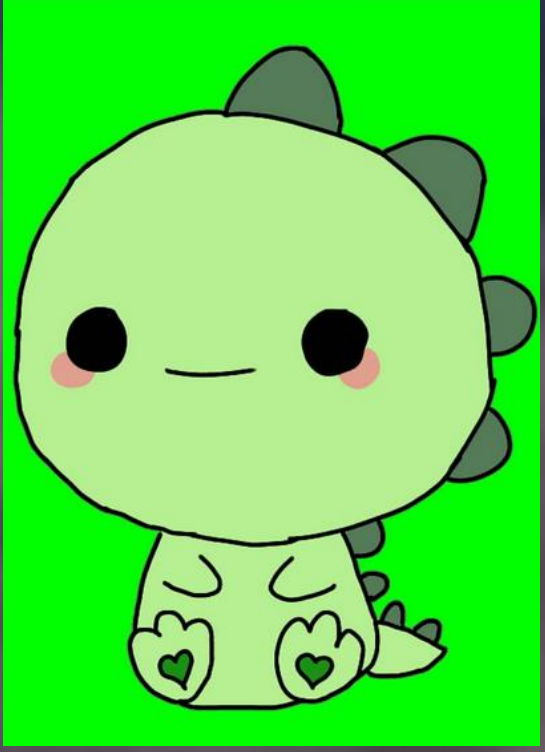
Impact of aerosol changes on Earth's pre-anthropogenic radiative budget

CESM Paleoclimate Working Group Meeting, June 11th, Boulder

Dr. Irina Thaler

Prof. Christian Bjerrum

Why Paleo-aerosols?



Large uncertainty in paleo and preindustrial natural aerosol emissions due to lack of observations

aerosol emission models were calibrated using current observations and applied to past climates

natural emission processes not constant over time

Possibly large radiative impact through aerosol variations

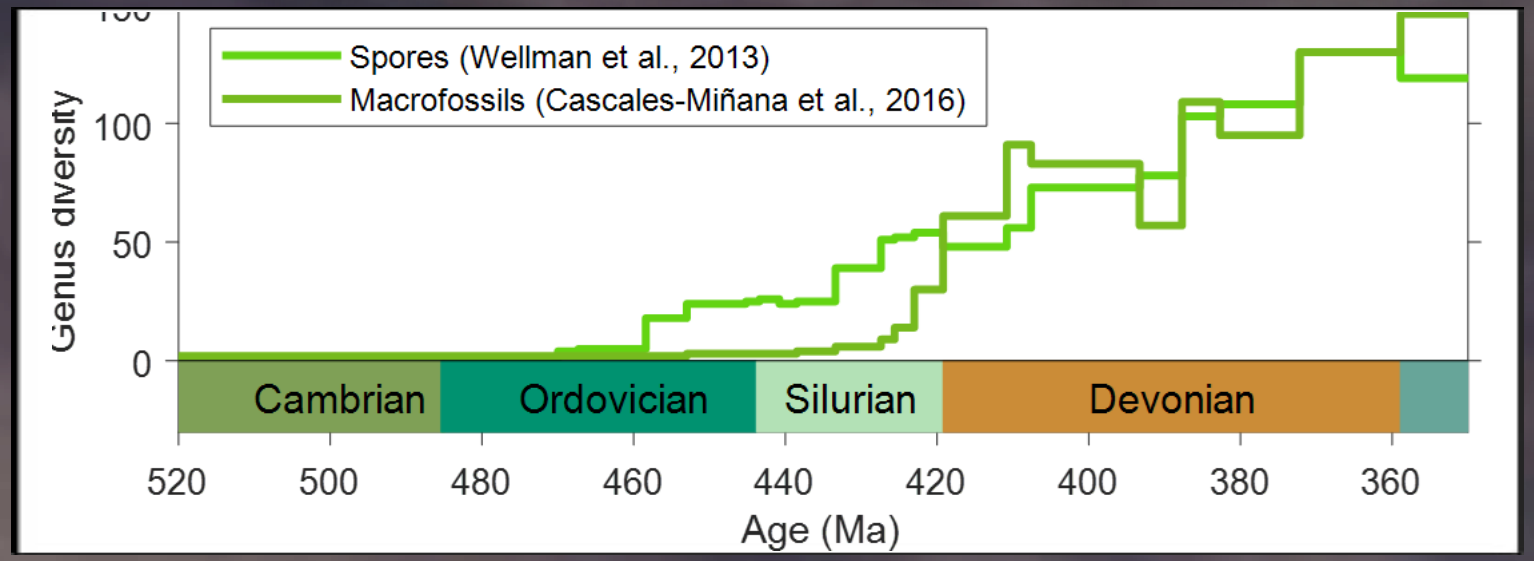
Mahowald et al. 2024

Largest Experiment in Earth history

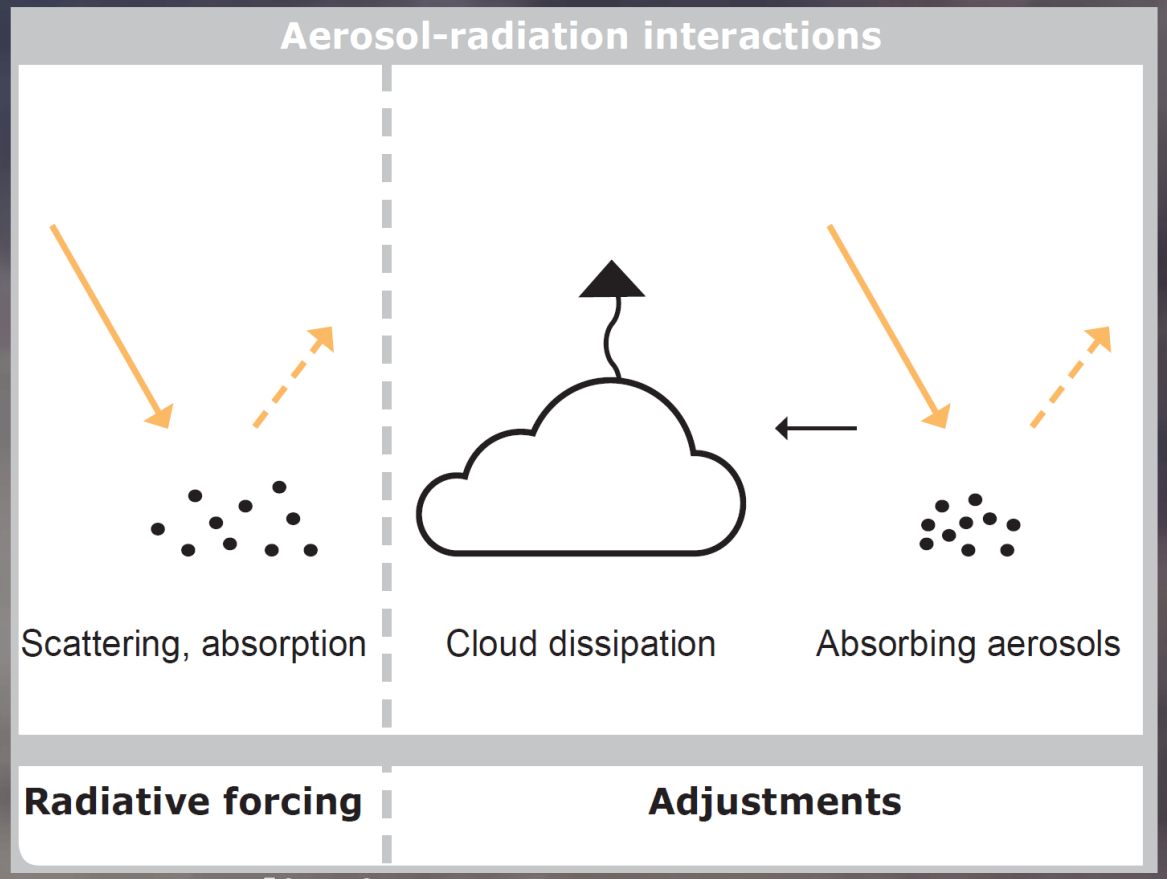
500 - 400 million years ago (Cambrian to Silurian):

