Evolution of Dust and Its Climatic Impact during Earth's History

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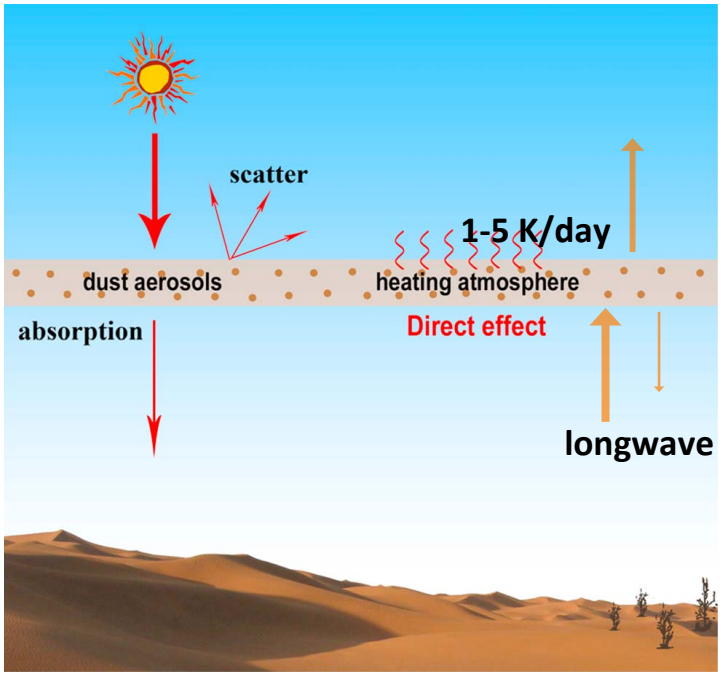
Radiative Effect of Dust



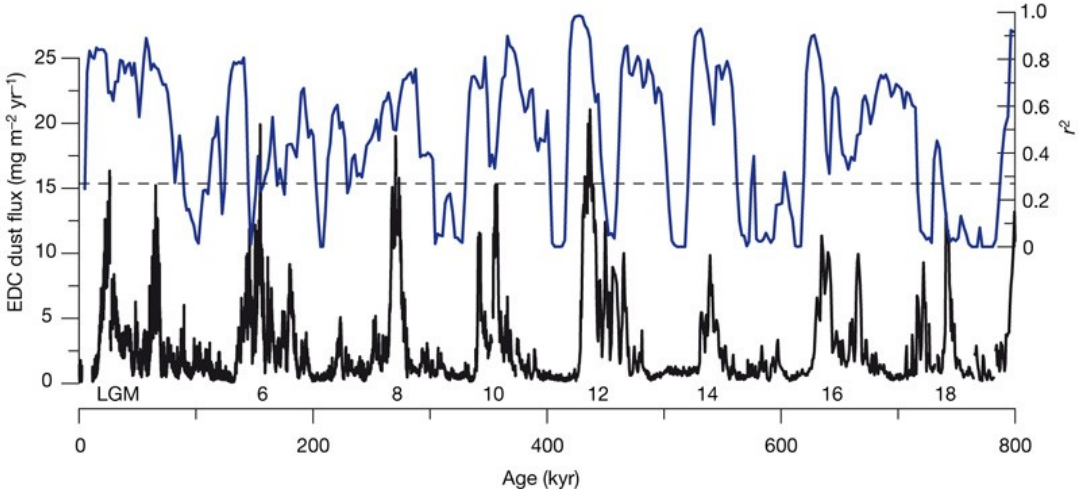
Huang et al. (2014, JGR)

Francis (2018)

The indirect effect of dust as cloud condensation nuclei and biogeochemical effect of dust as nutrient are not considered in the work presented herein

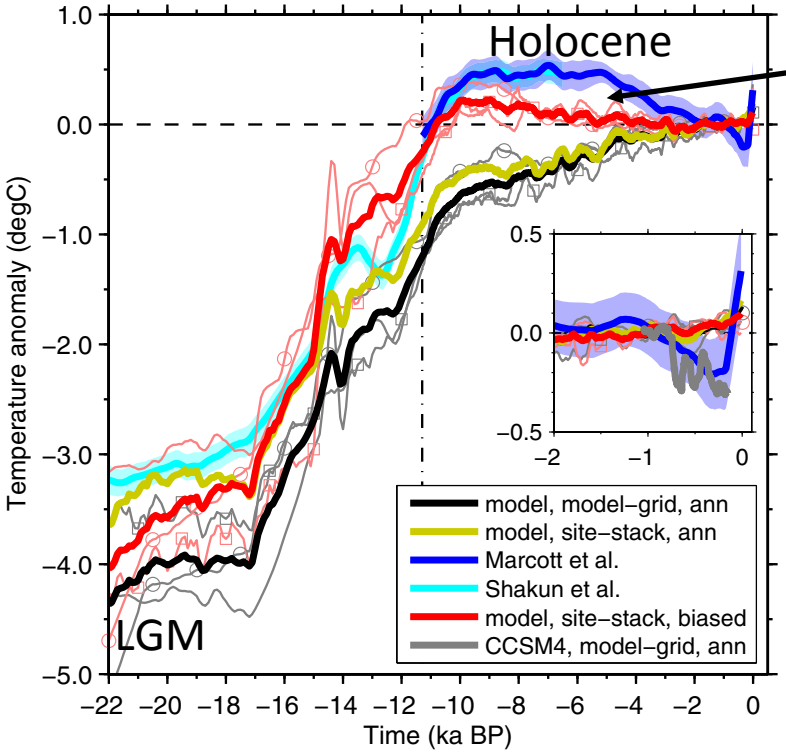
Variation of Dust in the Past

http://lindseynicholson.org



Lambert et al., (2008, Nature)

