

# Associations between optical, physical and chemical properties of aerosols measured at ground-based networks

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**Abstract.** The abstract goes here. It can also be on *multiple lines*.

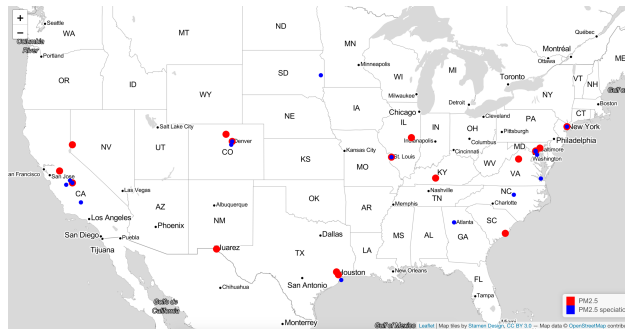
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## 1 Introduction

A large body of literature has shown that satellite-derived aerosol optical depth (AOD) reliably correlates with mass-volume concentrations of particulate matter with aerodynamic diameter less than  $2.5 \mu\text{m}$  ( $\text{PM}_{2.5}$ ) Van Donkelaar et al. (2019). Studies that have used satellite AOD to generate  $\text{PM}_{2.5}$  have been instrumental in facilitating exposure assessments for both global Cohen et al. (2017) and regional Chau et al. (2020) health effects research. The associations between AOD and different components of PM are lesser known. A handful of studies using the Multiangle Imaging SpectroRadiometer (MISR), an instrument onboard the NASA Terra satellite that provides observations of aerosol optical depth by particle type (size, shape, absorption), have provided evidence that different optical properties relate to different physical Franklin et al. (2017) and chemical properties of particulate matter Meng et al. (2018); Franklin et al. (2018); Chau et al. (2020). However, results have been inconsistent, showing differences depending on geographic area of analysis, optical components used, and statistical tools applied. Satellite AOD is retrieved The purpose of this analysis is to make a detailed examination of the statistical relationships between ground-level  $\text{PM}_{2.5}$  and  $\text{PM}_{2.5}$  chemical components (nitrate, sulfate, elemental carbon, organic carbon, dust) and optical measures of aerosols (e.g. aerosol optical depth, angstrom exponent).

AERONET Holben et al. (1998); Shin et al. (2018, 2019a, b)

AERONET sun/sky radiometers measure direct solar radiation and sky radiation. The measured data are automatically analysed using the AERONET inversion algorithm (Dubovik et al., 2006). The retrieved aerosol products are available from the AERONET database (<https://aeronet.gsfc.nasa.gov/>, last access: 31 August 2018). The recently released version 3 of the AERONET retrieval added



**Figure 1.** Map of Study Area

## 2 Methods

The study encompasses three regions of the continental U.S., west (California Central Valley), central (Colorado), and east (New York, Maryland, Virginia) (Figure 1). At these sites there are co-located instruments from EPA’s chemical speciation network (CSN), EPA’s air quality system (AQS) and NASA’s AERONET network.

### 2.1 Data

#### 2.1.1 Aerosol Optical Properties

AERONET sites are sunphotometers providing a “ground-up” measurement of aerosol optical properties at multiple wavelengths and have been used extensively to validate “top-down” satellite observations of related properties. Wavelength-specific AOD and angstrom exponents are the primary sunphotometer variables. Using quadratic log-log interpolation we calculated AOD 550 nm from AOD 440, 500, 675, 870 nm in log-log space Sorek-Hamer et al. (2020). AOD at 550 nm is the most common wavelength retrieved from satellite instruments. A retrieval-based AERONET product, called the inversion product, provides an additional suite of aerosol properties that help distinguish size (fine, coarse effective radius), shape (asymmetry), and absorption. We excluded sunphotometer and inversion variables that had a significant proportion of missing data (~90% missing). A list of the variables included in the analysis are shown in the Appendix. In a separate test we examine data from the SPARTAN site in Rehovot, Israel. The SPARTAN network provides data for  $PM_{2.5}$  mass and speciation concentrations on an integrated 1 in 9 day sampling schedule, and is colocated with an AERONET site (We don’t have the speciation data for this site so we could only look at  $PM_{2.5}$  for now).

