Multiyear Measurements of Aerosols at Storm Peak Laboratory, a Colorado Mountain-Top Site

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Located on Steamboat Springs Ski Resort
Elevation: 3220 m (10,530 ft)
Pressure: ~690 mb
In cloud ~25% of time in winter
Mixed Phase Clouds
9 Person Bunkhouse
Full Kitchen, Running Water
Facility and Guest Instruments
Wet Chemistry Lab
## Climate Emission Drivers

<table>
<thead>
<tr>
<th>Emitted Compound</th>
<th>Radiative Forcing by Emissions and Drivers</th>
<th>Level of Confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CO₂</strong></td>
<td></td>
<td>Very High</td>
</tr>
<tr>
<td><strong>CH₄</strong></td>
<td></td>
<td>High</td>
</tr>
<tr>
<td><strong>Aerosols and precursors</strong></td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Mineral Dust</td>
<td>Sulphate</td>
<td></td>
</tr>
<tr>
<td>Nitrate</td>
<td>Black Carbon</td>
<td></td>
</tr>
<tr>
<td>Organic Carbon</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cloud adjustments due to aerosols</strong></td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td><strong>Man’s impact relative to the year 1750</strong></td>
<td></td>
<td>High</td>
</tr>
</tbody>
</table>

### Radiative Forcing relative to 1750 (W m²)

- 1950
- 1980
- 2011

- 1950
- 1980
- 2011
Climate Change

Aerosols

Wildfires

Dust Events

Water (Drought)
Increasing Wildfires in Western U.S.

Wildfire activity strongly associated with spring snowmelt timing, which is sensitive to changes in temperature.

Source: Dennison et al., GRL, 2014

Source: Westerling et al., Science 2006
Increasing Dust in Western U.S.

Neff et al., 2008; Nature Geoscience

“dust load levels increased by 500% above the late Holocene average following the increased western settlement of the U.S. during the 19th century. ...caused by the expansion of livestock grazing in the early 20th century.”

Painter et al., 2007, Nature

Frequency of dust deposition and radiative forcing doubled when the Colorado Plateau experienced intense drought.
Visible Multifilter Rotating Shadowband Radiometer (vis-MFRSR)
USDA monitoring network
Data from 1999-2013
Calibrated using Langley plots (Michalsky et al. 2001)
Cloud screening (Michalsky et al., 2013)
Daily AOD calculated from measurements that passed cloud screening

TSI integrating nephelometer (Model 3563, St. Paul, Minnesota)
Data from 2011-2014
Calibrated with particle-free air and CO₂
Zero checks on filtered air were performed hourly

Ångström Exponent

$$\alpha_{\text{Inst}} = \ln\left(\frac{\bar{\sigma}_{\text{sp},2}}{\bar{\sigma}_{\text{sp},1}}\right)/\ln\left(\frac{1}{2}\right)$$

MFRSR $\lambda_1=500$ nm, $\lambda_2=870$ nm;
Nephelometer $\lambda_1=450$ nm, $\lambda_2=700$ nm.
Seasonality of AOD at Storm Peak Laboratory
1999-2013
<table>
<thead>
<tr>
<th>Start Time (UTC)</th>
<th>End Time (UTC)</th>
<th>Origin</th>
<th>MFRSR Data Available</th>
<th>Nephelometer Data Available</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 27, 2000</td>
<td>August 6, 2000</td>
<td>NW US 1</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>June 15, 2002</td>
<td>July 10, 2002</td>
<td>Hayman</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>July 30, 2002</td>
<td>Aug 3, 2002</td>
<td>AR, OR, CA</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Sept 4, 2006</td>
<td>Sept 9, 2006</td>
<td>CA</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Aug 29, 2009</td>
<td>Sept 3, 2009</td>
<td>Station Fire</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>June 4, 2011 0700</td>
<td>June 8, 2011 0000</td>
<td>Wallow</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>June 30, 2012 0700</td>
<td>July 5, 2012 0700</td>
<td>Waldo/High Park</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

Identified by MODIS - Val Martin et al., ACP, 2013
Observation of Fires at Storm Peak Laboratory
1999-2013

