite consistent with the lidar observed smoke plume intrusions in time (Fig.1a). In addition, sunphotometer-measured aerosol column optical properties (level-1.5 after cloud screening) show the total AOD sharply increased from 0.2 to 0.6 at ~16:00 LT on Aug.14. In particular, the Angstrom exponents increase from 1.5 to 1.8 by late afternoon on Aug. 14 indicating an increase of fine mode particulates. Further, a large fraction of AOD is from the fine-mode particles which is consistent with the aerosol fine mode dominated volume size distribution from sunphotometer inversion at 16:40 pm LT. Aerosol single-scattering albedo (SSA) from SP-inversion data is 0.85 at wavelength 675-nm, highly suggestive of absorbing aerosols. With the characteristics of high Angstrom exponent, fine-mode and large absorption, we can definitively classify these plume layers as smoke particles. On Aug.15, the column AODs remained at a high level with values of 0.6~0.8 at wavelength 500-nm, and the Angstrom coefficients remained consistently high, indicating the same type of transported particulates. These results are also in good quantitative agreement with the CCNY-lidar retrievals.

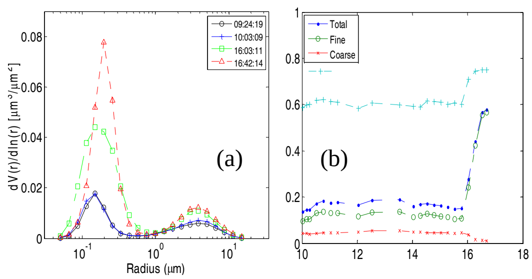

Figure 2. (a) Aerosol particle size distribution, (b) aerosol optical depth and Angstrom exponent observed by AERONET sunphotometer on Aug.14, 2007.

In addition, satellite-borne MODIS sensor on NASA's Aqua observations detected active fire in US Idaho, Montana and Wyoming states and the fire-smokes spread northeasterly and then moved easterly across the plains at the foothills of the Northern Rocky Mountains as far away as the US east coast at 2:00 p.m. local time (US Mountain Daylight Time) on Aug.13, 2007. The NOAA-HYSPLIT model apparently showed that the air-mass traveled from Idaho/Montana forest fire area to the lidar site for about 40-hour. Figure 3 (a) gives the MODIS/Aqua level-2 aerosol optical depth at 550-nm over the US continent on Aug.15, 2007; and the lines-N1, D1 and D2 are the CALIPSO ground-tracks (night and day) in the US east coast. The red-pattern with high aerosol optical depths (AOD>=1) indicates the fire-smoke source region in Idaho/Montana state. In the US east coast or even over the ocean, the smoke stripes can be seen with the mid-level AOD in magnitude. Figure 3 (b)-(c) gives the total attenuated backscatter coefficients at 532-nm measured by CALIPSO in the early-morning (night) and noon (day) in the US east coast. First, Fig.3 (b) shows the smoke plumes located at 5~7 km altitude, which is similar as the CCNY-lidar observation (Fig.1b) except that the CCNY-lidar observed another lower layer at 2-4 km altitude. Second, for the night orbit N1 (early morning, ~3 am local time on Aug.15) in the US east coast, Fig.3(c) clearly shows the dense smoke plume distribution at 4~6 km altitude over 45º N to 30º N latitudes. We further plot the corresponding vertical-feature-mask product (VFM level-2 version-3.01) in Fig.3 (d) to see the classification of aerosol/cloud and aerosol subtypes. Mostly, CALIPSO VFM products properly classify the smoke layer as aerosol and further classify them as smoke. However, for some highly dense layers, they are misclassified as clouds, and occasionally some plume layers are misclassified as polluted dust.

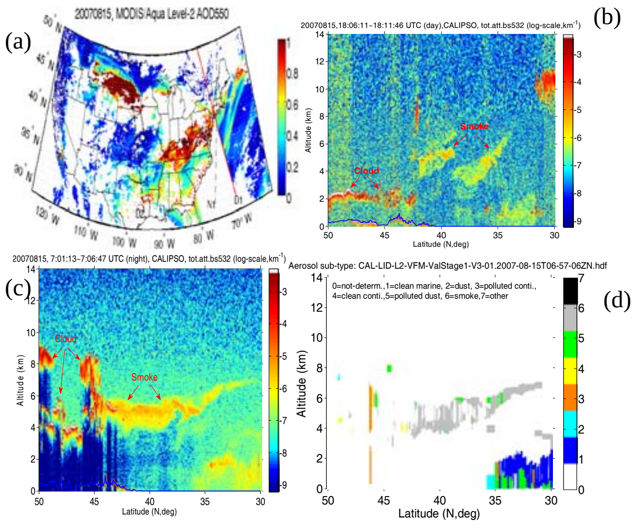

Figure 3. (a) MODIS/Aqua level-2 aerosol optical depth at 550 nm on 15 August, 2007 (Lines-D1, D2 and N1 are the CALISPO ground-tracks). Attenuated backscatter coefficients of CALIPSO at 532-nm at (b) 7:01:12-7:06:47 UTC (track-N1 night), (c) 18:06:11-18:11:45 UTC (track-D1 day), (d) aerosol subtypes corresponding to (c).

3.2 Asian-dust plumes on Mar.19, 2010

Fig. 4 shows a dust event observed by CCNY-lidar on Mar. 19, 2010. The range-corrected lidar returns show the thick plume layers at 3~9 km altitude. Aerosol extinction-related ångstrom exponents show the smaller values in these aerosol layers indicating the coarse-mode dominated. The SP-AOD constrained lidar ratios are 52 ± 5 sr at 532-nm and 57 ± 3 sr at 1064-nm, respectively. The time-height cross-section of aerosol extinctions coefficients and Angstrom exponents are derived with 15-min average, which indicate the dust aerosol layers having the Angstrom exponents of 0.5~1.0. Meanwhile, the AERONET-SP observations show that the total AODs vary from 0.4 to 0.15 with the column Angstrom exponents of 0.7~1.0; and the coarse-mode fractions of AOD are in the range of 0.6~0.4. Additionally, the linear depolarization ratios of lidar are estimated to be 0.135 from the above SP-inversions. The properties of coarse-mode and non-sphere in shape imply that these aloft plumes layers are likely the dust particles.

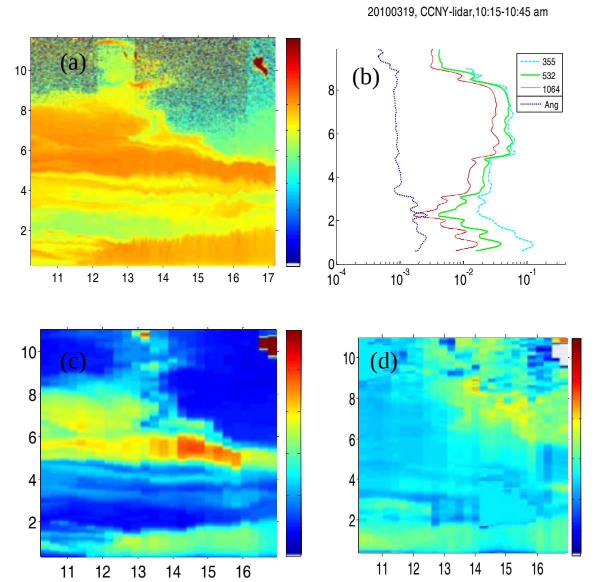

Figure 4. (a) Range-square corrected lidar returns at 1064-nm; (b) aerosol extinction and Angstrom exponent profiles at 10:15-10:45 am; time-height cross sections of (c) aerosol extinction and (d) Agstgrom exponent on Mar.19, 2010 (15-min ave).

