Stripping back the Modern to reveal Cretaceous climate underneath

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November 24, 2022

Abstract

In the context of climate change, a clear understanding of the processes and factors driving global warming is a major concern. During past geological times, Earth suffered several intervals of global warmth but the priming factors remain equivocal. Yet a careful appraisal of all processes being implied during those past events is essential to evaluate how they can inform future climates, in order to provide decision makers a clear understanding of the processes at play in a warmer world. In this context, the global warmth of the Cretaceous era, specifically during the Cenomanian-Turonian, is of particular interest. Here we use the IPSL-CM5A2 Earth System model to unravel the forcing parameters of the Cenomanian-Turonian greenhouse climate. We perform six simulations, from the preindustrial to the Cretaceous by implementing one additional boundary condition change at a time, i.e. (1) polar ice cap retreat, (2) pCO2 increase to 1120 ppm, (3) vegetation and soil parameters, (4) solar constant reduction (~ -1%) and (5) paleogeography (90Ma). Between the first preindustrial simulation and the last Cretaceous simulation, a global warming of more than 11°C is simulated. Most of this warming is driven by the increase in pCO2 to 1120 ppm. Paleogeographic changes represent the second major contributor to the warming while the solar constant reduction counteracts most of this geographically-driven warming. Finally, changes in vegetation and soil parameters as well as the retreat of polar ice caps have a minor impact at the global scale. A full assessment of the processes driving warming or cooling under each boundary condition change will be presented. Ultimately, our work supports the overarching influence of atmospheric carbon dioxide in driving the Earth's global climate and global warming.

STRIPPING BACK THE MODERN TO REVEAL CRETACEOUS CLIMATE UNDERNEATH

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M. Green[3], L. Bopp[4], F. Raisson[5]

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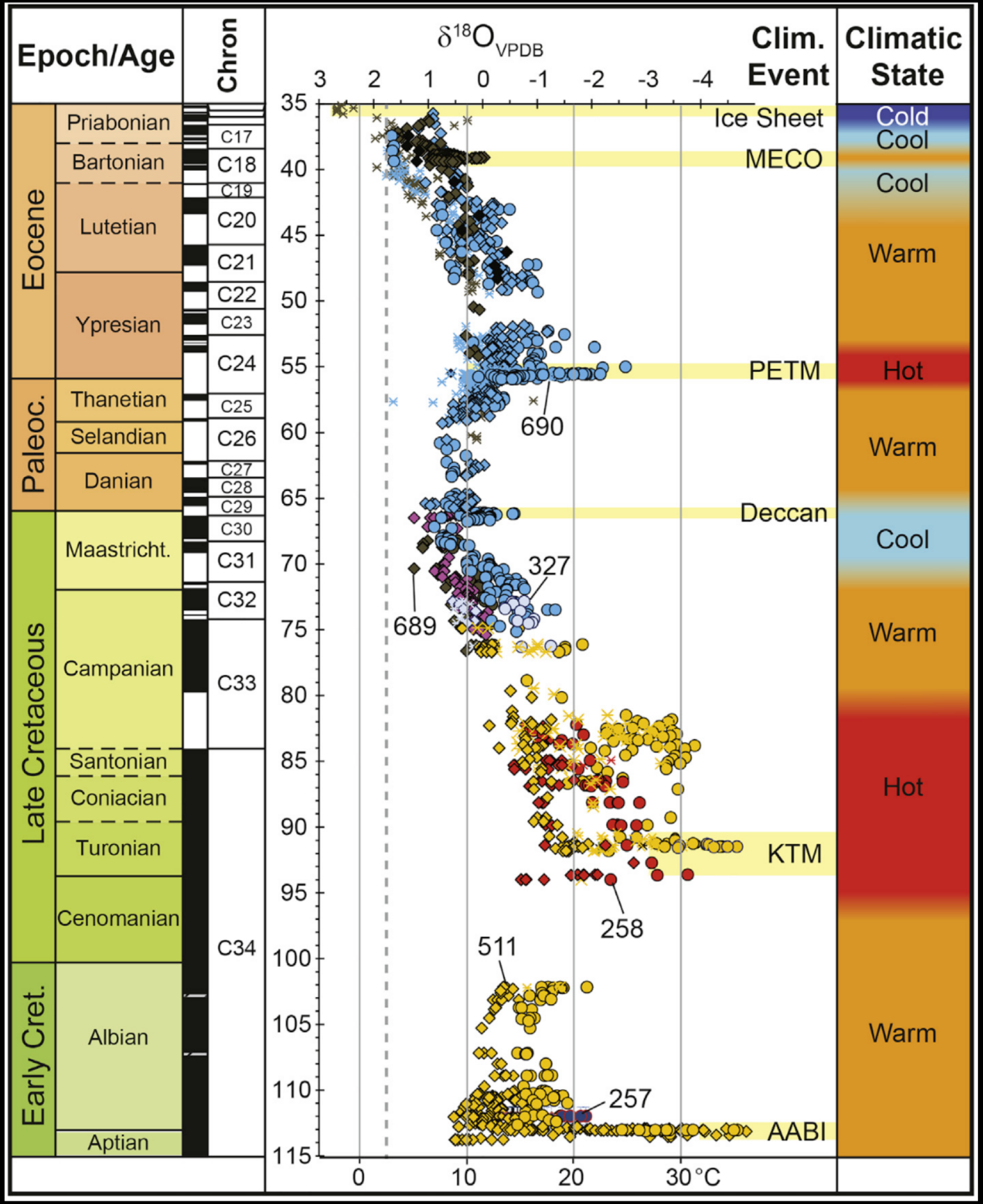
2 UNIVERSITY OF MICHIGAN