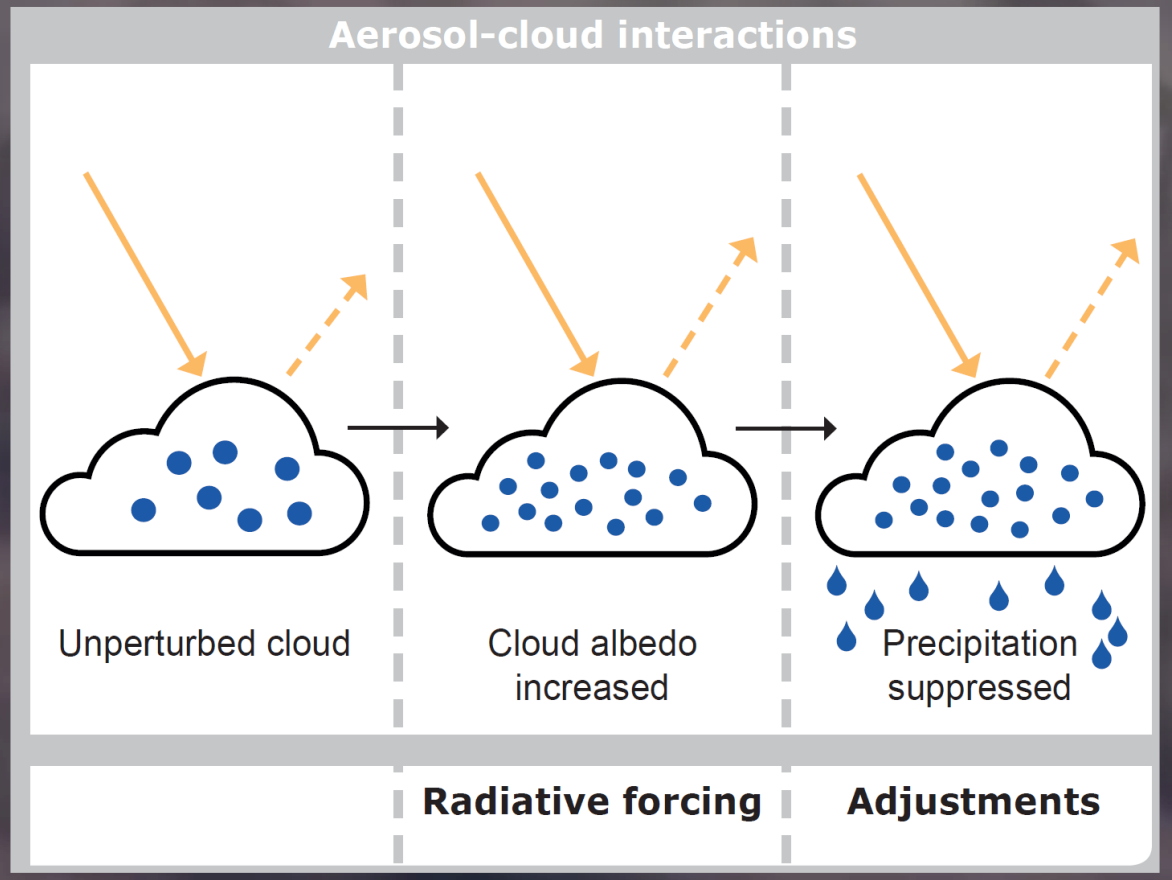
greening of both land and oceans by plants and algae

Modification of Earth's pristine atmosphere aerosol loading



Aerosol climate impact





Less radiation reaches the surface: COOLING

more CCN, higher cloud albedo, less radiation reaches the surface: COOLING

Frey 2019

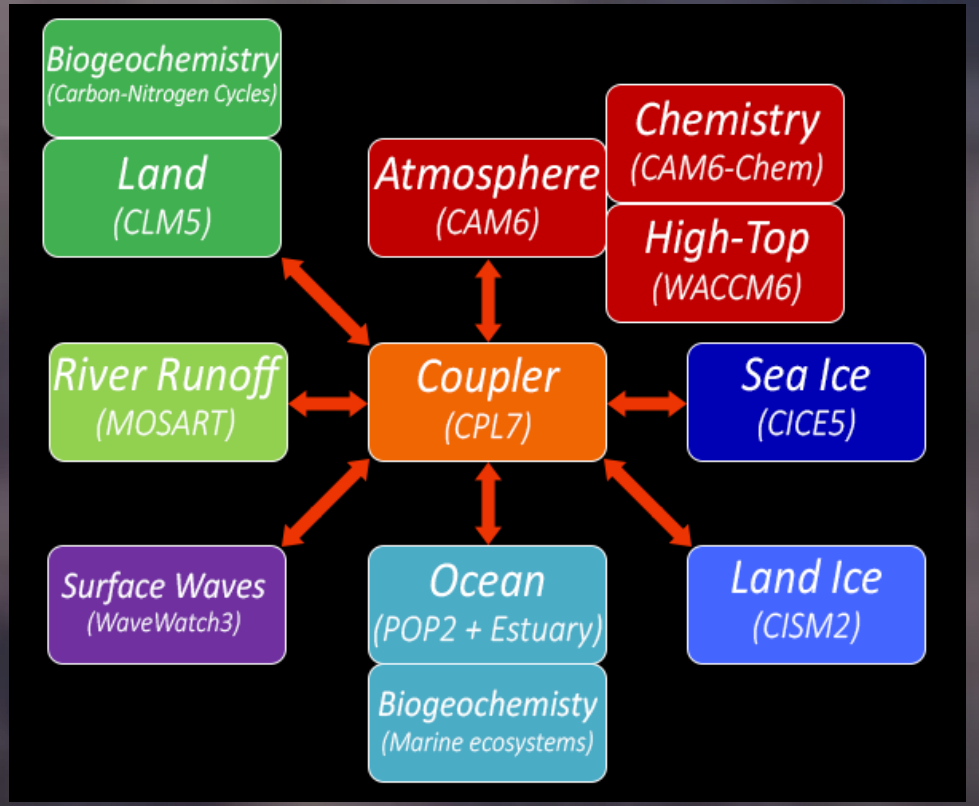
ACI uncertainty

- heterogeneity of aerosols in space, time, composition, size in current climate
- Aerosol (microscopic) – cloud (macroscopic) interactions complex
- Major uncertainty in current climate models BUT also in historical and paleoclimate conditions

(Albani et al., 2018; Bellouin et al., 2020; IPCC, 2021; Carslaw et al., 2017; Gulev et al., 2021; Szopa et al., 2021).

