Characterizing smoke optical properties, transport and mixture with urban aerosols with lidar and AERONET sunphotometer observations in New York City Area

Yonghua Wu [1, 2*], Thomas Ely[1, 2], Kolawole Owoeye[1, 2], Dingdong Li[1], Fred Moshary[1, 2]

[1] City College of New York (CCNY), New York, NY 10031, USA, [*] *Email: yhwu@ccny.cuny.edu*

[2] NOAA–Cooperative Science Center for Earth System Sciences and Remote Sensing Technologies

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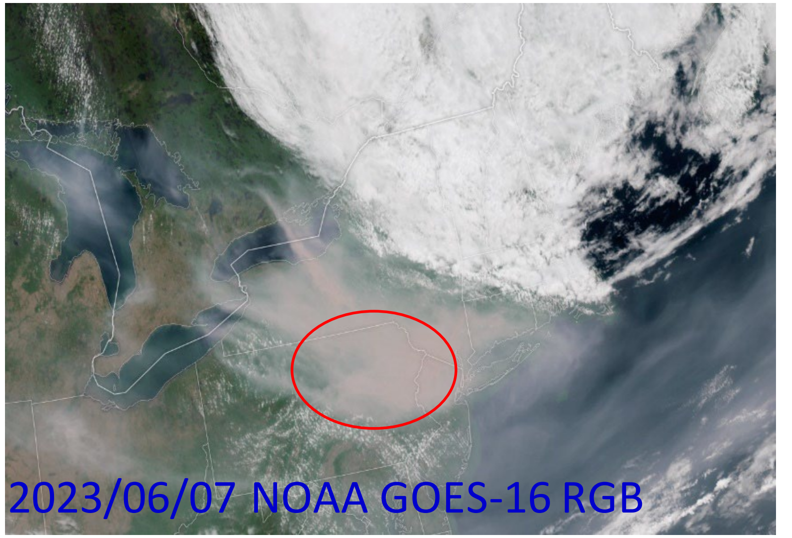
1. Motivation

- Wildfires show increase trends with climate change; smoke plume can make impacts on air quality (AQ) in regional scale.
- Smoke plume transports have been observed in NYC area; NASA-AERONET, lidar, satellite, NOAA-HRRR smoke model, …
- How do the transported smoke plumes interact with urban PBL and and urban local emissions?
- How much do they contribute to ground-level AQ ($PM_{2.5}$,OC,BC,O_3)?



This study will present the case analysis of smoke plume transport observed by AERONET sunphotometers ad lidar in NYC area:

- Characterize the aged/transported smoke optical properties;
- Discriminate the aged smoke aerosols from local urban aerosols;
- Demonstrate the smoke plumes mixing into urban PBL, and their potential impacts on the AOD-PM2.5 relationship, and ground AQ ($PM_{2.5}$, OC, BC, particle size, O_3).

2. Ground Remote Sensing and In-situ Observations at CCNY

CCNY site (40.821N/73.949W in NYC urban area):

- **AERONET Cimel Sunphotometer since Dec. 2001 (#237, #1040)**

- **Elastic-Raman Lidar: λ=1064-532-355 nm, 3-elastic + 2-Raman**
  Require a constant of lidar-ratio (aerosol ext. to backscatter ratio)*,
  AERONET-AODs provide good constraints on the lidar-ratio;

- **Ozone UV-DIAL: λ=287.2-299.1nm, O_3 profile (0.25~8 km), a part of NASA-TOLNet**
  (a constant of lidar-ratio for aerosol ext./bs. retrieval, and O_3 corr.)

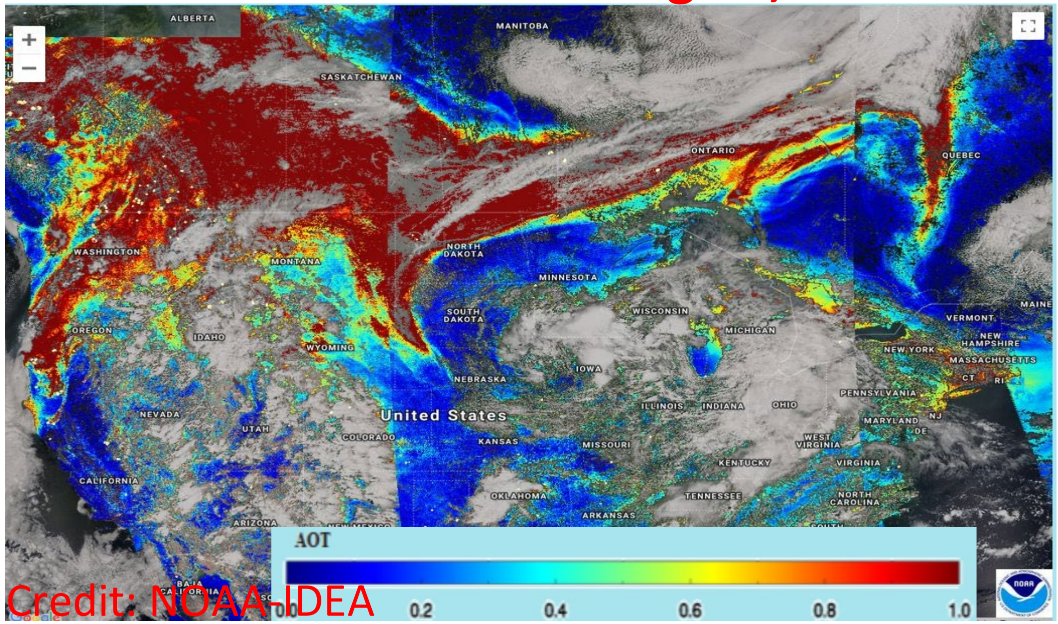
- Ceilometer (Lufft CHM15K, CL51 and 31): MLH, cloud base,
- Doppler Wind lidar (Windcube 200S): 3D winds
- MWR: T, RH profiles,
- NYSDEC Air Quality Station at CCNY: $PM_{2.5}$, O_3, CO(NYSDEC), OPC, NO_2, CO2/H2O (CCNY), Black Carbon (LDEO/CU).

AERONET other sites in NYC region: Flushing (QC), LISCO, BNL, …

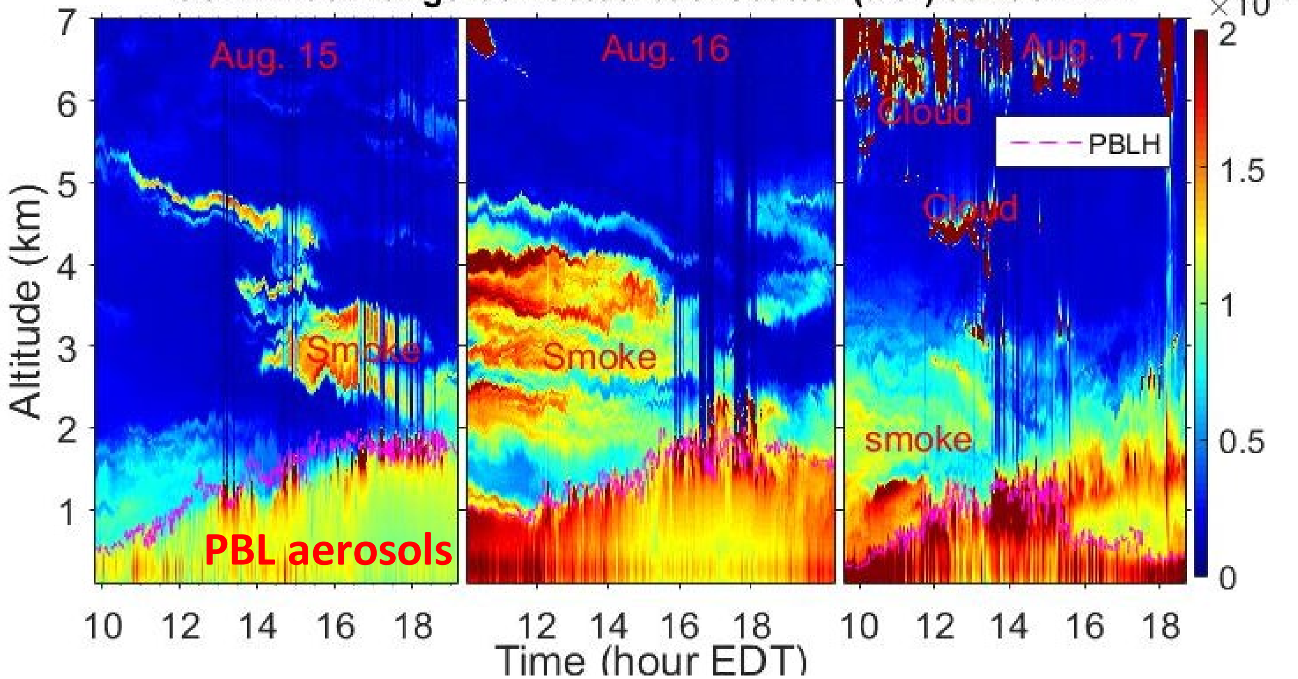
* Ali H Omar, et al., 2005, Development of global aerosol models using cluster analysis of Aerosol Robotic Network (AERONET) measurements, JGR, 110 (D10), D10S1420