3 PRIFYSGOL BANGOR UNIVERSITY

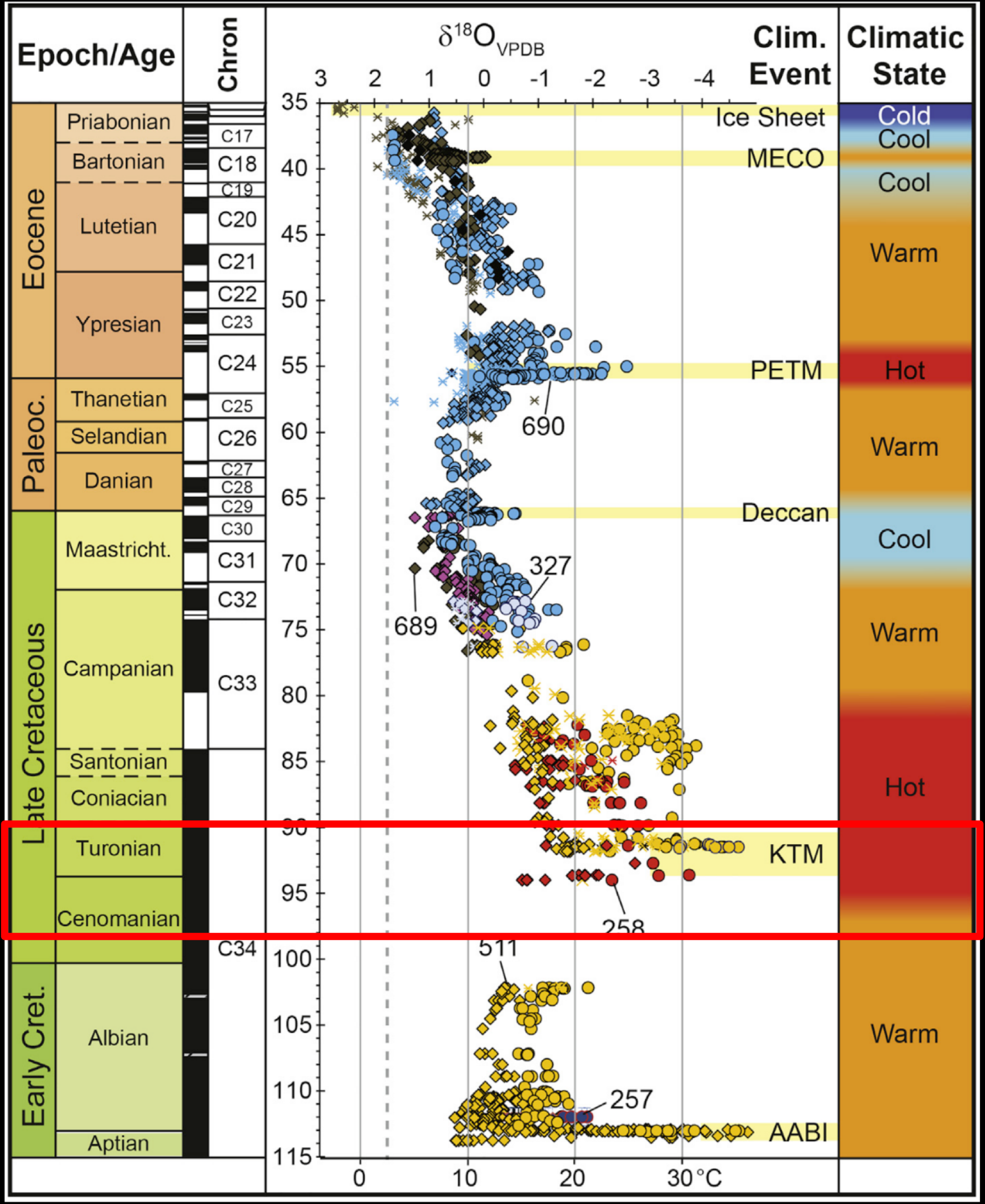
4 ENS

5 TOTAL

AGU 100 FALL MEETING



Huber et al., 2018 – Global and Planetary Change



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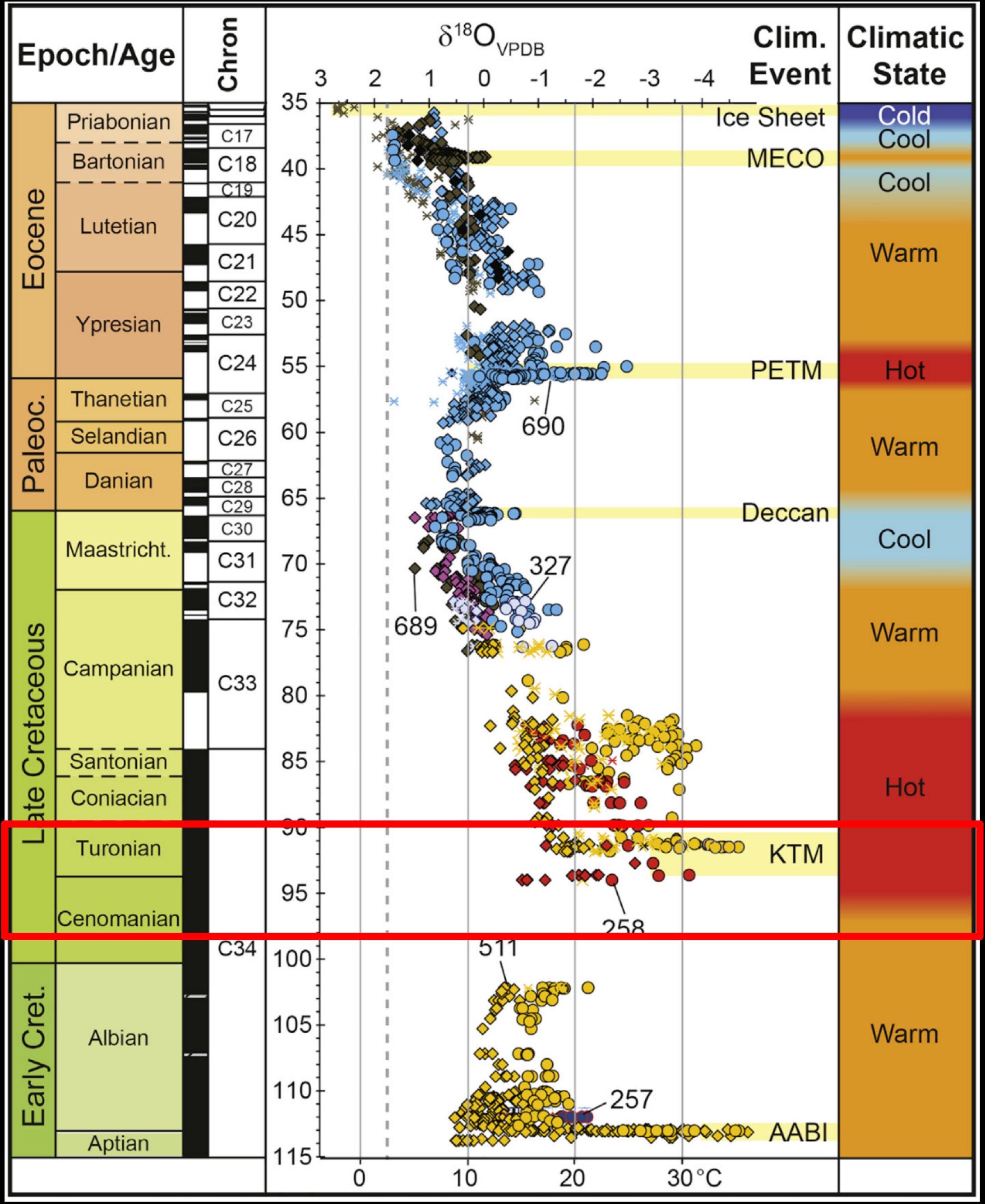
Primary climate forcing → CO_2



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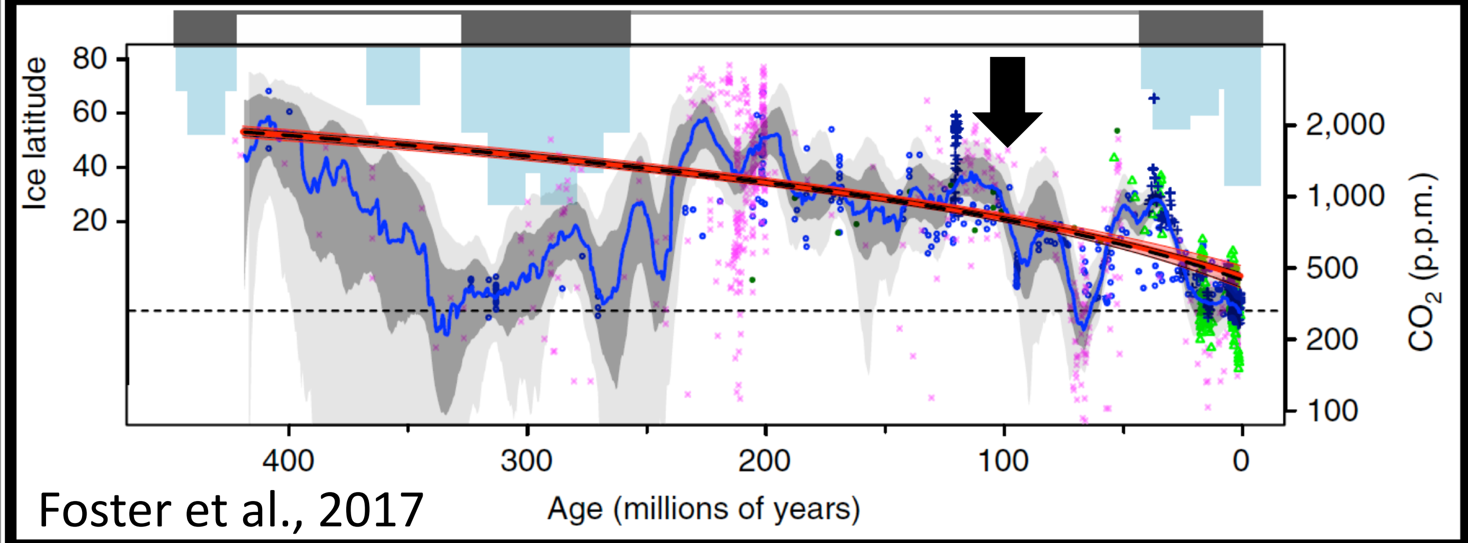

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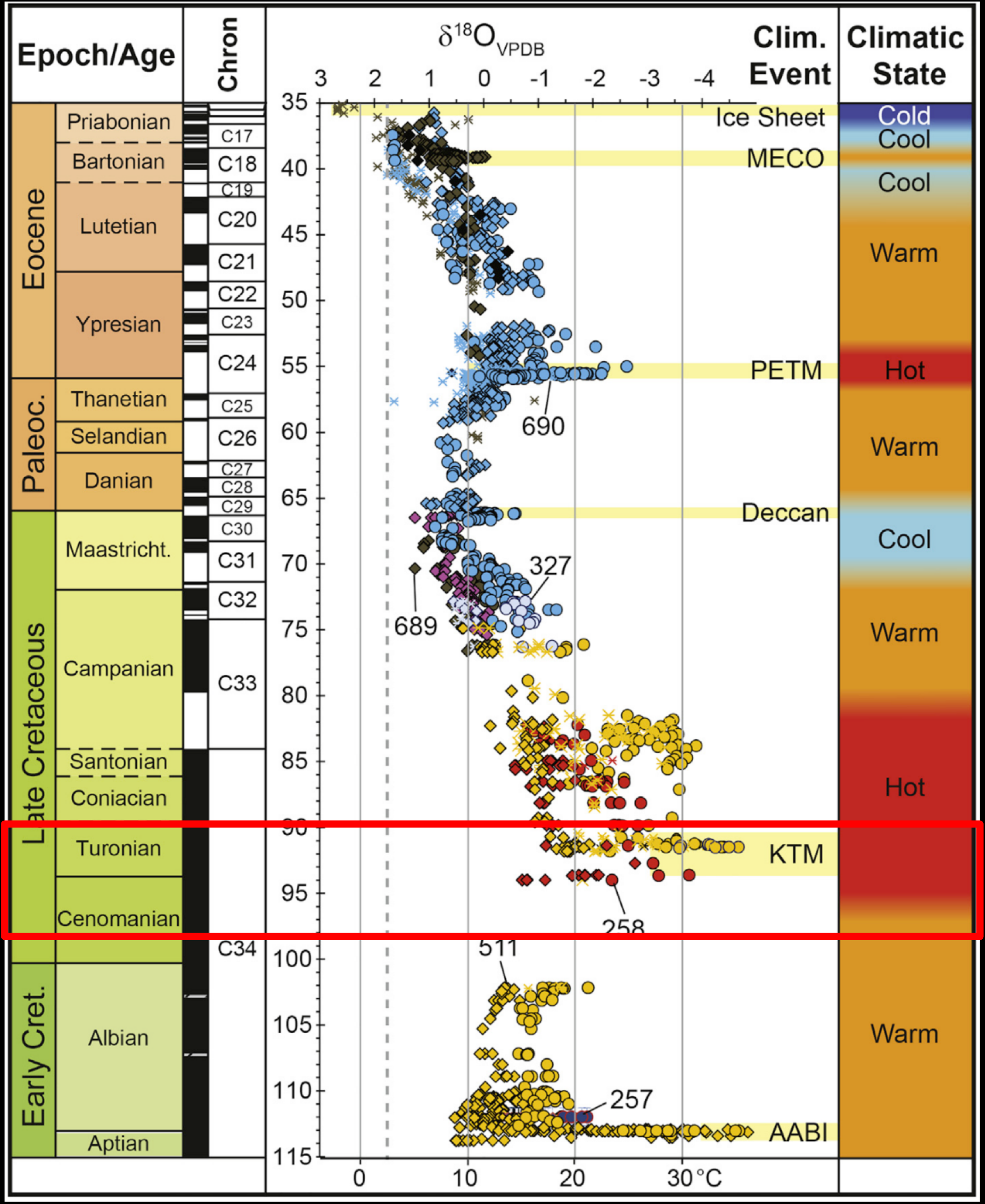