#### 2.1.2 Particulate Matter

The AQS monitors provide daily concentrations of  $PM_{2.5}$  mass by the EPA’s Federal Reference Method, which is the highest quality gravimetric measurement method used for regulatory purposes.

The CSN monitors are on a 1-in-3 or 1-in-6 day sampling schedule, providing  $\text{PM}_{2.5}$  mass and component  $\text{PM}_{2.5}$  concentrations of metals (e.g. Aluminium Al, Silicon Si, Calcium Ca, Titanium Ti, Iron Fe) obtained from X-ray fluorescence (XRF), ions (nitrate  $\text{NO}_3^-$  and sulfate  $\text{SO}_4^{2-}$ ) from ion chromatography, and carbons (organic OC and elemental EC) from thermal/optical analysis. To quantify dust we use the following equation Chow et al. (2015):  $\text{dust} = 2.2\text{Al} + 2.49\text{Si} + 1.63\text{Ca} + 1.94\text{Ti} + 2.42\text{Fe}$

## 2.2 Statistical methods

Prior to model building we examined a cluster-based correlation heat map (Figure 2), which provides the Pearson correlations between all pairs of AERONET variables grouped by a decision tree. To avoid collinearity in the regression models, we kept the most relevant of a group of variables that had a correlation coefficient  $> 0.9$ . We then examined and picked a subset of variables connected at the mid-tier level of the tree to construct interactions. We fit simple linear regression models separately for  $\text{PM}_{2.5}$  mass, sulfate, nitrate, EC, OC, and dust with AOD 550 nm as the sole predictor variable. Multiple linear regression models were again fit separately for  $\text{PM}_{2.5}$  mass, sulfate, nitrate, EC, OC, and dust, but with the combined AERONET sunphotometer and inversion product as predictor variables and model selection was conducted using the “all possible subset method”. This method constructs models based on all combinations from 1 to k variable models. We select the best model from the combinations based on highest  $R^2$ , lowest RMSE, and Mallows’  $C_p$  statistic that is close to  $k+1$ . Model selection for the Fresno and Bakersfield sites were examined separately and in combination in a “total CA” analysis, which combined data from Fresno, Bakersfield, Modesto, Visalia, and a special DRAGON campaign in late 2012-early 2013 over the region (8 co-located sites with  $\text{PM}_{2.5}$  mass).

All models were cross validated (CV) with 10-fold CV, and we report the CV  $R^2$  and RMSE. Models were fit in R using the `leaps()` library.

## 3 Results

### 4 Content section with R code chunks

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You can add verbatim code snippets without extra styles by using `` `` `` without additional instructions.

