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NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

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Contributions to Pliocene Arctic warmth from removal of anthropogenic aerosol

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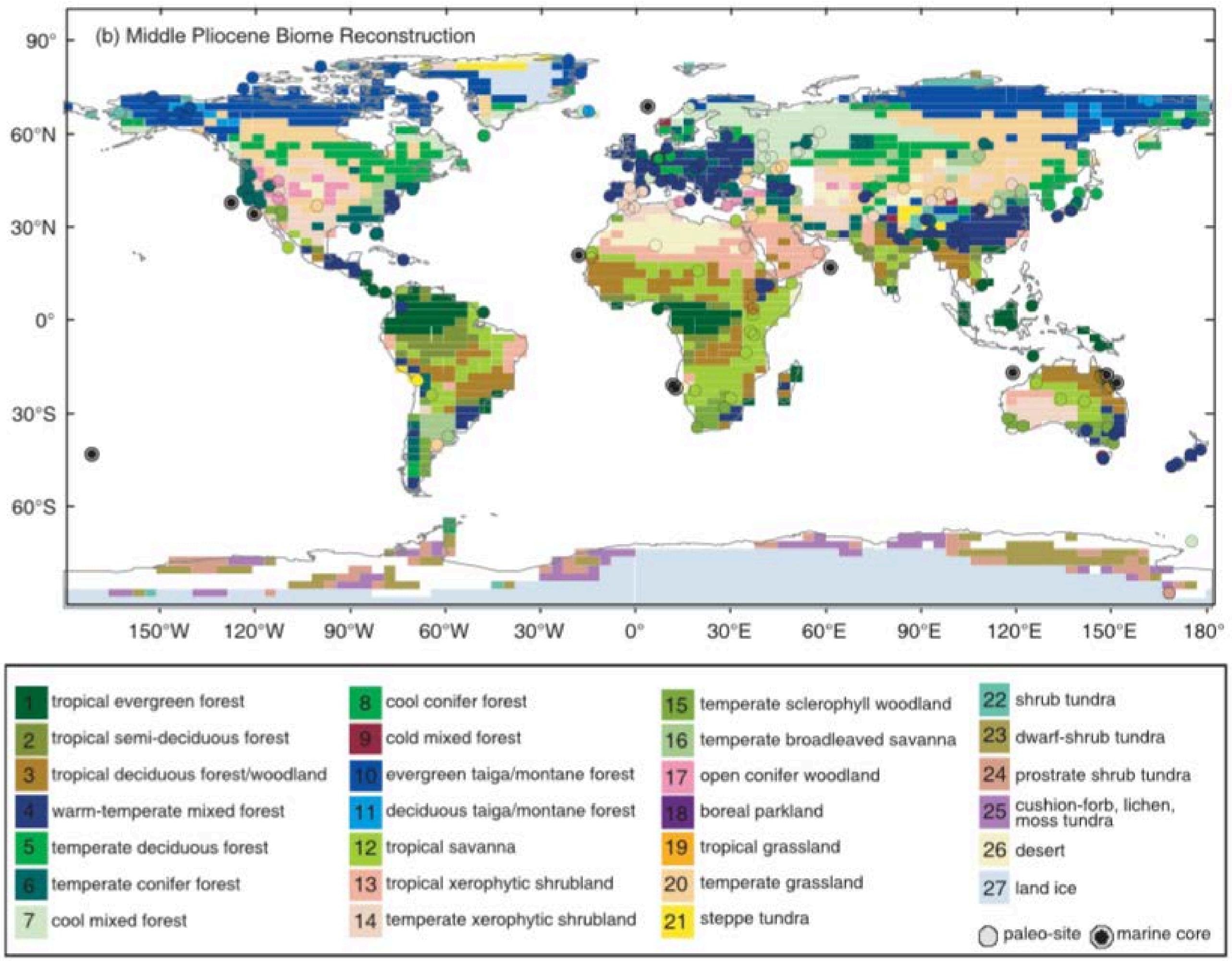
Arctic climate during the Pliocene