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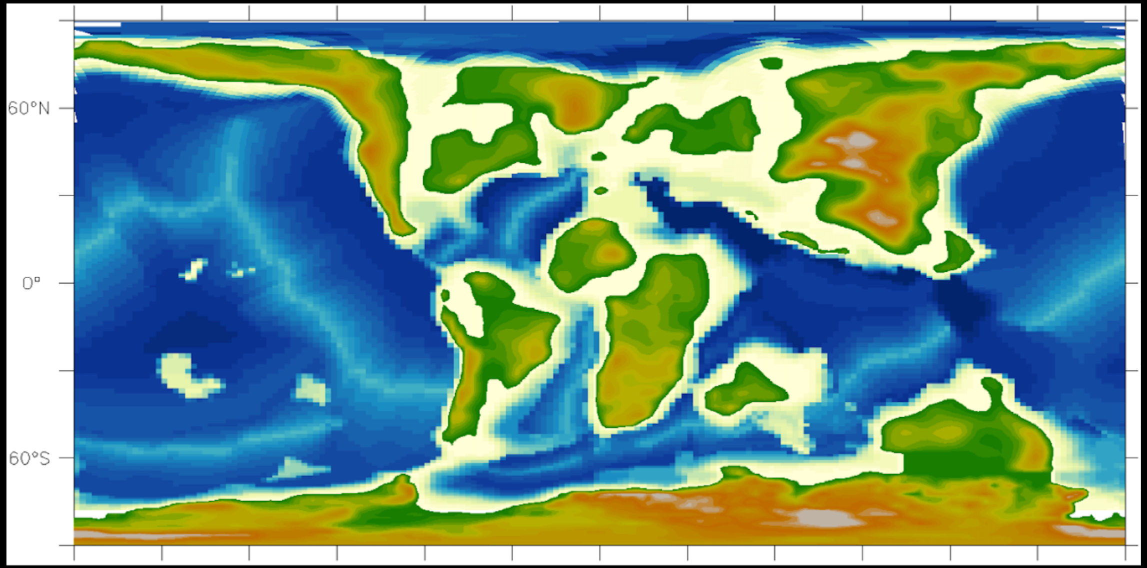
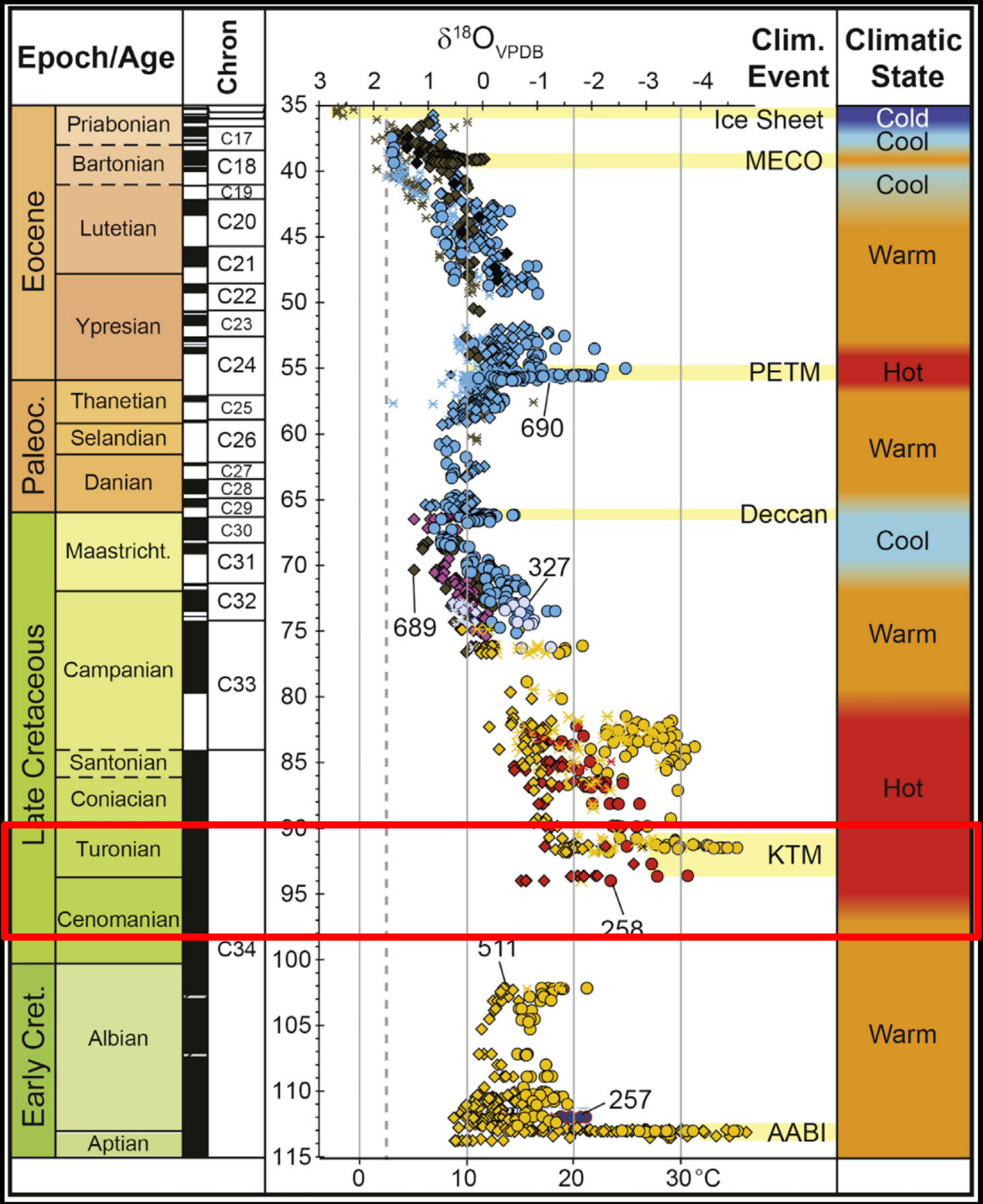


CT Paleogeography (90 Ma) – After Scotese and Müller



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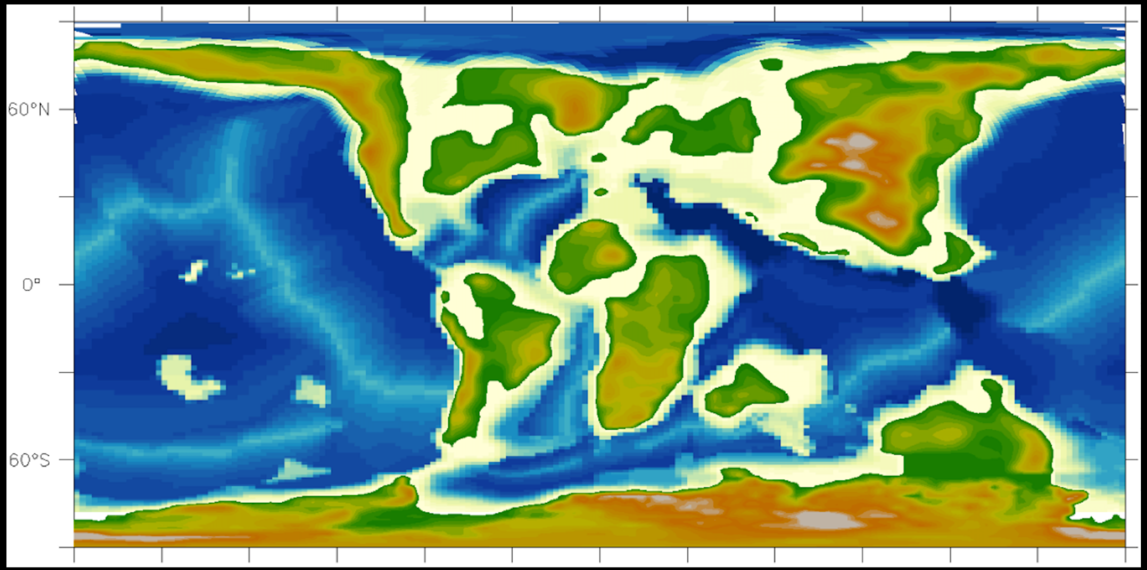
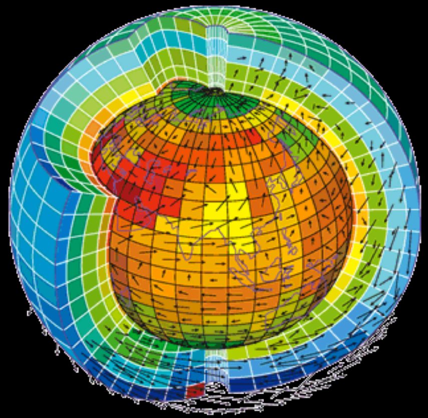


CT Paleogeography (90 Ma) – After Scotese and Müller

- Negligible? (Barron et al., 1995)
  - Only regional? (Lunt et al., 2016; Tabor et al., 2016)
    - As strong as a doubling of pCO_2? (Crowley et al., 1986, Ladant & Donnadieu, 2016)

MODELING SET-UP

IPSLCM5A2 Earth System Model



LMDZ atmosphere:
3,75° x 1,875° x 39
ORCHIDEE
land surface model:
3,75° x 1,875°
NEMO ocean:
2° x 0,5-2° x 31

Pre-Industrial
piControl

1X-NOICE

4X-NOICE

4X-NI-PFT-SOIL

4X-NI-PFT-SOIL-SOLAR

Cenomanian-Turonian
4X-CRETACEOUS

- 2000 year simulations
- Present-day orbital configuration

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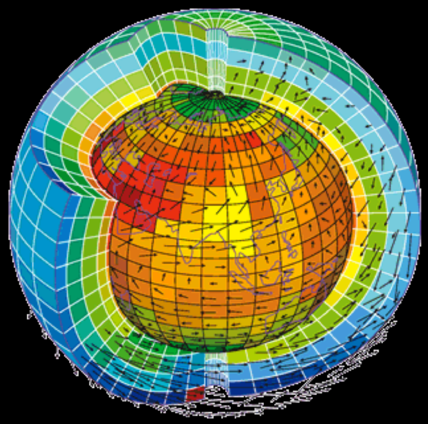

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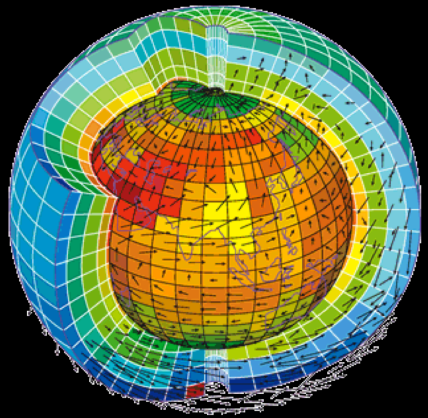

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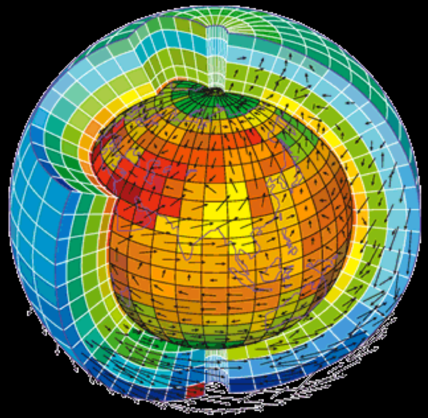

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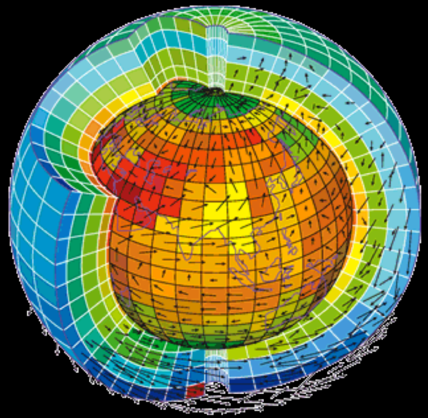

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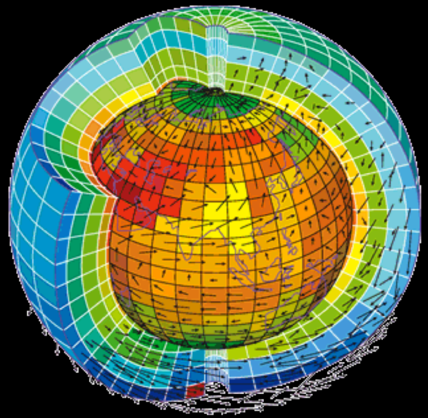