Methods

- CAM6-Chem with comprehensive chemistry in troposphere and stratosphere (Emmons et al 2020)
- includes aerosol and aerosol precursor emission sources (biomass burning, plant emissions, oceans, volcanos, sea salt, dust)
- Biogenic SOA (isoprene, monoterpene and aromatic oxidation) are calculated online using the MEGAN emissions (Guenther et al, 2012; Lawrence et al 2019)
-



Setup

- Emission scenario from 1850-2010
- Switch off all anthropogenic sources
- Scale the source strength of biogenic emissions from plants, wildfires and DMS (produced by algae) from 100% to 50% and 10% (preplant world)
- Compute the years 1850-1865
- Filter out the years with volcanic eruption impacts
- Compute the effective radiative forcing according to method of Ghan 2013

Results

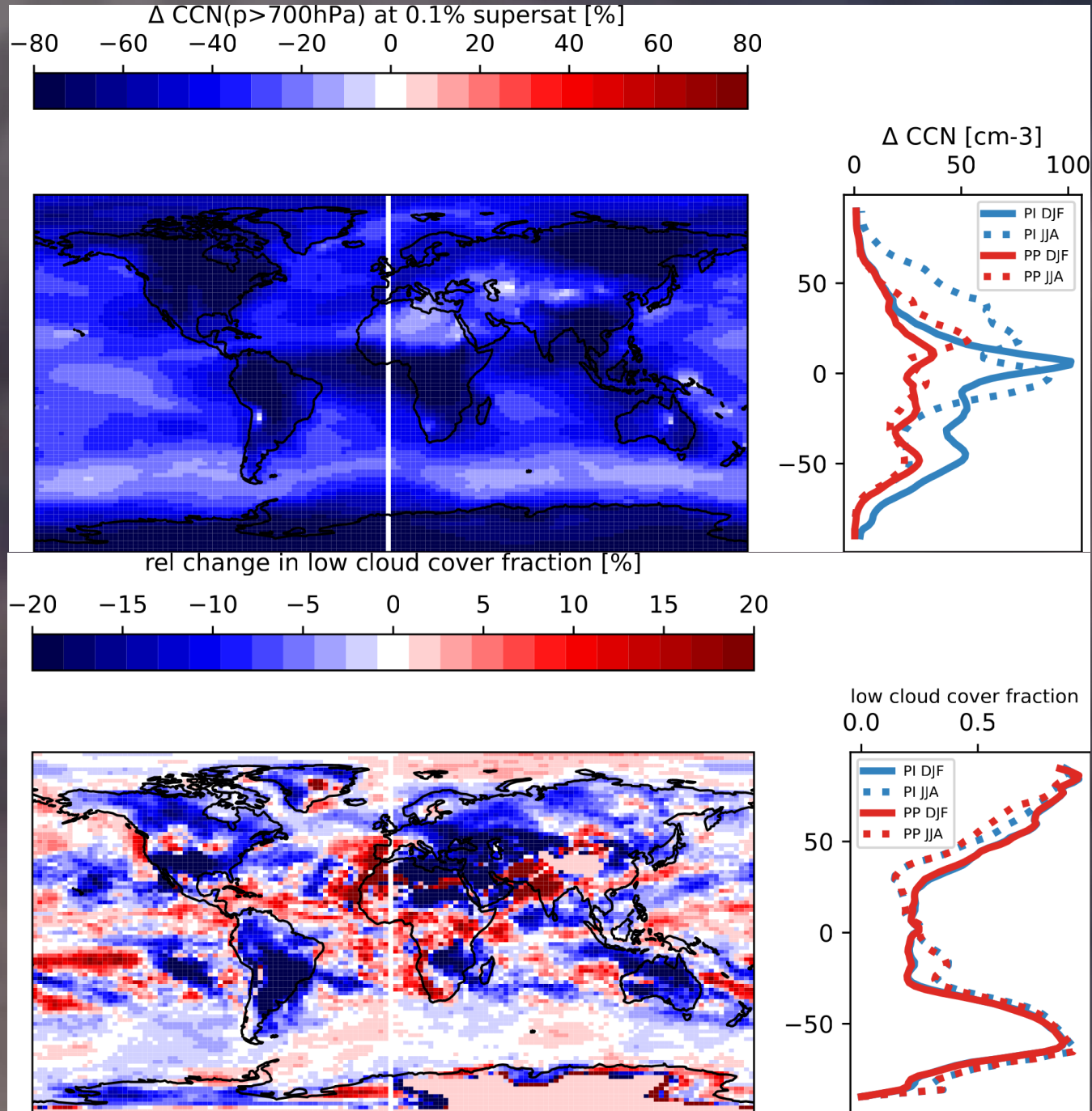
Reducing biogenic derived aerosols To 10% of PI:

- **Low level cloud CCN:**

  drop by up to 80% over continents

- **Low level cloud cover:**

  Up to 20% decrease in NH/SH midlatitudes



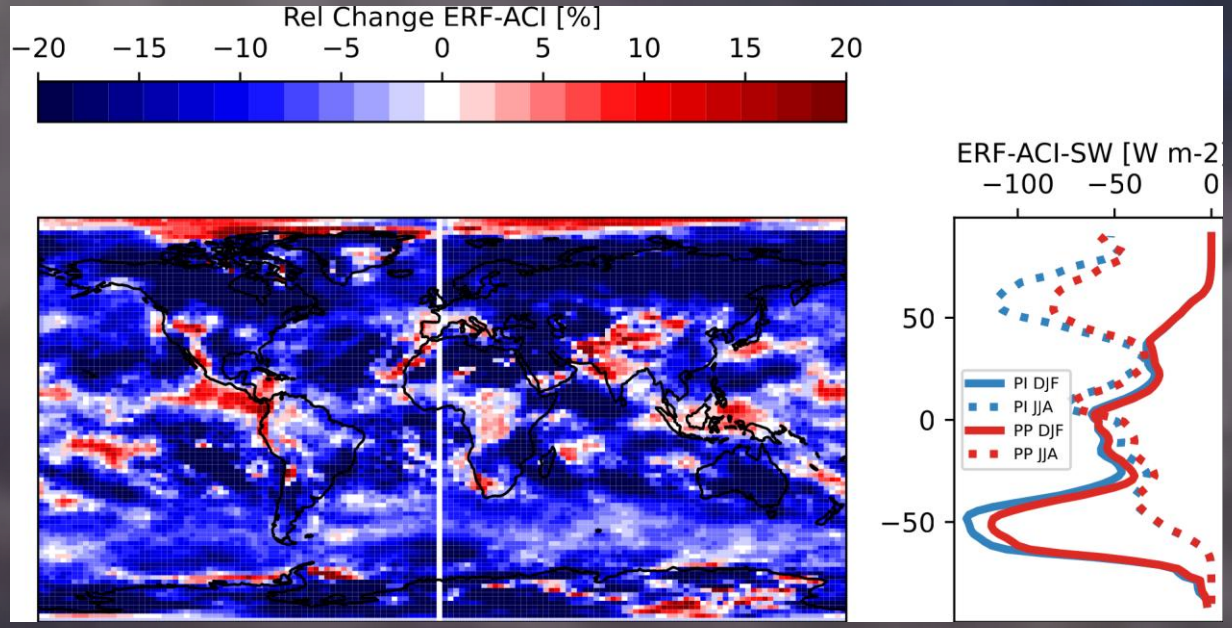
Results

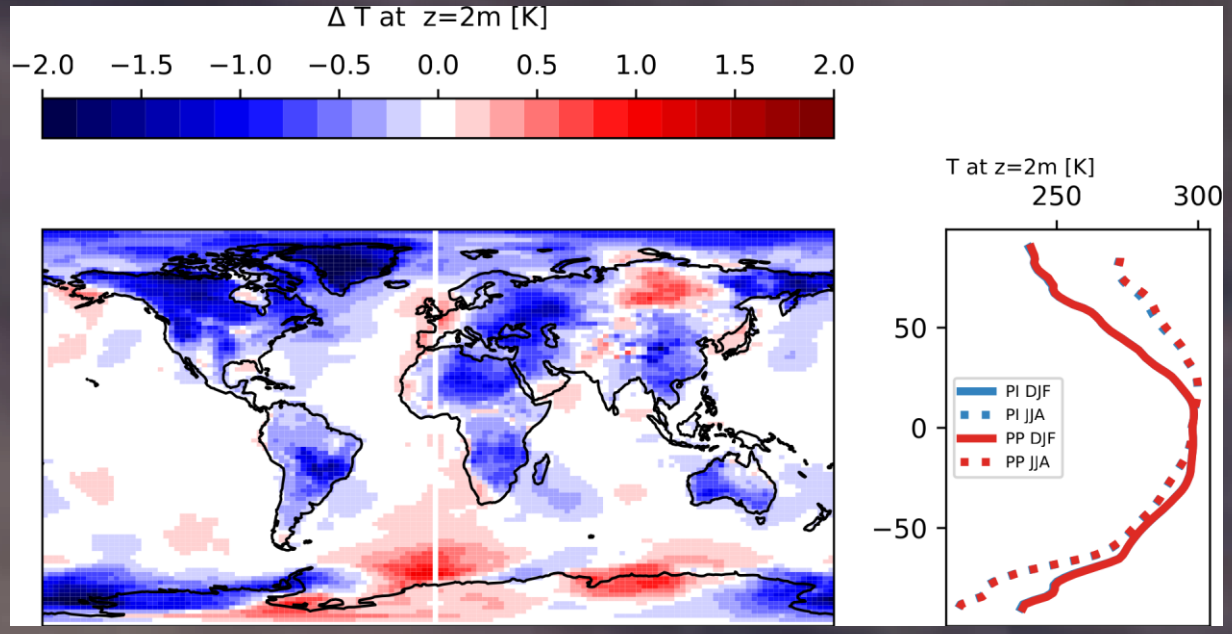
Reducing biogenic derived aerosols To 10% of PI:

- **ERF-ACI decreased:**

  20% reduction in NH midlatitudes, is due to a ACI reduction in the summer months

Temperature for PI 1-2 K lower over continents than for PI x 0.1 (we fixed sea surface temperatures)





Results

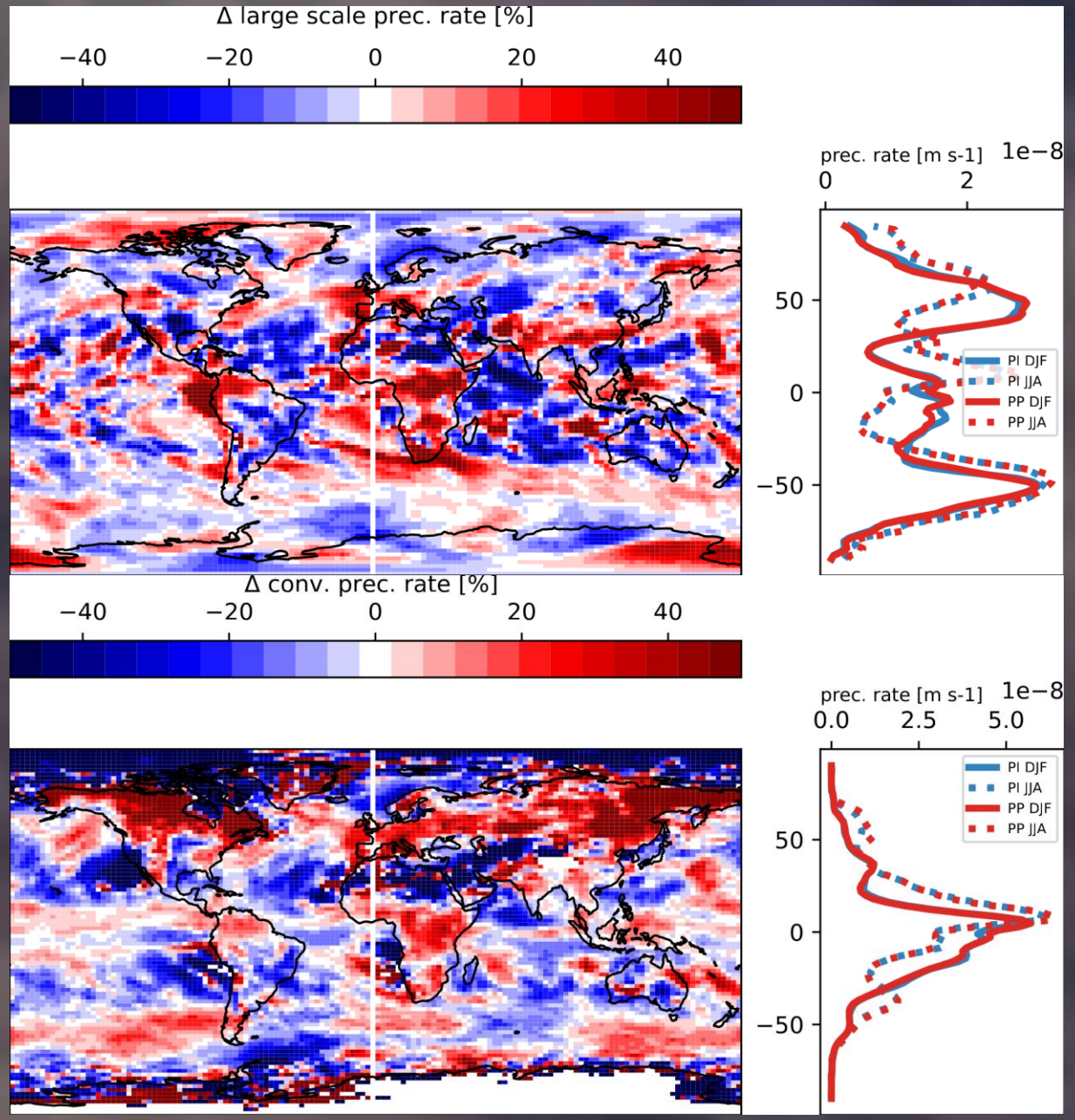
Reducing biogenic derived aerosols To 10% of PI:

Large-scale precipitation rate:

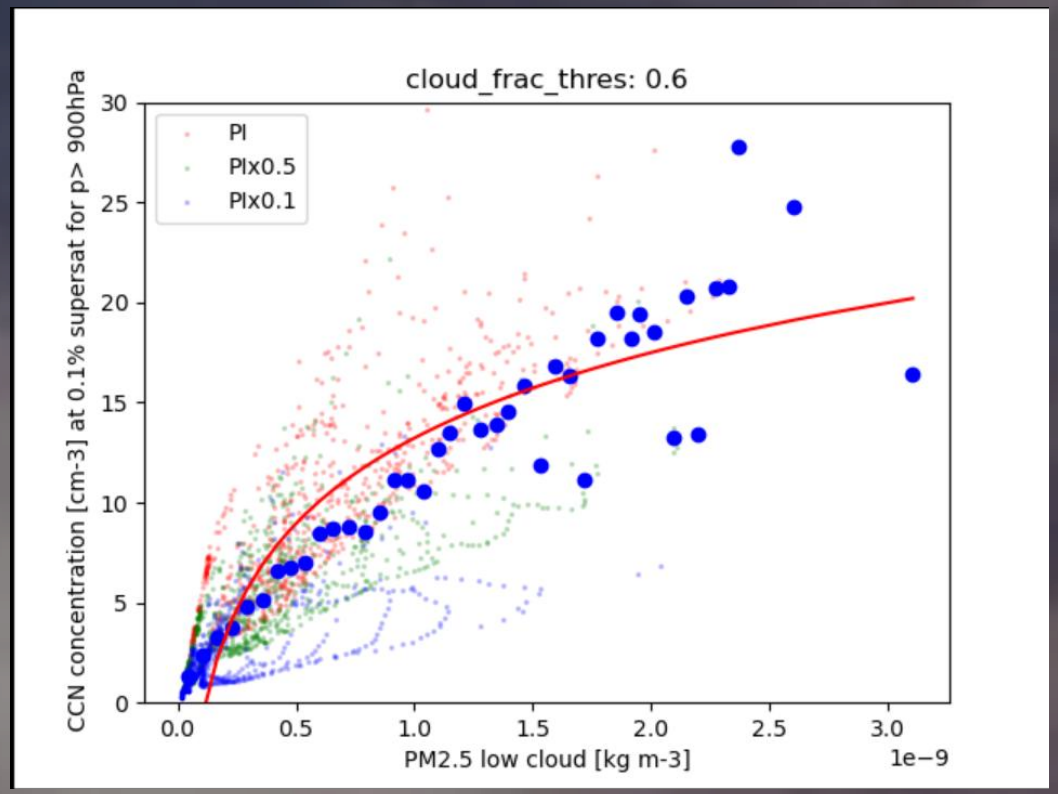
Patchy signal

Convective precipitation rate:

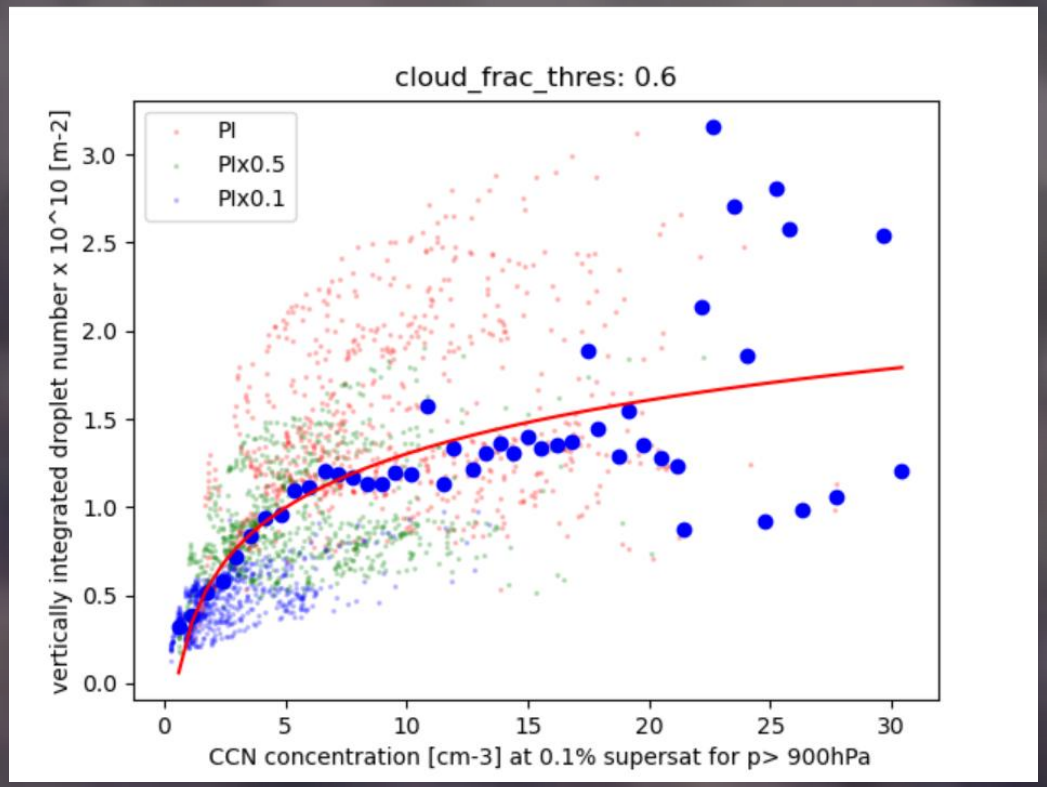
Increase of convective precipitation rate
By up to 50% in the NH mid-latitudes



Results



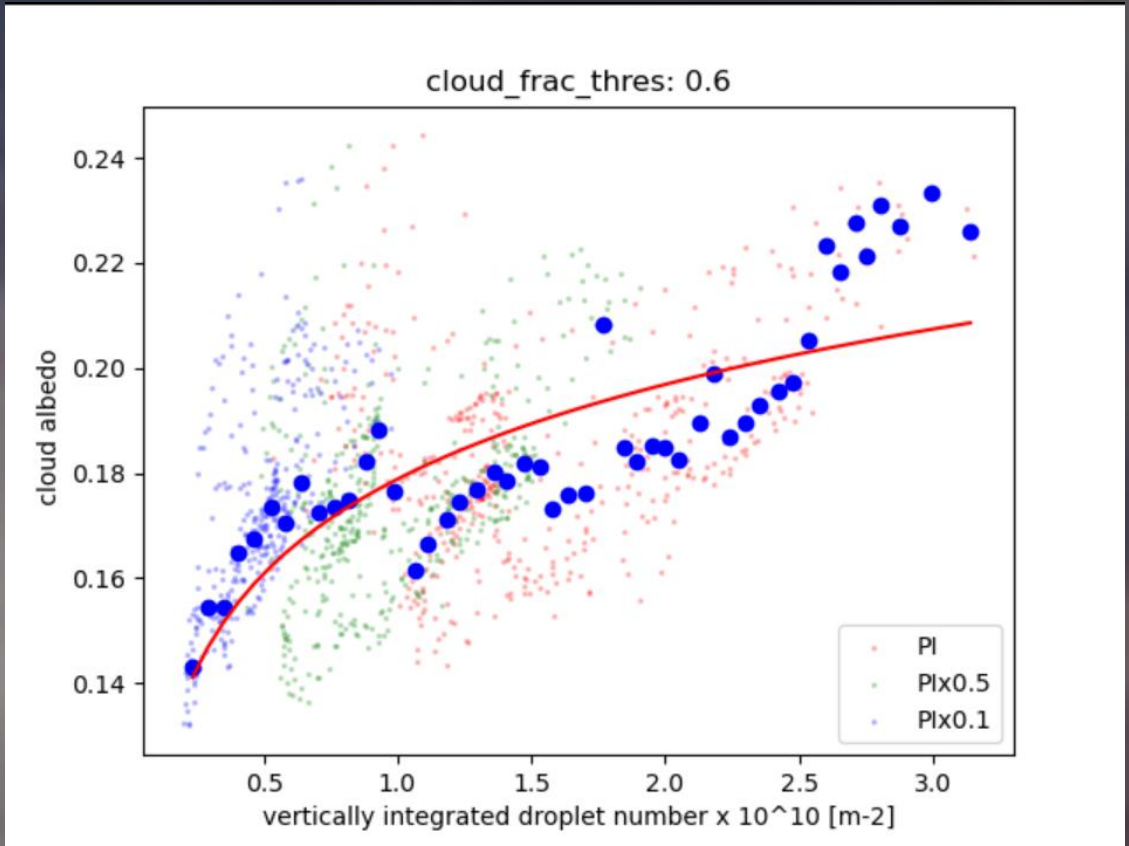
CCN sensitivity to emissions larger in clean atmosphere:
More efficient nucleation and growth