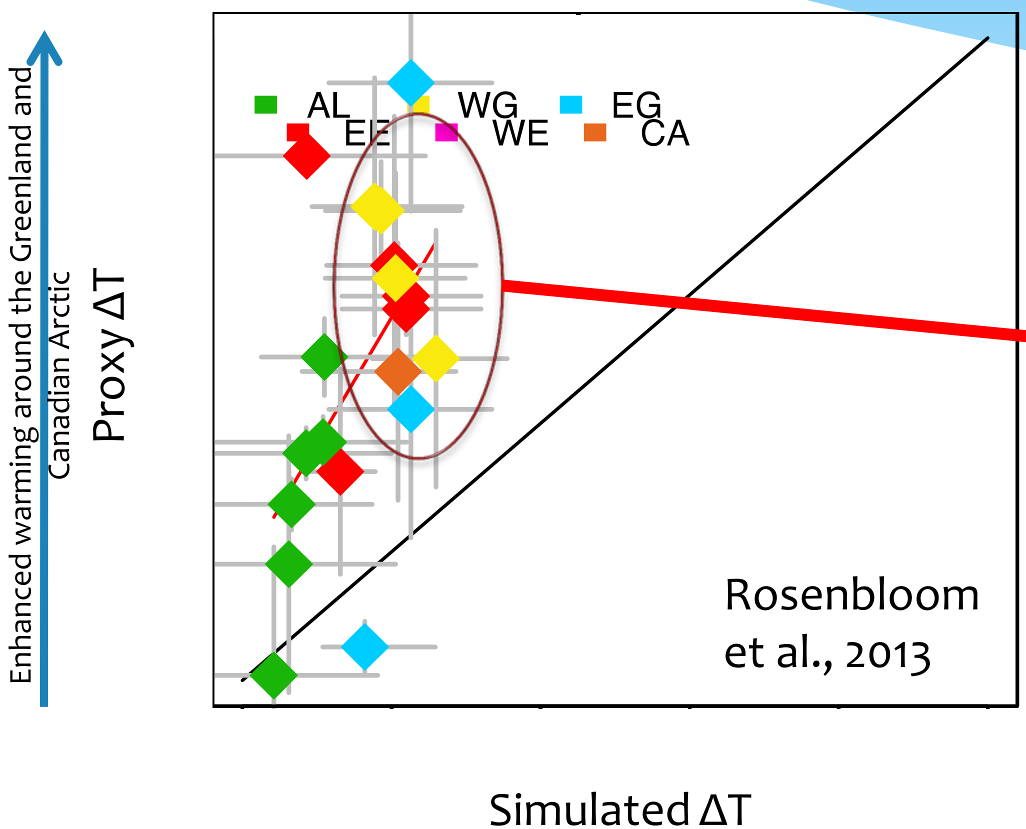
Mid-Pliocene warm period: 3 – 3.3 Ma

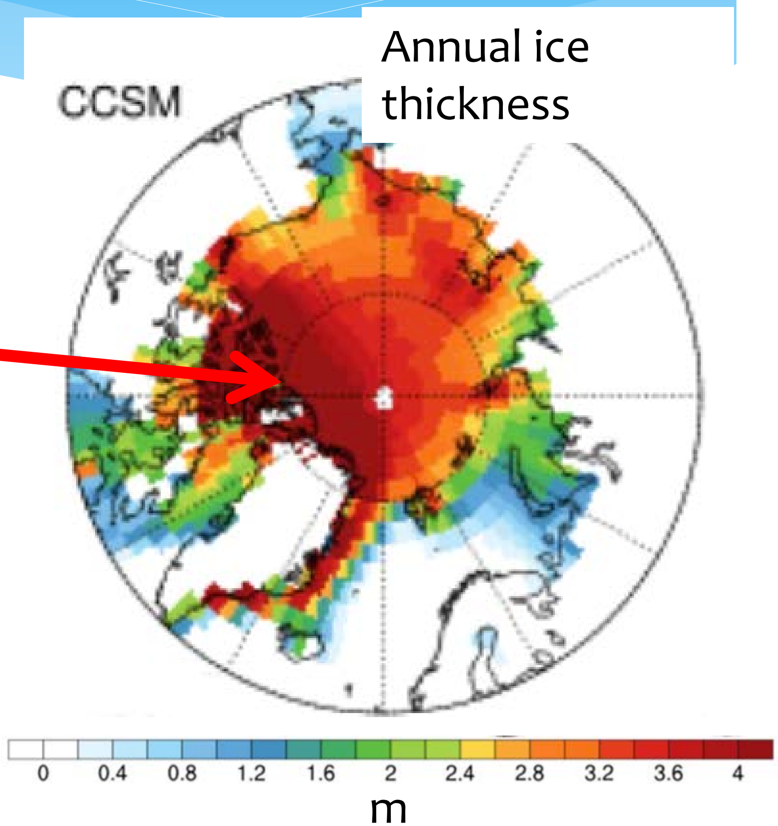
Ts-Arctic: > 5 °C, up to ~20°C warmer

CO_2: 405 ppm

Maximum solar insolation: ~0.5 W/m^2 more annual insolation than present

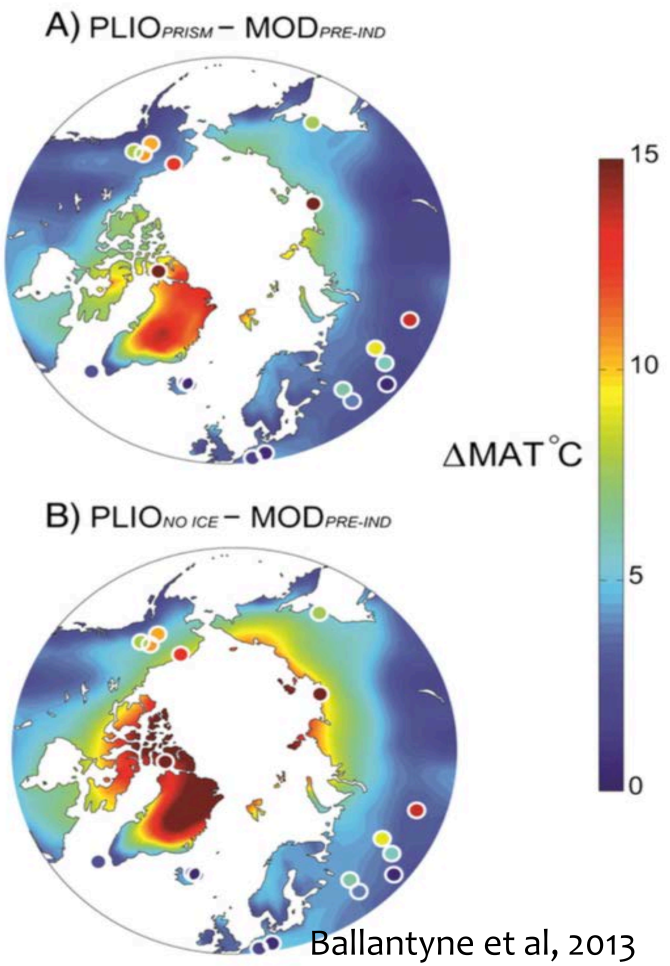