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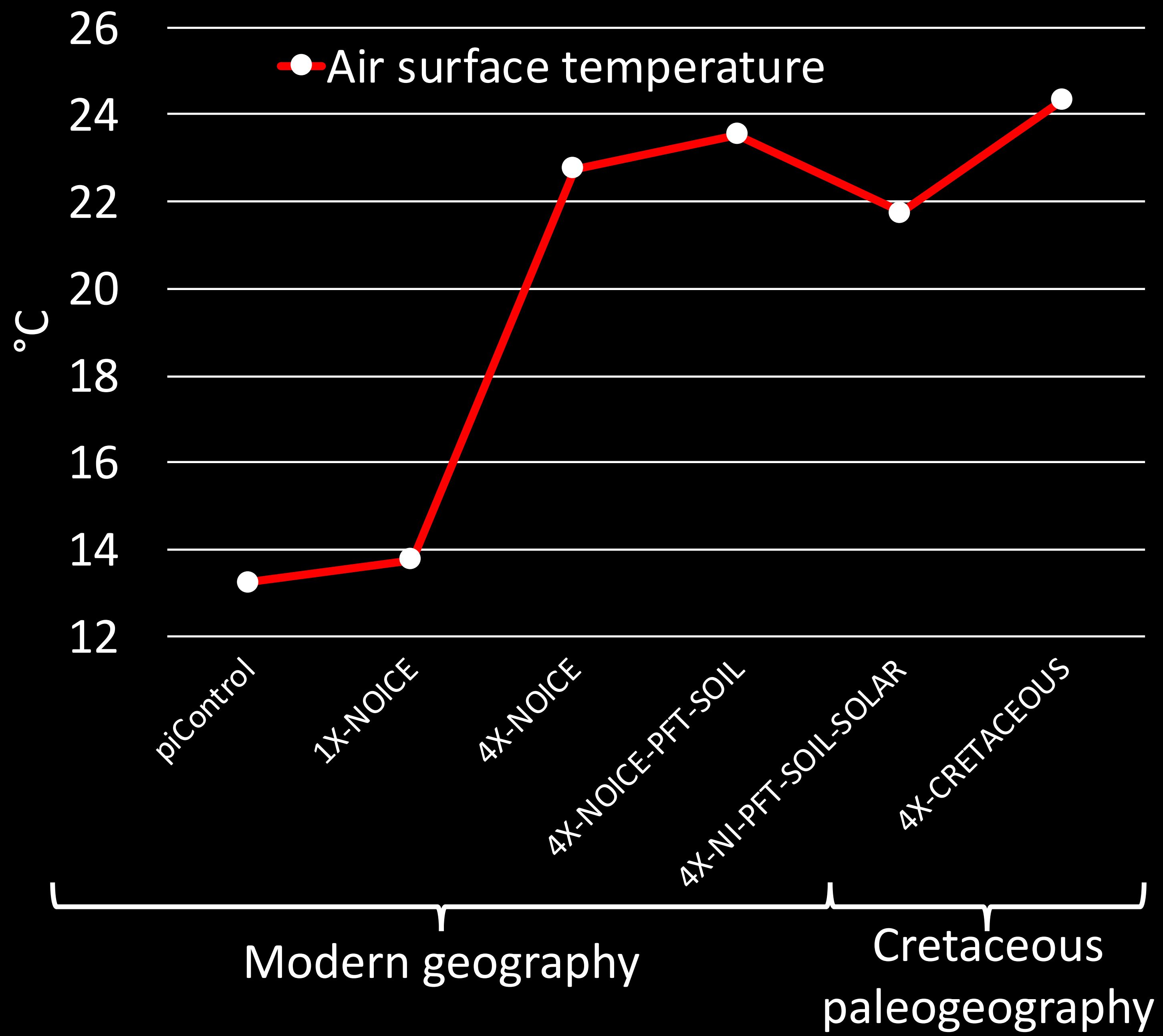
GLOBAL ANNUAL TEMPERATURE EVOLUTION



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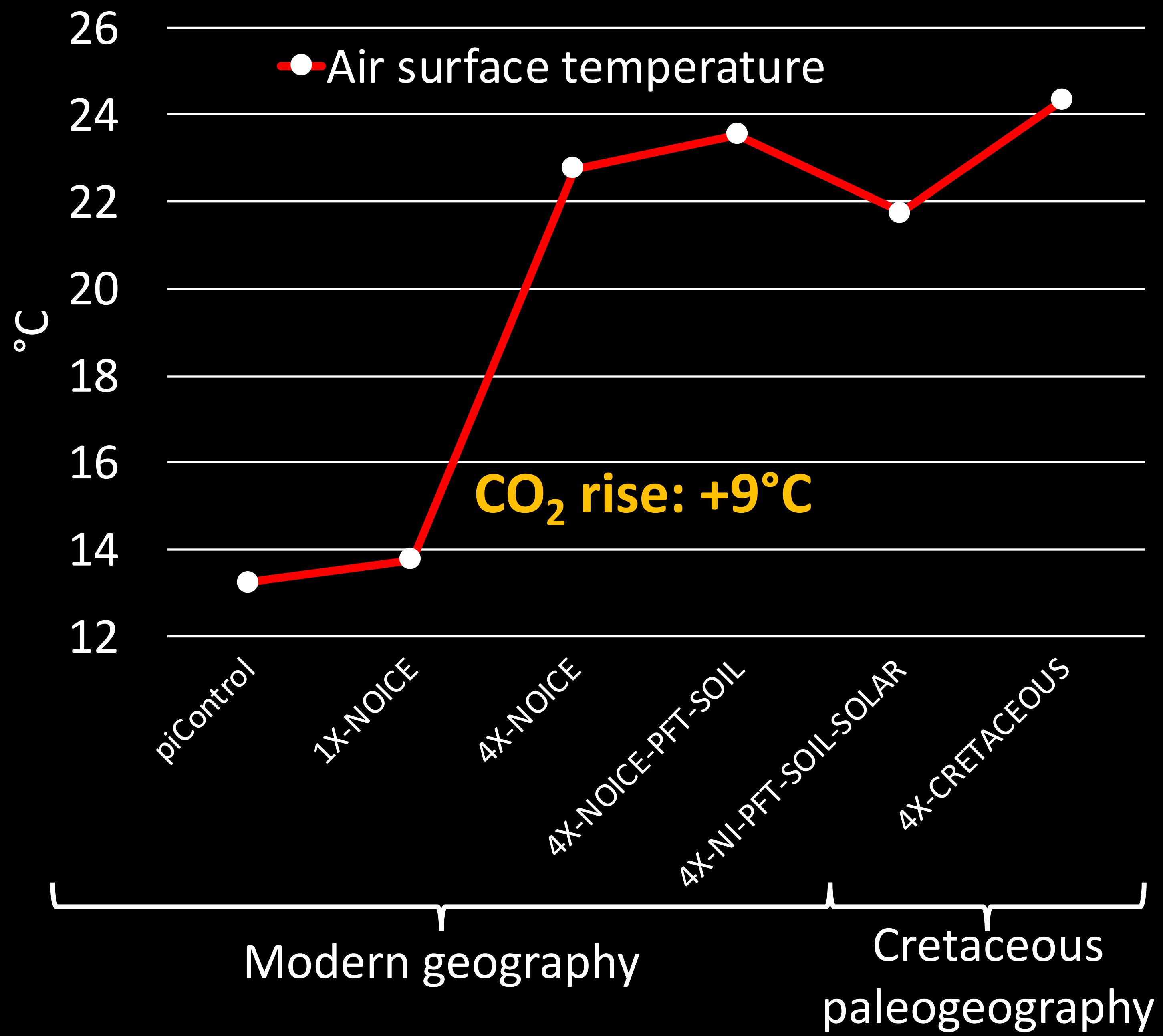

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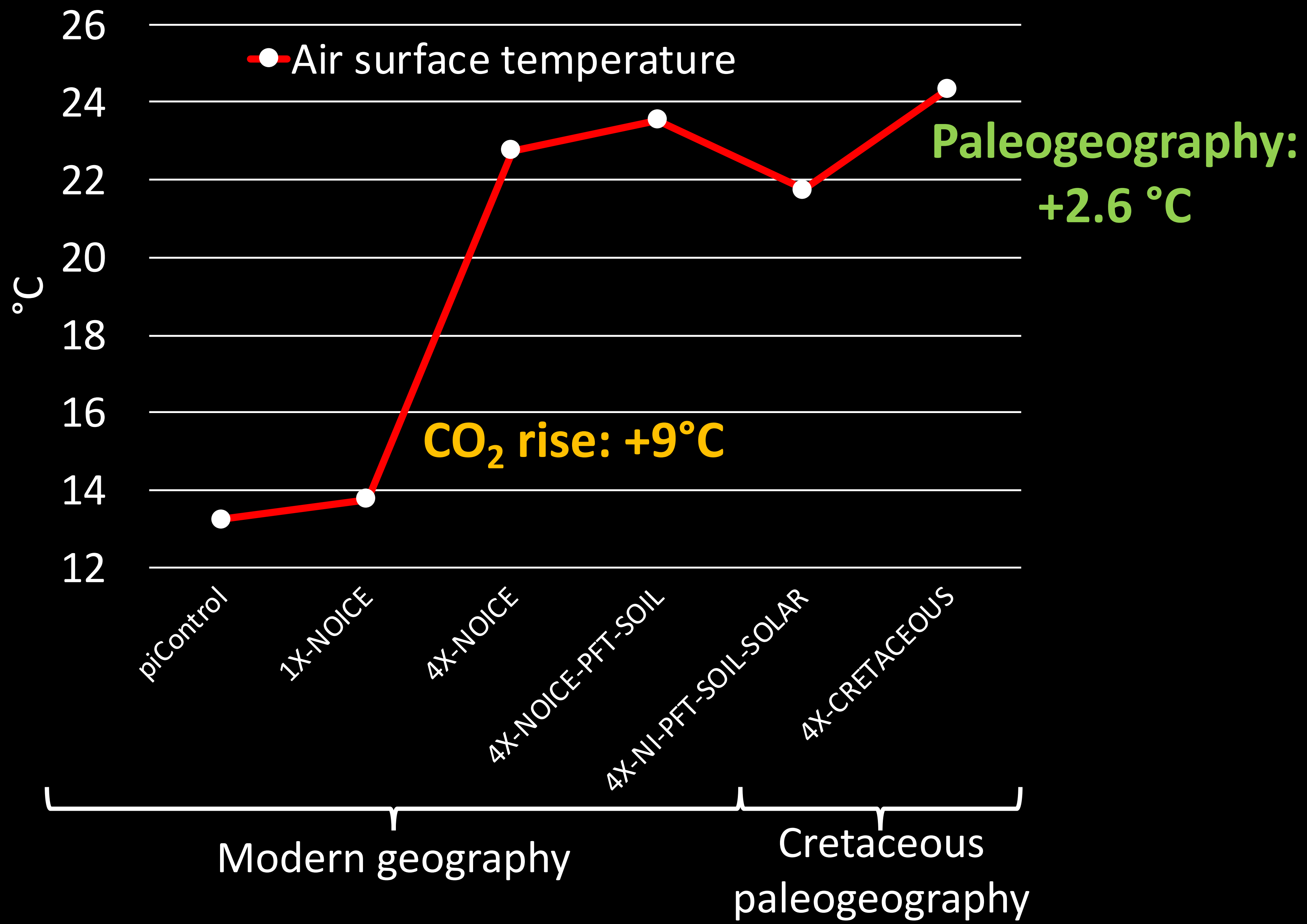
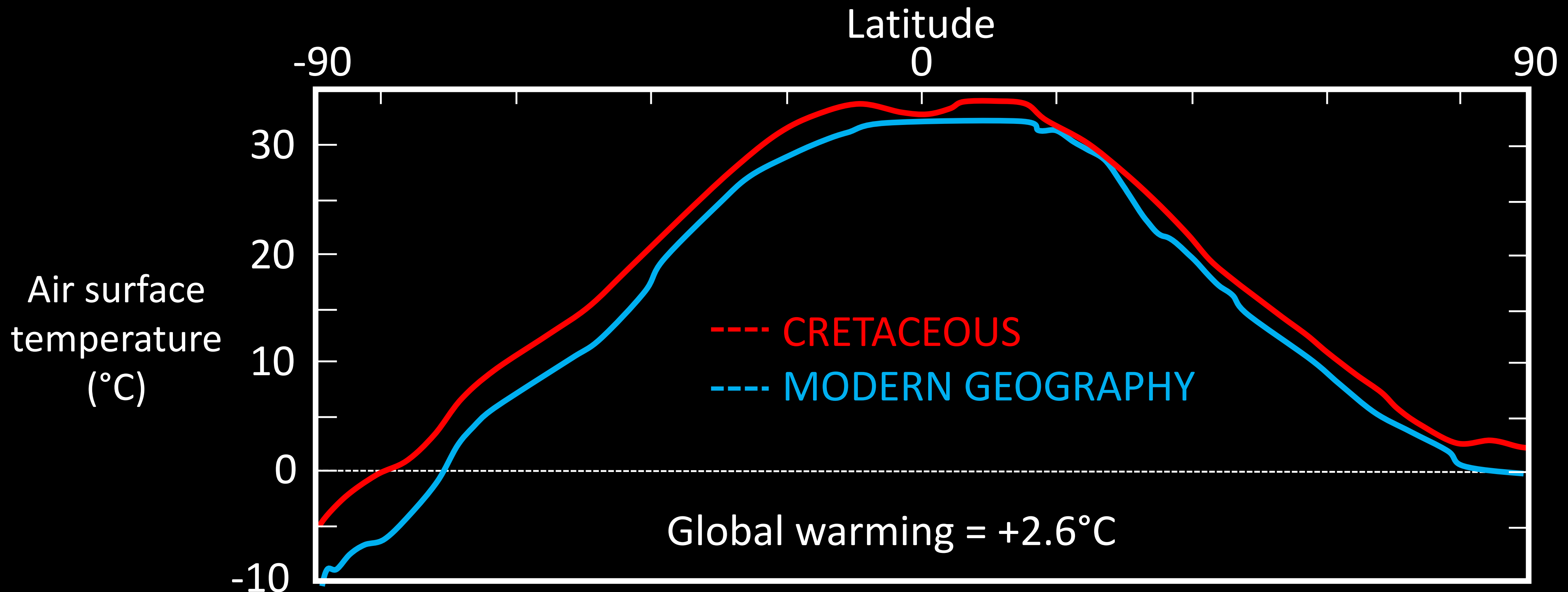


