

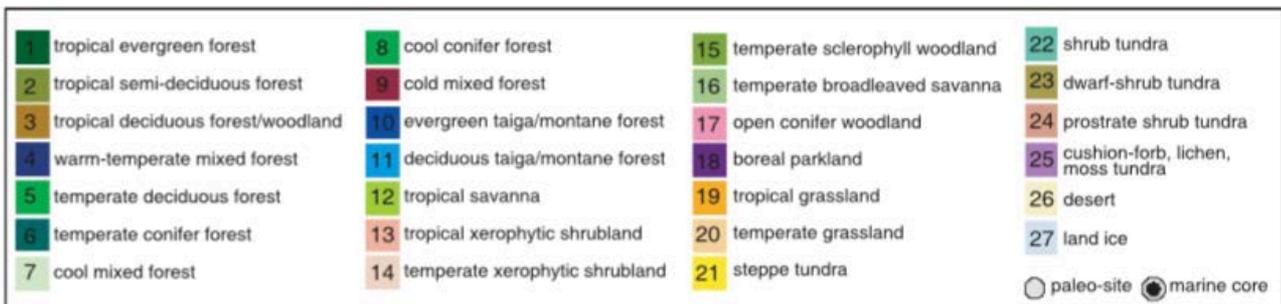
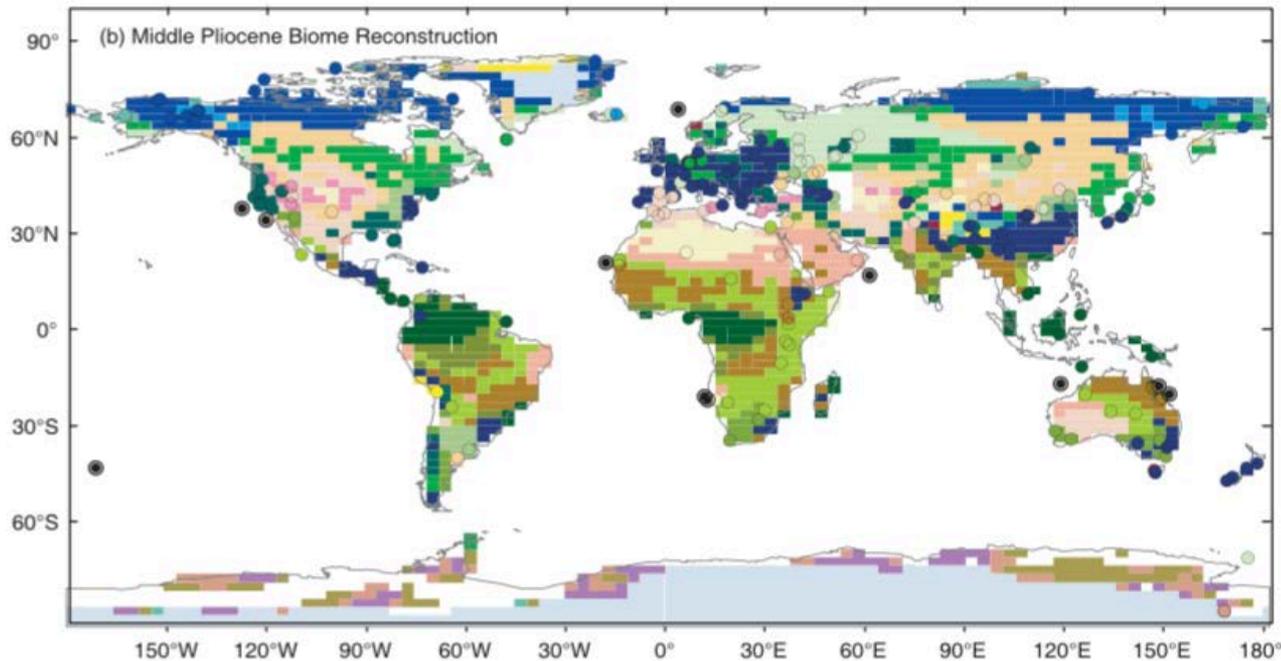
Contributions to Pliocene Arctic warmth from removal of anthropogenic aerosol