CCSM4 simulations





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

Terrestrial warming from removing the Arctic sea ice

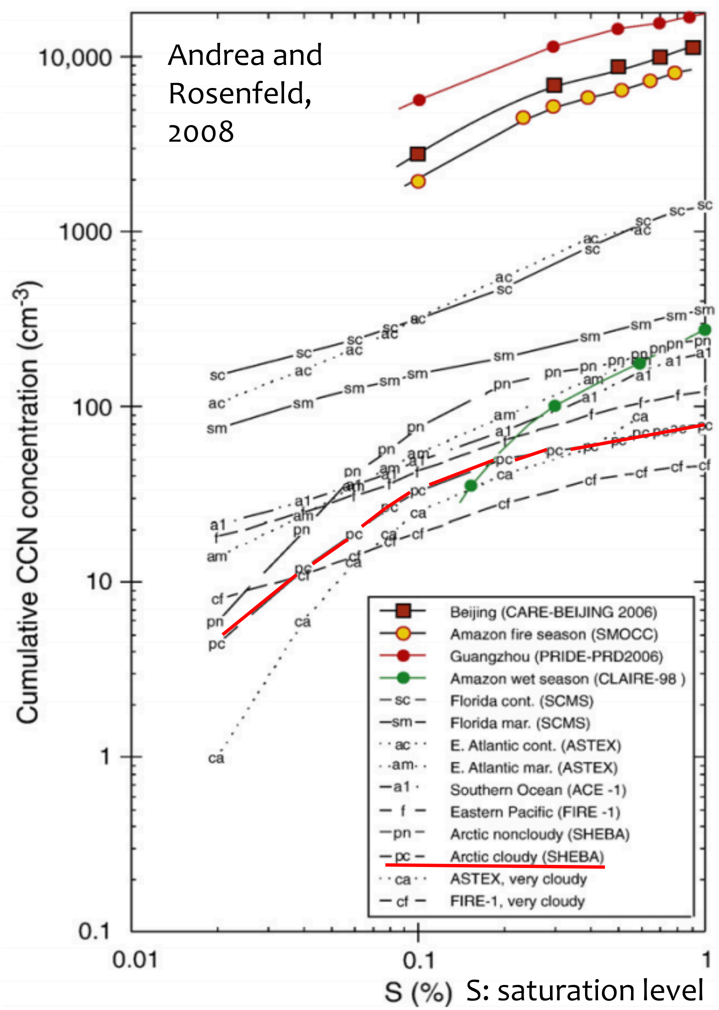


Ballantyne et al, 2013

What contributes to reduced Arctic sea ice during the Pliocene?