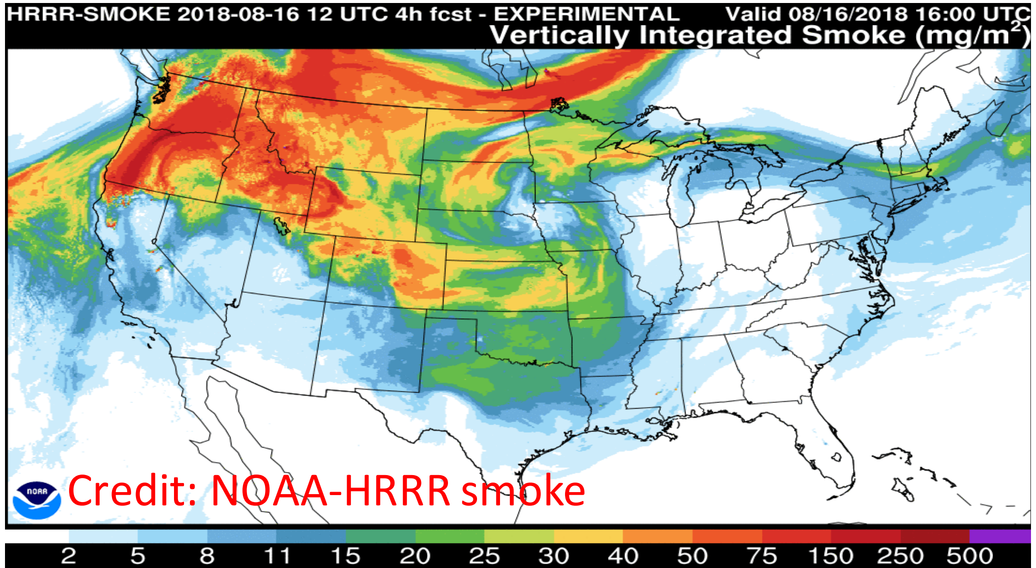
3. Results: Smoke plumes transported from the Pacific NW Wildfires

VIIRS-AOD on Aug.16, 2018



CCNY-lidar range-corrected backscatter (a.u.) at 1064-nm

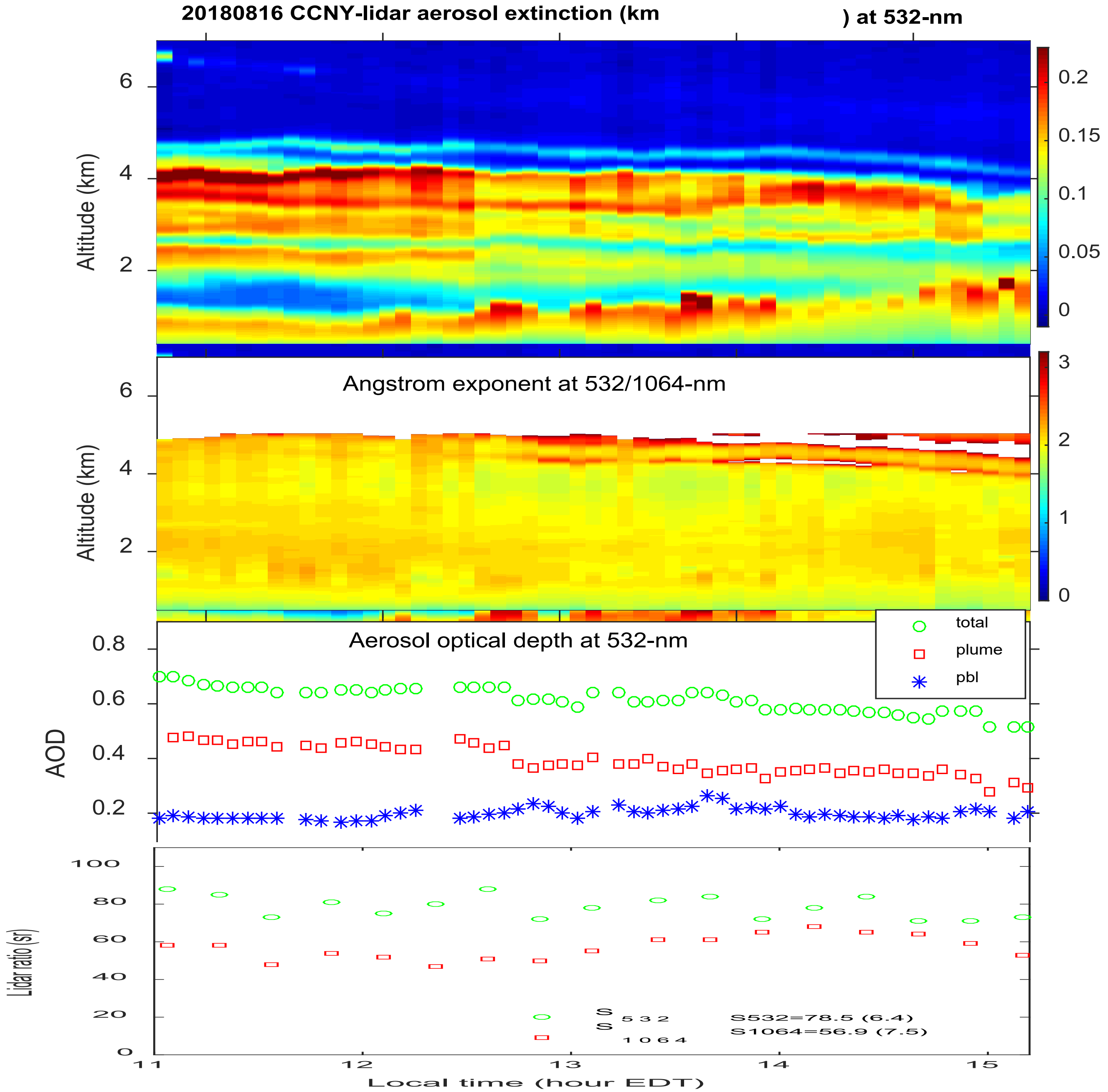


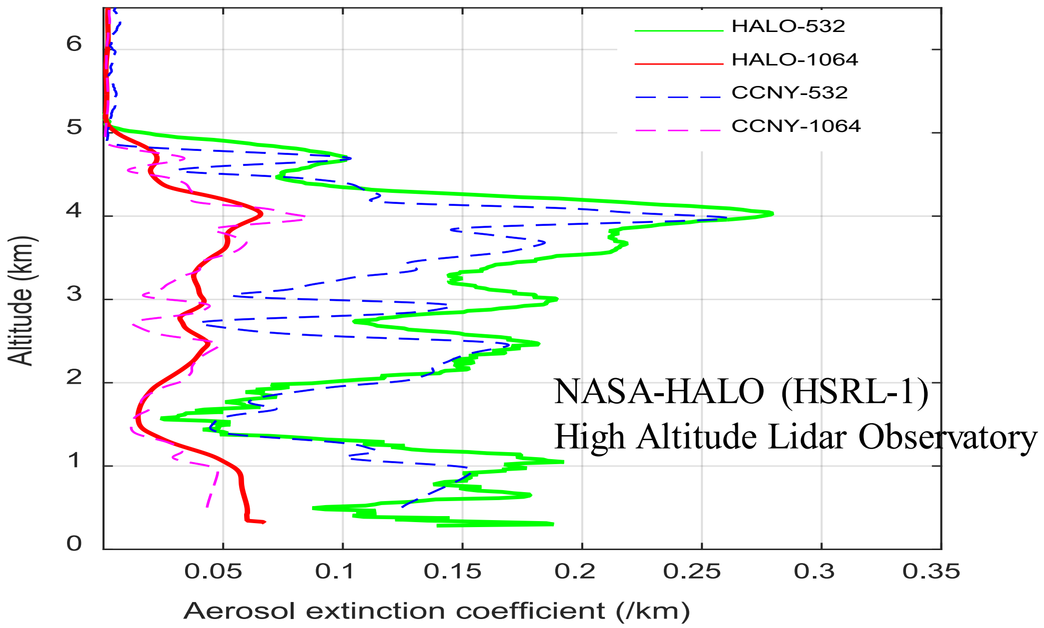


Questions:

- Do these dense smoke plumes affect the ground air quality in NYC?
  --vertical or range-resolved distribution
- How much the aged smoke contribute to ground air quality ($PM_{2.5}$)?
  --discrimination of smoke and urban aerosols
- How well the AQ forecast model capture them?
  -- observation comparison near the ground and vertical distribution.