Ran Feng

Bette Otto-Bliesner

Esther Brady

Arctic climate during the Pliocene



Mid-Pliocene
warm period: 3 –
3.3 Ma

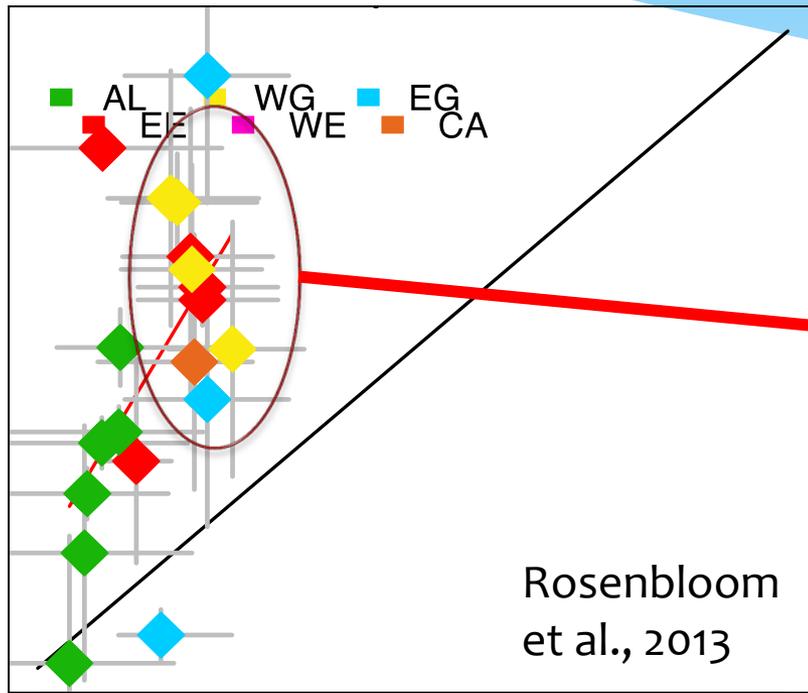
Ts-Arctic: > 5 °C,
up to ~20°C
warmer

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

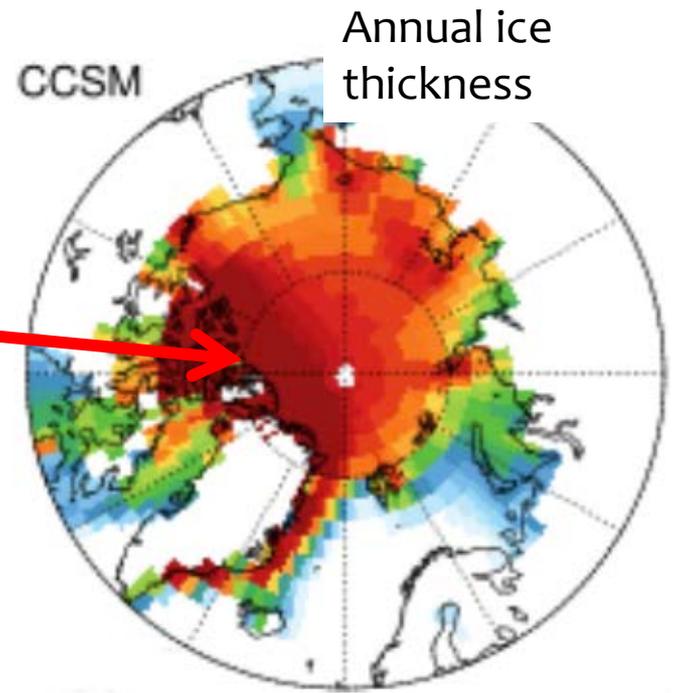
CCSM4 simulations

Enhanced warming around the Greenland and Canadian Arctic

Proxy ΔT

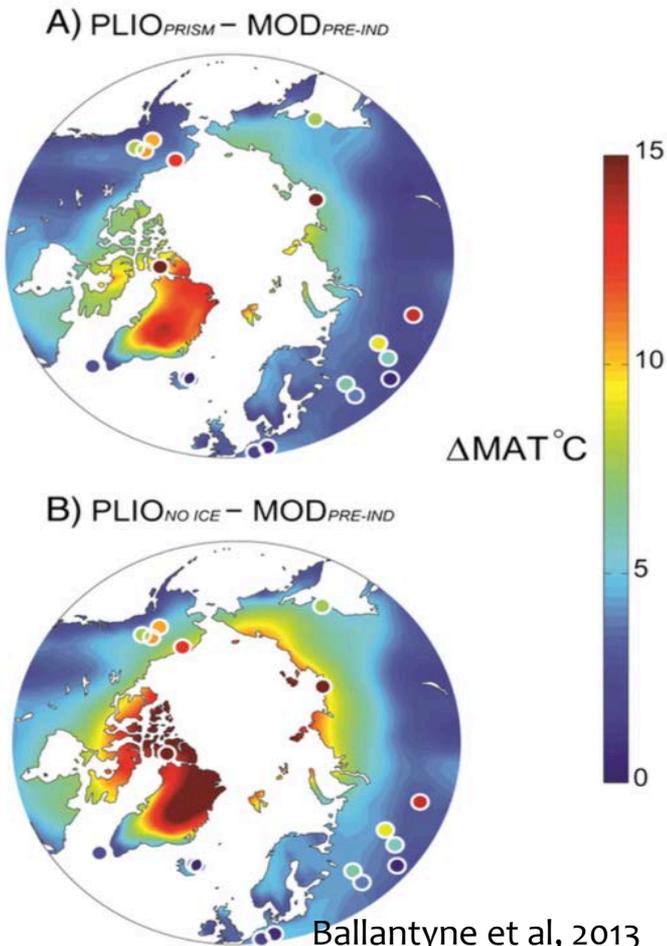


Simulated ΔT