Decreasing Particle Size

Angstrom Exponent

AOD

- Summer, DOY 170–225
- All DOY
- NW US 1
- NW US 3
- AZ_OR_CA

CA
Wallow
Station
Hayman
Observation of Fires at Storm Peak Laboratory
2011-2013

Scattering (550 nm)

Angstrom Exponent (450nm/700nm)

All data
Summer (DOY 170-225)
Smoke events
## Dust observed at Storm Peak Laboratory

<table>
<thead>
<tr>
<th>Start Time (UTC)</th>
<th>End Time (UTC)</th>
<th>MFRSR Data Available</th>
<th>Nephelometer Data Available</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DUST EVENT</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>April 15, 2001 1200</td>
<td>April 16, 2001 1200</td>
<td>Asian</td>
<td>X</td>
</tr>
<tr>
<td>April 27, 2006</td>
<td>May 1, 2006</td>
<td>Asian</td>
<td>X</td>
</tr>
<tr>
<td><strong>Regional Events</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>April 19, 2007 1900</td>
<td>April 20, 2007 0700</td>
<td>201</td>
<td>X</td>
</tr>
<tr>
<td>April 16, 2008 1900</td>
<td>April 17, 2008 0700</td>
<td>219</td>
<td>X</td>
</tr>
<tr>
<td>April 4, 2009 0500</td>
<td>April 5, 2009 0700</td>
<td>206</td>
<td>X</td>
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<tr>
<td>April 13, 2010 0800</td>
<td>April 13, 2010 1300</td>
<td>188</td>
<td>X</td>
</tr>
<tr>
<td>May 22, 2010 0900</td>
<td>May 24, 2010 1500</td>
<td>192</td>
<td>X</td>
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<tr>
<td>April 22, 2011 2200</td>
<td>April 24, 2011 0000</td>
<td>258</td>
<td>X</td>
</tr>
<tr>
<td>May 1, 2011 1200</td>
<td>May 4, 2011 0600</td>
<td>279</td>
<td>X</td>
</tr>
<tr>
<td>March 7, 2012 0900</td>
<td>March 8, 2012 0900</td>
<td>197</td>
<td>X</td>
</tr>
<tr>
<td>March 20, 2012 0900</td>
<td>March 22,2012 0000</td>
<td>193</td>
<td>X</td>
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<tr>
<td>March 27, 2012 1800</td>
<td>March 29, 2012 1200</td>
<td>207</td>
<td>X</td>
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<tr>
<td>April 2, 2012 2000</td>
<td>April 3, 2012 1000</td>
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<tr>
<td>April 7, 2012 1800</td>
<td>April 11, 2012 1400</td>
<td>201</td>
<td>X</td>
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<tr>
<td>May 20, 2012 0000</td>
<td>May 23, 2012 1400</td>
<td>213</td>
<td>X</td>
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<tr>
<td>May 24, 2012 1400</td>
<td>June 1, 2012 0000</td>
<td>217*</td>
<td>X</td>
</tr>
<tr>
<td>May 25, 2013 0000</td>
<td>May 25, 2013 1800</td>
<td>207</td>
<td>X</td>
</tr>
</tbody>
</table>

*Average of 3 consecutive dust events at CSAS
Observation of Dust at Storm Peak Laboratory
1999-2013

AOD

Angstrom Exponent

- Dust Peak, DOY 91–136
- All DOY
- Regional Dust Events
- 2001 Asian Dust
- 2006 Asian Dust
Observation of Dust at Storm Peak Laboratory
2011-2013

![Graph showing Angstrom Exponent (450 nm/700 nm) vs. Scattering (550 nm). The graph includes data points for all measurements, dust peak (DOY 91-136), and dust events.](image-url)
Summary

Dataset highlights wide scale implications of a warmer drier climate on aerosol loading in the Western U.S.

Spring AOD is dominated by dust aerosols

Summer AOD dominated by aerosols associated with biomass-burning

Supported with nephelometer measurements at surface

Median contribution to spring and summer AOD by dust and biomass-burning is comparable.

Summer AOD correlates with large scale aridity
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References:


