Aerosols & Climate Change

Presentation by Kristen Yeager
Introduction—Aerosols

What are they?

Solid or liquid particles suspended in air

Where do they come from?

(1) Emitted directly
(2) Formed from pollution gases

Why are they important?

(1) Absorb sunlight—black carbon
(2) Scatter sunlight—sulfates
Introduction—Aerosols

What do we know?
The global mean effect of aerosols is cooling

What are we unsure about?
The magnitude of this cooling
## Introduction—Aerosols

### Radiative Forcing Components

<table>
<thead>
<tr>
<th>RF Terms</th>
<th>RF values (W m⁻²)</th>
<th>Spatial scale</th>
<th>LOSU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-lived greenhouse gases</td>
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<tr>
<td>Long-lived greenhouse gases</td>
<td>1.66 [1.49 to 1.83]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>$\text{CO}_2$</td>
<td></td>
<td></td>
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<tr>
<td>$\text{N}_2\text{O}$</td>
<td>0.48 [0.43 to 0.53]</td>
<td>Global</td>
<td>High</td>
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<tr>
<td>$\text{CH}_4$</td>
<td>0.16 [0.14 to 0.18]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>Halocarbons</td>
<td>0.34 [0.31 to 0.37]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>Ozone</td>
<td></td>
<td></td>
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<tr>
<td>Stratospheric</td>
<td>-0.05 [-0.15 to 0.05]</td>
<td>Continental to global</td>
<td>Med</td>
</tr>
<tr>
<td>Tropospheric</td>
<td>0.35 [0.25 to 0.65]</td>
<td>Continental to global</td>
<td>Med</td>
</tr>
<tr>
<td>Stratospheric water vapour from $\text{CH}_4$</td>
<td>0.07 [0.02 to 0.12]</td>
<td>Global</td>
<td>Low</td>
</tr>
<tr>
<td>Surface albedo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land use</td>
<td>-0.2 [-0.4 to 0.0]</td>
<td>Local to continental</td>
<td>Med - Low</td>
</tr>
<tr>
<td>Black carbon on snow</td>
<td>0.1 [0.0 to 0.2]</td>
<td>Local to continental</td>
<td>Med - Low</td>
</tr>
<tr>
<td>Total aerosol</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct effect</td>
<td>-0.5 [-0.9 to -0.1]</td>
<td>Continental to global</td>
<td>Med - Low</td>
</tr>
<tr>
<td>Cloud albedo effect</td>
<td>-0.7 [-1.8 to -0.3]</td>
<td>Continental to global</td>
<td>Low</td>
</tr>
<tr>
<td>Linear contrails</td>
<td>0.01 [0.003 to 0.03]</td>
<td>Continental</td>
<td>Low</td>
</tr>
<tr>
<td>Natural</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Solar irradiance</td>
<td>0.12 [0.06 to 0.30]</td>
<td>Global</td>
<td>Low</td>
</tr>
<tr>
<td>Total net anthropogenic</td>
<td>1.6 [0.6 to 2.4]</td>
<td>Global</td>
<td></td>
</tr>
</tbody>
</table>

**Figure:** This figure summarizes the radiative forcing (RF) associated with aerosols. RFs are expressed in W m⁻² as the change in solar radiation due to changes in the concentration of absorbing and scattering aerosol species. LOSU indicates the level of uncertainty in the data.
Introduction—Aerosols

How have aerosol concentrations changed from preindustrial to present times?

- BC 6 times higher
- Sulfates 3-4 times higher
Present time and preindustrial emissions of black carbon (A), organic carbon (B), and sulfate (C).
Introduction—Aerosols

☀ At the surface, BC and sulfates cause cooling
Since the Earth’s energy balance is determined at the TOA, there is less aerosol cooling of the Earth system

☀ At the top of the atmosphere, sulfates have a cooling effect and BC has a warming effect
Introduction—Aerosols

How do aerosols affect climate?
Global aerosol models: simulate change in aerosol abundance due to human activity

Observational data from satellites: derive the change in atmospheric optical depth (AOD) due to human activity

*Radiative forcing calculated through radiative transfer models
Observational based studies consistently yield a larger aerosol cooling than do model based studies.

What accounts for the large discrepancy between the two methods??
Methods

- Estimates from both a global aerosol AOD and an observational method used to find consistency.

- Observational method unable to assess AOD occurring over desert and snow/ice-covered regions.
Hypothesis: Discrepancy between model and observation-based results is accountable to anthropogenically induced changes in aerosol optical properties
Methods

Seven simulations were run:

- Oa—does not take into account direct aerosol effect in areas of missing MODIS data
- Ob—uses model data in regions with missing MODIS data
- Oc—Uses modeled aerosol optical properties and anthropogenic change
- Mc\textsubscript{ext}—BC externally mixed
- Mc\textsubscript{int}—BC internally mixed
- Mb’—uses observation-based approach with constant aerosol optical properties
- Mb—uses observation-based approach with observed aerosol optical properties
Methods

Radiative forcing (the change in solar irradiance at TOA) calculated for two scenarios in each simulation:

☀️ “Cloud Mask”: does not take into account radiative forcings in cloudy regions

☀️ “All Sky”: radiative forcing in both clear and cloudy regions taken into account
Results

Simulation returned a forcing of \(-0.42\) W/m\(^2\) which is similar to \(M_{\text{int}}\) and \(M_{\text{ext}}\). Simulation \(O_{\text{c}}\) returned an even smaller forcing of \(-0.37\) W/m\(^2\) which is almost identical to \(M_{\text{int}}\) and \(M_{\text{ext}}\). Simulation \(O_{\text{b}}\) returned a forcing of \(-0.48\) W/m\(^2\), which is even closer to \(O_{\text{c}}\).
The discrepancy between forcings in the model and the observation-based method can be resolved by:

- Including aerosols in regions without MODIS retrievals
- Including change in the aerosol optical properties from preindustrial to present time
Conclusion

Anthropogenically induced changes in the aerosol optical properties cause the discrepancy between model-based and observation-based results, rather than the assumed aerosol optical properties in either the modeling or observational studies.

Study also suggests that the direct aerosol effect offsets only 10% of the radiative forcing due to increases in GHG.
This study narrows the uncertainty range of radiative forcing due to aerosols, but many questions still remain.

- What are the indirect effects of aerosols on energy balance?
- How do aerosols alter cloud brightness, abundance, and geometry?
References

1. G. Myhre, Consistency between satellite-derived and modeled estimates of the direct aerosol effect, *Science* 325, 187; published online 18 June 2009 [10.1126/science.1174461].

2. J. Quaas, Smoke and climate change, *Science* 325, 153; published online 18 June 2009 [10.1126/science.1176991].