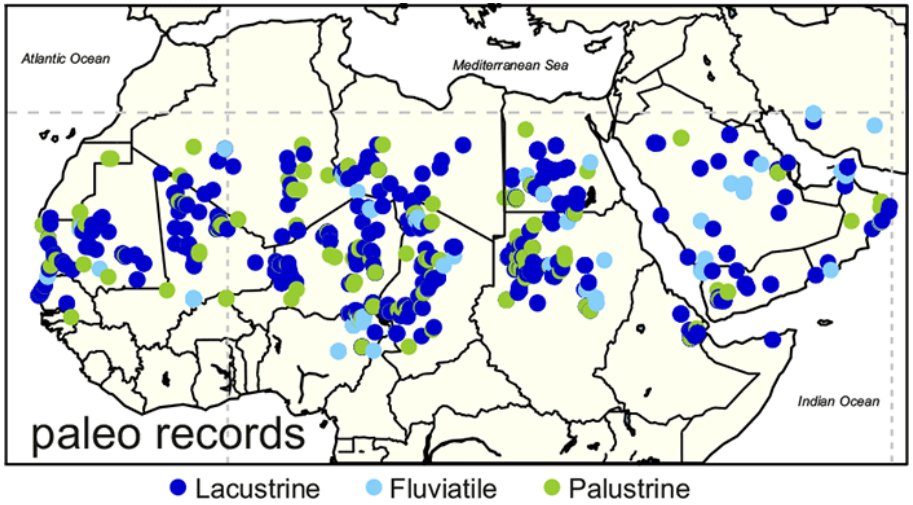
Last Glacial Maximum and Holocene



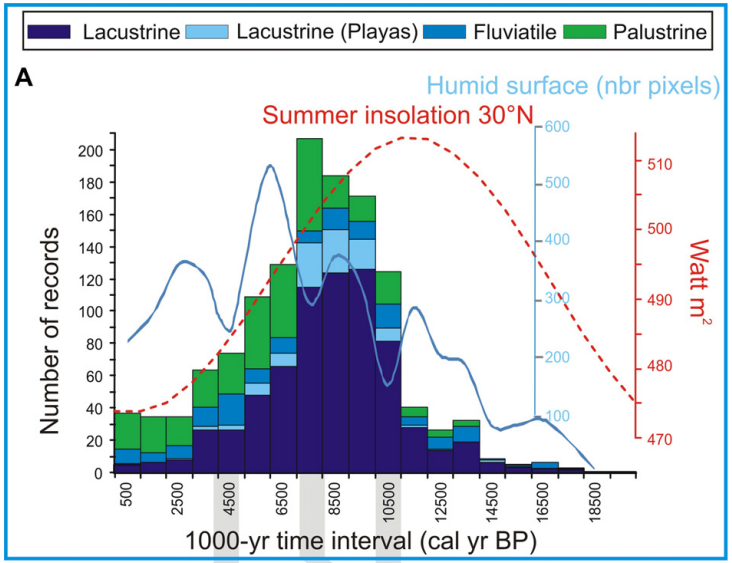
Holocene temperature conundrum

Liu Z et al. (2014, PNAS)

Early and Mid-Holocene Wetting in North Africa and Arabian Region

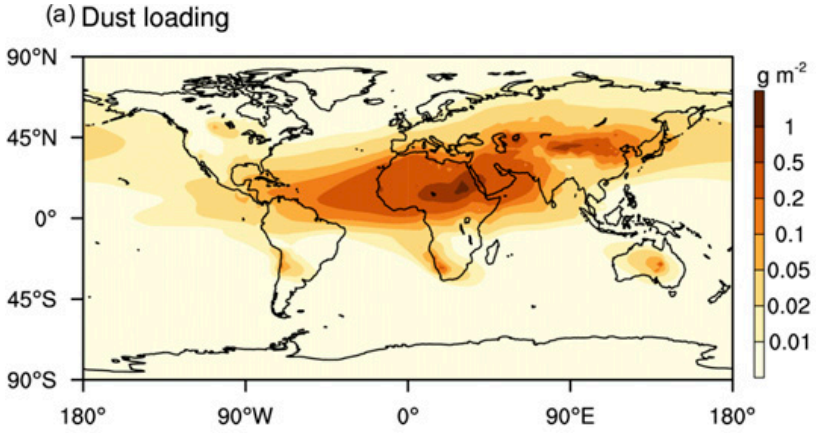


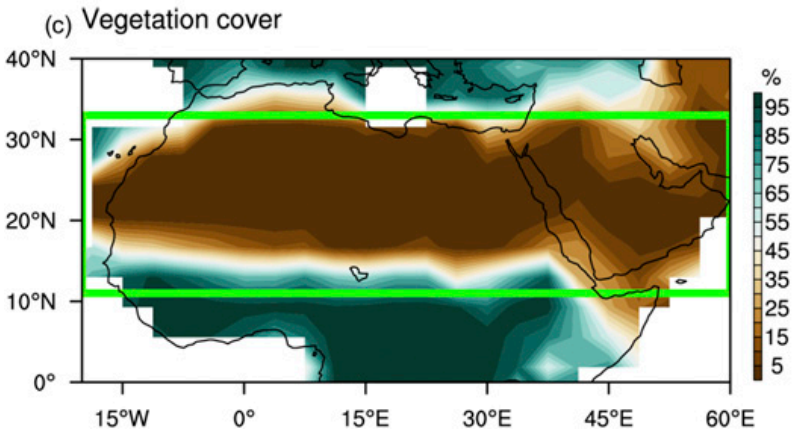
Lézine et al. (2014)



Impact of Sahara Greening on the Mid-Holocene (MH) Climate

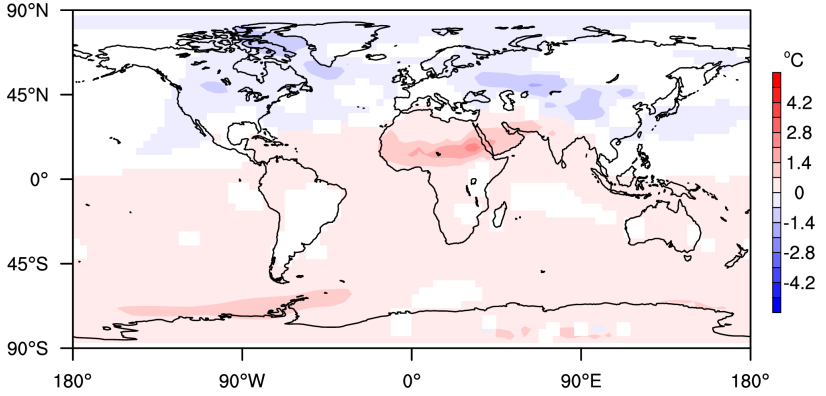
Remove global dust and increase vegetation over North Africa and Arabian Peninsula