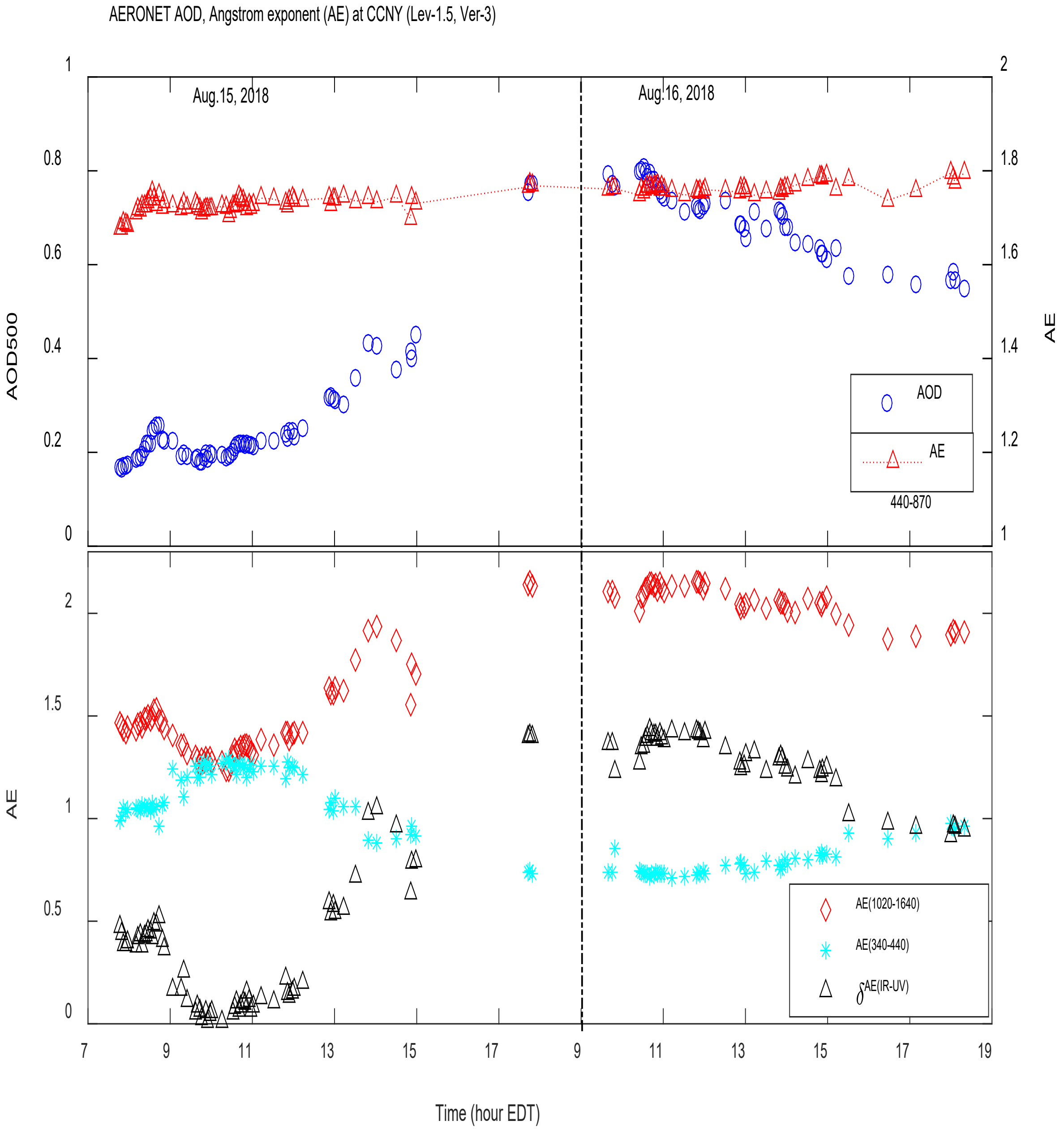
Smoke optical properties and vertical distribution observed by CCNY-lidar

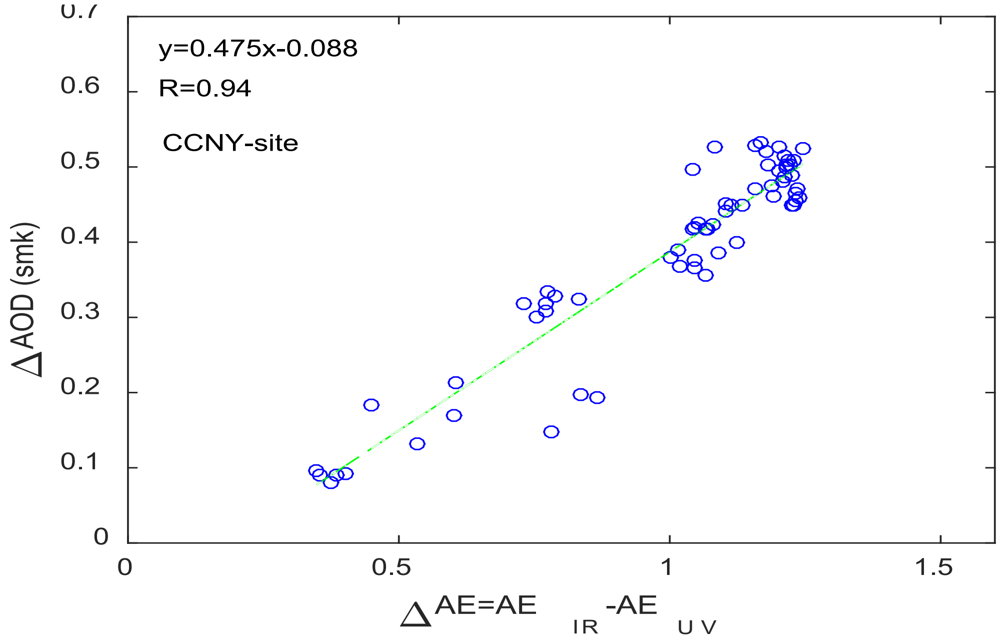




- Vertical profiles of aerosol extinction/bs profiles constrained by AERONET-AOD under the clear sky;
- Large Angstrom exponent(AE) or v: $\alpha(\lambda) \sim \lambda^{-v}$
  - fine mode particles dominant
- Aloft smoke plume contribution to total AOD: ~ 70%
- Large lidar-ratio(532)=78.5 +/- 6.4 sr for smoke (but 50-sr for urban aerosols)

AERONET-CCNY site: Aerosol optical properties, AOD, AE (Vis-UV-IR)