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)

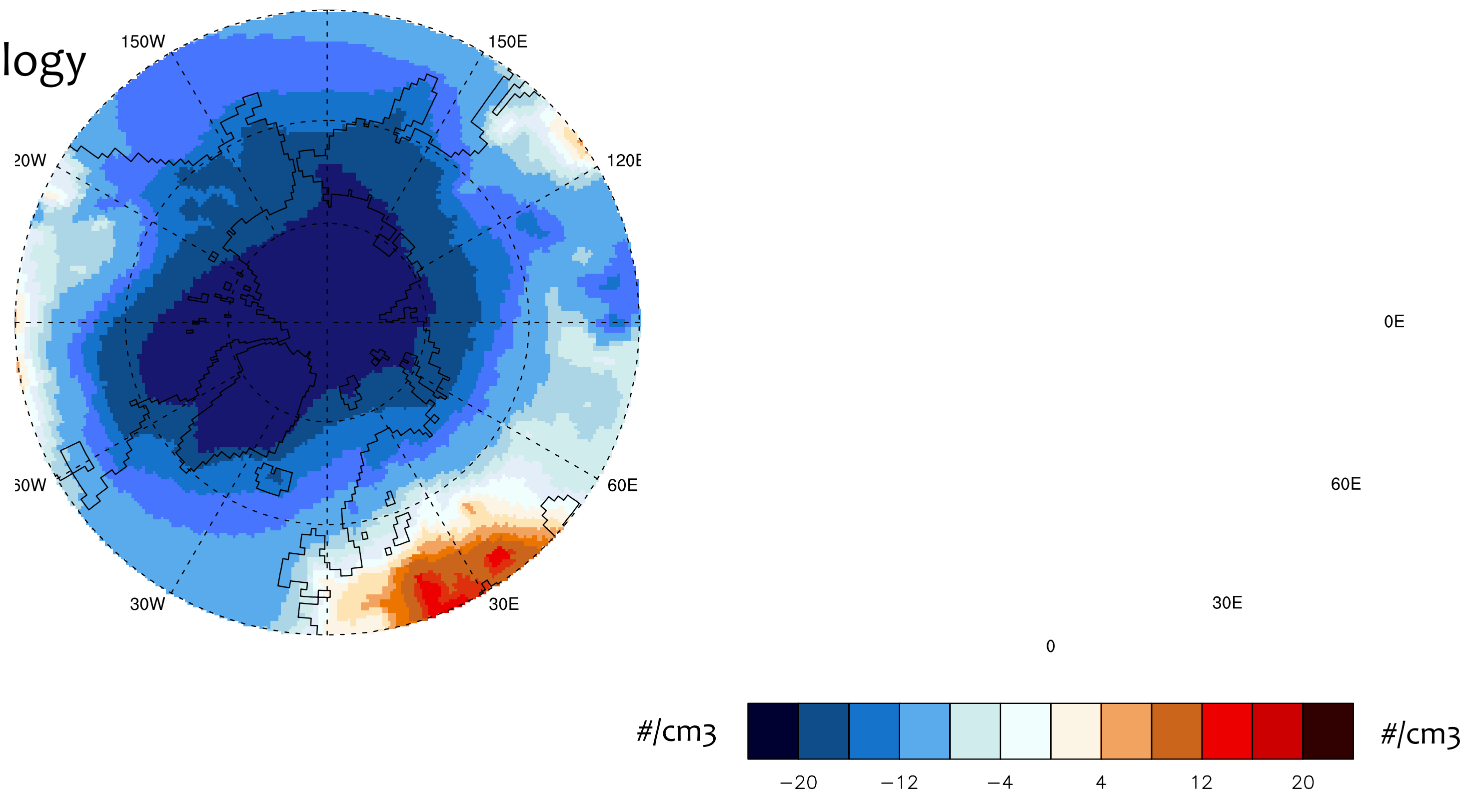
↓

CAM5.3-Slab (CESM1.2) 1 °C resolution	**Common boundary conditions**	**Emission**
Plio-preind	Topography; Vegetation; CO_2=405 ppm; Icesheet reconstructions; Ocean heat flux;	Year-1850 emission
Plio-2000		Year-2000 anthropogenic emission with Year-1850 natural emission

Note: Black carbon emission is kept the same.