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

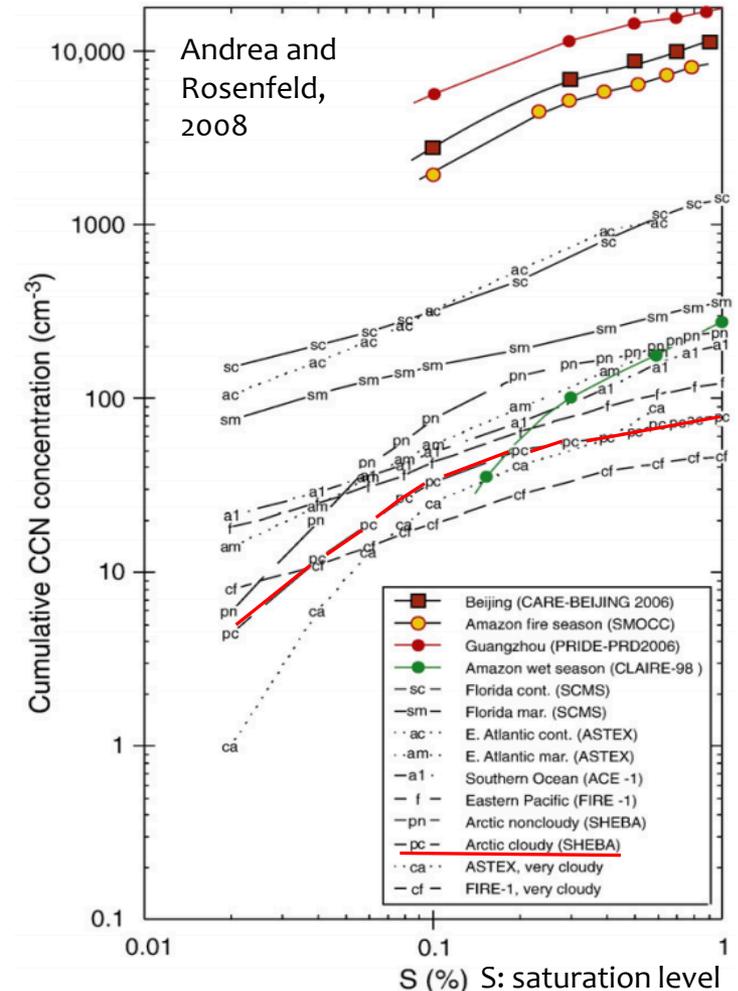
Terrestrial warming from removing the Arctic sea ice



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 = $75/\text{cm}^3$ over the sea ice, droplet size of liquid = $14 \mu\text{m}$
- CAM5-MAM: prognostic CCN from simulating aerosol particle nucleation and activation



Experiment setup

Coupled Pliocene
simulation (Rosenbloom
et al., 2013)