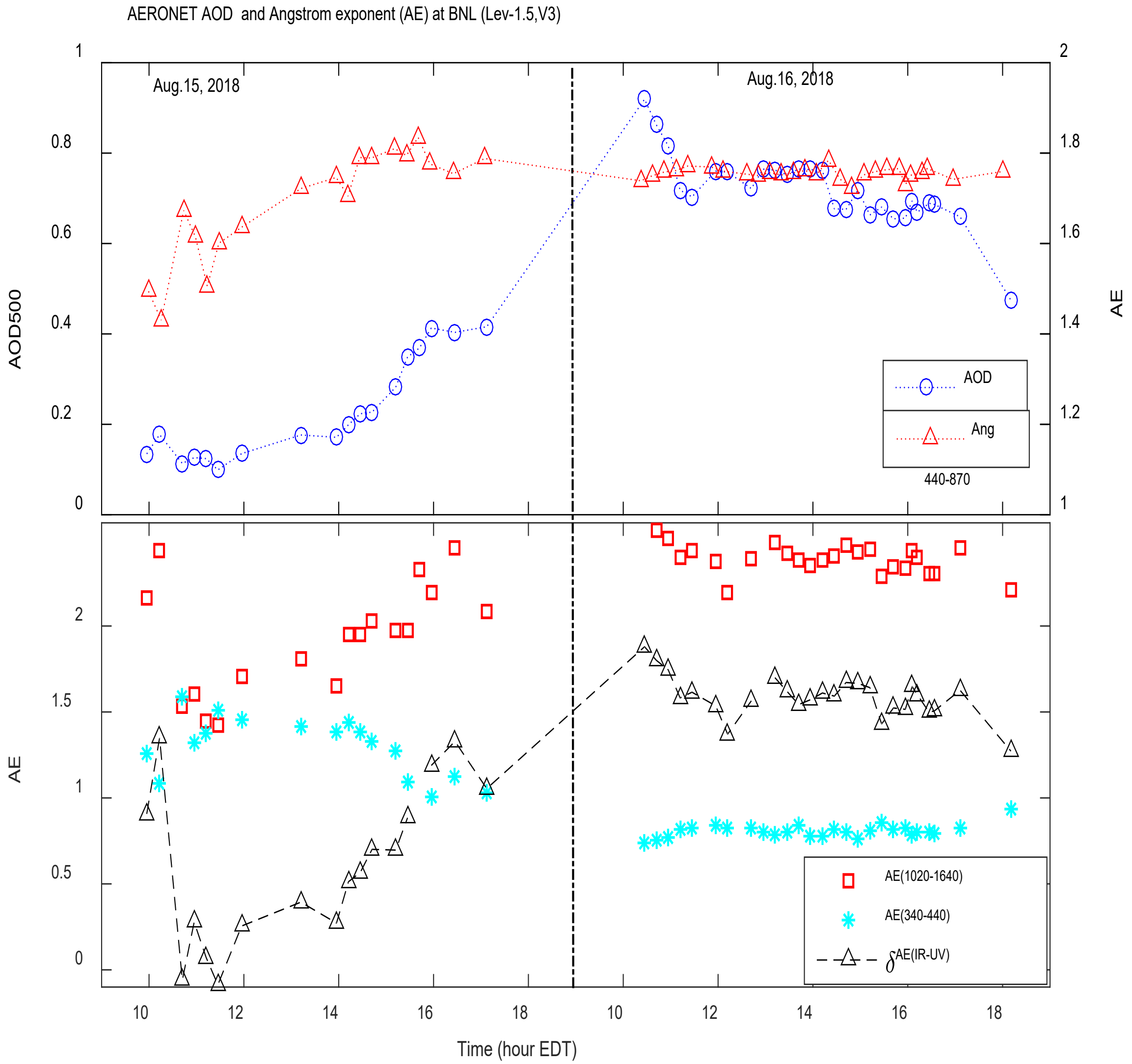


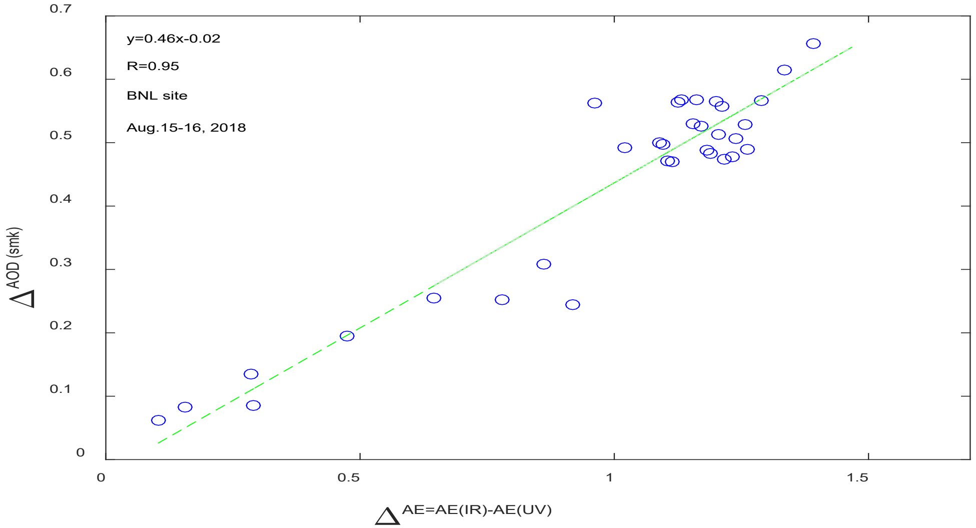


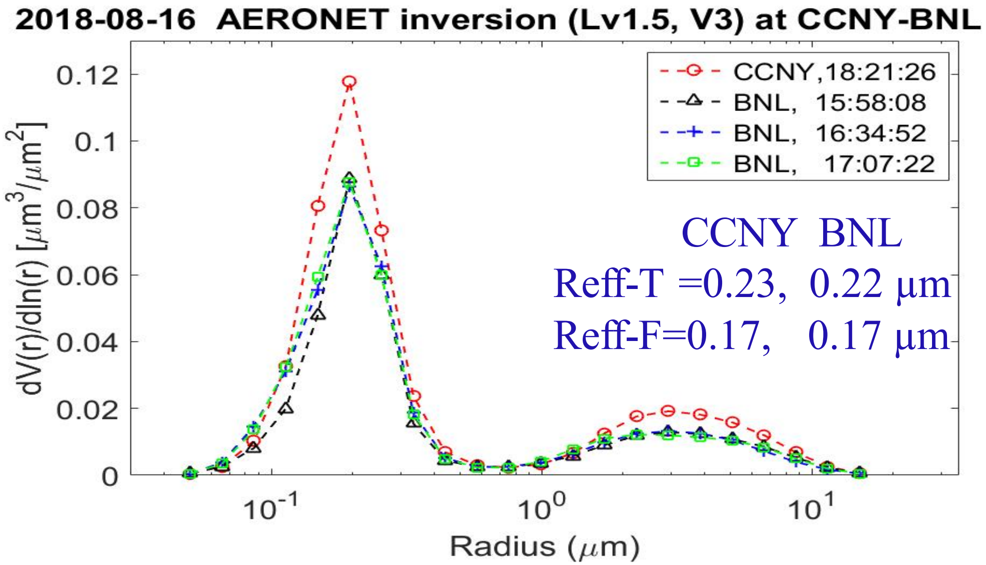
- AOD at 500-nm increase from 0.2 to 0.8 on Aug.15-16; Large AE_{vis}(440-870)=1.7-1.8 (not change much).

➢ Aged smoke vs. urban aerosols (size + absorption)
1) AE_{IR}(1020-1640) increase while AE_{UV}(340-440) decease from 1.3 to 0.8 during the smoke intrusions;
2) Dramatic increase for $\Delta AE = AE_{IR} - AE_{UV}$; Strong correlation between the smoke-AOD and ΔAE.