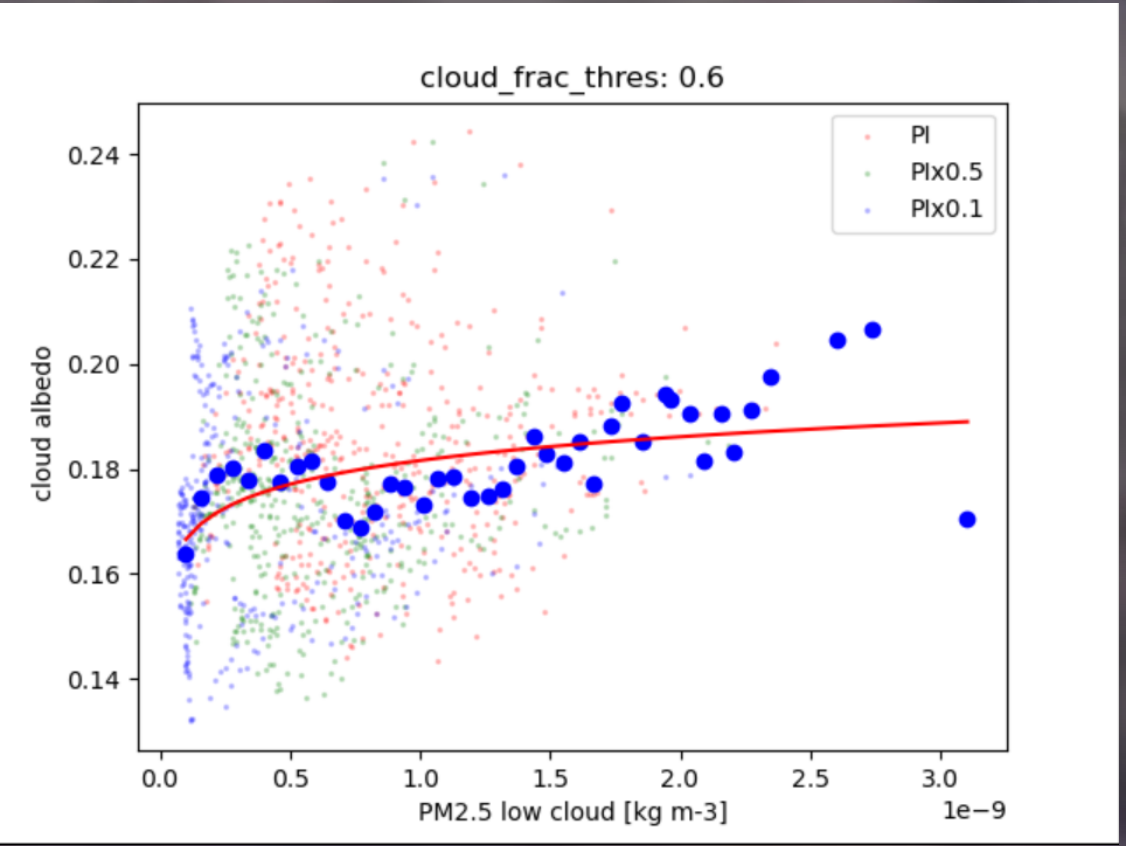


Cloud droplet number concentration increases more steeply in clean atmosphere:
High droplet concentrations limit in cloud supersaturation

Interpretation based on Carslaw et al 2013 (doi:10.1038/nature12674)