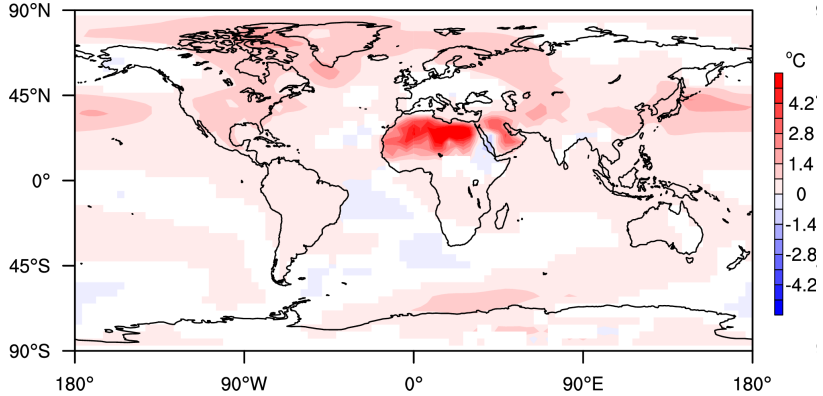


Temperature Response to Dust Removal and Sahara Greening

Dust removal (+0.09 ℃)

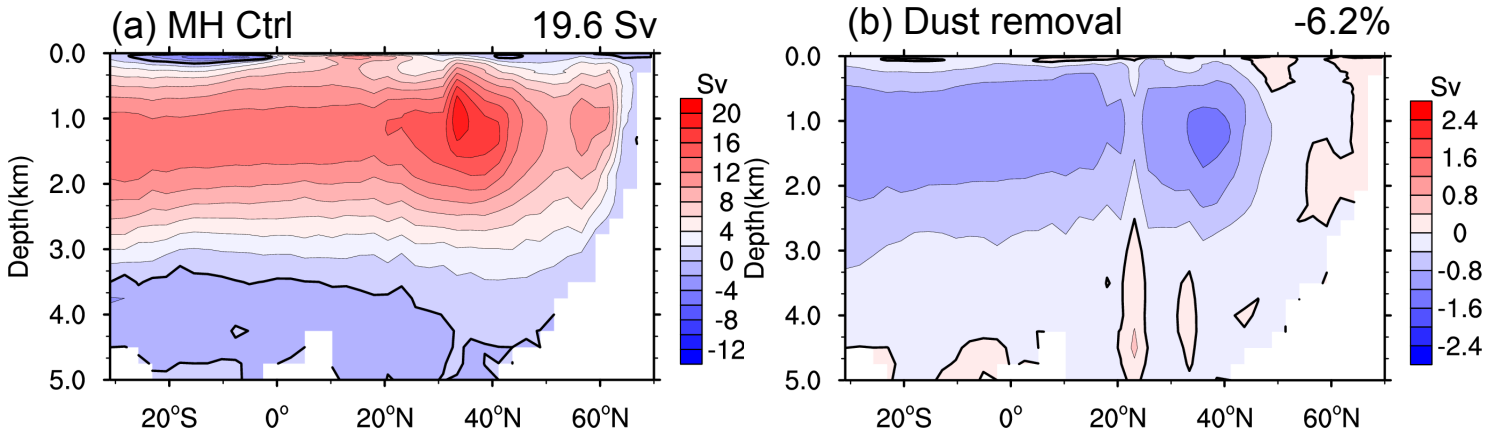


Sahara greening (+0.40 ℃)



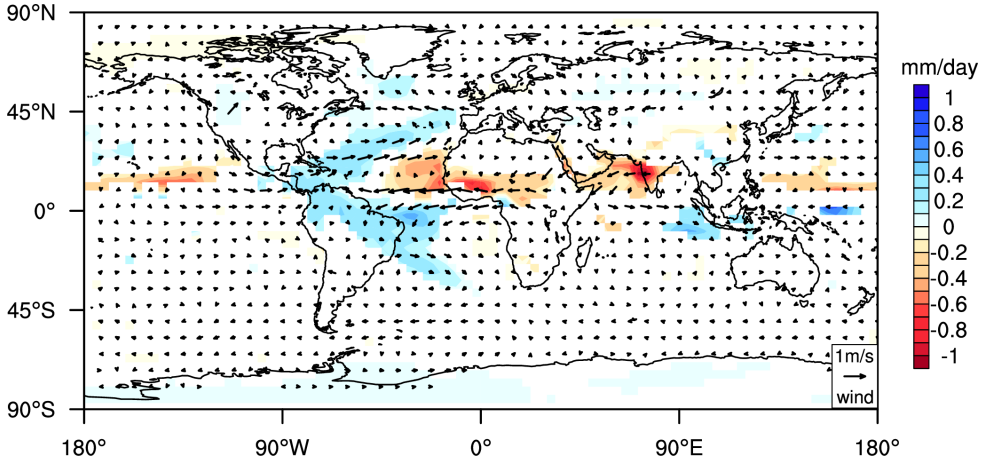
Zhang, Liu* et al (2021, J Clim)

Response of AMOC to Dust Removal



Zhang, Liu* et al (2021, J Clim)