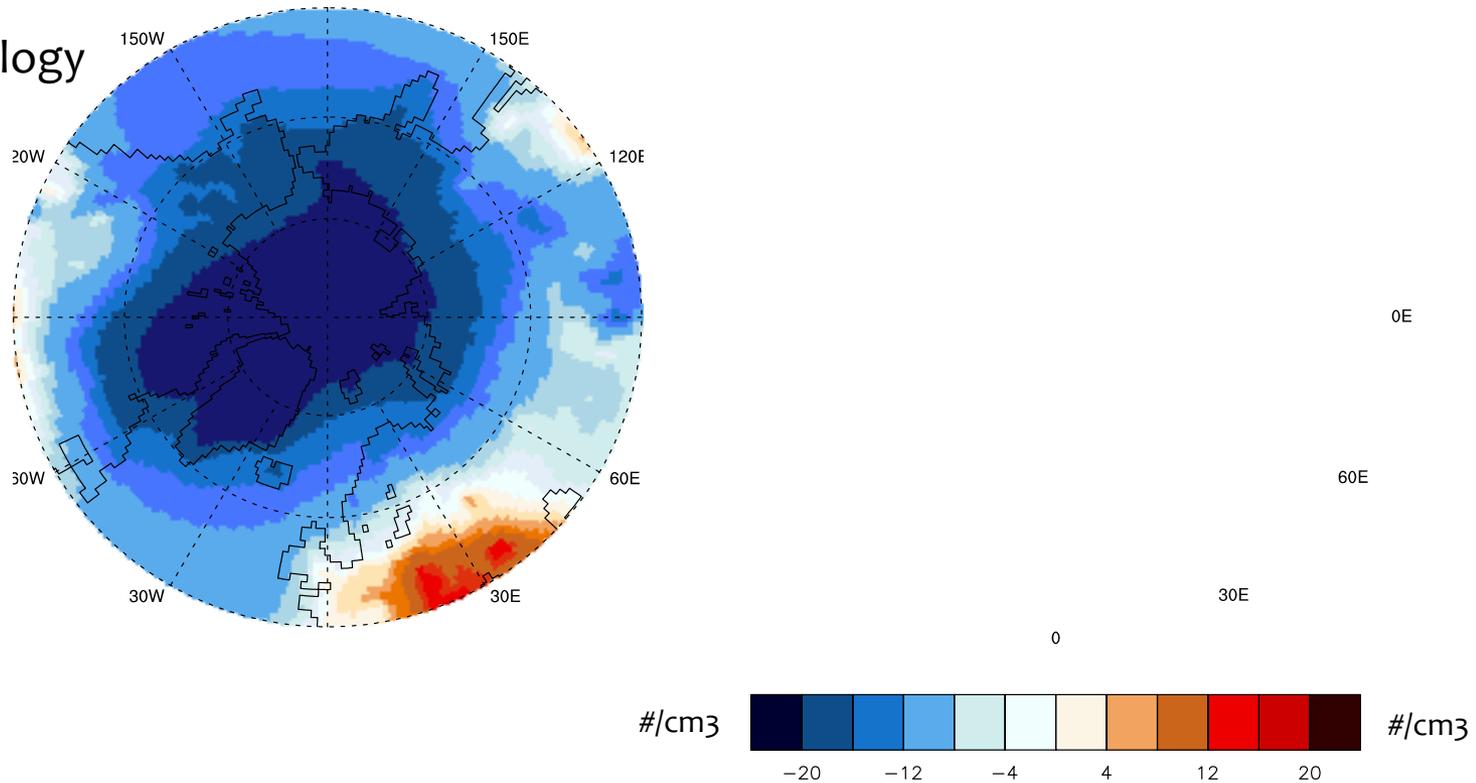


CAM5.3-Slab (CESM1.2) 1 °C resolution	Common boundary conditions	Emission
Plio-preind	Topography; Vegetation; CO ₂ =405 ppm; Icesheet reconstructions; Ocean heat flux;	Year-1850 emission
Plio-2000		Year-2000 anthropogenic emission with Year-1850 natural emission

Note: Black carbon emission is kept the same.

