Contributions to Pliocene Arctic warmth from removal of anthropogenic aerosol

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Arctic climate during the Pliocene

Mid-Pliocene warm period: 3 – 3.3 Ma

Ts-Arctic: > 5 °C, up to ~20°C warmer

CO₂: 405 ppm
Maximum solar insolation: ~0.5 W/m² more annual insolation than present
CCSM4 simulations

Enhanced warming around the Greenland and Canadian Arctic

Simulated ΔT

Proxy ΔT

Potential ΔT mismatch due to too much sea ice in CCSM simulation

Rosenbloom et al., 2013
Terrestrial warming from removing the Arctic sea ice

What contributes to reduced Arctic sea ice during the Pliocene?

Ballantyne et al, 2013
Warming caused by aerosol-cloud indirect effect?

- Using CCSM3, reduction of number of cloud condensation nuclei (CCN) and increasing droplet size create a significant global warming effect for other geological time periods (Kiehl and Shields, 2013)

- CAM4: prescribed CCN = 75/cm³ over the sea ice, droplet size of liquid = 14 μm

- CAM5-MAM: prognostic CCN from simulating aerosol particle nucleation and activation
**Experiment setup**

**Coupled Pliocene simulation (Rosenbloom et al., 2013)**

<table>
<thead>
<tr>
<th>CAM5.3-Slab (CESM1.2) 1 °C resolution</th>
<th>Common boundary conditions</th>
<th>Emission</th>
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</thead>
<tbody>
<tr>
<td>Plio-preind</td>
<td>Topography; Vegetation; $\text{CO}_2=405 \text{ ppm};$ Icesheet reconstructions; Ocean heat flux;</td>
<td>Year-1850 emission</td>
</tr>
<tr>
<td>Plio-2000</td>
<td></td>
<td>Year-2000 anthropogenic emission with Year-1850 natural emission</td>
</tr>
</tbody>
</table>

**Note:** Black carbon emission is kept the same.
Changes in CCN from polluted present-day to pristine Pliocene environment

1. Less CCN in CAM5 simulations than those prescribed in CAM4
2. Largest reduction of CCN in circum-Arctic region from Plio-2000 to Plio-preind
Arctic responses

Plio-preind:
• 2-5 °C warmer than the CCSM4 Pliocene control between 60° - 90°N (1-1.5 °C warmer in Plio-2000)

Plio-preind:
• Nearly sea ice free Arctic during the fall season
Role of aerosol-cloud effect: which season/month?

1. Earliest ice area reduction occurs during July

2. Good correspondence between July sea ice changes and changes during the following months from August to December

→ Importance of summer melting on determining the annual sea ice response
Accelerated sea ice melting in plio-preind during July

Faster sea ice retreating rate in Plio-preind during July
July cloud responses

- Contour: cloud droplet concentration (#/cm³ at interval of 1/cm³, Dash line: negative)
- Shaded: TOA cloud forcing difference (Plio-preind minus Plio-2000)
- Hatched: July sea ice coverage in Plio-preind

Positive anomalies of cloud forcing from reduction of low clouds and greater high clouds

Shaded: Cloud fraction

Contour: cloud droplet concentration (#/cm³ at interval of 1/cm³, Dash line: negative)
Shaded: Cloud fraction
Mechanism

Modern emission regime:
More CCN $\rightarrow$
more summer low clouds over the open ocean $\rightarrow$
shortwave cloud cooling

Pristine air regime:
Less CCN $\rightarrow$
less summer low clouds and more high clouds over the open ocean $\rightarrow$
reduced shortwave cooling
Cloud forcing primarily occurs during the July and August.

Cloud-aerosol effect

Melting due to feedbacks
Summary

* CAM5-slab simulates warmer Pliocene Arctic climate possibly due to better representation of CCN

* Pliocene Arctic warmth may partially come from pristine atmospheric conditions through reduction of summer cloudiness surrounding the sea ice edges
Questions?

Giant high Arctic camels (middle Pliocene)
Role of aerosol-cloud effect: which season/month?

Net TOA Cloud forcing: net radiation\textsubscript{cloudy sky} minus net radiation\textsubscript{clear sky}

Annual mean

Plio-Preind minus Plio-2000

Amplified annual responses to forcings at intraannual time-scale
Contributors to warming

\[ \Delta T = \Delta T_{H-\text{transport convergence}} + \Delta T_{\text{albedo}} + \Delta T_{\text{emissivity}} + \Delta T_{\text{synergy}} \]

Positive feedback loop: Sea ice melting $\rightarrow$ Enhanced evaporation $\rightarrow$ Latent heat release $\rightarrow$ Warming and melting

$< 3\%$ change in aerosol optical depth at visible band
Global responses

Plio-preind – pre-industrial control

$T_{s\text{-global mean}} = 289.6K$, $\sim 3^\circ$C warmer than 1850 simulation and 1.6 $^\circ$C warmer than Pliocene control