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sum <- 1 + 41
```

### 5 Content section with list

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- empty lines
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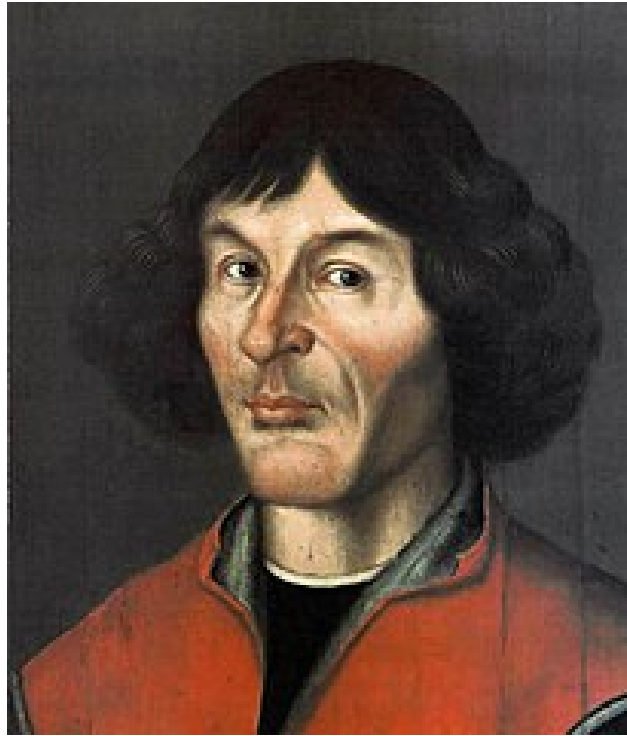
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10    - between each list item

## **6   Examples from the official template**

### **6.1   FIGURES**

When figures and tables are placed at the end of the MS (article in one-column style), please add



**Figure 2.** one column figure

between bibliography and first table and/or figure as well as between each table and/or figure.

### **6.1.1 ONE-COLUMN FIGURES**

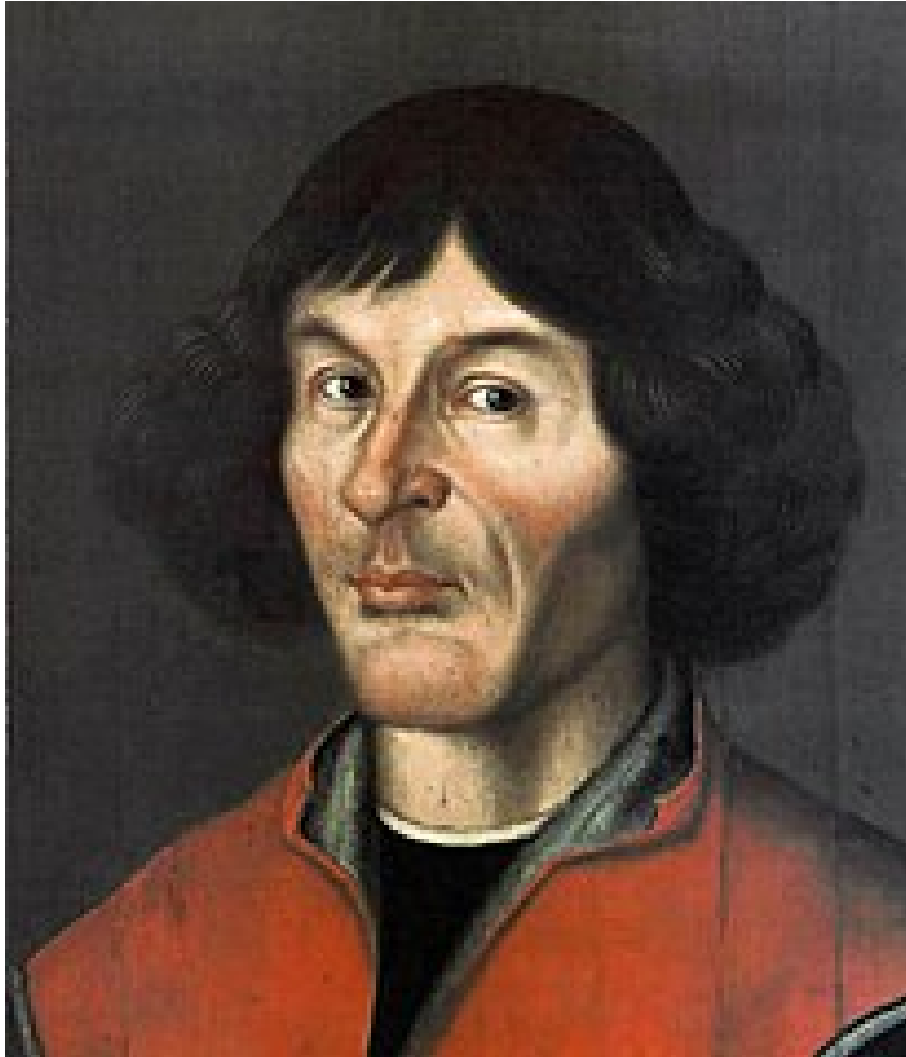
- 5 Include a 12cm width figure of Nikolaus Copernicus from Wikipedia with caption using R Markdown.

### **6.1.2 TWO-COLUMN FIGURES**

You can also include a larger figure.

## **6.2 TABLES**

You can add `\LaTeXtable` in an R Markdown document to meet the template requirements.



**Figure 3.** two column figure

**Table 1.** TEXT

a	b	c
1	2	3

Table Footnotes

**Table 2.** TEXT

a	b	c
1	2	3

Table footnotes

**6.2.1 ONE-COLUMN TABLE**

**6.2.2 TWO-COLUMN TABLE**

**5 6.3 MATHEMATICAL EXPRESSIONS**

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Physical quantities/variables are typeset in italic font (t for time, T for Temperature)

10 Indices which are not defined are typeset in italic font (x, y, z, a, b, c)

Items/objects which are defined are typeset in roman font (Car A, Car B)

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Abbreviations from 2 letters are typeset in roman font (RH, LAI)

Vectors are identified in bold italic font using  $\boldsymbol{x}$

15 Matrices are identified in bold roman font

Multiplication signs are typeset using the LaTeX commands `\times` (for vector products, grids, and exponential notations)

or `\cdot`

The character `*` should not be applied as multiplication sign

## 6.4 EQUATIONS

### 6.4.1 Single-row equation

- 5 Unnumbered equations (i.e. using `$$` and getting inline preview in RStudio) are not supported by Copernicus.

$$1 \times 1 \cdot 1 = 42 \tag{1}$$

$$A = \pi r^2 \tag{2}$$

$$x = \frac{2b \pm \sqrt{b^2 - 4ac}}{2c}. \tag{3}$$

### 6.4.2 Multiline equation

10  $3 + 5 = 8$  (4)

$$3 + 5 = 8 \tag{5}$$

$$3 + 5 = 8 \tag{6}$$

## 6.5 MATRICES

$$\begin{matrix} x & y & z \end{matrix}$$

$$\begin{matrix} x & y & z \end{matrix}$$

$$\begin{matrix} x & y & z \end{matrix}$$

15 **6.6 ALGORITHM**

If you want to use algorithms, you can either enable the required packages in the header (the default, see `algorithms: true`), or make sure yourself that the ~~LaTeX~~ packages `algorithms` and `algorithmicx` are installed so that `algorithm.sty` respectively `algorithmic.sty` can be loaded by the Copernicus template. Copernicus staff will remove all undesirable packages from your LaTeX source code, so please stick to using the header option, which only adds the two acceptable pack-

20 ages.

## 6.7 CHEMICAL FORMULAS AND REACTIONS

For formulas embedded in the text, please use `\chem{ }`, e.g.  $A \rightarrow B$ .

The reaction environment creates labels including the letter R, i.e. (R1), (R2), etc.