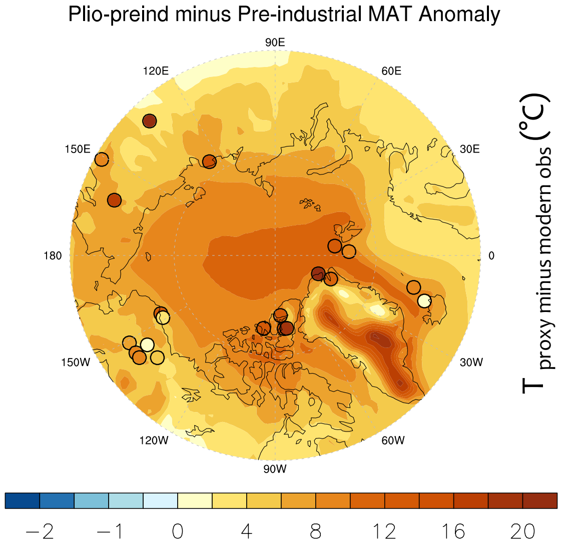
Changes in CCN from polluted present-day to pristine Pliocene environment

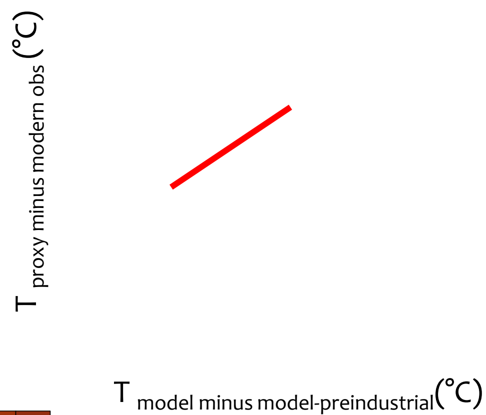
Annual climatology



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

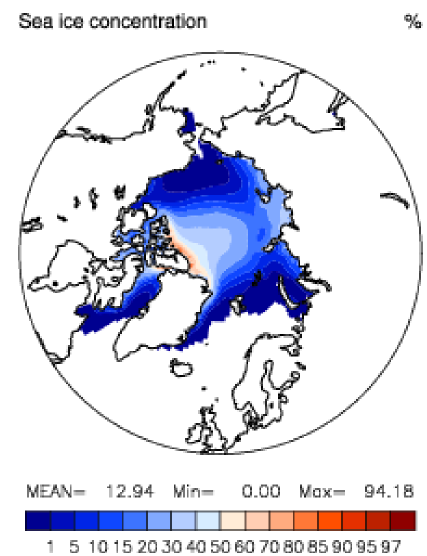
Arctic responses





Plio-preind:

- Nearly sea ice free Arctic during the fall season

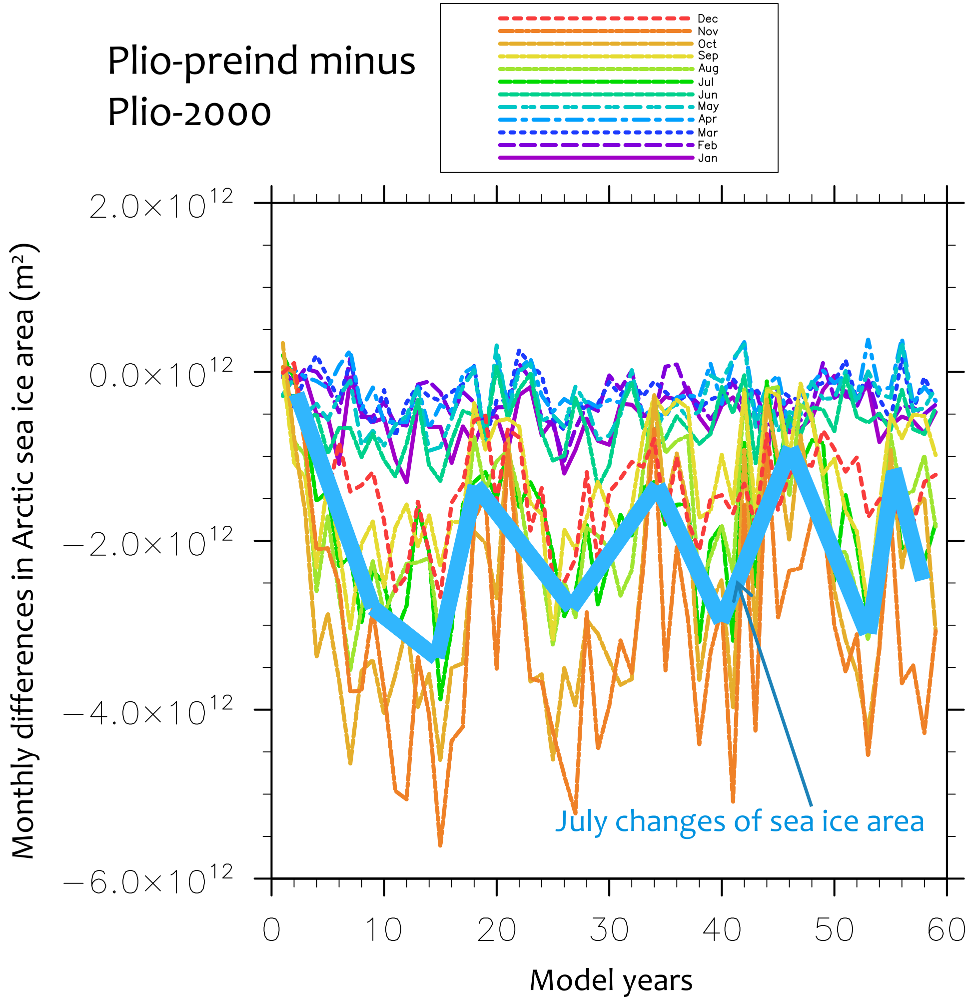


Plio-preind:

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

Role of aerosol-cloud effect: which season/month?