Mechanism for the AMOC Change

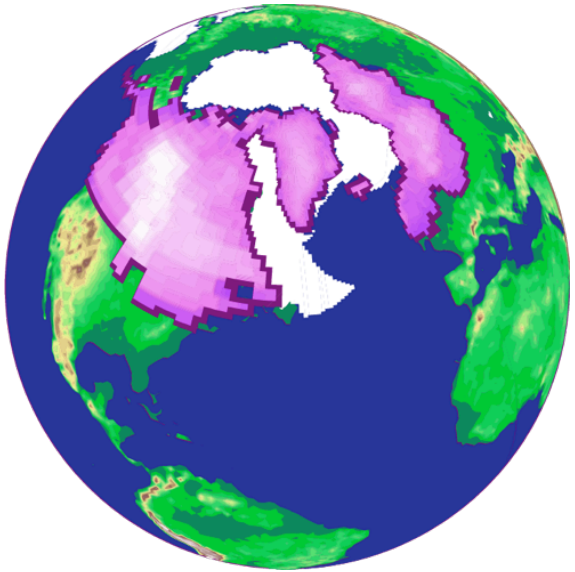


Dust removal

1) weakens African summer monsoon

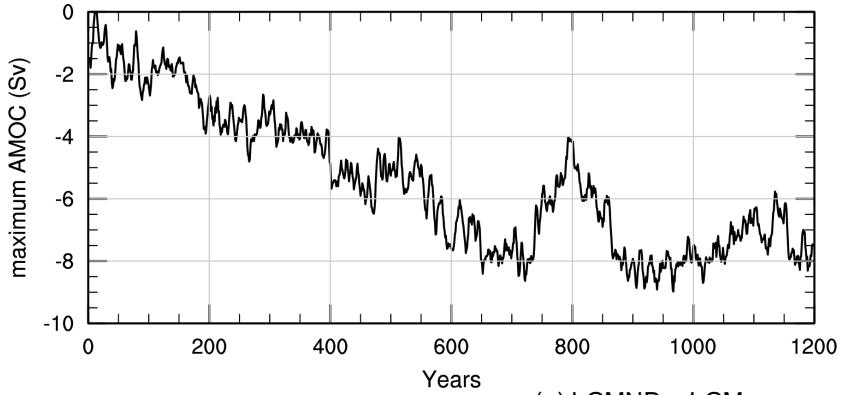
2) Freshens the North Atlantic

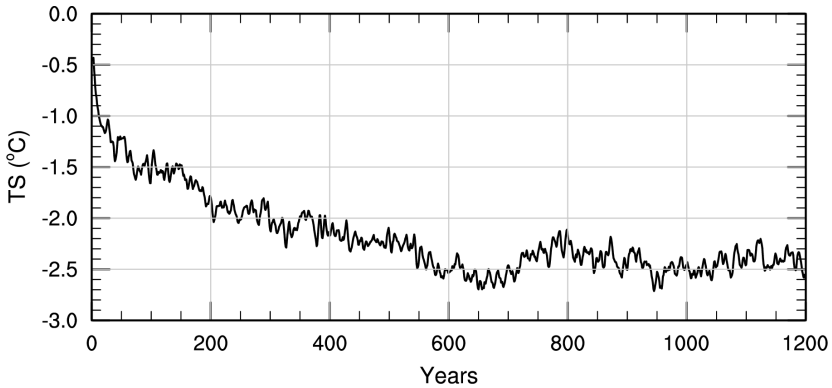
Impact of Dust on LGM Climate

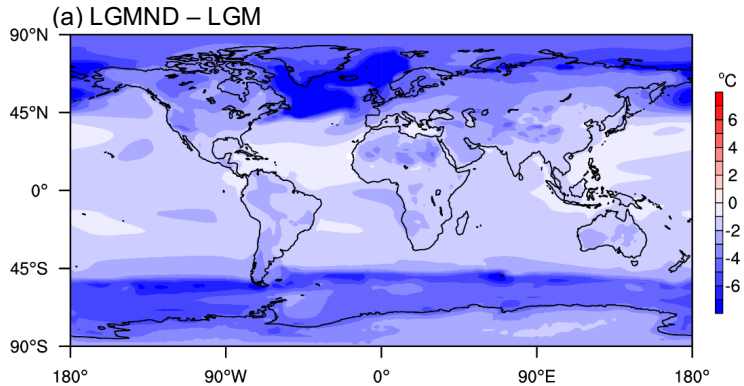


Question: if there were no dust, how would the climate change?

Response of AMOC and Surface Air Temperature

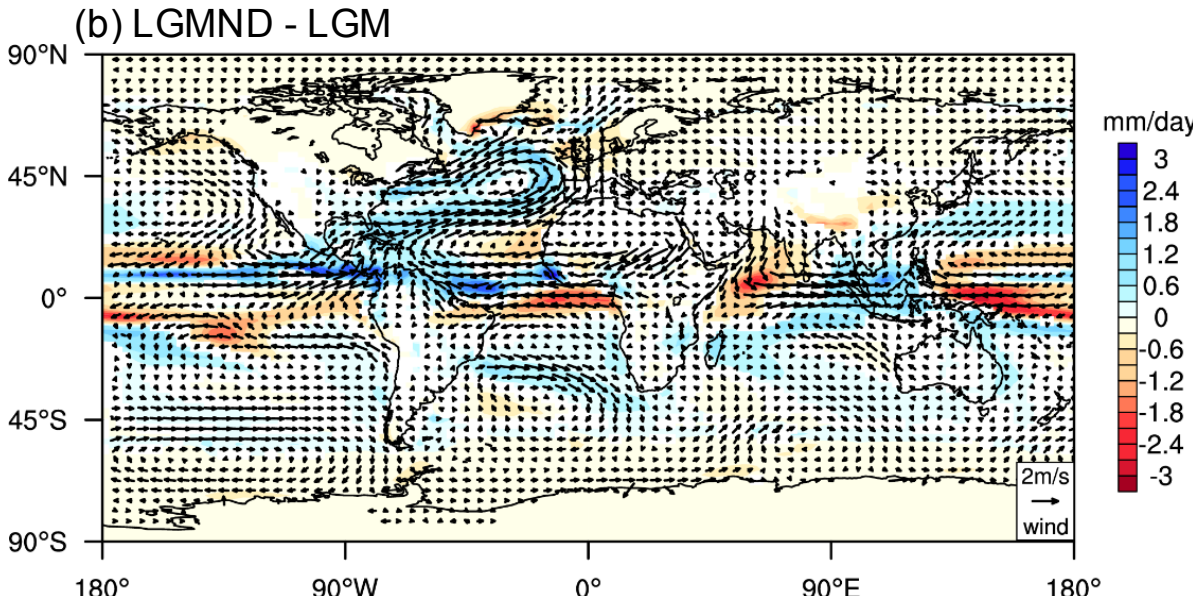




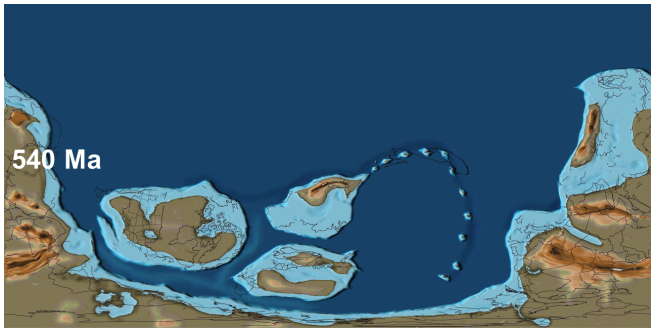


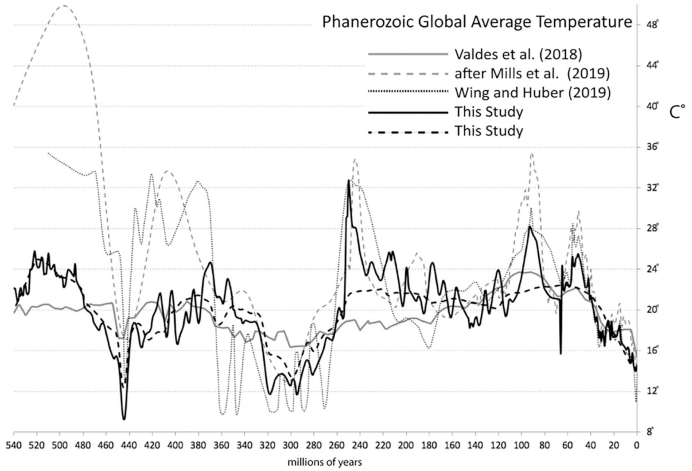
Zhang, Liu* et al (2022, GRL)