```
i ← 10
if i ≥ 5 then
  i ← i − 1
else
  if i ≤ 3 then
    i ← i + 2
  end if
end if
```

---

- \rightarrow should be used for normal (one-way) chemical reactions
- \rightleftharpoons should be used for equilibria
- 5 - \leftrightarrow should be used for resonance structures



6.8 PHYSICAL UNITS

Please use `\unit{}` (allows to save the `math/$` environment) and apply the exponential notation, for example  $3.14\text{ km h}^{-1}$  (using LaTeX mode: `\( 3.14\,, \unit{...} \)`) or  $0.872\text{ ms}^{-1}$  (using only `\unit{0.872\,, m\,, s^{-1}}`).

7 Conclusions

- 15 The conclusion goes here. You can modify the section name with `\conclusions[modified heading if necessary]`.

*Code and data availability.* use this to add a statement when having data sets and software code available

*Sample availability.* use this section when having geoscientific samples available

## Appendix A: Figures and tables in appendices

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### A2 Option 2

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Please add `\clearpage` between each table and/or figure. Further guidelines on figures and tables can be found below.

15 *Author contributions.* M. Franklin conducted analyses and wrote the manuscript. M. Sorek-Hamer conducted analyses and reviewed the manuscript. O. Kalashnikova and D. Diner conceptualized the study. D. Diner edited the manuscript.

*Competing interests.* The authors declare no competing interests.

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