Spatial and Temporal Variability of Satellite-based Aerosol Optical Depth in the Dynamic Urban Environment

Chenghao Wang[1] (cwang210@asu.edu), Chuyuan Wang[2], Soe W. Myint[2], and Zhi-Hua Wang[1]

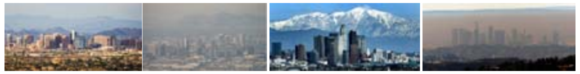
[1]School of Sustainable Engineering and the Built Environment, Arizona State University, Tempe, AZ 85287

[2]School of Geographical Sciences and Urban Planning, Arizona State University, Tempe, AZ 85287

Background and Motivation

Aerosol is one of the main stressors of global climate change. The majority of aerosols, especially the particulate matters (PMs), has been recognized as one of the primary contributors to the urban air pollution and related issues. The ***aerosol optical depth*** (AOD) is an important indicator of air pollution, suggesting the column atmospheric aerosol loading from the ground surface to the top of atmosphere.

High concentration of aerosols in a dynamic urban environment is a result of the intricate interplay of multiple ***determinants***, including anthropogenic emissions, natural sources, land use categories, topography, etc. In addition, using remotely sensed AOD as a ***proxy*** for PM can be questionable due to the mismatch in both spatial and temporal resolutions.



The present study aimed to untangle the landscape determinants of the spatio-temporal patterns of AOD in the two most polluted metropolitans in the U.S., i.e. ***the Los Angeles Metropolitan Area*** and ***the Phoenix Metropolitan Area***, using 15-year remotely sensed AOD data. We also scrutinized the relationship between ground-measured PMs and AOD.

Data and Methodology

(1) **AOD data**: Moderate Resolution Imaging Spectroradiometer (MODIS) Terra Collection 6 Atmosphere Aerosol Level 2 product (MOD04_3K) [resolution: 3 km, 2001–2015, daily]

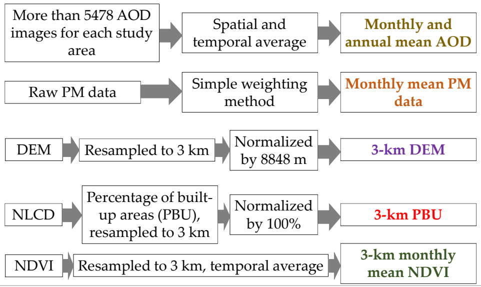
(2) **$PM_{2.5}$ and PM_{10} data**: US Environmental Protection Agency (EPA), station measurements with the temporal coverage 2001–2015 [spatial scales: 0–100 m to 4–5 km]

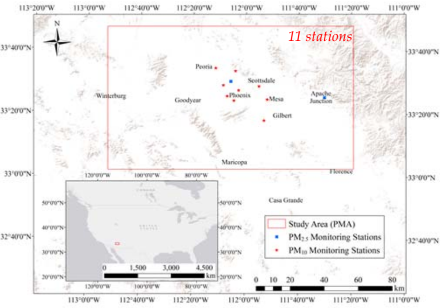
(3) **Elevation**: Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) V2 [resolution: 30 m]

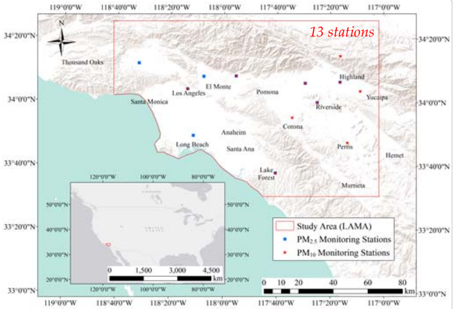
(4) **Built-up areas**: National Land Cover Database (NLCD) 2001 and 2011 [resolution: 30 m]

(5) **Vegetation**: MODIS global vegetation indices land product (MOD13A3.V006) – Normalized Difference Vegetation Index (NDVI) [resolution: 1 km, 2001–2015, monthly]

Data processing:



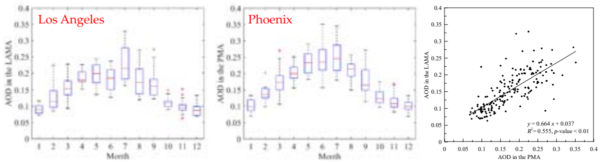




Result A. Temporal dynamics of AOD

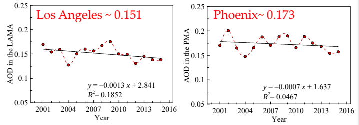
(1) Monthly mean AOD: similar pattern, highest in July, lowest in winter months

Reasons: (a) similar anthropogenic and industrial activities; (b) summer peak results from different natural sources – dust storms in monsoon seasons for Phoenix, while wildfires and prescribed fires for Los Angeles; (c) synoptic advection in the lower troposphere (Li et al., 2015a).

