Trends in Seasonal Mean Speciated Aerosol Composition

Jenny Hand$^1$
A. Prenni$^2$, B. Schichtel$^2$, W. Malm$^1$

$^1$CIRA, Colorado State University, Fort Collins, CO
$^2$NPS, ARD, Lakewood, CO/Fort Collins, CO

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Motivation

From 1990 to 2021:

- 91% Decrease in SO$_2$
  EGU: 70% to 48%

- 70% Decrease in NO$_x$
  EGU: 26% to 12%
  Transportation ~ 50%
Status and Trends

• Current concentrations of major aerosol species (2018-2021)

• Trend analysis: 2000-2021, Theil regression, seasonal and regional analysis

• How has PM$_{2.5}$ mass changed and what is contributing to that change?
2018-2021 Annual mean
2002-2021
Regional, Annual Mean

Fine Dust (FD)
Elemental Carbon (EC)
Particulate Organic Matter (POM = 1.8*OC)
Ammonium Nitrate (AN = 1.29*NO3)
Ammonium Sulfate (AS = 1.375*SO4)
2000-2021 Seasonal Mean FM (PM$_{2.5}$) Trends
2000-2021 Seasonal Mean Sulfate Trends

(a) 2000-2021 Winter Sulfate
(b) 2000-2021 Spring Sulfate
(c) 2000-2021 Summer Sulfate
(d) 2000-2021 Fall Sulfate
2000-2021 Seasonal Mean Nitrate Trends
2000-2021 Seasonal Mean Organic Carbon Trends

(a) 2000-2021 Winter OC

(b) 2000-2021 Spring OC

(c) 2000-2021 Summer OC

(d) 2000-2021 Fall OC
2000-2021 Seasonal Mean Elemental Carbon Trends
2000-2021 Seasonal Mean Fine Dust Trends

(a) 2000-2021 Winter Dust

(b) 2000-2021 Spring Dust

(c) 2000-2021 Summer Dust

(d) 2000-2021 Fall Dust
How do these trends reflect changes in emissions?

- EPA National Emission Inventory emissions: $\text{SO}_2$, $\text{NO}_x$, VOC
- NIFC Burn Area
- Large-scale climate variability
Total U.S. SO$_2$ Emissions and Annual Mean Sulfate

Annual U.S. SO$_2$ and Sulfate

Sulfate SO$_2$  SO$_2$ ↓ by 87%  (2002-2021)

- $r = 0.98$
- Slope: $0.070 \pm 0.003 \, \mu g \, m^{-3}$ of sulfate per Mton yr$^{-1}$
- Intercept: $0.48 \pm 0.03 \, \mu g \, m^{-3}$ corresponding to a “background” sulfate
Total U.S. NO\textsubscript{x} Emissions and Annual Mean Nitrate

Annual U.S. NO\textsubscript{x} and Nitrate

Nitrate NO\textsubscript{x} NO\textsubscript{x} ↓ by 70% (2002 to 2021)

\begin{itemize}
  \item r = 0.93
  \item Slope: 0.010 ± 0.001 µg m\textsuperscript{-3} per Mton yr\textsuperscript{-1} emission
  \item Intercept: 0.21 ± 0.02 µg m\textsuperscript{-3}
\end{itemize}
Burn area includes contributions from the entire U.S. and not all OC is due to fire emissions.

The fraction of VOC emissions due to wildfires has increased over the last two decades, from 8% in 2002 to 28% in 2021.
Large-Scale Climate Variability

**ENSO (El Niño Southern Oscillation)**

**El Niño**: westerly flow shifts southward- storms that travel this branch tap into moisture at low latitudes of the eastern Pacific and bring winter precipitation to the Southwest (SW).

**La Niña**: Typical flow (northward) resulting in warmer and dryer conditions over the SW (Sheppard et al. 2002).

**Pacific Decadal Oscillation (PDO)**: leading principal component of monthly SST anomalies in north Pacific Ocean (poleward of 20N): Negative (or cool): similar impacts as La Nina.

The effects of ENSO and the PDO can amplify each other, resulting in increased annual variability in precipitation over the Southwest.
Spring SW Regional Mean FD and March Pacific Decadal Oscillation (PDO)

$r = -0.46$
2002-2021 Seasonal, Regional Mean Fine Mass Trends

FM Regional Mean Trend

Trend (% yr⁻¹)

Winter  Spring  Summer  Fall  Annual

Regions: Alaska  Northwest  California  Southwest  Central US  Midsouth  Northeast  Southeast  Caribbean

Regions West to East →

* p< 0.05
Summary

Annual U.S. Trends (2002-2021)

<table>
<thead>
<tr>
<th>Component</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>FM</td>
<td>-1.8% yr^{-1} *</td>
</tr>
<tr>
<td>Sulfate</td>
<td>-6.1% yr^{-1} *</td>
</tr>
<tr>
<td>Nitrate</td>
<td>-2.7% yr^{-1} *</td>
</tr>
<tr>
<td>EC</td>
<td>-2.2% yr^{-1} *</td>
</tr>
<tr>
<td>FD</td>
<td>-1.3% yr^{-1} *</td>
</tr>
<tr>
<td>OC</td>
<td>-0.9% yr^{-1}</td>
</tr>
</tbody>
</table>

* Statistically significant (p<0.05)

- Regulatory activity has been successful in reducing FM, especially in the East
- Unregulated anthropogenic emissions, such as oil and gas and agricultural emissions, are likely influencing FM trends
- Impacts from natural sources- such as dust and smoke- are likely going to increase with climate change
Acknowledgments

Funding:
NPS Air Resources Division

Data:
IMPROVE
(http://views.cira.colostate.edu/fed/)

EPA National Emissions Inventory (NEI)
(https://www.epa.gov/air-emissions-inventories/air-pollutant-emissions-trends-data)

NIFC National Interagency Fire Center
(https://www.nifc.gov/fire-information/statistics/wildfires)

NOAA National Centers for Environmental Information (NCEI)
(https://www.ncei.noaa.gov/access/monitoring/pdo/).
Regional Mean Summer
(a) Alaska

Regional Mean Summer
(b) Hawaii

Regional Mean Summer
(c) Northwest

Regional Mean Summer
(d) California

Regional Mean Summer
(e) Southwest

Regional Mean Summer
(f) Central US

Regional Mean Summer
(g) MidSouth

Regional Mean Summer
(h) Northeast

Regional Mean Summer
(i) Southeast

Regional Mean Summer
(k) Virgin Islands

Regional Mean Summer
(ij) US

FD
EC
OC
Nitrate Ion
Sulfate Ion