Optical Measurements of Particulate Matter in the El Paso–Juarez Region: Natural Mineral Dust and Soot

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Particulate matter in desert cities contains significant amounts of mineral dust and soot[1,2,3]. Both have large components that may be considered as natural emissions because mineral dust results from wind dislodging loose matter from the Earth's surface while in regions, such as the American West, a significant fraction of soot results from wildfires. Mineral dust and soot affect climate through their effects on solar radiation[4,5]. Mineral dust may scatter solar radiation, while soot absorbs radiation, warming Earth. Both mineral dust and soot have some effects on cloud formation. In addition, it is well established that soot leads to cardiopulmonary disease and lung cancer, while recent studies show that mineral dust is also a danger to human health[2,6].

El Paso-Juarez with a population near 2.7 million[1,7] is an example of an urban area where mineral dust and soot affect urban air quality, Figure 1. This region is surrounded by the Chihuahuan desert where severe dust storms lead to high mineral dust concentrations. There are several measurement and modeling studies that identify mineral dust and soot as the predominant particulate matter pollutants here[3,8].

Figure 1

Making Measurements with an Extinctiometer

Much of the instrumentation used to measure particulate matter at urban sites routinely only provides time averages over a day or longer[1]. However, particulate matter concentrations at urban sites can change over time scales of minutes or less. Electromagnetic radiation absorbance and scattering by aerosols can be used to obtain particle concentrations with much better time resolution. Here we discuss soot as black carbon (BC) which consists mainly of elemental carbon. BC detection methods and instruments can be grouped into three categories: a) Optical Methods, b) Thermal-Optical Analysis (TOA) Methods, c) Laser-Induced Incandescence (LII) Methods[9].

a) Optical Methods: These methods involve the measurement of light absorption, light scattering, and/or light attenuation that are used to calculate an equivalent BC mass from a constant mass absorption cross-section. Photoacoustic Spectrometers (PAS) and Photoacoustic Extinctiometers (PAX) are examples of optical instruments[10]. A PAS uses an acoustic resonator cell to measure radiation absorption by particulate matter while a PAX combines a photoacoustic cell with a second cell to measure particle scattering.

b) Thermal-Optical Analysis (TOA) Methods: These are filter-based methods where sampled air is passed through a filter and all measurements are based on the filter-content to determine Organic and Elemental Carbon. Two examples are the Multi-Angle Absorbing Photometer (MAAP) and the Sunset OCEC Analyzer. The MAAP measures optical absorption by aerosols collected on a filter; the measured absorption is enhanced due to multiple scattering on the filter[11]. The Sunset OCEC Analyzer can analyze for BC and brown carbon particles (which have higher concentrations of organic compounds)[9].

c) Laser Induced Incandescence (LII) Methods: A laser heats particles to the point of incandescence. One example is the Single Particle Soot Photometer, a Nd:YAG intracavity laser to determine the aerosol particle’s size, mass, heat of vaporization, and particle’s coating.

For the work shown here, we choose a PAX extinctiometer. The PAX is widely used by researchers from all levels of academia and experience. It requires minimal maintenance and calibration because it comes calibrated by the manufacturer for use in a laboratory or in the field. Our PAX uses electromagnetic radiation at 870 nm which is especially attuned to detect black carbon (BC) particles. It offers two instruments in one, combining a reciprocal nephelometer and a photoacoustic cell, from where the extinction coefficient (the sum of the absorption and scattering coefficients) is obtained. It is important to have this capability as some aerosols are primarily scatterers and others are mainly absorptive. These measurements yield the SSA (Single-scattering albedo, the ratio between scattering and extinction coefficients), and the BC Mass.

Sample Results

We present a representative sample of the aerosol number distribution per unit volume for April 18, 2013,