Plio-preind minus Plio-2000

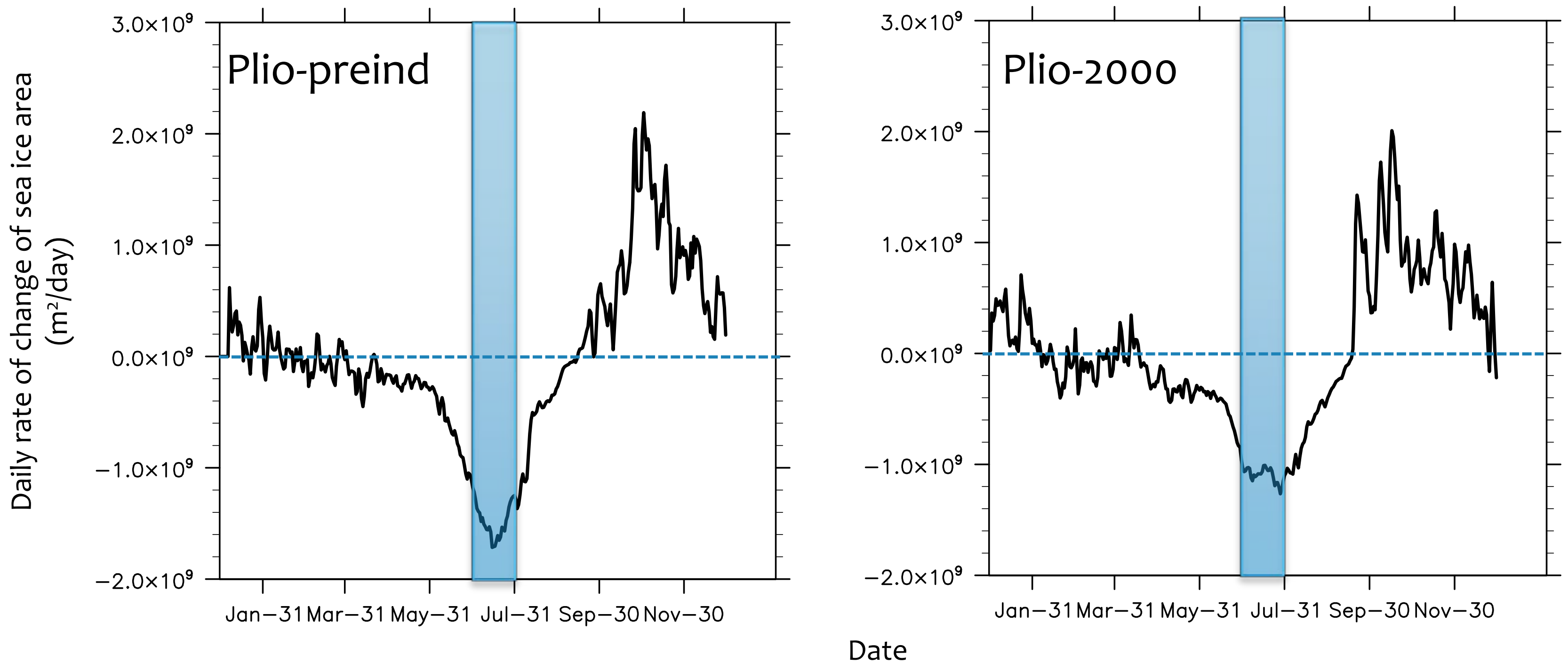


1. Earliest ice area reduction occurs during July

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

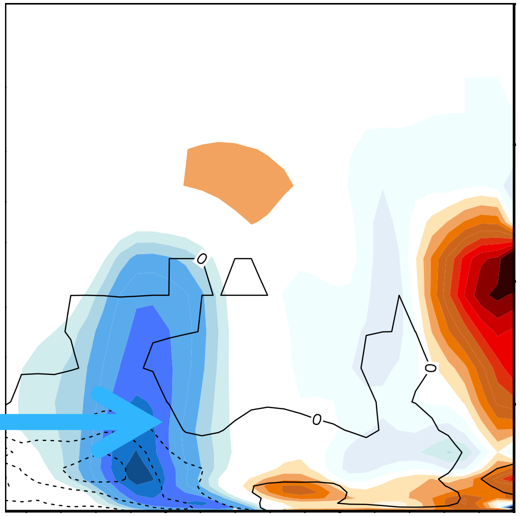


Faster sea ice retreating rate in Plio-preind during July

July cloud responses

Plio-preind minus Plio-2000

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



Shaded: TOA cloud forcing difference (Plio-preind minus Plio-2000)
Hatched: July sea ice coverage in Plio-preind

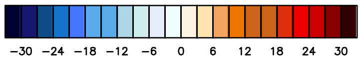
Contour: cloud droplet concentration (#/cm^3 at interval of 1 /cm^3, Dash line: negative)
Shaded: Cloud fraction

Mechanism

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

Pristine air regime:
Less CCN →
less summer low clouds and more high clouds over the open ocean →
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)

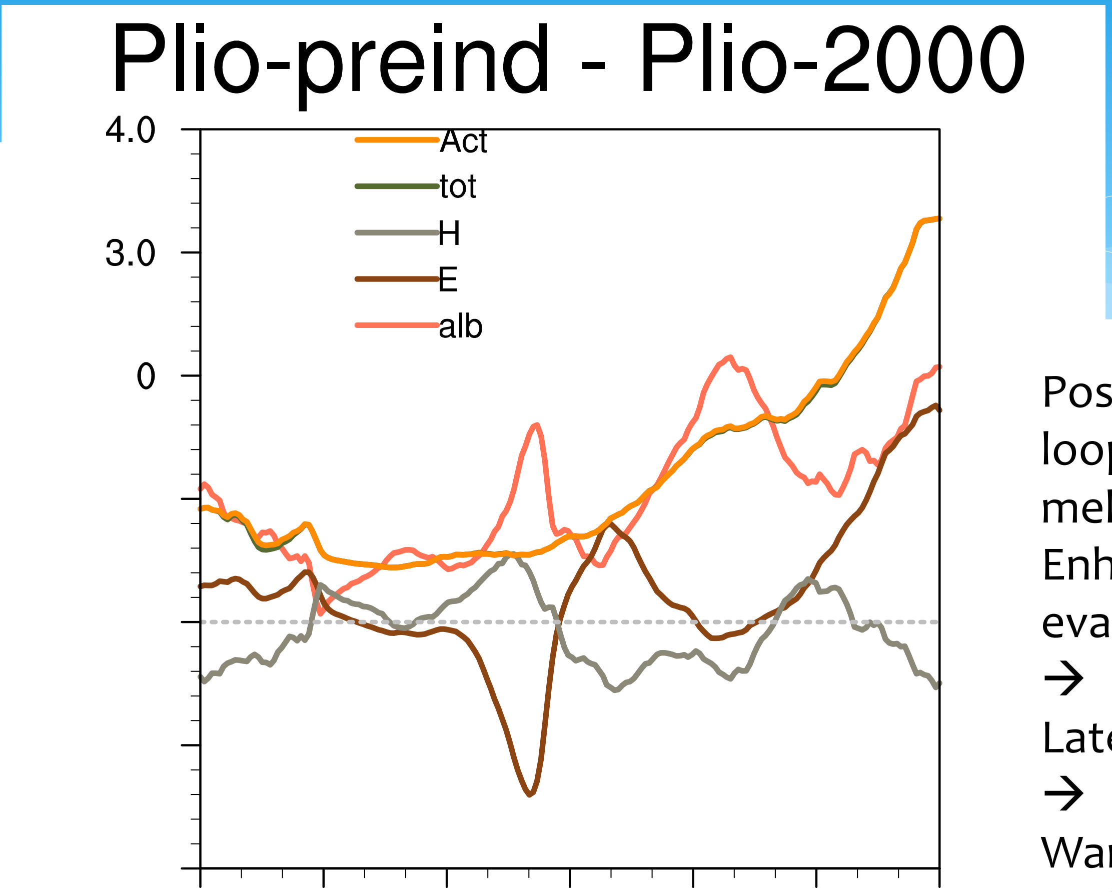
Role of aerosol-cloud effect: which season/month?