AERONET-BNL site: Aerosol optical properties AOD, AE(Vis-UV-IR), dVdr

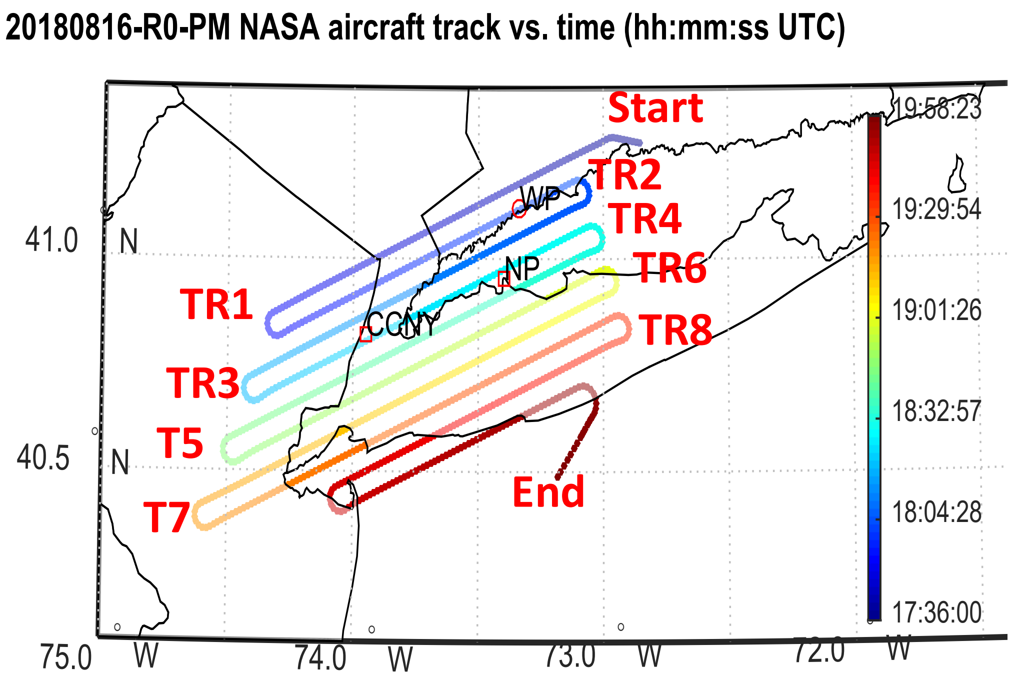


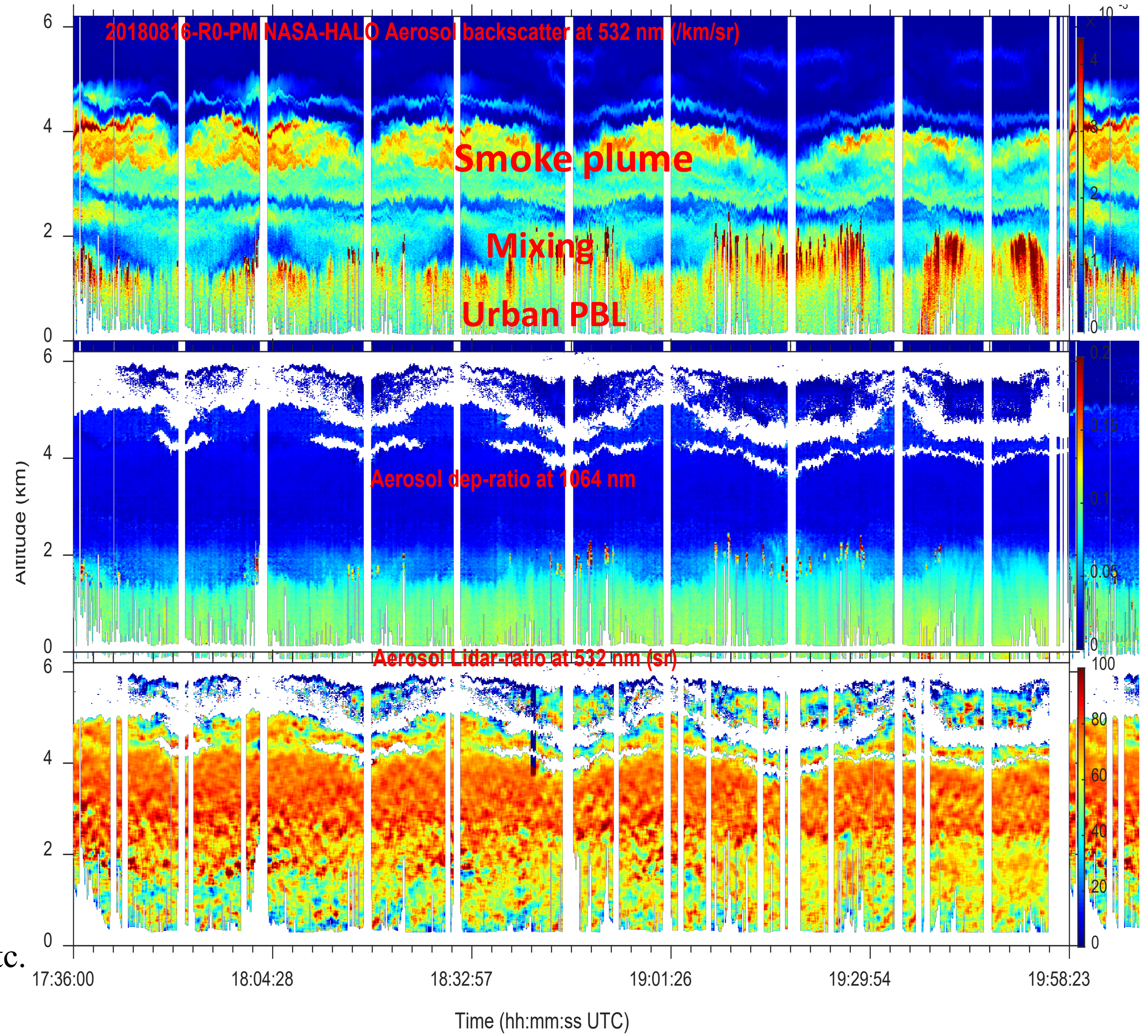




- AE_{IR}(1020-1640) increases while AE_{UV}(340-440) deceases from 1.5 to 0.8 during the smoke intrusions;
- Dramatic increase for $\Delta AE = AE_{IR} - AE_{UV}$; Strong correlation between the smoke-AOD and ΔAE; fine mode dominated *;
- Consistent with the results at CCNY site. ** Thomas F. Eck, et al., Atmos. Environ., 305, 119798, 2023*

Aerosol optical properties by NASA airborne HALO (HSRL-1)*, LISTOS 2018



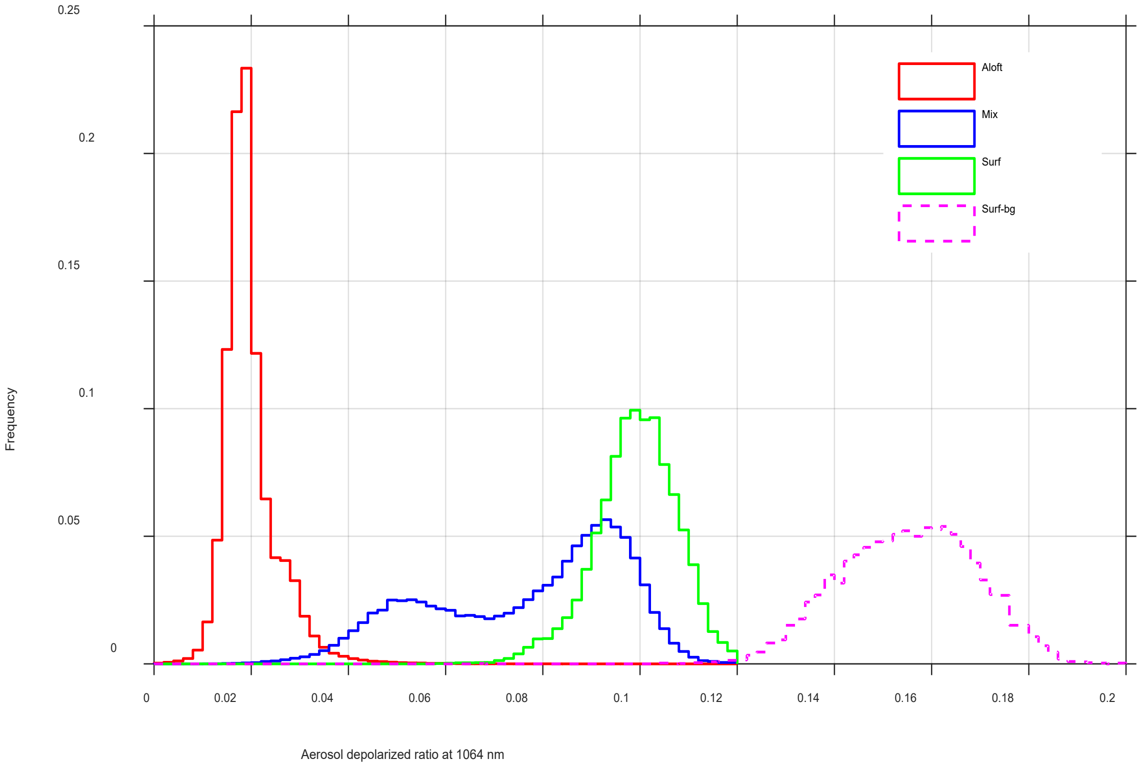


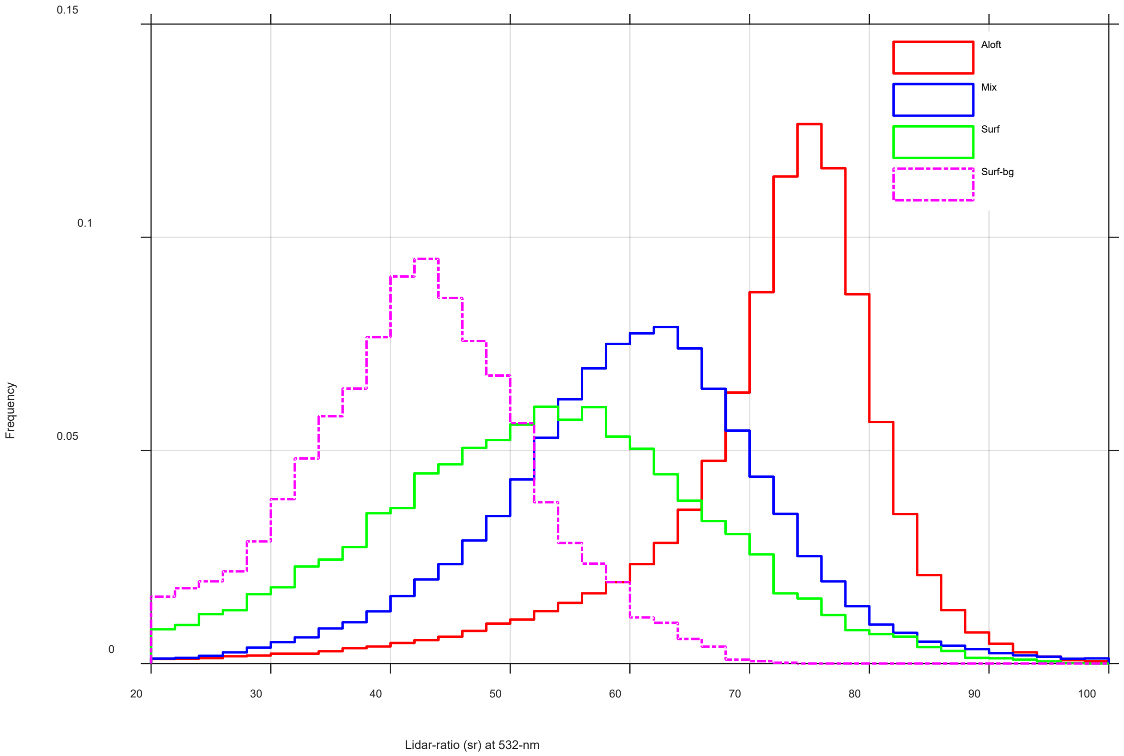
- Aloft smoke plumes below 5-km altitude; mixing into the PBL in the urban area;
- Aerosol depolarization ratio at 1064-nm: small for aloft smoke #, but large in the PBL (urban);
- Lidar-ratio: larger for smoke aerosols than those for the urban aerosols in PBL #.