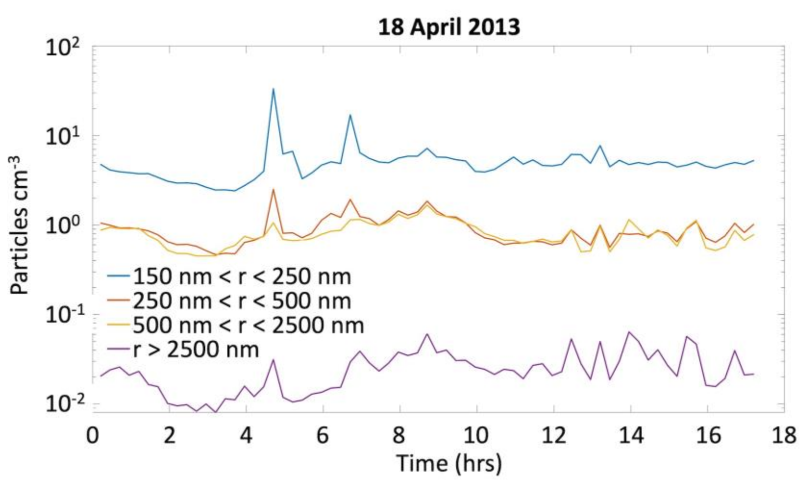

Figure 2.

Figure 3 shows a representative sample of the inter-comparison of the scattering coefficients between the models and the experimental data for April 18, 2013. These data were compared with models using T-matrix theory and a maximum likelihood estimator (MLE), that we have previously published and there was good agreement[1].

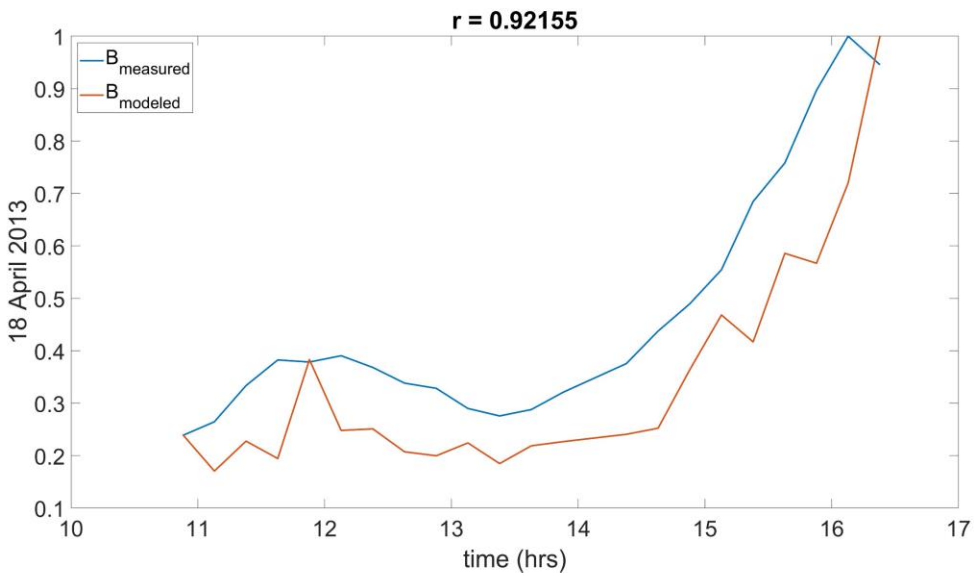

Figure 3

Subsequently, we show the following results for soot resulting from wildfires.

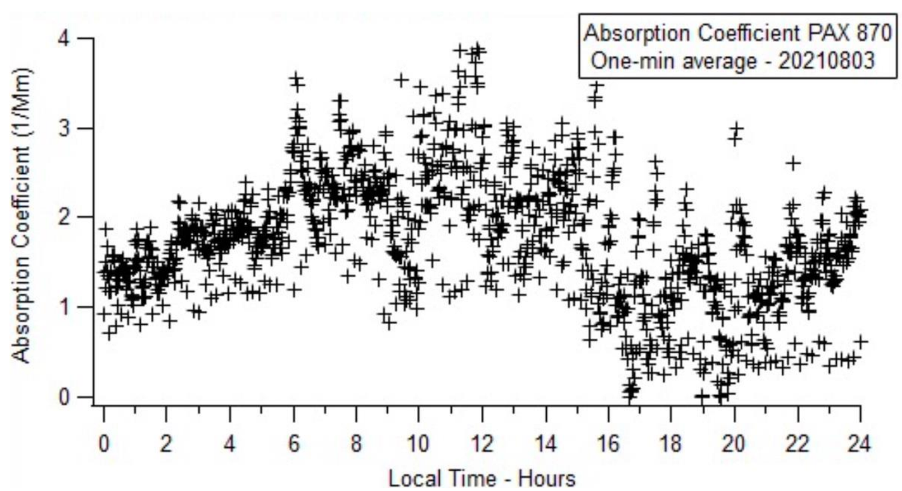

Figure 4

For August 03, 2021, Figure 4 shows the absorption coefficient in units of 1/length. We see that the data clearly separates from the x-axis (at y = 0) starting at around 00 hours and peaks at midday, then declines in the evening to rise again at nighttime.

Figure 5 shows Black Carbon Mass ($\frac{\mu g}{m^3}$) at 870 nm in El Paso, which increased in the region due to the presence of soot from the nearby wildfires. It is notable that, according to the HRRR-Smoke graph, a 6 to 12 $\frac{\mu g}{m^3}$ (color nomenclature) of BC mass arrived at the west cone of Texas. Our instruments detected ~ 10th of that range with an average of 0.4 $\frac{\mu g}{m^3}$. There isn't numeric data available from the HRRR model for us to quantitatively compare results.

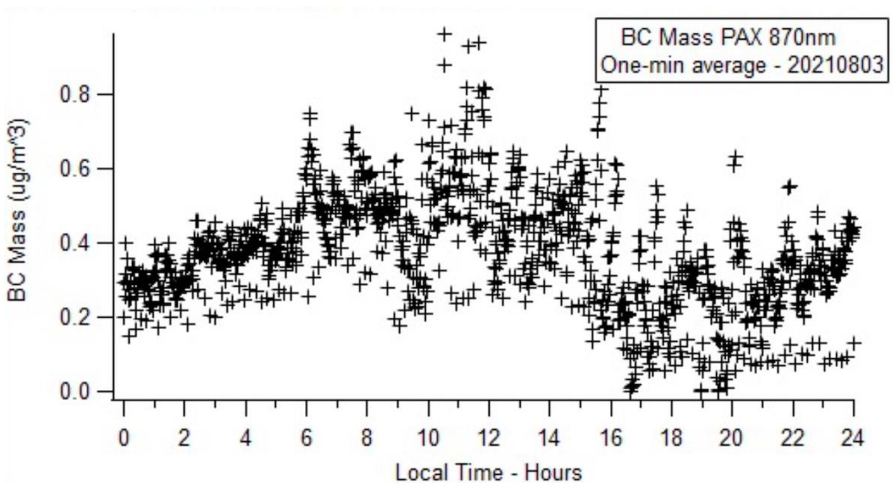

Figure 5

Figure 6 shows at 11:00 AM local time or 18 UTC a light to medium green color-code for W Texas, 6 to 12 $\frac{\mu g}{m^3}$, for Near-Surface smoke (~ 8 m above ground), which as observed in figures 4,5, our extinctiometer detected.

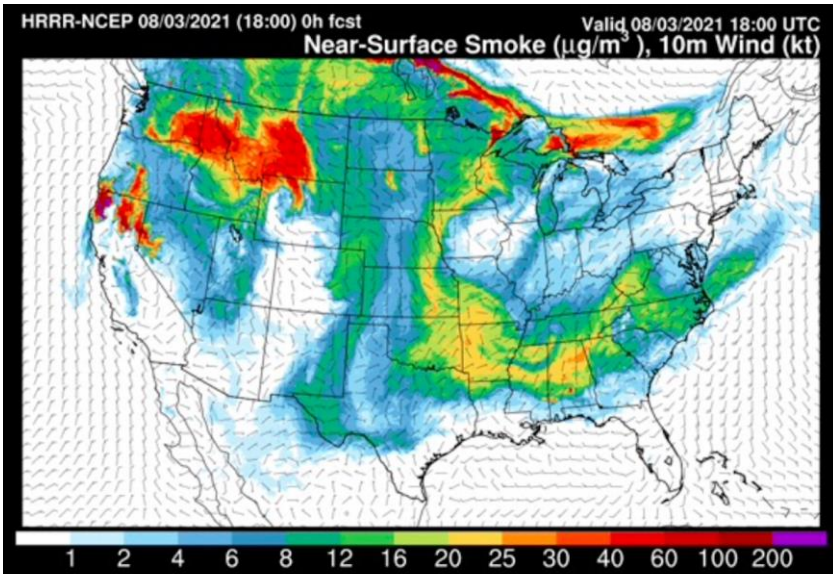

Figure 6

The Effect of the Windblown Dust and Soot Concentrations on the Planetary Boundary Layer

Knowledge of the planetary boundary layer (PBL) height is critical for understanding air quality and pollutant transport. Ceilometer aerosol backscatter data is an excellent proxy for the PBL layer height. The Atmospheric Physics group at the University of Texas, El Paso (UTEP), introduced this instrument for the first time in the city of El Paso and has been collecting ceilometer aerosol backscatter data since 2015.

As observed on Figure 7, windblown dust reduces the turbulent mixing within the PBL[12].

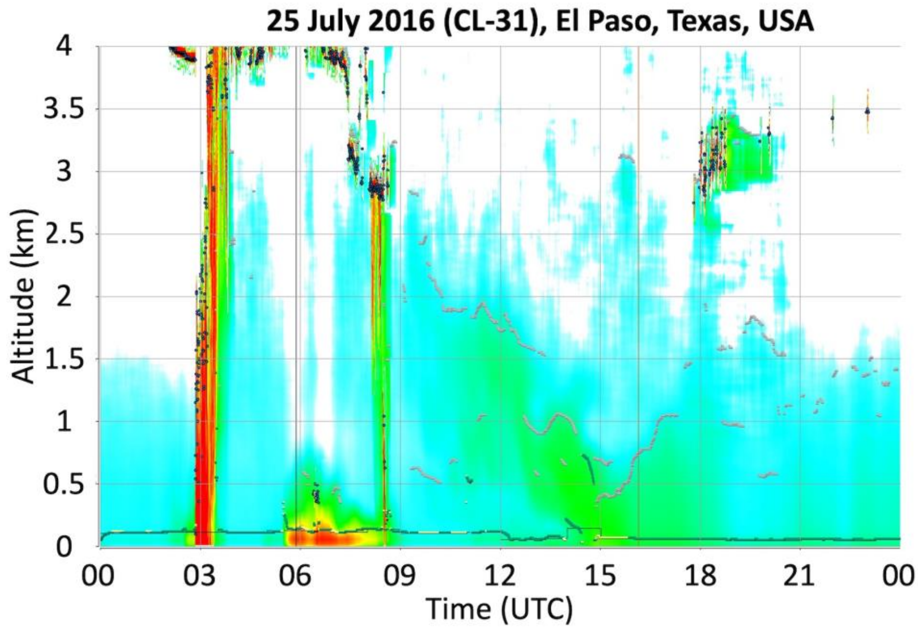

Figure 7

This, in turn, reduces the downward transport of momentum and surface wind speed, hence lowering dust emission. El Paso region exhibits higher PBL heights (as high as 3-4 km) in the late afternoon in summer[13]. However, as seen in Figure 7, a Vaisala ceilometer CL31, located at the UTEP site, recorded heavy dust concentration depicted by an intense aerosol backscattered profile (dark green) at 1300 to 1800 UTC on July 25, 2016. This large concentration of dust through radiative forcing has altered the daytime convective boundary layer (grey dots) growth after a strong early morning evolution (1500-1800 UTC) and restricted the peak PBL height to less than 2 km around 2000 UTC.

The absorbing effect of soot suppresses the daytime PBL height and impedes its growth by heating the air above PBL. This can have serious impacts on air quality, especially in the summer and winter seasons[14]. Shallow PBL leads to confinement of the pollutant precursors and resulting in high pollution episodes. Therefore, ceilometer and photoacoustic extinctiomers are ideal for air quality studies and can provide air quality policymakers useful information.

References

1. Polanco, J.; Ramos, M.; Fitzgerald, R.M.; and Stockwell, W.R.; An improved method for optical characterization of mineral dust and soot particles at the El Paso-Juárez Airshed; *Atmosphere* **2020**, *11*, 866.

2. Kim, D.; Chin, M.; Diehl, T.; Bian, H.; Remer, L.A.; Yu, H.; Brown, M.E.; and Stockwell, W.R.; The role of surface wind and vegetation cover in multi-decadal variations of dust emission in the Sahara and Sahel; *Atmos. Environ.* **2017**, *148*, 282–296.

3. Esparza, E.; Fitzgerald, R..; Gill, T.; and Polanco, J.; Use of light-extinction method and inverse modeling to study aerosols in the Paso del Norte Airshed; *Atmos Environ.* **2011**, *45*, 7360–7369. doi: 10.1016/j.atmosenv.2011.07.039

4. Kim, K.-M.; Lau, W.-K.; Sud, Y.C.; Walker, G.K.; Influence of aerosol-radiative forcings on the diurnal and seasonal cycles of rainfall over West Africa and Eastern Atlantic Ocean using GCM simulations; *Clim. Dyn.* **2010**, *11*, 115–126. doi:10.1007/s00382-010-0750-1.

5. Haywood, J.M.; Francis, P.; Osborne, S.; Glew, M.; Loeb, N.; Highwood, E.; Tanre, D.; Myhre, G.; Formenti, P.; Hirst, E.; Radiative Properties and Direct Radiative Effect of Saharan Dust Measured by the C-130 Aircraft during SHADE: 1. Solar spectrum; *J. Geophys. Res.* **2003**, *108*, 8577. doi:10.1029/ 2002JD002687.

6. Giannadaki, D.; Pozzer, A.; Lelieveld, J.; Modeled Global Effects of Airborne Desert Dust on Air Quality and Premature Mortality; *Atmos. Chem. Phys.* **2014**, *14*, 957–968. doi:10.5194/acp-14-957-2014.

7. Mahmud, S.; Karle, N.N; Fitzgerald, R.M.; Lu, D.; Nalli, N.R.; and Stockwell, W.R.; Intercomparison of Sonde, WRF/CAMx and Satellite Sounder Profile Data for the Paso Del Norte Region; *Aerosol Sci. Eng.* **2020**, *4*, 277–292. doi:10.1007/s41810-020-00075-1

8. Medina, R.; W.R. Stockwell; and R.M. Fitzgerald; Optical Characterization of Mineral Dust and Soot Particles in the El Paso-Juarez Airshed; Aerosol Sci. Eng. 2018, 2, 11–19. doi: 10.1007/s41810-017-0019-8

9. Li, H., Lamb, K. D., Schwarz, J. P., Selimovic, V., Yokelson, R. J., McMeeking, G. R., May, A. A. 2019. Inter-comparison of black carbon measurement methods for simulated open biomass burning emissions. Atmospheric Environment, Volume 206, 156-169. ISSN 1352-2310. https://doi.org/10.1016/j.atmosenv.2019.03.010.

10. Gillis, K. A., Havey, D. K., Hodges, J. T. 2010. Standard Photoacoustic Spectrometer: Model and Validation Using O2 A-band Spectra. Review of Scientific Instruments 81, 064902. Doi:10.1063/1.3436660

11. Valentini S., Bernardonei, V., Bolzacchini, E., Ciniglia, D., Ferrero, L., Corina Forello, A., Massabo, D., Pandolfi, M., Prati, P., Soldan, F., Valli, G., Yus-Diez, J., Alastuey, A., Vecchi, R. 2021. Appliccability of Benchtop Multi-wavelength Polar Photometer to Off-line Measurements of the Multi-Angle Absorption Photometer (MAAP) Samples. Journal of Aerosol Science 152 (2021) 105701, https://doi.org/10.1016/j.jaerosci.2020.105701

12. Miller, R. L.; Perlwitz, J.; and Tegen; I.: Feedback upon dust emission by dust radiative forcing through the planetary boundary layer; *J. Geophys. Res.-Atmos.*, **2004**, *109*, D24209.

13. Karle, N.N.; Mahmud, S.; Sakai, R.K.; Fitzgerald, R.M.; Morris, V.R.; Stockwell, W.R.; Investigation of the Successive Ozone Episodes in the El Paso–Juarez Region in the Summer of 2017; *Atmosphere* **2020**, *11*, 532.

14. Gao, J.; Zhu, B.; Xiao, H.; Kang, H.; Pan, C.; Wang, D.; and Wang, H.; Effects of black carbon and boundary layer interaction on surface ozone in Nanjing, China; *Atmos. Chem. Phys.* **2018**, *18*, 7081–7094, https://doi.org/10.5194/acp-18-7081-2018.

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Figure Captions

Figure 1. The El Paso-Juarez Region

Figure 2. A representative sample of the aerosol number distribution per unit volume for April 18, 2013

Figure 3. A representative sample of the inter-comparison of the scattering coefficients between the models and the experimental data for April 18, 2013

Figure 4. The absorption coefficient in El Paso for August 03, 2021

Figure 5. Black Carbon Mass ($\frac{\mu g}{m^3}$) at 870 nm in El Paso for August 03, 2021.

Figure 6. HRRR-Smoke graph for August 03, 2021.

Figure 7. Aerosol backscatter profile of a dusty morning, July 25, 2016.