ATMOSPHERIC TEMPERATURES – MERIDIONAL AVERAGE



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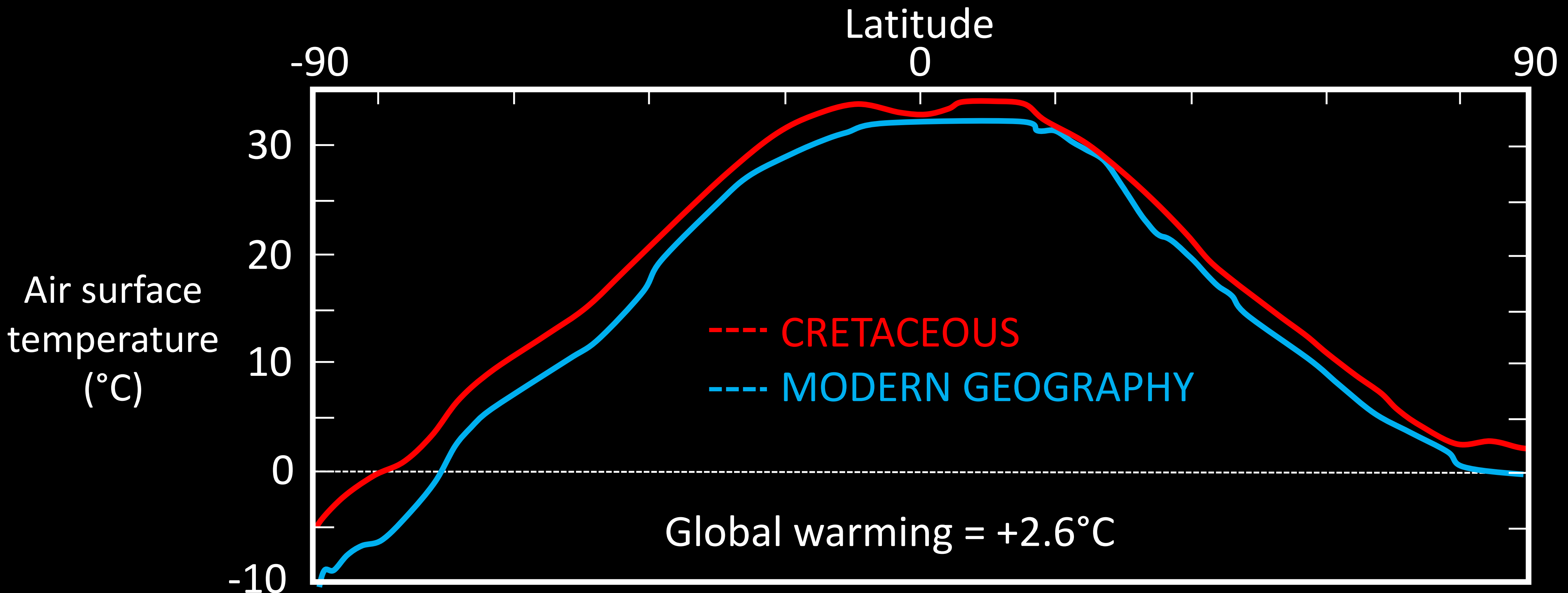

Planetary Albedo
-1.53 % → + 1,6°C

Atmospheric Emissivity (Greenhouse effect)
- 0.73 % → + 1°C

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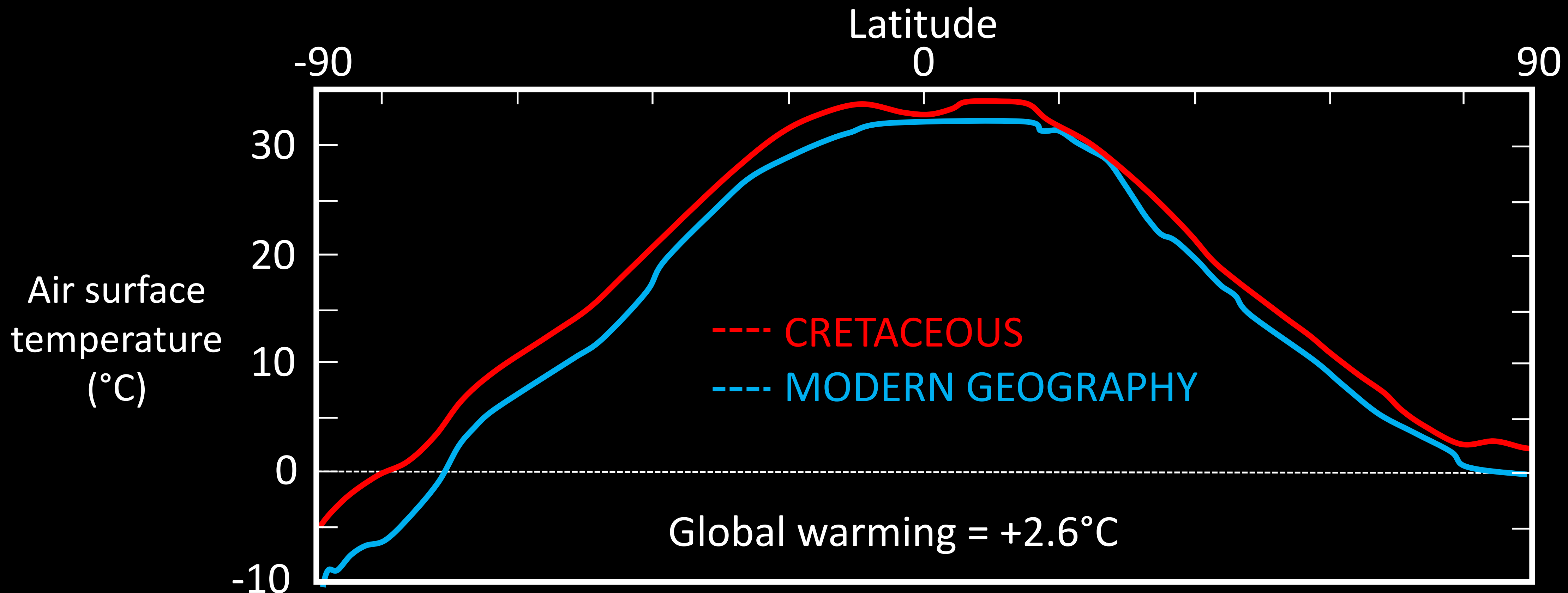

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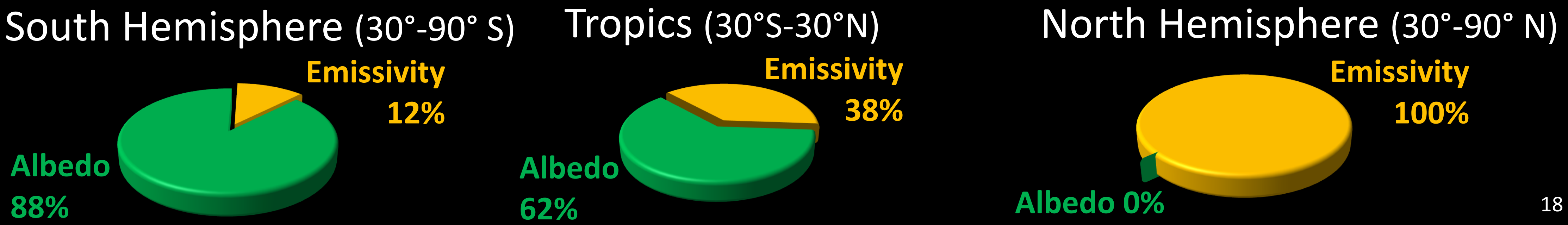
Contribution to warming:



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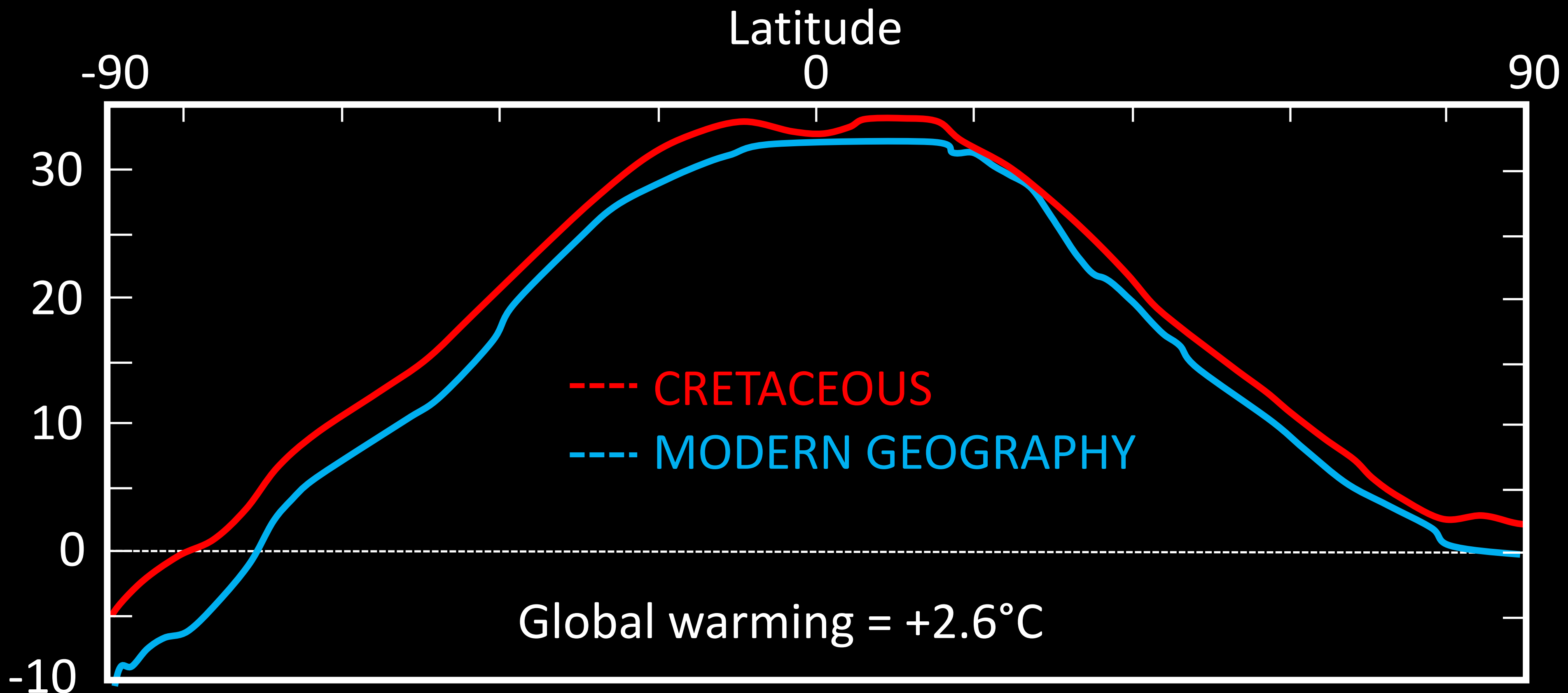
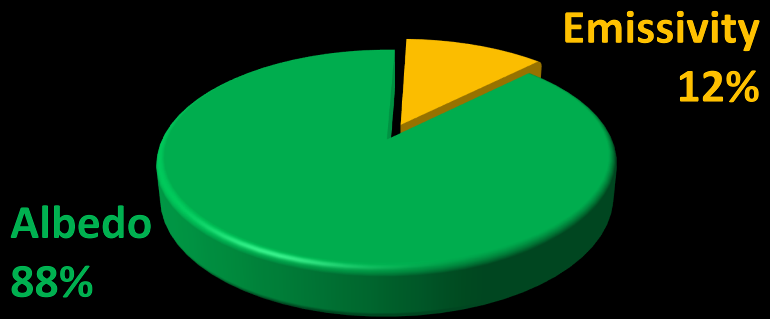


South Hemisphere



→ Surface albedo ?

→ Low-altitude cloudiness decrease ?

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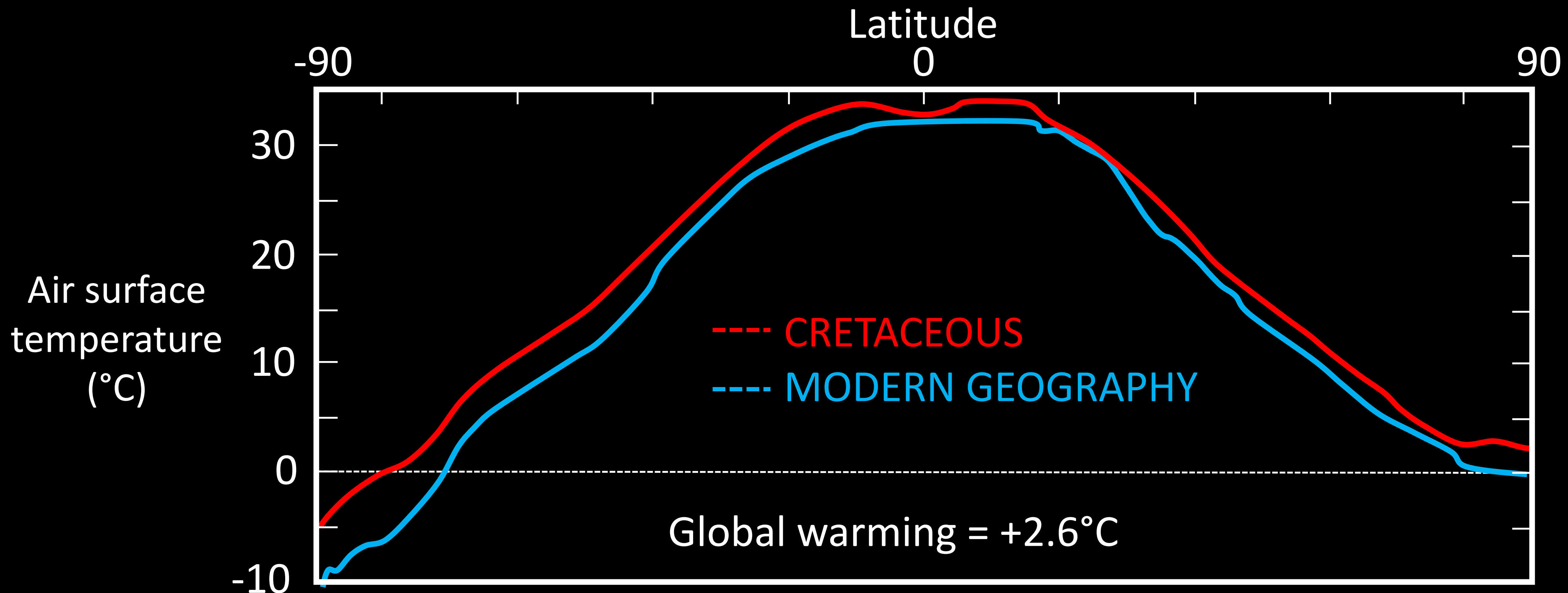

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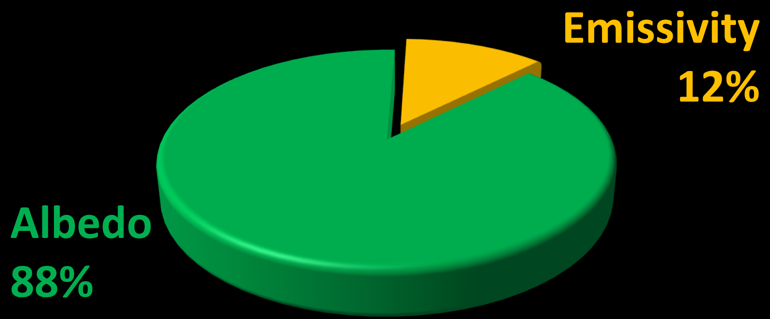

→ Surface albedo ? +0.4% = cooling …

→ Low-altitude cloudiness decrease ? -12% = warming !

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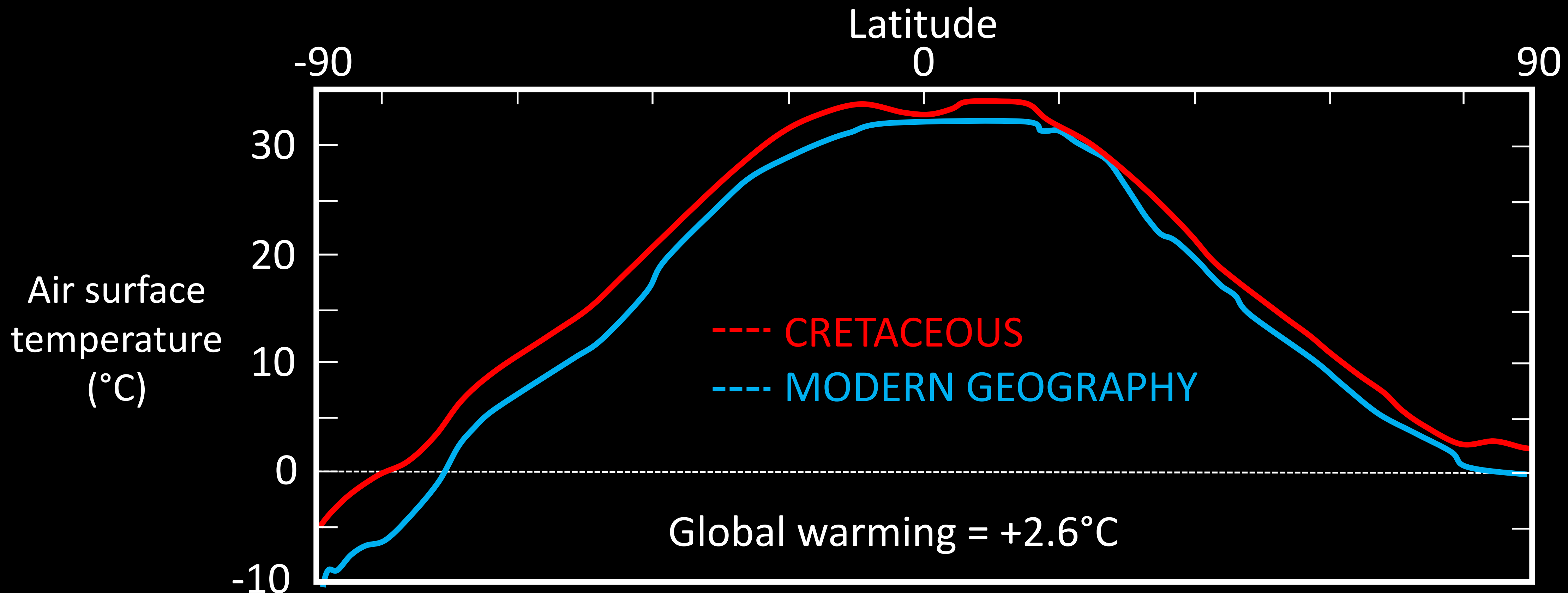
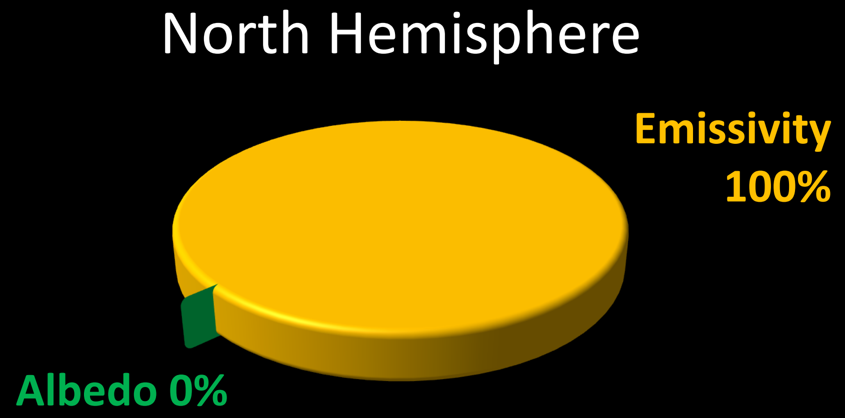


→ Greenhouse gases?