Results



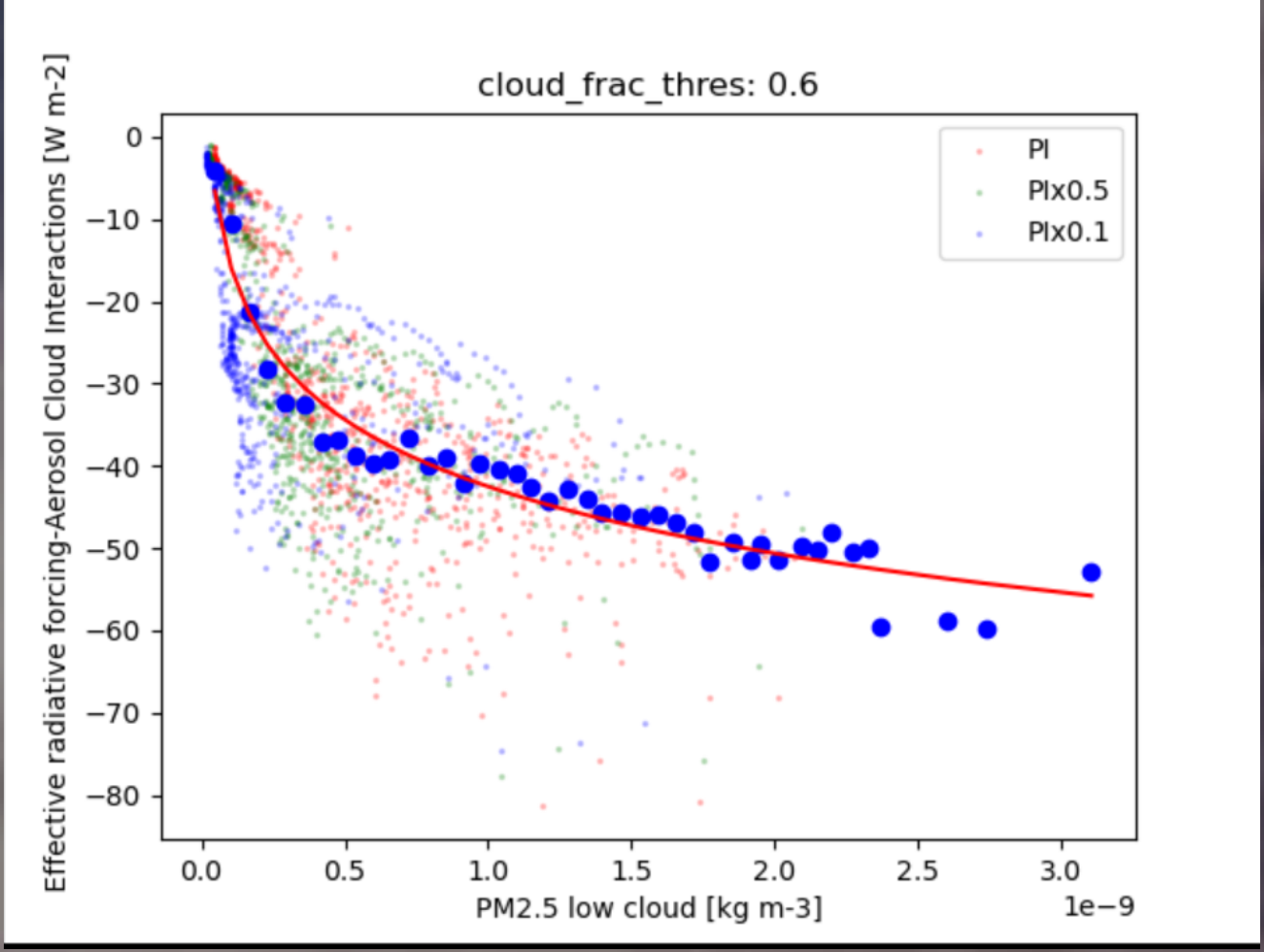


Cloud albedo changes due to change in droplet concentration higher for clean atmosphere

Combination of three effects: cloud albedo more sensitive to aerosol changes in clean atmosphere

Interpretation based on Carslaw et al 2013 (doi:10.1038/nature12674)

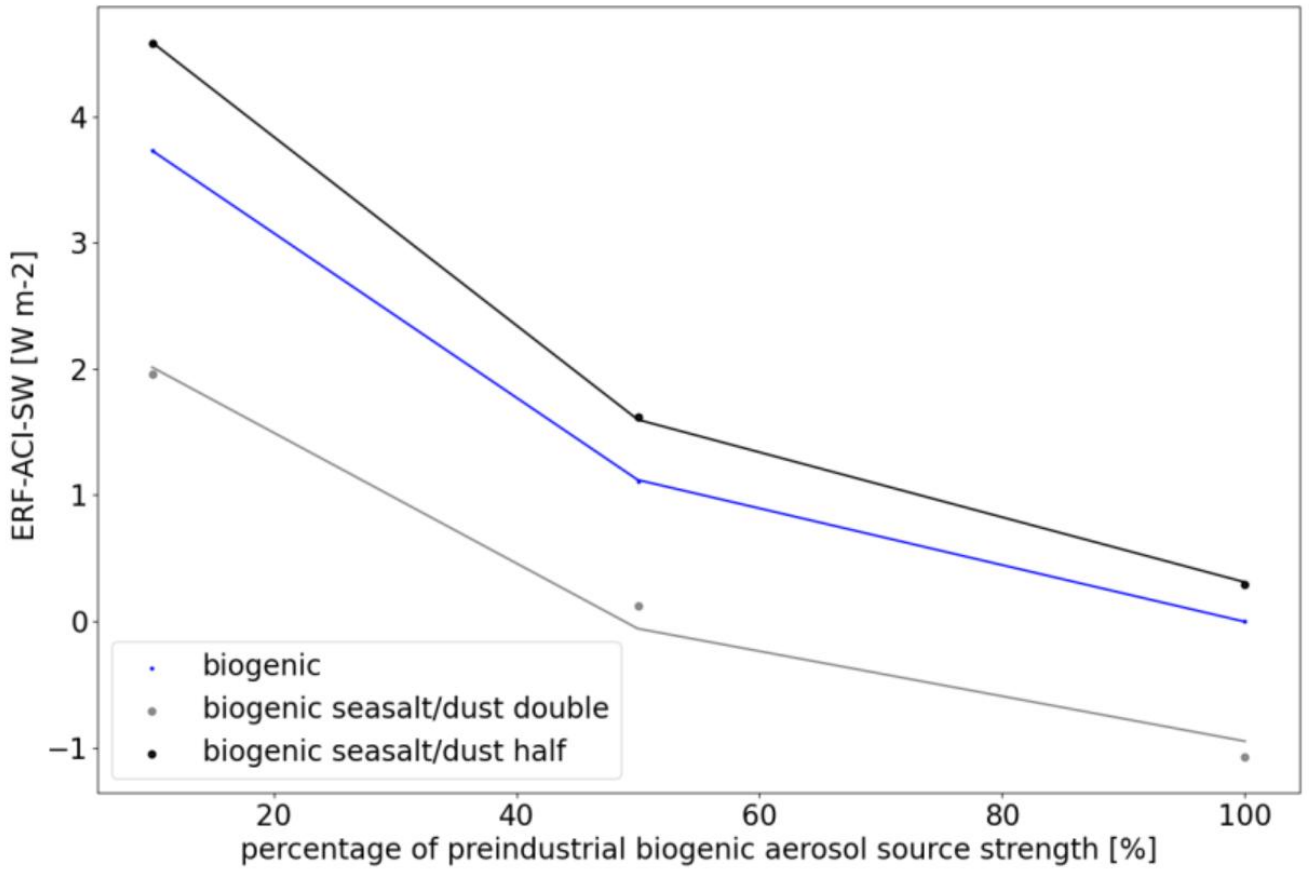
Results



Effective radiative forcing due to Aerosol Cloud Interactions strongly depend on Aerosol emissions and precursor gases

Interpretation based on Carslaw et al 2013 (doi:10.1038/nature12674)

Results



Non-linear effective radiative forcing
Response to linear variation in natural
Biogenic source strength