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

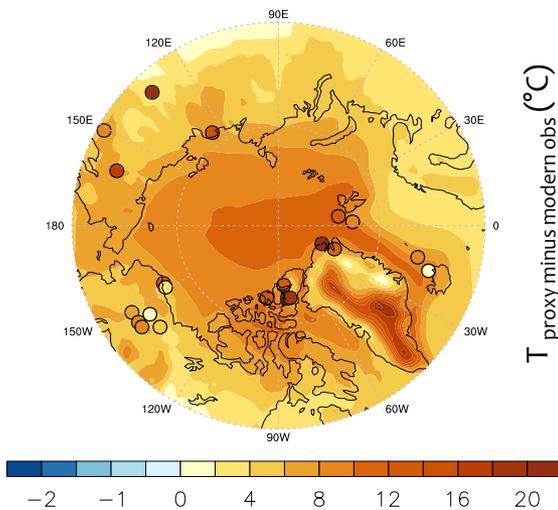
Annual
climatology



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

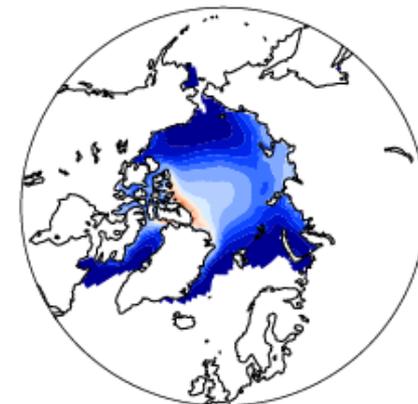
Plio-preind minus Pre-industrial MAT Anomaly



Plio-preind:

- Nearly sea ice free Arctic during the fall season

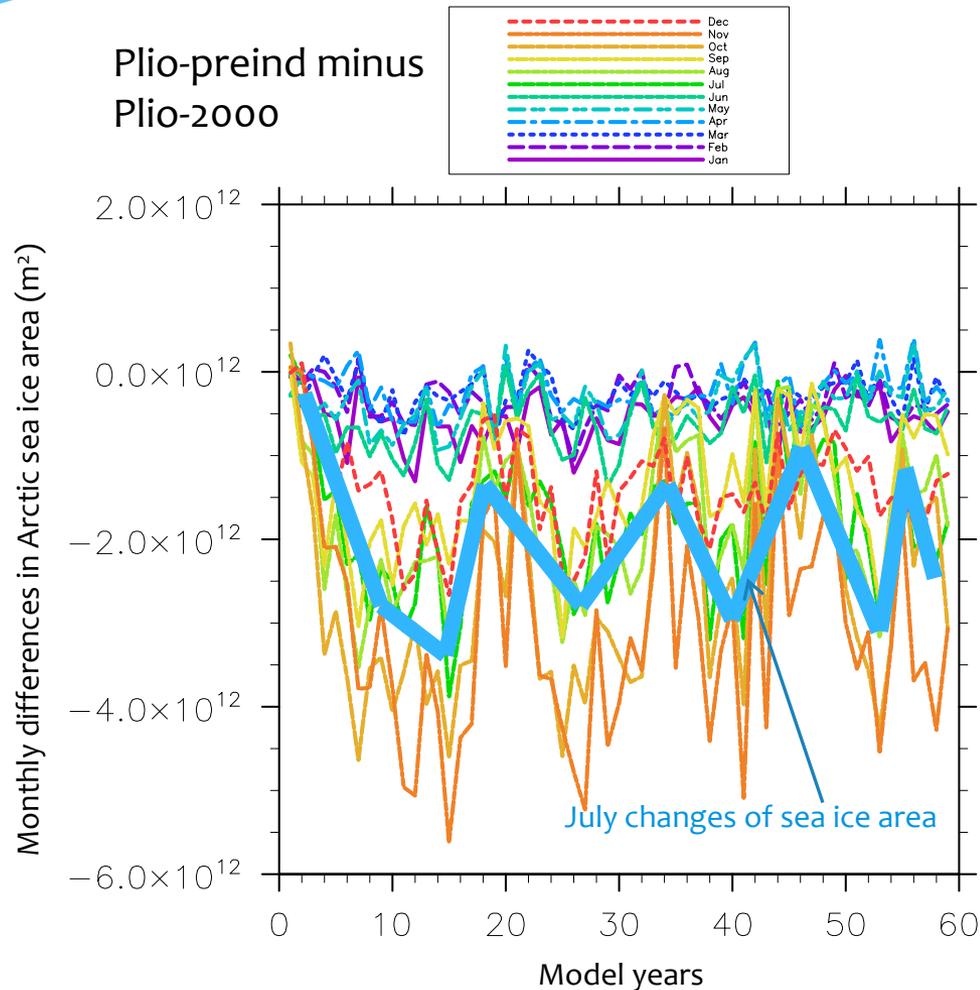
Sea ice concentration %



Plio-preind:

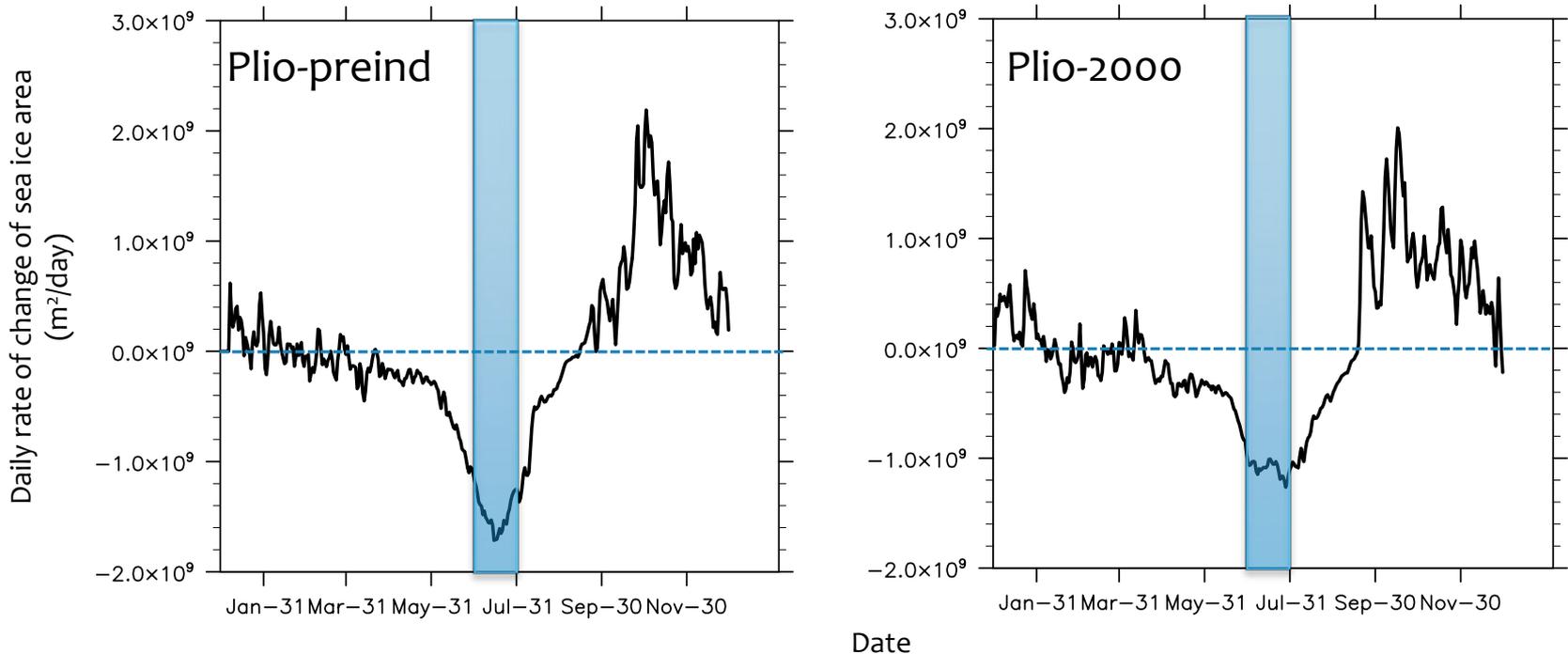
- 2-5 °C warmer than the CCSM4 Pliocene control between 60° - 90°N (1~1.5 °C warmer in Plio-2000)

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



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

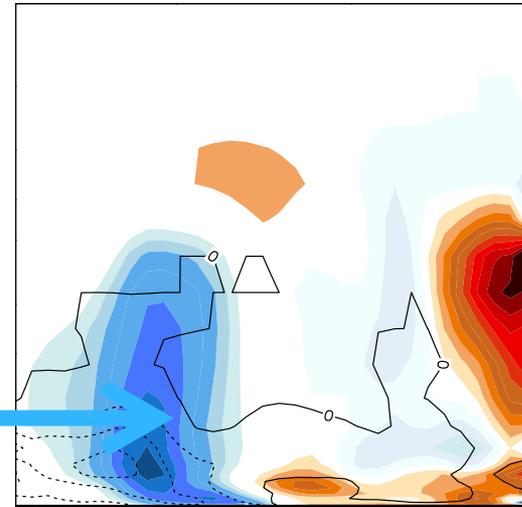


Faster sea ice retreating rate in Plio-preind during July

July cloud responses

Plio-preind minus Plio-2000

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



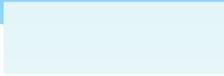
Shaded: TOA cloud forcing difference
(Plio-preind minus Plio-2000)
Hatched: July sea ice coverage in Plio-preind