→ High-altitude cloudiness increase?



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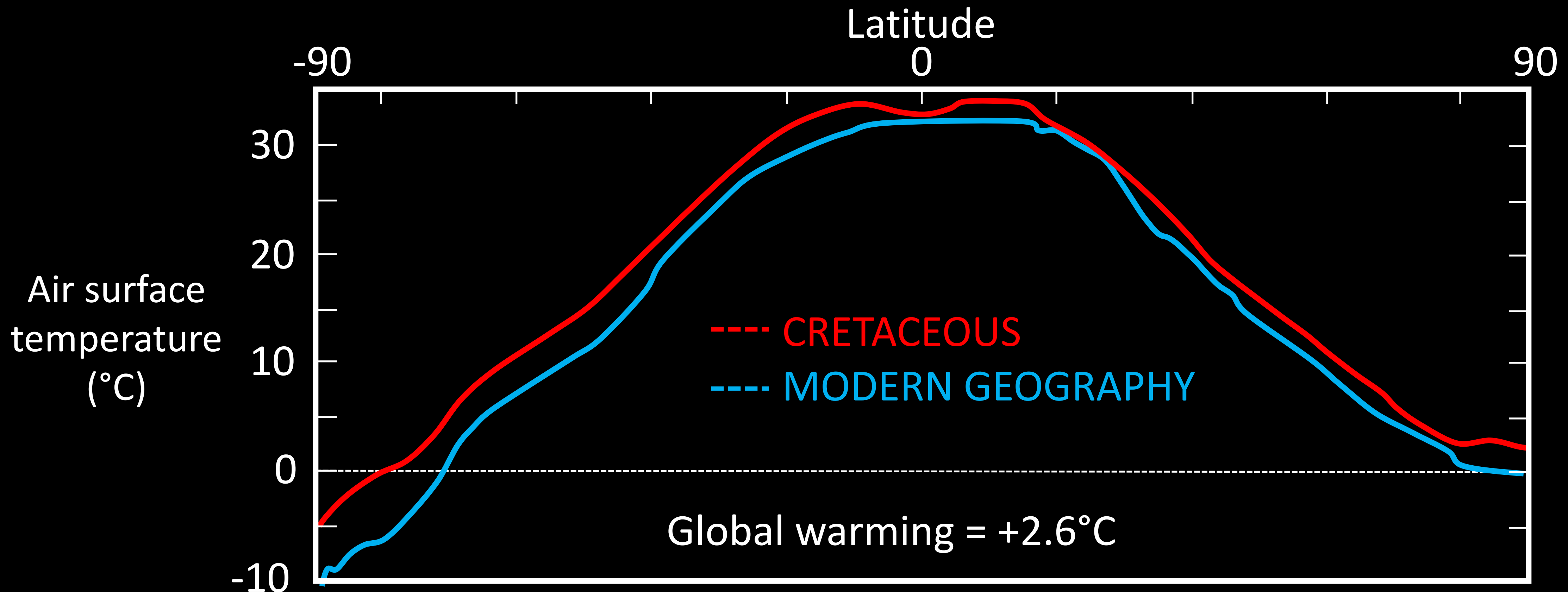
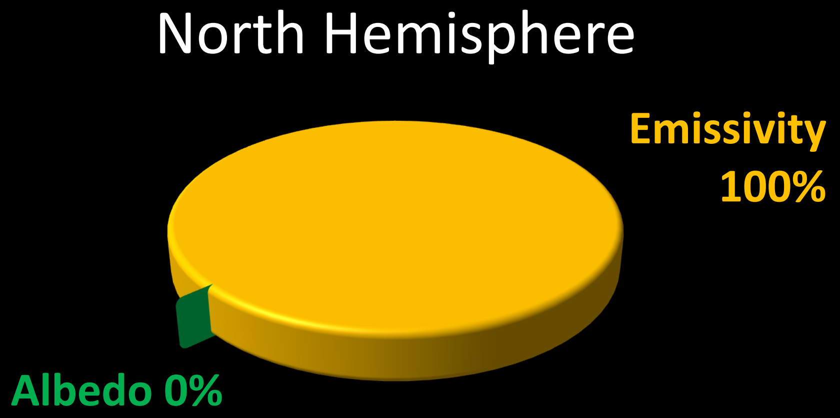


→ Greenhouse gases?

H_20 (+0.3‰)

→ High-altitude cloudiness increase?

+1% = Warming



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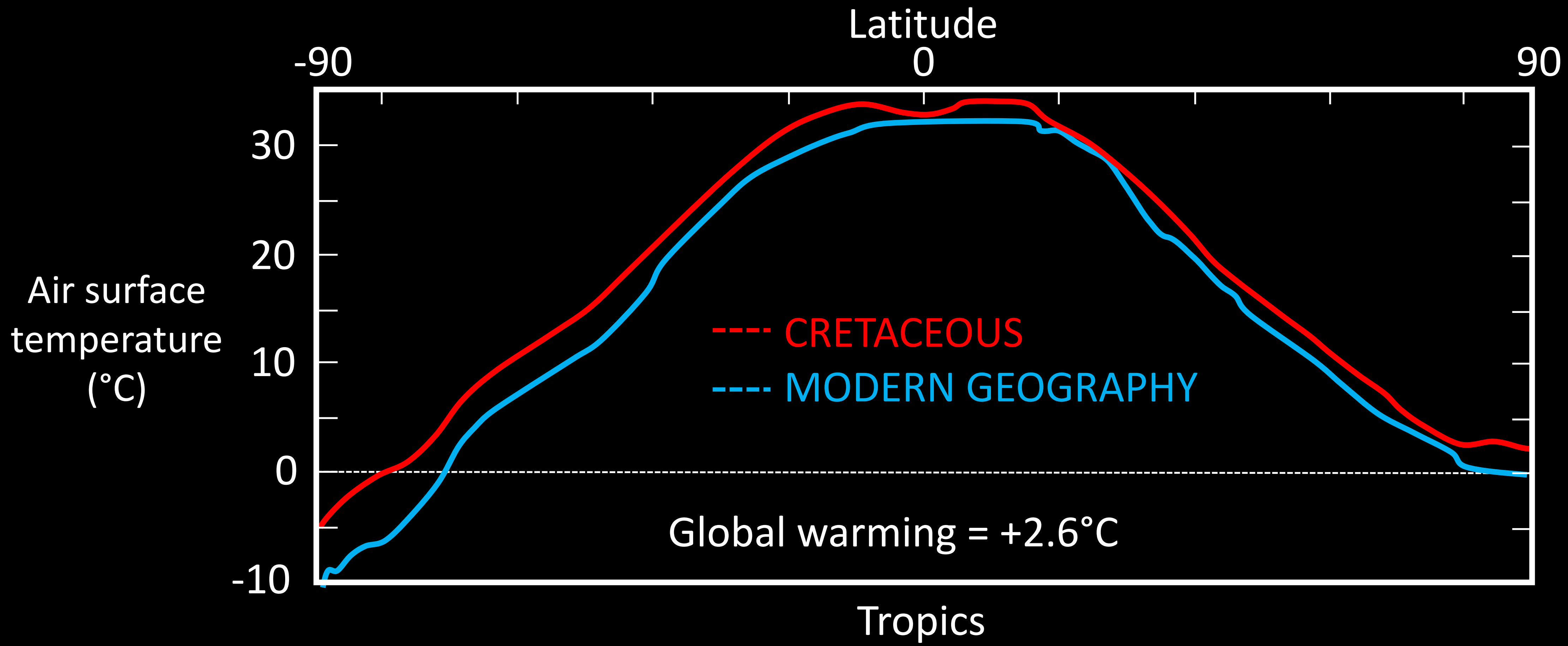