Effective radiative forcing in PI world
- 4 W m-2: cooler than preplant world

BUT: ERF-ACI-SW depends
also on non-biogenic background
aerosol concentration

Summary

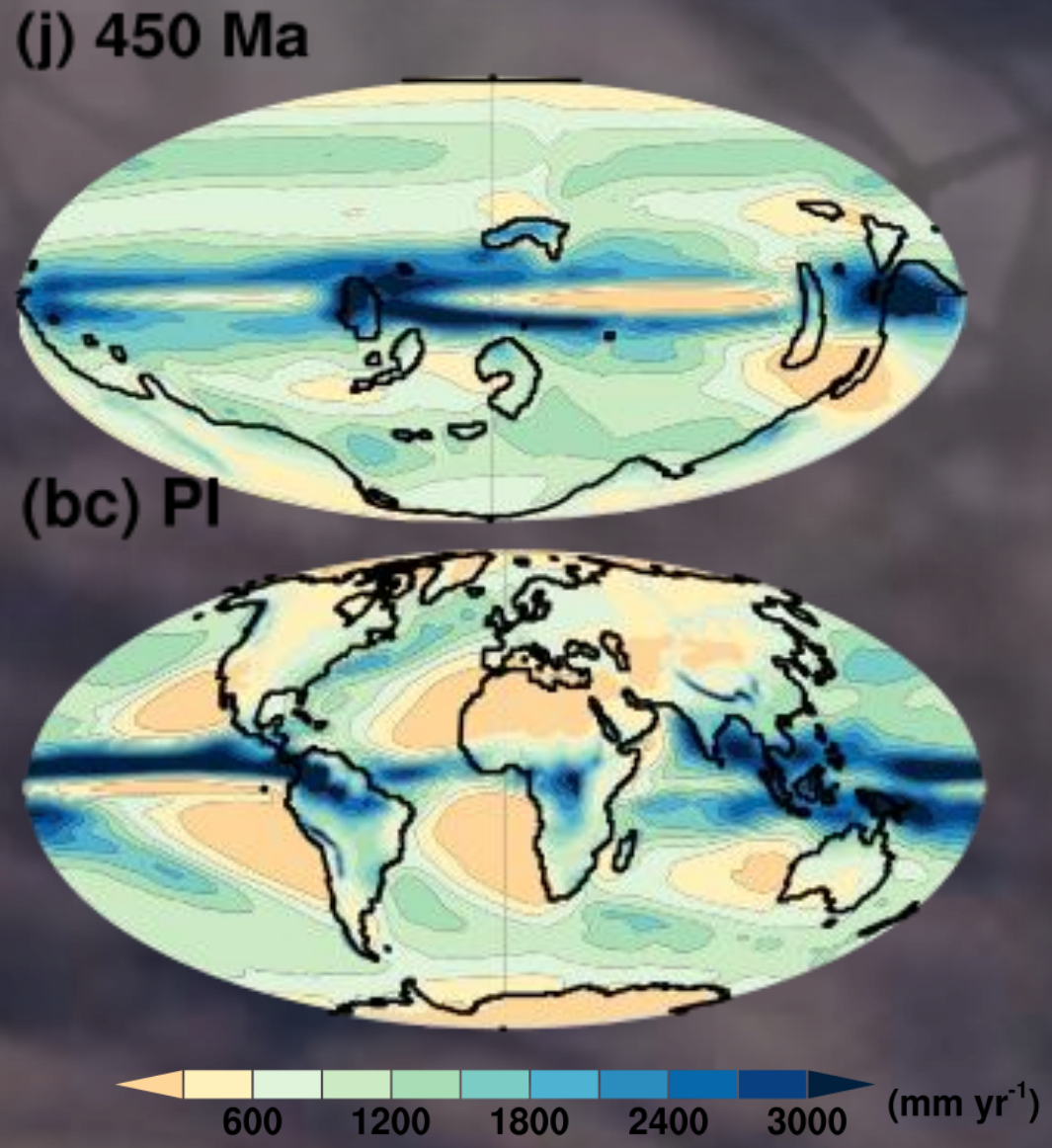
Greening of Earth might have had a large climate impact

BUT: realism of our experiment limited:

We use present day continents + Present day atmospheric circulation

Aerosol transport and source distribution 450 Mio years ago different

Climate sensitivity probably too large



Xiang Li et al 2022

Take home message

The magnitude of Aerosol-Cloud Interactions (ACI) depend on the aerosol background concentration

Fast climate feedback from ACI is climate state dependent

=> Aerosols can influence climate sensitivity

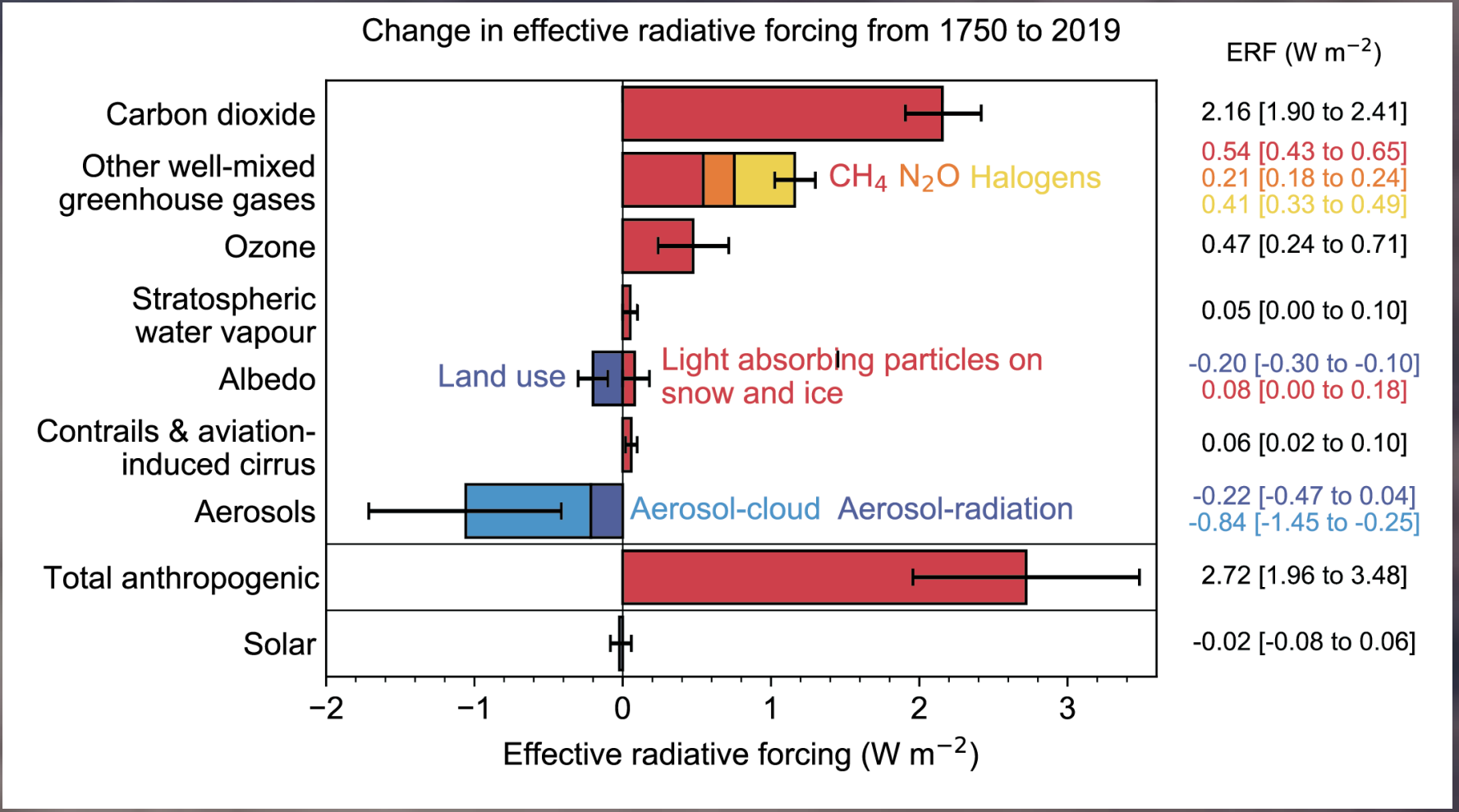
important in periods of Earth's history where major changes in aerosol emission and precursor gases occurred due to volcanism, ocean biogenic productivity, wildfires, desertification..

Outlook

- Use paleogeography
- Use fully coupled CESM to take into account atmospheric and ocean feedback effects as well as vegetation feedback
- Use paleo CO2 levels from new biomarker measurements
- Scan through several time slices in the Ordovician-Silurian period

THANK YOU FOR YOUR ATTENTION!

Change of radiative forcing between 1750-2019



Effective Radiative Forcing (ERF):

net change in downward radiative flux (shortwave +longwave) at TOA due to an externally imposed driver

IPCC 2021, Forster et al., 2021