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

Mechanism

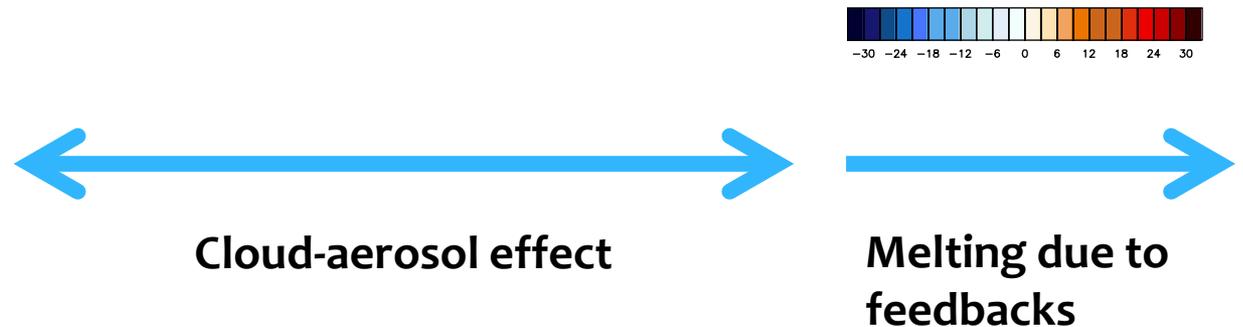


Modern emission regime:
More CCN →
more summer low clouds over the
open ocean →
shortwave cloud cooling



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



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?



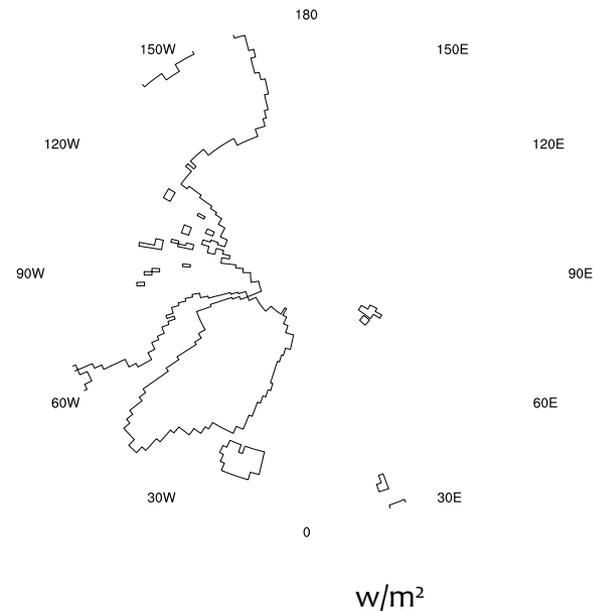
Giant high Arctic camels (middle Pliocene)

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

Net TOA Cloud forcing: net radiation_{cloudy sky} minus net radiation_{clear sky}