Response of Precipitation

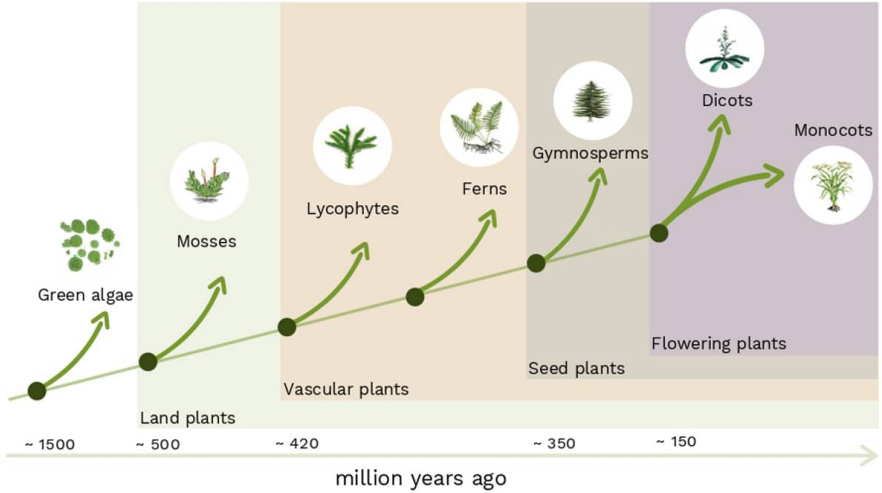


Evolution of Earth's Continents, Vegetation and Climate





Scotese et al. (2020, Earth-Sci Rev)



Three periods are picked:

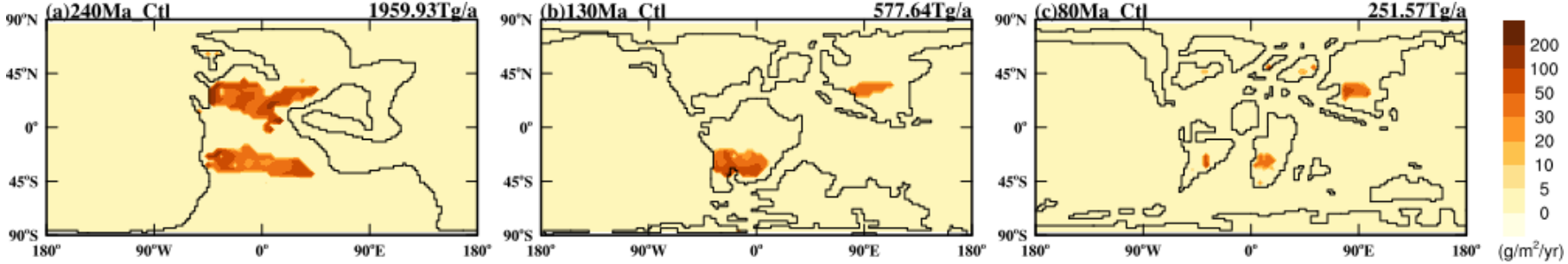
240 Ma supercontinent & warm

130 Ma broken & cool

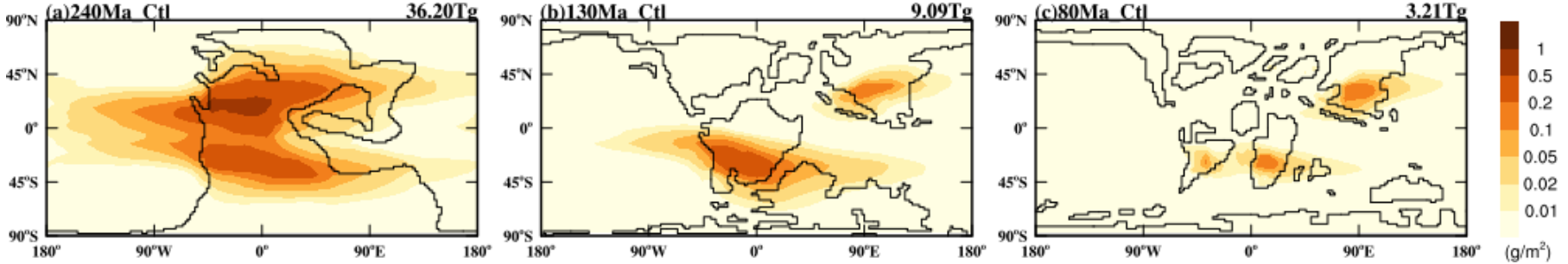
80 Ma very broken & warm

Modeled Dust Emission and Atmospheric Dust Loading

Dust emission

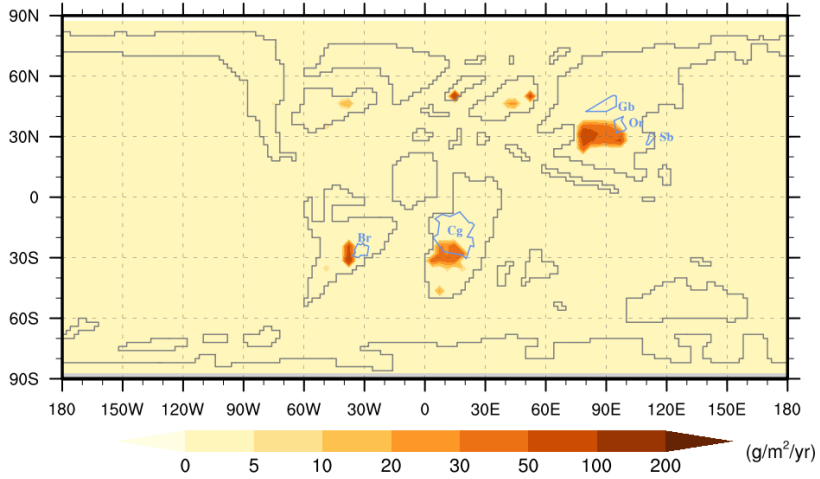


Atmospheric dust loading

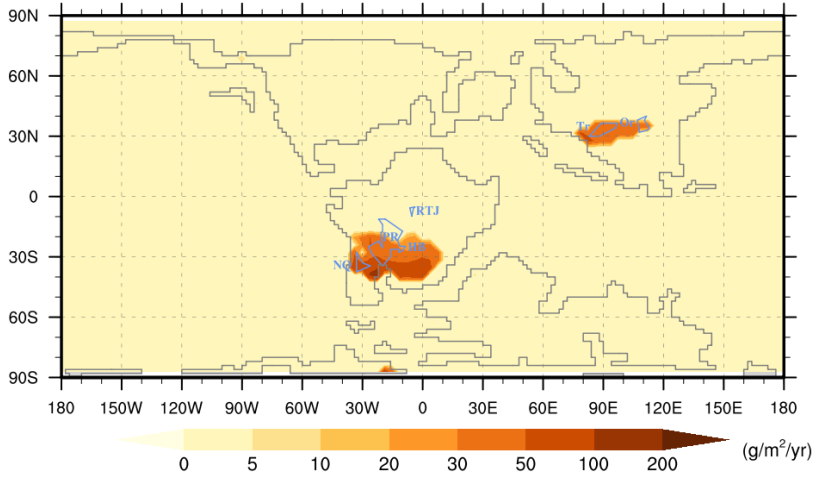


Modeled Dust Emission versus Aeolian Deposits (dunes)

130 Ma



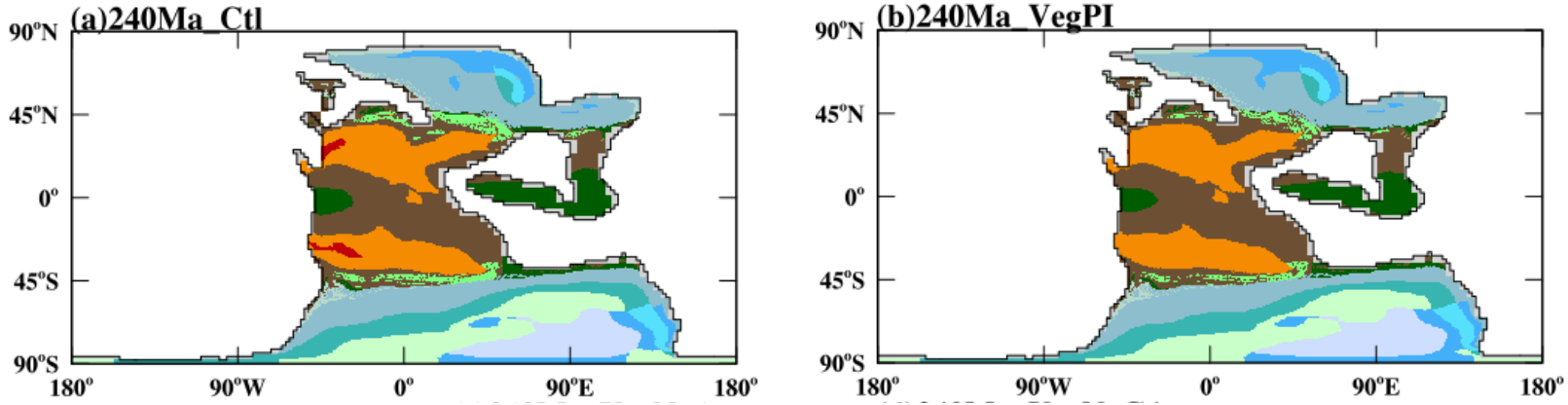
80 Ma



Influence of Plant Evolution on Dust

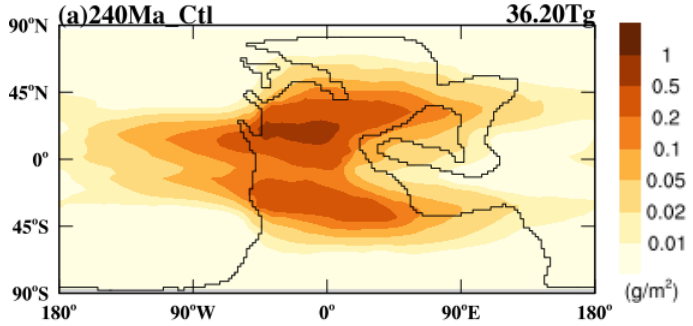
No Angiosperms and C4

Present-day vegetation

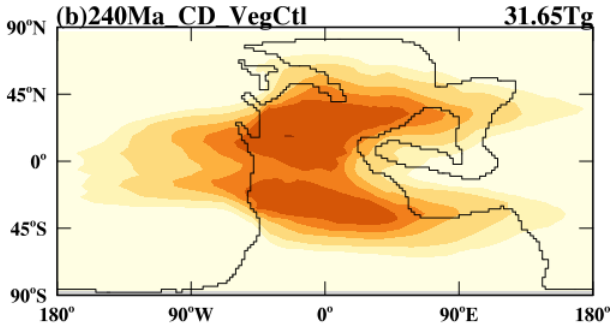


Dust emission changes little (not shown)!