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

Annual mean

Amplified annual responses to forcings at intraannual time-scale

Contributors to warming



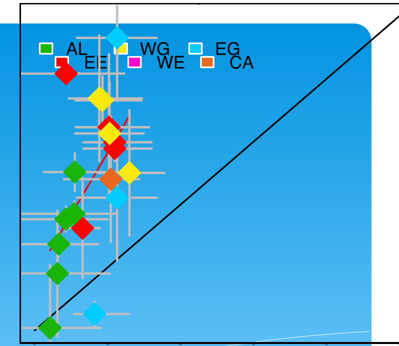
Positive feedback loop: Sea ice melting → Enhanced evaporation → Latent heat release → Warming and melting

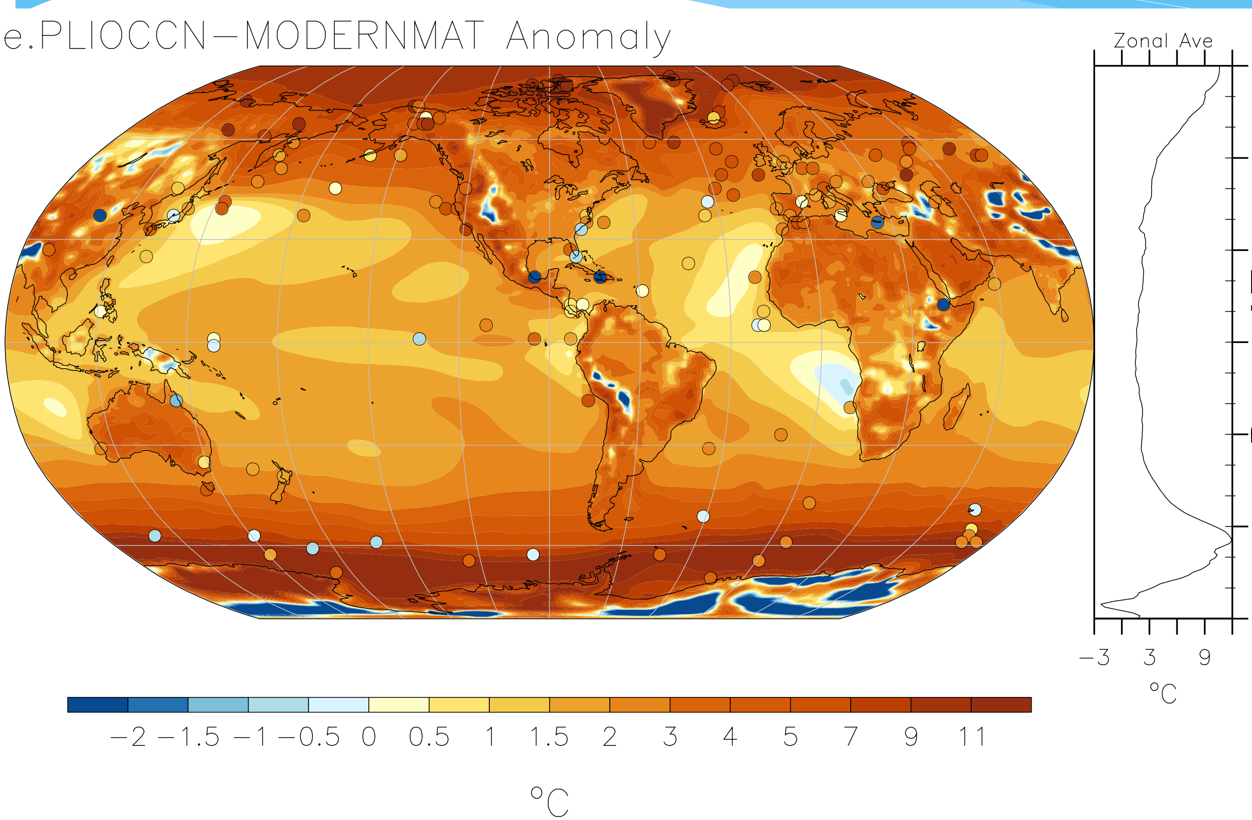
$$\Delta T = \Delta T_{\text{H-transport convergence}} + \Delta T_{\text{albedo}} + \Delta T_{\text{emissivity}} + \Delta T_{\text{synergy}}$$

< 3% change in aerosol optical depth at visible band

Global responses

Plio-preind – pre-industrial control





Proxy ΔT

Plio-preind

Simulated ΔT

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