* Data are from NASA Langley Res Center, Dr. Amin Nehrir, etc.

Burton, S., et al., Atmos. Chem. Phys., 2015.

Discriminate the aged smoke aerosols from local urban aerosols:
Aloft aged smoke vs. PBL aerosols (mixture) vs. Near-surface aerosols (urban)

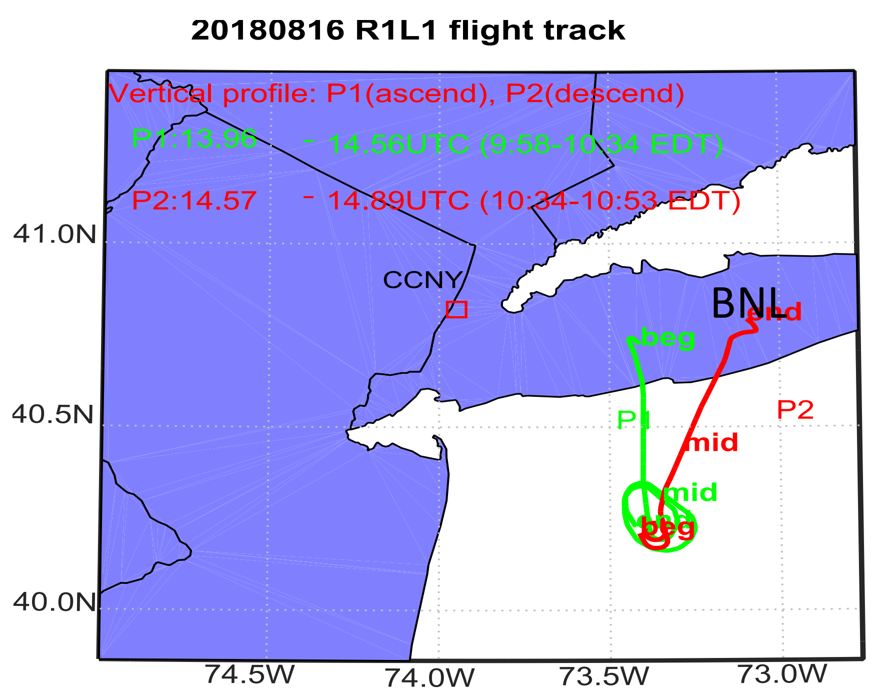


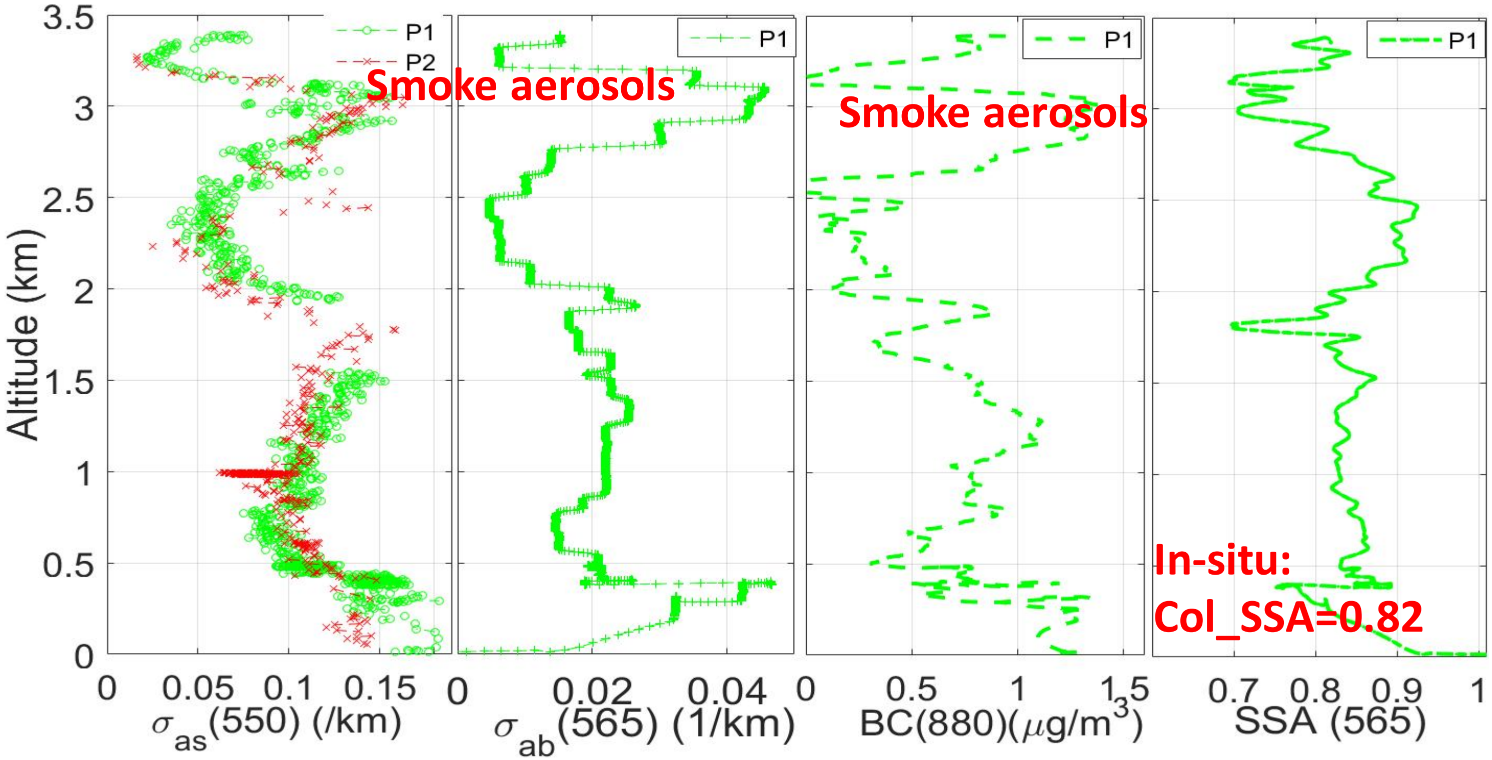


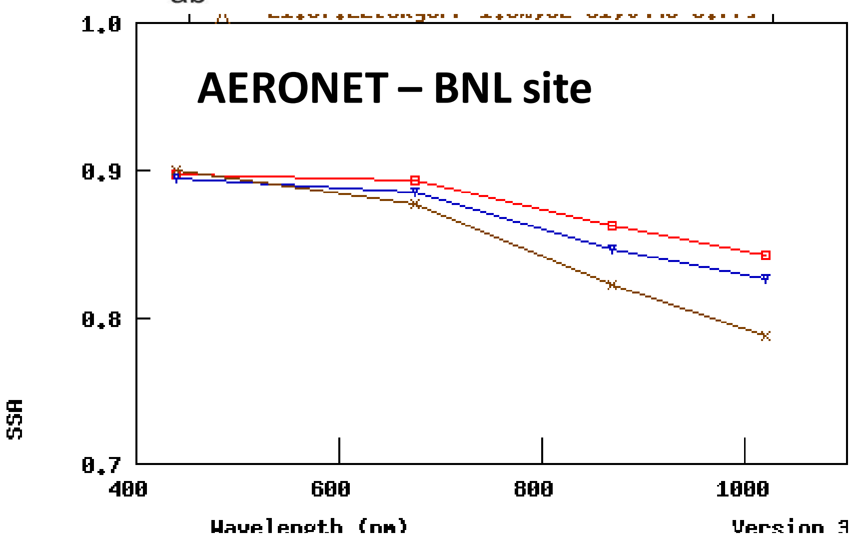
- Aloft plume at 2.5-4.5 km, surface aerosol z<0.5 km, PBL urban+smoke aerosols at 0.5-2.0 km;
- Aerosol depolarization ratio at 1064-nm: smaller (~0.02) for aloft smoke, larger (0.1-0.16) for urban (near surface) *;
- Lidar-ratio at 532-nm: larger (75-sr) from smoke aerosols, smaller (45-55 sr) for urban aerosols;
- **Mixture of the aged smoke with urban aerosols at 0.5-2.0 km;**
- *Surf_clr: 20180815_am (9:00 – 11:00 EDT), before the smoke intrusion in the PBL.*

* Michael I. Mishchenko, et al., Linear depolarization of lidar returns by aged smoke particles, Appl. Opt. **55**, 9968-9973 (2016)
Burton, S., et al., Observations of the spectral dependence of linear particle depolarization ratio…., Atmos. Chem. Phys., 2015.

UMD aircraft in-situ observations*: Aged smoke aerosol optical properties/BrC



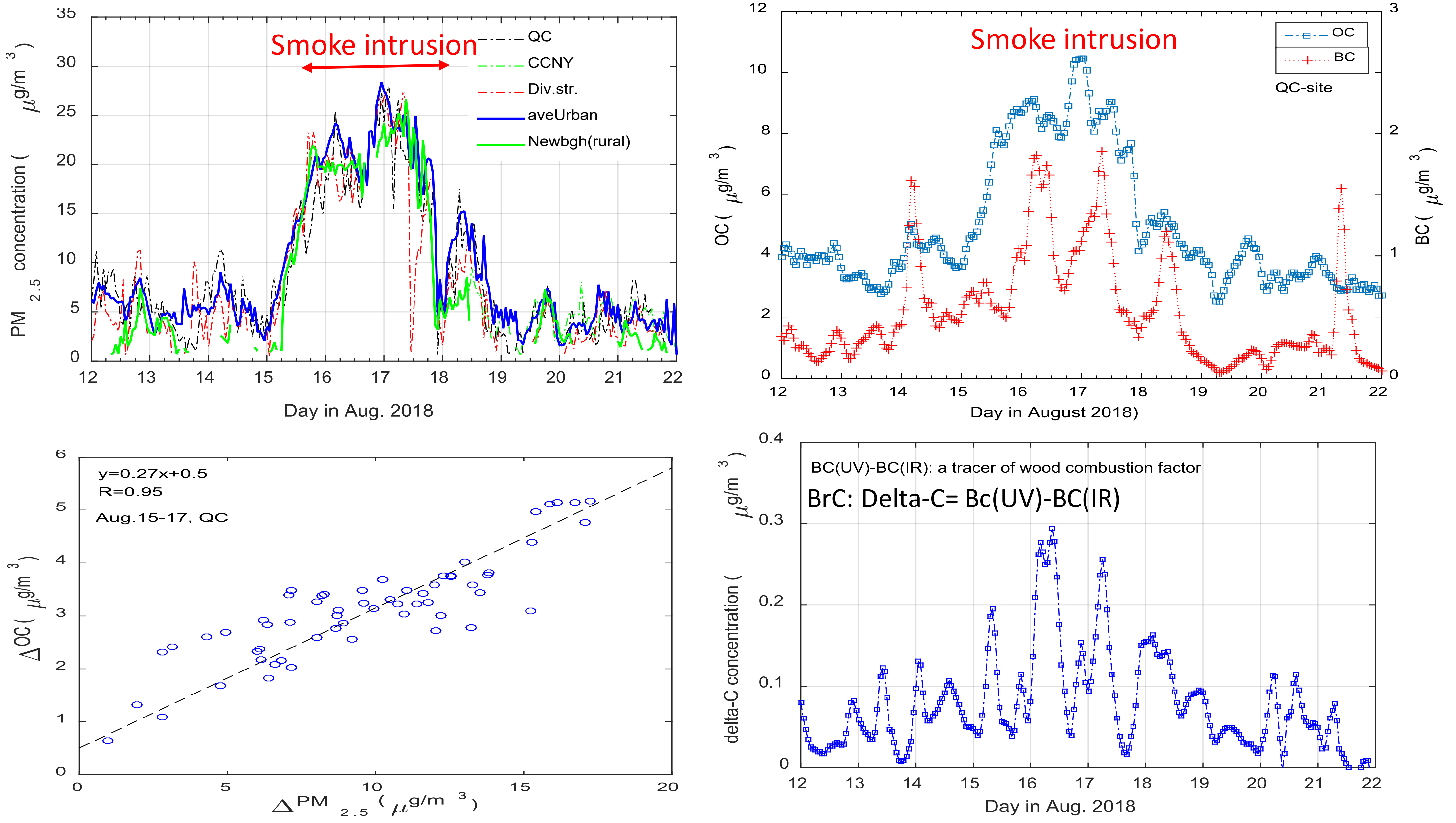




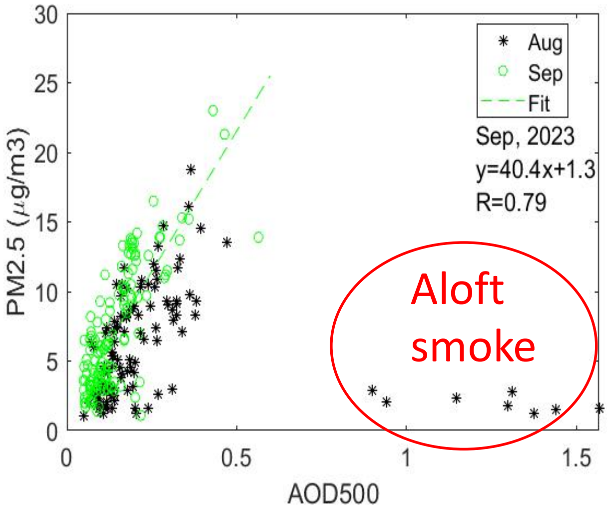
- Two plume layers at 1-2 km and 2.5-3.2 km altitude;
- **High BC and absorption in the smoke layers;**
- **SSA(565) =0.7-0.82 in the aged smoke layer,**
  Slightly smaller than AERONET inversions at BNL.

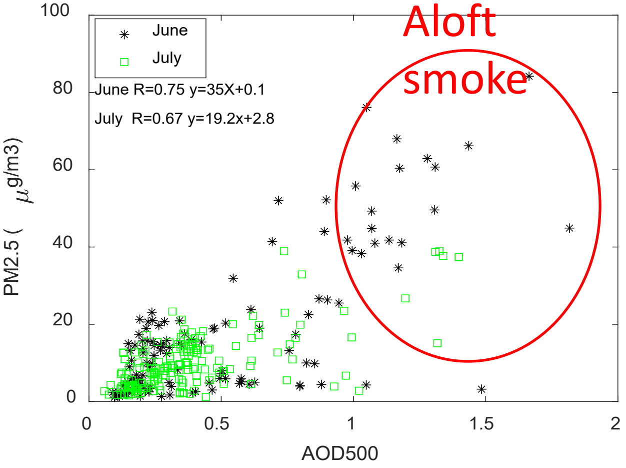
* Data from the UMD/NOAA-ARL aircraft team (Drs. Ren and Dickerson)

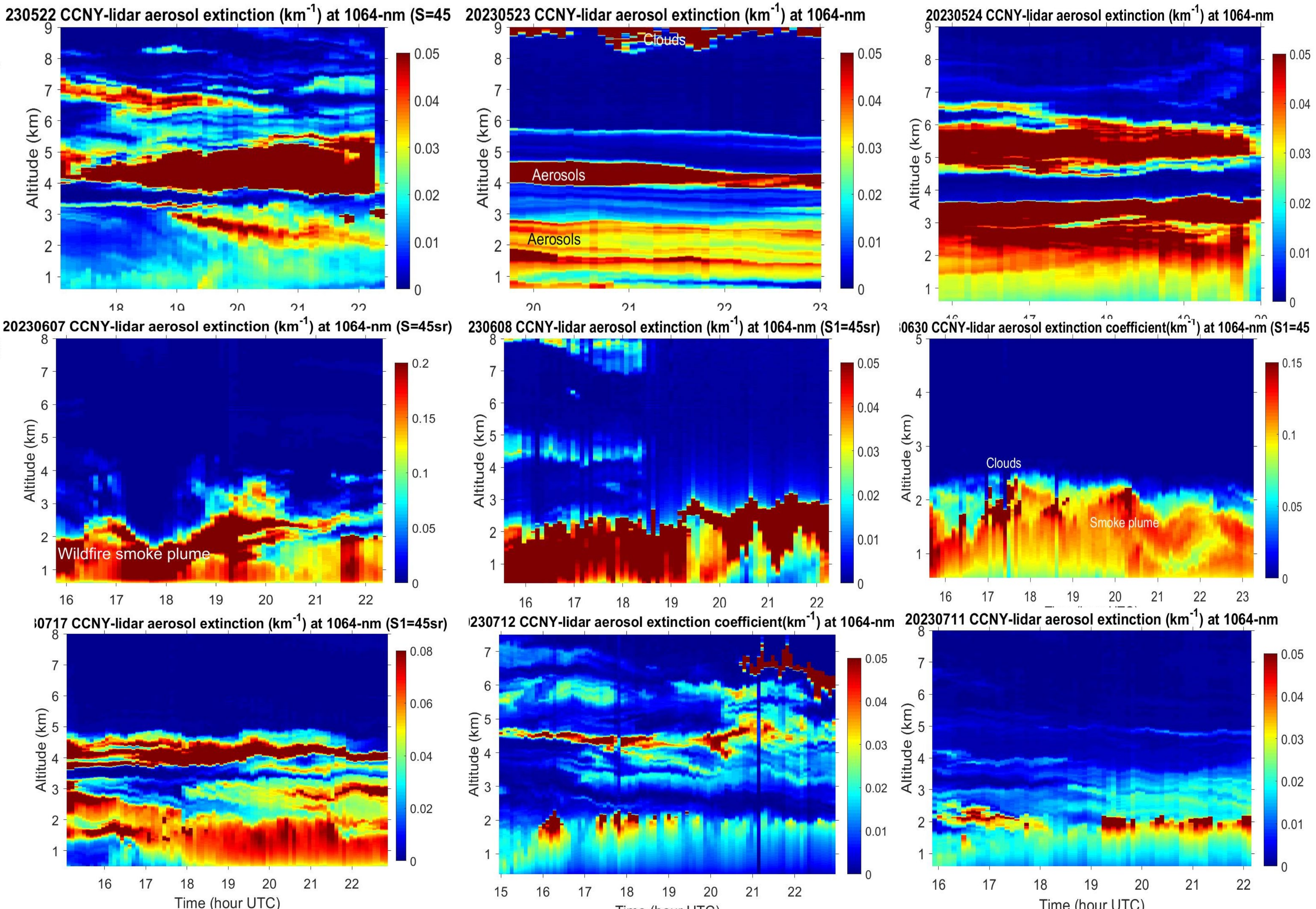
Potential impacts on local air quality in NYC area