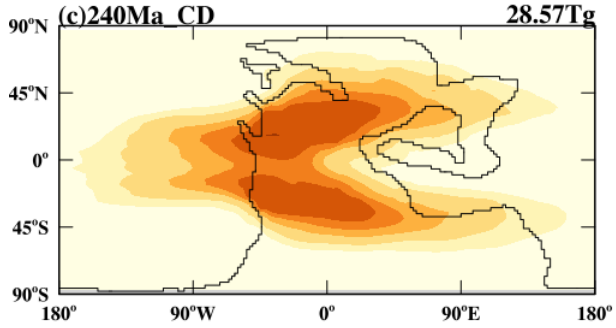
Influence of Climate on Dust



Cold climate, fixed veg



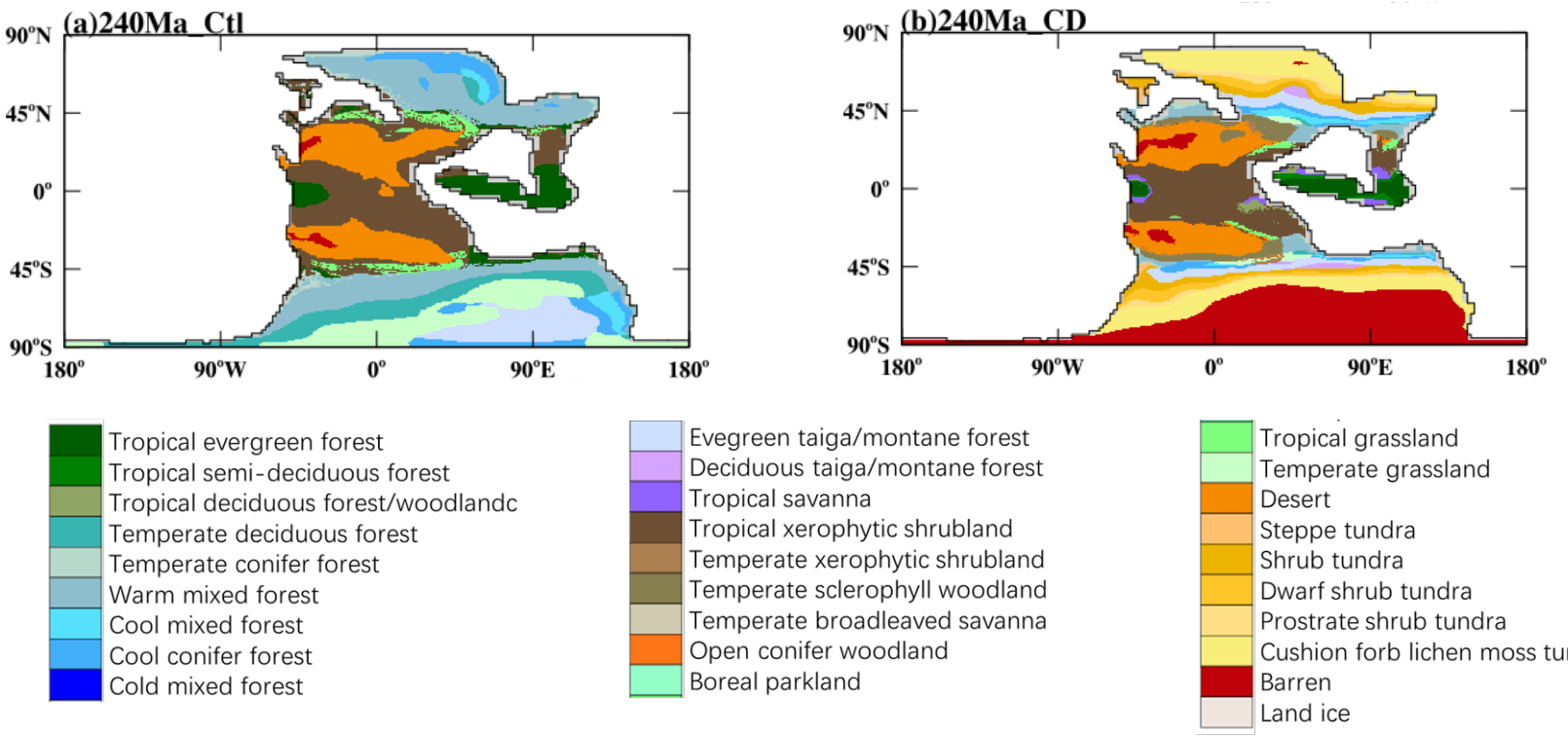
Cold climate, dynamic veg



The dust loading during the Pangea supercontinent era would be less and similar to that of today if the climate was as cold as today