With the NOAA-HYSPLIT model analysis, these aloft aerosol plumes are demonstrated to originate from the Taklamakan/Gobi deserts in the northwest China. The MODIS level-1B image captured this dust-storm episode near the source region on March. 12, 2010. The MODIS 8-day average of AOD and SPRINTARS model clearly show the transpacific transport pathway of Asian dust to the eastern US for this case. It takes about 5~6 days to arrive the eastern US from the dust source regions at the altitudes of 6 km, 7 km and 8 km as shown in Fig. 5. We also plot the CALIPSO ground-tracks along the air trajectories on the different days (the cross-line in Fig.5). To see the dust aerosol variation via long-distance transport, the multi-orbit observations of CALIPSO are illustrated in Fig. 5, where only the nighttime data under the clear skies are chosen in order to have more accurate aerosol/cloud classification with high SNR. First, the aloft dust or polluted-dust layers are discriminated by the CALIPSO vertical-feature product, e. g. aerosol-cloud and aerosol-subtypes products, and show the spatial height distribution at 4~10 km. Closer to dust source region, larger optical depths and higher depolarization ratios occur in the dust layers. The height distribution of dust plumes shows good consistency between the CCNY-lidar and CALIPSO observations. However, we note that large uncertainties may exist for the dust optical depths due to the potential retrieval errors and misclassifications.

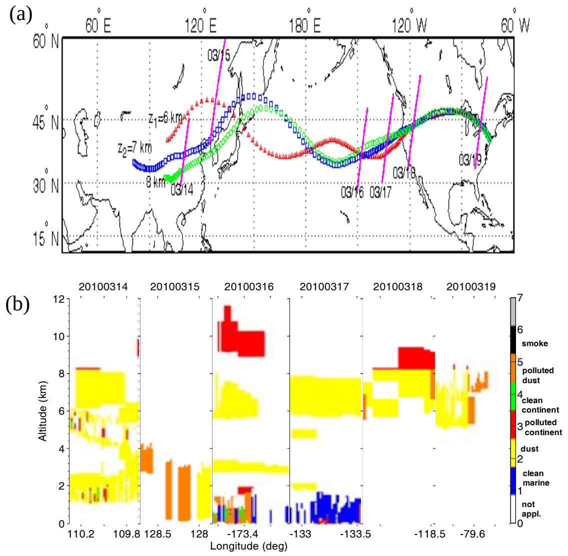

Figure 5. (a) Air backward trajectories at 6-km, 7-km and 8-km altitude by NOAA-HYSPLIT and CALIPSO tracks (cross lines) during Mar. 14-19, 2010; and CALIPSO-level-2 aerosol-layer products: (b) aerosol-subtype.

3.3 Aerosol plumes influences on the local air

Our regular lidar observations frequently illustrate the aloft smoke plumes intrusions in summer, and Asian-dust layers in spring. They not only modify the local aerosol optical properties, but also potentially affect the local air quality by subsidence into the PBL and surface under the suitable weather conditions. We analyzed AERONET level-2 quality-assured data over Dec. 2001 to Feb. 2009 at the CCNY-site. Generally the AOD at 500-nm shows the highest value in summer and lowest in winter, however, the Angstrom exponent and fine-mode-fraction of AOD show the smaller value in spring. In addition, the effective radius of aerosol is bigger in spring than summer. Overall, the aerosols show the more coarse-mode in spring but fine-mode dominance in summer. These significant seasonal differences are probably associated to the springtime Asian dust and summertime smoke-plumes intrusions to NYC area. We also investigate the connection of surface $PM_{2.5}$ measurements to column AOD, which show the dramatically different regression relationships under the aloft aerosol plumes days and clear days.

4. SUMMARY

We have analyzed the smoke and dust plumes optical properties, long-range transport and their potential influences on the local aerosol with the synergy of ground-based multi-wavelength lidar, sunphotometer and satellite observations. The multi-wavelength aerosol extinction profiles are derived from the lidar-sunphotometer combinations, and hence the Angstrom exponent profile is calculated and used to discriminate the smoke/dust particles. The smoke plumes from Montana/Idaho forest fire show the high AODs of 0.6-0.8 at 500-nm with large Angstrom exponents of ~1.8, while the Asian dust plumes on March 19, 2010 indicates the column AOD at 0.1~0.4 at 500-nm but with the small Angstrom exponents (<1.0) implying the coarse-mode dominance. The satellite observations by MODIS and CALIPSO and air backward trajectories by NOAA-HYSPLIT clearly show the transport pathway of these plumes to the eastern US. Multi-year statistics show significant monthly or seasonal differences of aerosol optical-microphysical properties, which are probably associated to the Asian dust and smoke-plumes intrusions to NYC area. In addition, we investigate the aloft plumes influences on the connection of surface $PM_{2.5}$ measurements to column AOD.

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