Aloft smoke plumes impacts on AOD-PM2.5 in summer 2023





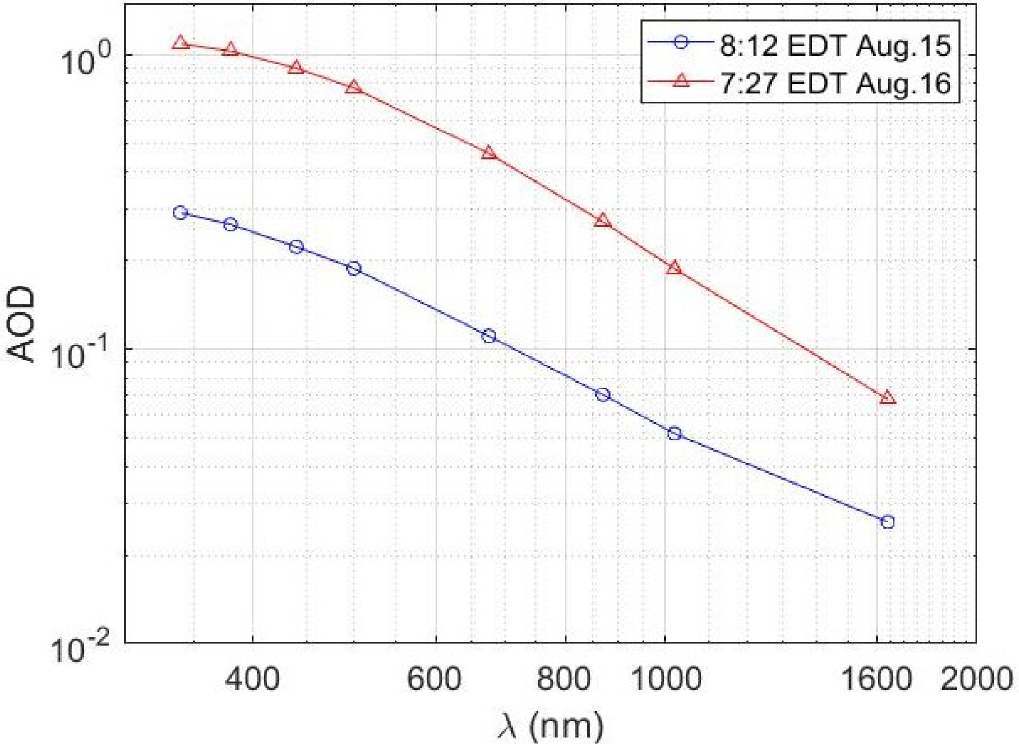


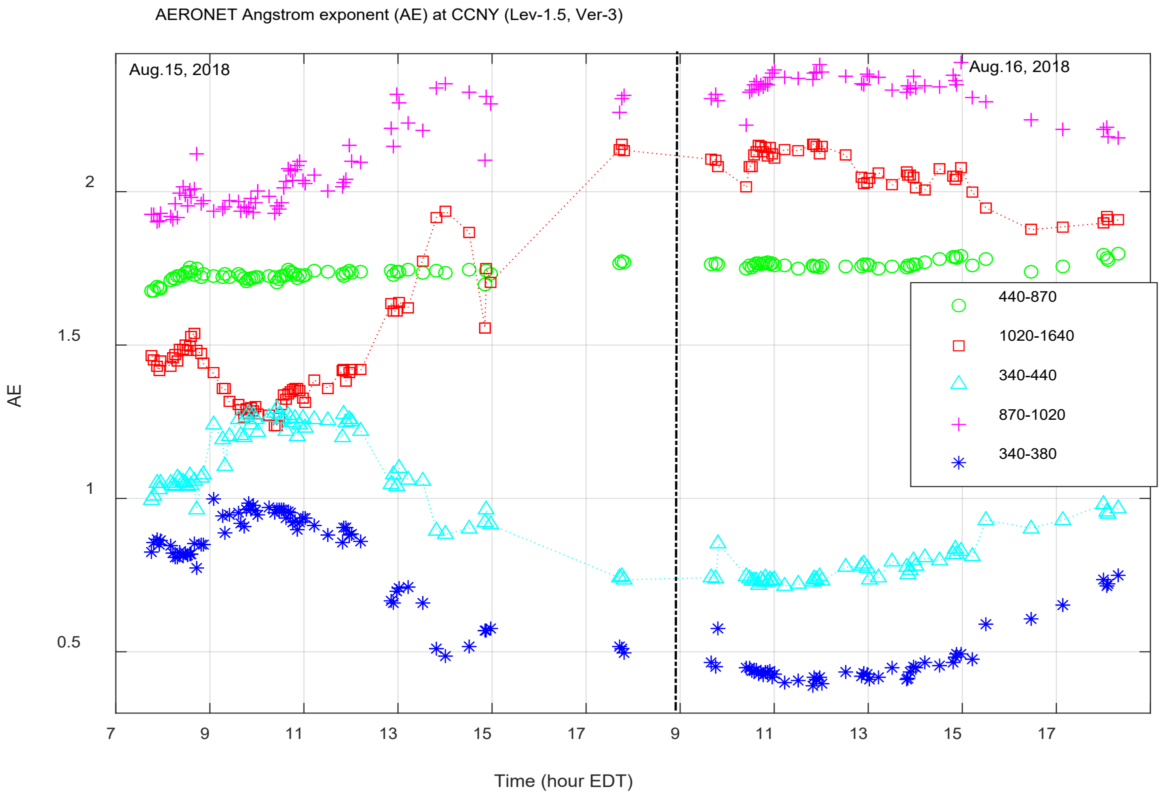
Large AODs (>0.5) are more scattered that are associated with aloft smoke plume.

4. Summary

- The combined AERONET sunphotometer and lidar measurements can retrieve aerosol extinction and backscatter vertical profiles, identify smoke mixing into urban PBL, and quantify smoke contribution to total AOD, and ground AQ (PM2.5).
- The aged/transported smoke aerosols show different optical properties from the urban aerosols in NYC area: AE(IR) increases while AE(UV-Vis) decreases due to the differences of particle size and absorption; smaller depolarization ratio at 1064 nm for the aged smoke particles, discriminating the aged smoke, urban aerosols and their mixture.
- The combined AERONET and lidar observations help understand the smoke interaction with urban PBL, impacts on local air quality, and the AOD-PM2.5 relationship.
- Synergistic observations of AERONET with CCNY aerosol-O_3 lidar observations indicate coincident increase of the O_3 in the aloft smoke layers that makes the AQ worse.

Acknowledgements: New York State Energy Resources Development Authority (NYSERDA), NESCAUM, NOAA under the CESSRST Cooperative Agreement (# NA22SEC4810016), NASA-AERONET and TOLNet, NOAA and NYSDEC.


8:12 EDT Aug.15
7:27 EDT Aug.16
AOD
λ (nm)


AERONET Angstrom exponent (AE) at CCNY (Lev-1.5, Ver-3)
Aug.15, 2018
Aug.16, 2018
440-870
1020-1640
340-440
870-1020
340-380
AE
Time (hour EDT)