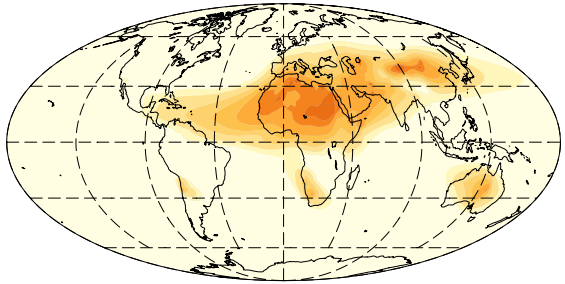
Influence of Climate on Dust

Vegetation coverage increases when climate becomes colder

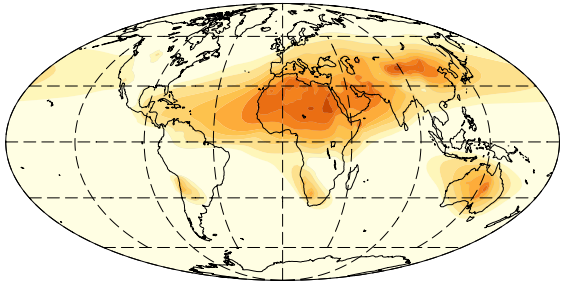


Climate Impact of Dust before Land Plant Appeared

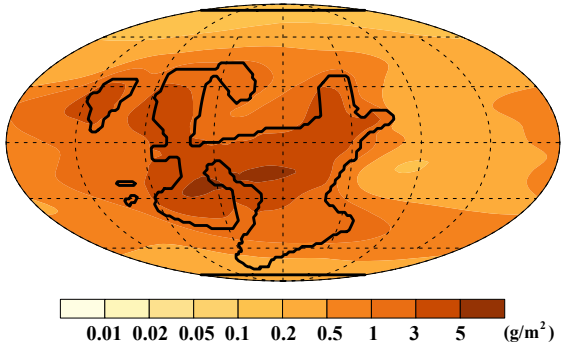
Pre-industrial



Last Glacial maximum



Before 400 Ma

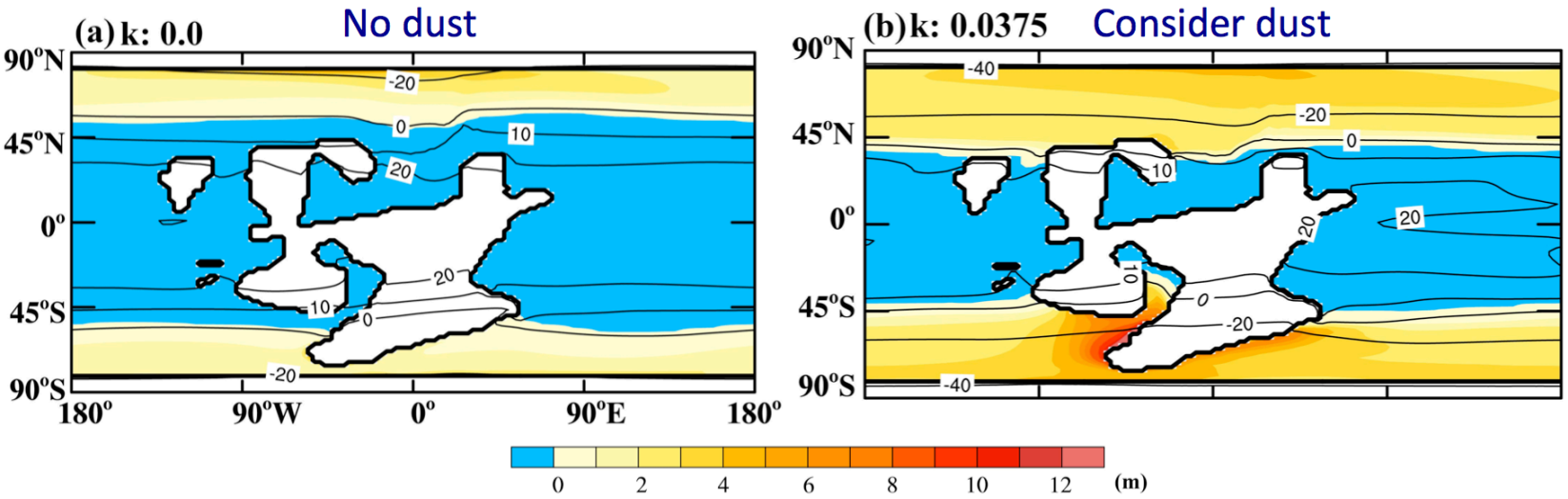


Liu, Liu# et al. (2020, Nature Communications)

- There was no land vegetation before 400 Ma, dust emission could be 10 times that of present day

Climate Impact of Dust before Land Vegetation Appeared

Solar constant is 94%, CO_2 = 2000 ppmv, control climate is relatively warm



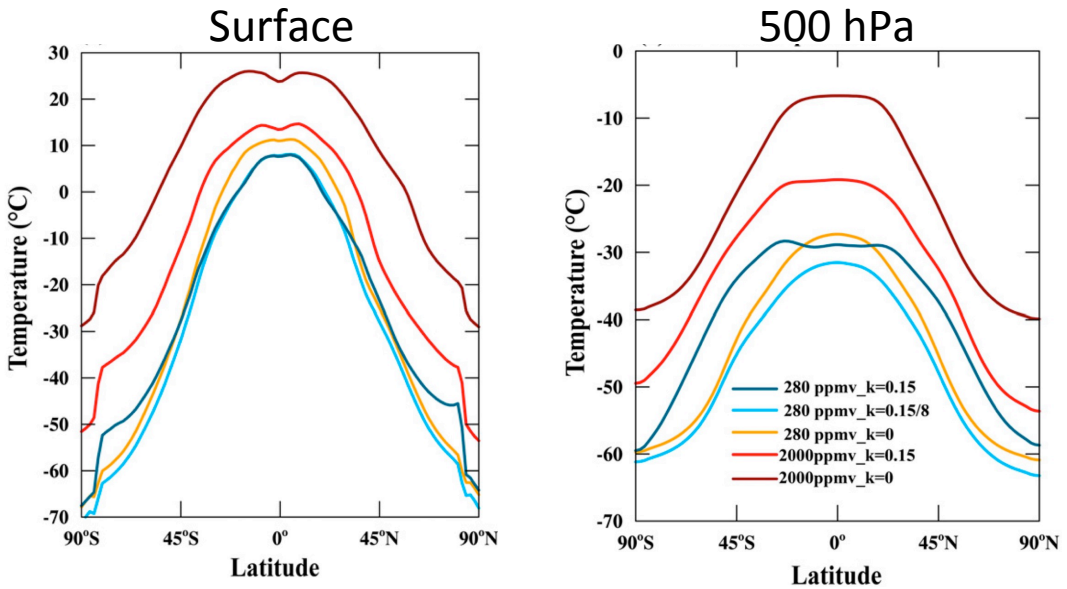
Liu, Liu# et al. (2020, Nature Communications)

Colors are sea-ice thickness, contours are annual mean surface temperature.

Global mean surface temperature is reduced by ~10 °C

Climate Impact of Dust before Land Vegetation Appeared

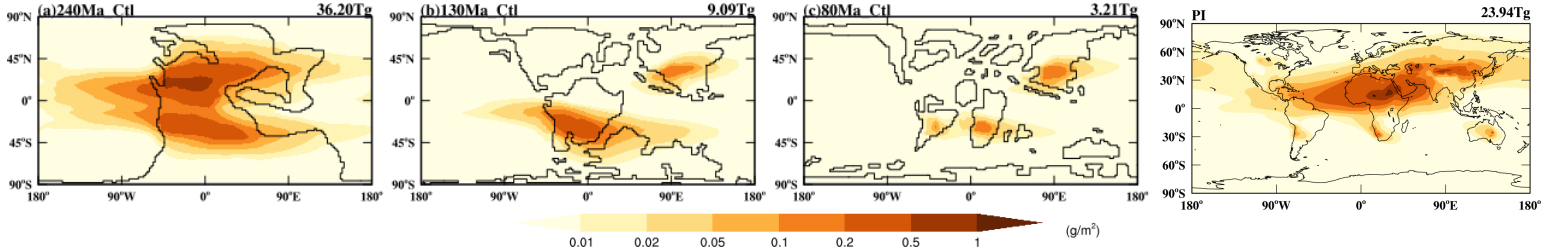
- When the control climate is cold, dust has little impact on the surface temperature
- The meridional temperature gradient is significantly affected by dust, which in turn affects the westerlies and the sea-ice transport



Liu et al. (2021，J Clim)

Summary

- The global dust emission is affected mainly by the distribution of land within the subtropical region, and little by the evolution of vegetation



- More dust emitted when climate is colder but the atmospheric dust loading may be less (e.g. for Pangea supercontinent)
- Dust likely has a cooling effect during warm interglacials but a warming effect during cold glacial periods
- Ocean dynamics is important in transmiting and amplifying the climate impact of dust and vegetation

Uncertainties

1. Idealized experimental setup (e.g. uniform surface erodibility)
2. Did not consider the influence of soil change and lakes
3. Did not consider the indirect effect of dust
4. The size distribution as well as radiative property of dust may be different from those simulated by the model
5. There could be glaciogenic dust sources (e.g. during LGM)

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