Annual mean

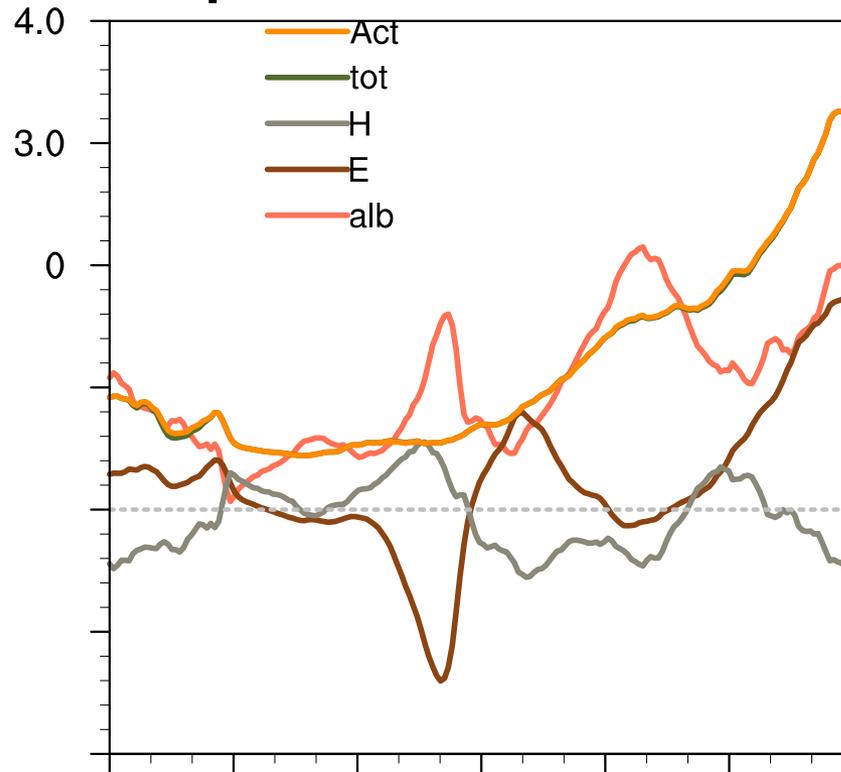
Plio-Preind minus Plio-2000



Amplified annual responses to forcings at intraannual time-scale

Contributors to warming

Plio-preind - Plio-2000



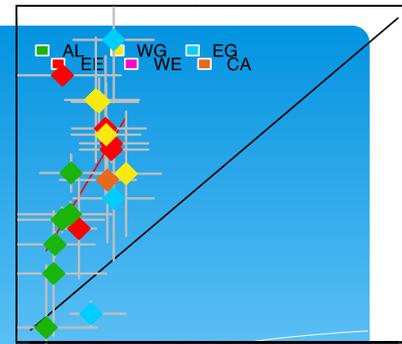
Positive feedback loop: Sea ice melting → Enhanced evaporation → Latent heat release → Warming and melting

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

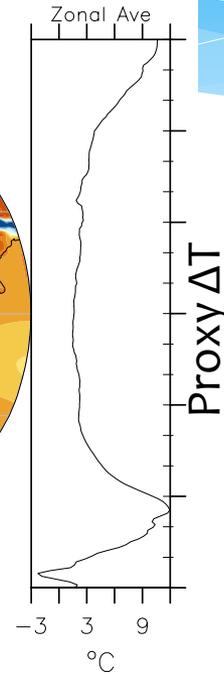
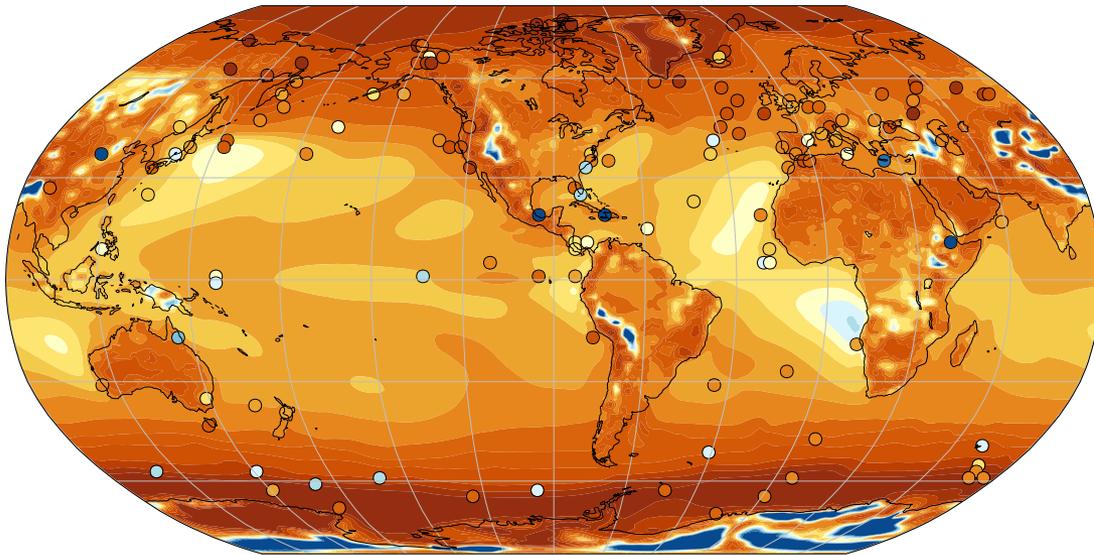
< 3% change in aerosol optical depth at visible band

Global responses

Plio-preind – pre-industrial control



e. PLIOCCN – MODERNMAT Anomaly



Plio-preind

Simulated ΔT



°C

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