High summertime aerosol loading in the Arctic: sources and radiative effects

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Current issues regarding Arctic summer aerosols

- There are still relatively few studies on Arctic summertime aerosols.
- The magnitude and sign of radiative forcing by Arctic summer aerosols are still currently not well known.
- Does pollution play any role in the Arctic climate during summer?
- If so, to what extent? What potential environmental effects could result from a summer pollution episode?
Alaskan Arctic
Summertime atmospheric measurements made at Barrow
High aerosol loading also present at other Arctic sites.
High altitude back trajectories for pollution periods
Potential source regions
Presence of absorbing aerosols in the Arctic summer
### Aerosol Chemistry during selected Episodes

<table>
<thead>
<tr>
<th>Event date</th>
<th>Max $\sigma_a$ (Mm$^{-1}$)</th>
<th>Ratio of polluted to clean conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>K$^+$</td>
</tr>
<tr>
<td>19 Jul 1998</td>
<td>1.16</td>
<td>2.4</td>
</tr>
<tr>
<td>20 Jul 1998</td>
<td>1.02</td>
<td>5.4</td>
</tr>
<tr>
<td>02 Aug 1999</td>
<td>1.11</td>
<td>2.4</td>
</tr>
<tr>
<td>06 Aug 1999</td>
<td>2.94</td>
<td>12.0</td>
</tr>
<tr>
<td>07 Aug 1999</td>
<td>1.60</td>
<td>12.0</td>
</tr>
<tr>
<td>10 Aug 1999</td>
<td>4.62</td>
<td>3.6</td>
</tr>
<tr>
<td>12 Aug 1999</td>
<td>2.35</td>
<td>3.6</td>
</tr>
<tr>
<td>23 Jul 2001</td>
<td>1.01</td>
<td>1.6</td>
</tr>
</tbody>
</table>
8-day back trajectories for days with the highest light absorption coefficients
NOAA-14 AVHRR image for 22:39 UTC August 1, 1999
Potential Implications: Direct Radiative Effect

\[ \omega_c = \frac{2\alpha}{[\beta \cdot (1-\alpha)^2+2\alpha]} \]

Where \( \omega_c \) is the critical single scattering albedo, \( \beta \) is the upscatter fraction and \( \alpha \) is the surface albedo.

Radiative forcing index \( \Delta \omega = \omega_0 - \omega_c \)

Aerosol impact: cooling if \( \Delta \omega > 0 \)

warming otherwise
Radiative forcing index $\Delta \omega$ as a function of surface albedo for very absorbing aerosols $\Delta \omega_{\text{abs}}$ (with $\omega_o < 0.88$) and scattering aerosols $\Delta \omega_{\text{sca}}$ (with $\omega_o > 0.95$)

<table>
<thead>
<tr>
<th>Measured surface albedo (%)</th>
<th>$N_\alpha$ (%)</th>
<th>$\Delta \omega_{\text{abs}}$</th>
<th>$\Delta \omega_{\text{sca}}$</th>
<th>$\Delta \omega_{\text{abs}} - \Delta \omega_{\text{sca}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha &lt; 25$</td>
<td>71</td>
<td>$0.23 \pm 0.17$</td>
<td>$0.38 \pm 0.14$</td>
<td>$-0.15$</td>
</tr>
<tr>
<td>$25 &lt; \alpha &lt; 50$</td>
<td>10</td>
<td>$0.008 \pm 0.08$</td>
<td>$0.12 \pm 0.055$</td>
<td>$-0.11$</td>
</tr>
<tr>
<td>$50 &lt; \alpha &lt; 75$</td>
<td>13</td>
<td>$-0.24 \pm 0.11$</td>
<td>$0.0033 \pm 0.019$</td>
<td>$-0.24$</td>
</tr>
<tr>
<td>$75 &lt; \alpha &lt; 100$</td>
<td>6</td>
<td>$-0.24 \pm 0.078$</td>
<td>$-0.033 \pm 0.011$</td>
<td>$-0.21$</td>
</tr>
</tbody>
</table>
The top of the atmosphere aerosol direct radiative forcing

\[ \Delta F^{TOA} = -D S_0 T^2_{at} (1-A_c) \omega_o \beta \tau \{ (1-\alpha)^2 - (2\alpha/\beta)[(1/\omega_o)-1] \} \]

- Haywood and Shine [1995]

Where \( D \) is the fractional day length, \( T_{at} \) is the atmospheric transmission and \( A_c \) is fractional cloud amount
Summer TOA direct radiative forcing as a function of aerosol single scattering albedo.
Aerosol radiative forcing at the surface

\[ \Delta F_{SRF} = F_{NETSW}^{SRF} - F_{NETSW}^{SRF(0)} \]

where \( F_{NETSW}^{SRF} \) is net shortwave flux with atmospheric aerosol and \( F_{NETSW}^{SRF(0)} \) is the aerosol-free net shortwave flux.

\( F_{NETSW}^{SRF(0)} \) obtained from a radiative transfer model - Richiazzi et al. (1998)
Surface aerosol forcing

![Graph showing the relationship between simulated and measured surface aerosol forcing.]

\[ F_{\text{netsw}}^{\text{SRF}} \text{ (simulated)} = 1.01 F_{\text{netsw}}^{\text{SRF}} \text{ (measured)} \]

\[ r^2 = 0.98 \]

\[ \Delta F_{\text{SRF}} = -153 \pm 30 \text{ W m}^{-2} \]

\[ r^2 = 0.77 \]
Although the Arctic generally exhibit low aerosol burden in the summer, cases of high loading occur 10±4 days. The frequency of transport from Russia is dominant for observed pollution cases, with 45% of the air mass trajectories originating from this sector. The days with the highest levels of aerosol absorption are associated with smoke from wild fires. Although a warming aerosol effect is facilitated by a bright surface and low aerosol single scattering albedo, we observe that even with a low surface albedo in the summer, $\Delta F_{TOA}$ turns positive for $\omega_0 \leq 0.85$. The surface radiative forcing ranges between $-3.2 \text{ W m}^{-2}$ and $-29 \text{ W m}^{-2}$ for observed cases of aerosol optical depth.
What still needs to be done

- Additional measurements needed to:
  - Further identify the chemical composition of summertime pollutants: What is the possibility of the presence of V, Mn, SO$_4$, Pb, Zn Cd, Cu?
  - Extend study to other polar sites
  - Investigate possible effects on clouds
  - Integrating these observations into climate and air quality models to help improve their representations of Arctic summertime conditions
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