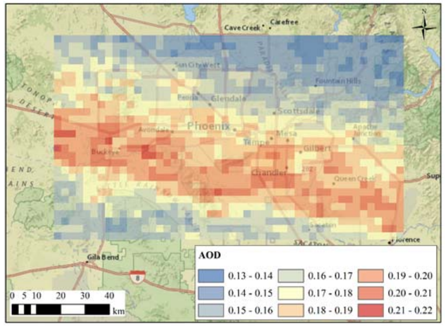


(2) Mean AOD value in Los Angeles is 12.72% lower than that in Phoenix

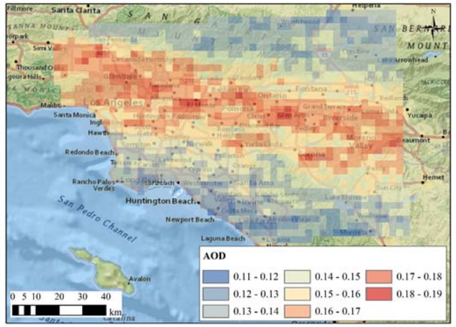
(3) Relatively faster decreasing trend of AOD in Los Angeles



Result B. Spatial pattern of AOD



Phoenix Metropolitan Area



Los Angeles Metropolitan Area

(1) Distribution: southeast-northwest corridor-like shape for both areas

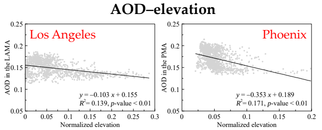
Reasons: (a) Anthropogenic emissions from built-up areas; (b) consistent with the local topography (high AOD in valleys); (c) lower AOD over coastal areas due to the sea-land breeze circulation (daytime) in Los Angeles.

(2) Geographical information for ameliorating air pollution and controlling respiratory and cardiovascular morbidity and mortality

(a) Implementing air quality-related emission standards in highly polluted areas

(b) Ideal places for susceptible population, e.g. Irvine and Lake Forest in Los Angeles, and Northern Scottsdale and Fountain Hills in Phoenix.

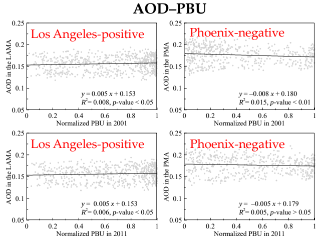
Result C. Determinants in the dynamic urban environment

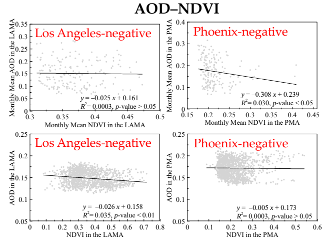


AOD–elevation: statistically significant negative relationships.

AOD–PBU: positive in Los Angeles (urban expansion), negative in Phoenix (due to the smaller portion of anthropogenic emissions)

AOD–NDVI: negative relationships – overall vegetation effect is to decrease the mass of aerosols [deposition > vegetation emission]

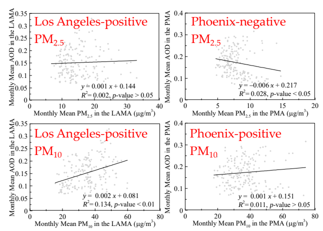




Based on slopes and R^2:

- Topography effect is stronger than land use (built/vegetated) effect
- Vegetation effect is stronger than urbanization effect

Result D. Relating AOD to ground-measured PM



Positive AOD–PM associations is not versatile (e.g. Phoenix $PM_{2.5}$):

(1) PMs are measured near the surface and within the lower troposphere, while AOD reflects the whole atmospheric column. Note that previous study showed that the $PM_{2.5}$ is strongly correlated with the lower troposphere (<500 m) AOD in the Western U.S. (Li et al., 2015b). The ground-measured PM concentrations vary with seasonal atmosphere boundary layer heights.

(2) Spatial heterogeneity of fine mode aerosols ($PM_{2.5}$). Higher fine mode aerosol ratio in Los Angeles shows the strong effect of anthropogenic emissions from transportation, and natural emission due to biomass burning.

(3) Mismatch of both spatial and temporal resolutions

	Los Angeles	Phoenix
Fine mode aerosol ratio (%)	42.670	21.551
Mean AOD	0.152	0.173

Note: Fine mode aerosol ratio (%) = fine mode aerosol ($PM_{2.5}$) concentration / PM_{10} concentration

Conclusions

- Strong similarity between the temporal and spatial patterns of AOD in two areas
- Determinants and their effects: topography > vegetation > urbanization
- The positive AOD–PMs associations can never be versatile

Acknowledgements

The authors would like to acknowledge the following financial supports for this study: National Science Foundation (NSF) under grant numbers CBET-1435881 and CBET-1444758, and National Aeronautics and Space Administration (NASA) under grant number NNX12AM88G.

References

Li, J., et al. (2015a). Regional-scale transport of air pollutants: impacts of Southern California emissions on Phoenix ground-level ozone concentrations. *Atmospheric Chemistry and Physics*, 15(16), 9345-9360. doi: 10.5194/acp-15-9345-2015

Li, J., et al. (2015b). How well do satellite AOD observations represent the spatial and temporal variability of PM 2.5 concentration for the United States? *Atmospheric Environment*, 102, 260-273. doi: 10.1016/j.atmosenv.2014.12.010

Wang, C., et al. (2017). Landscape determinants of spatio-temporal patterns of aerosol optical depth in the two most polluted metropolitans in the United States. *Science of the Total Environment*, 609, 1556-1565. doi: 10.1016/j.scitotenv.2017.07.273