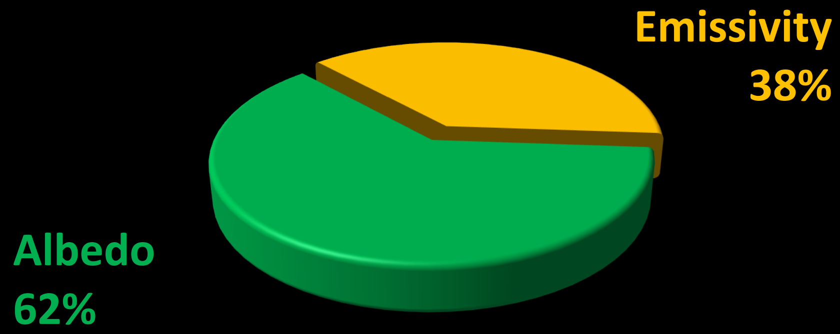

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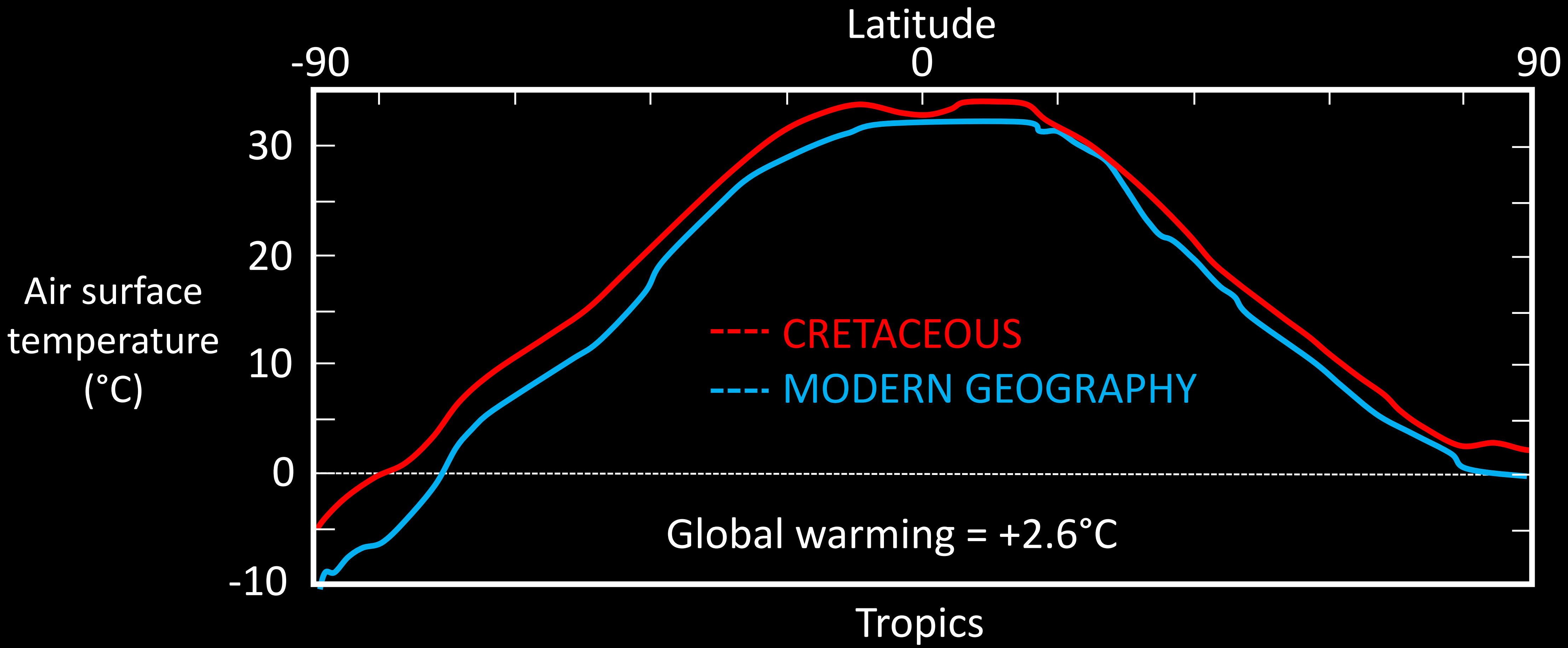
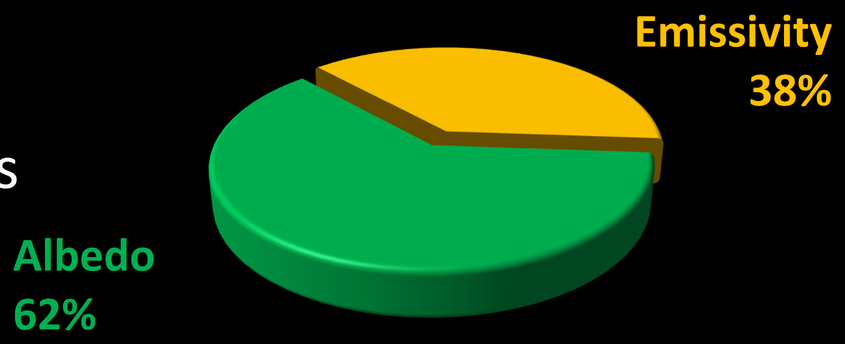


Surface albedo
= -0.1%
Low-altitude cloudiness
= -2%



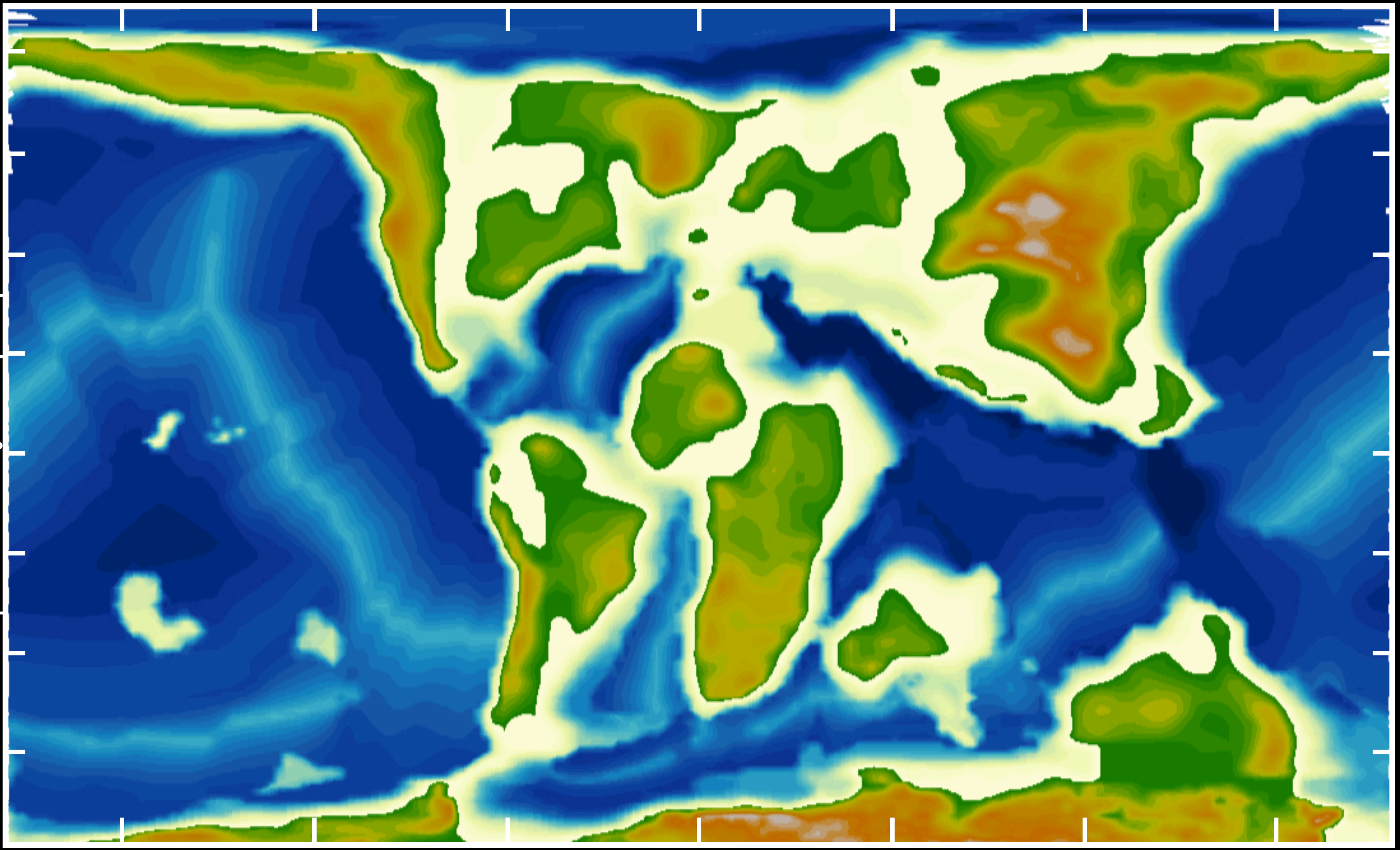
H_2O = +1‰

CENOMANIAN-TURONIAN PALEOGEOGRAPHY (90 MA)

High-altitude cloudiness increase + H_2O increase

Surface albedo + Low-altitude cloudiness decrease + H_2O increase

Low-altitude cloudiness decrease



Climate warming controller

From C. R. Scotese paleogeography (2014), with ocean ridges of Müller et al. (2008)

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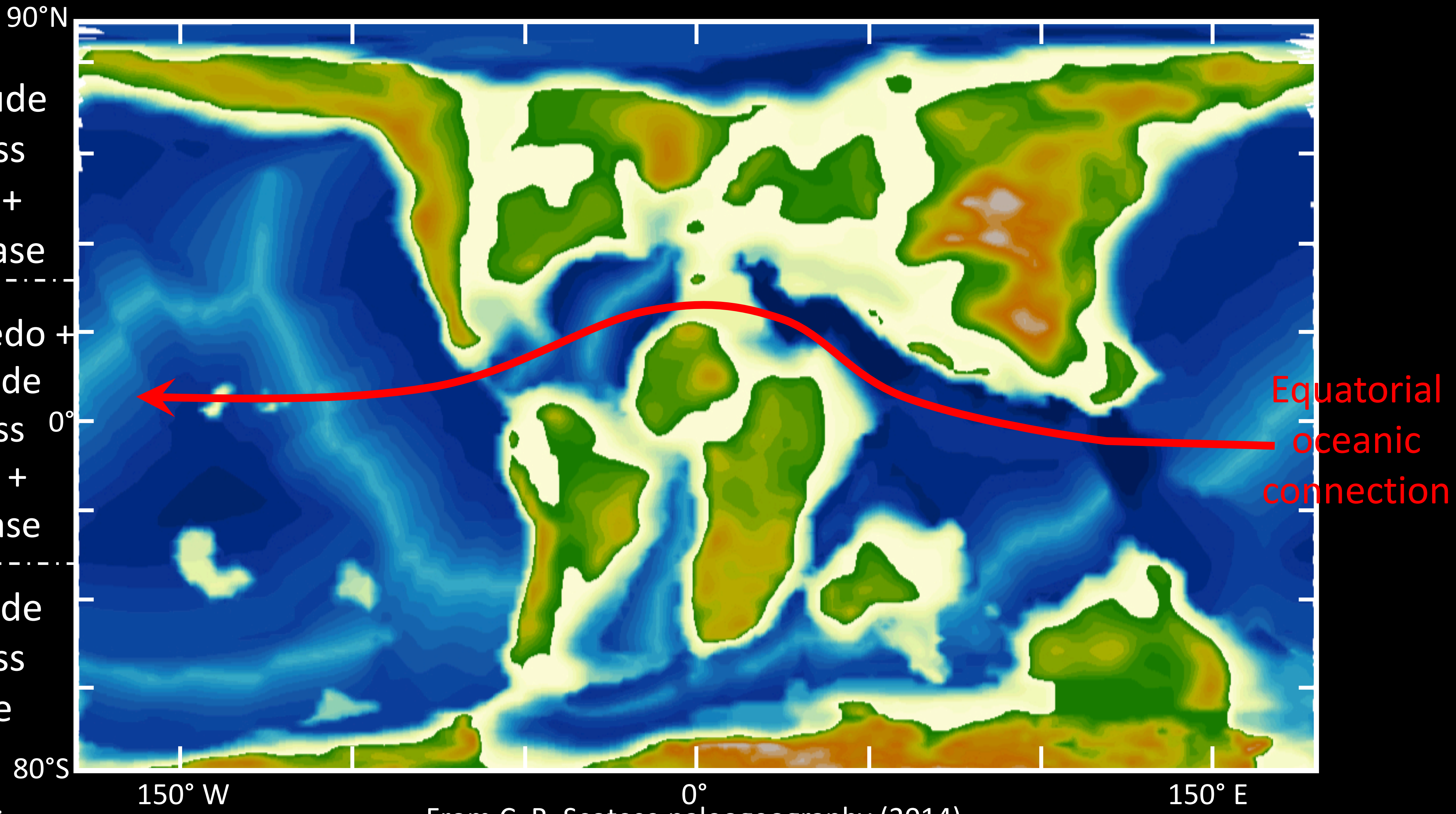

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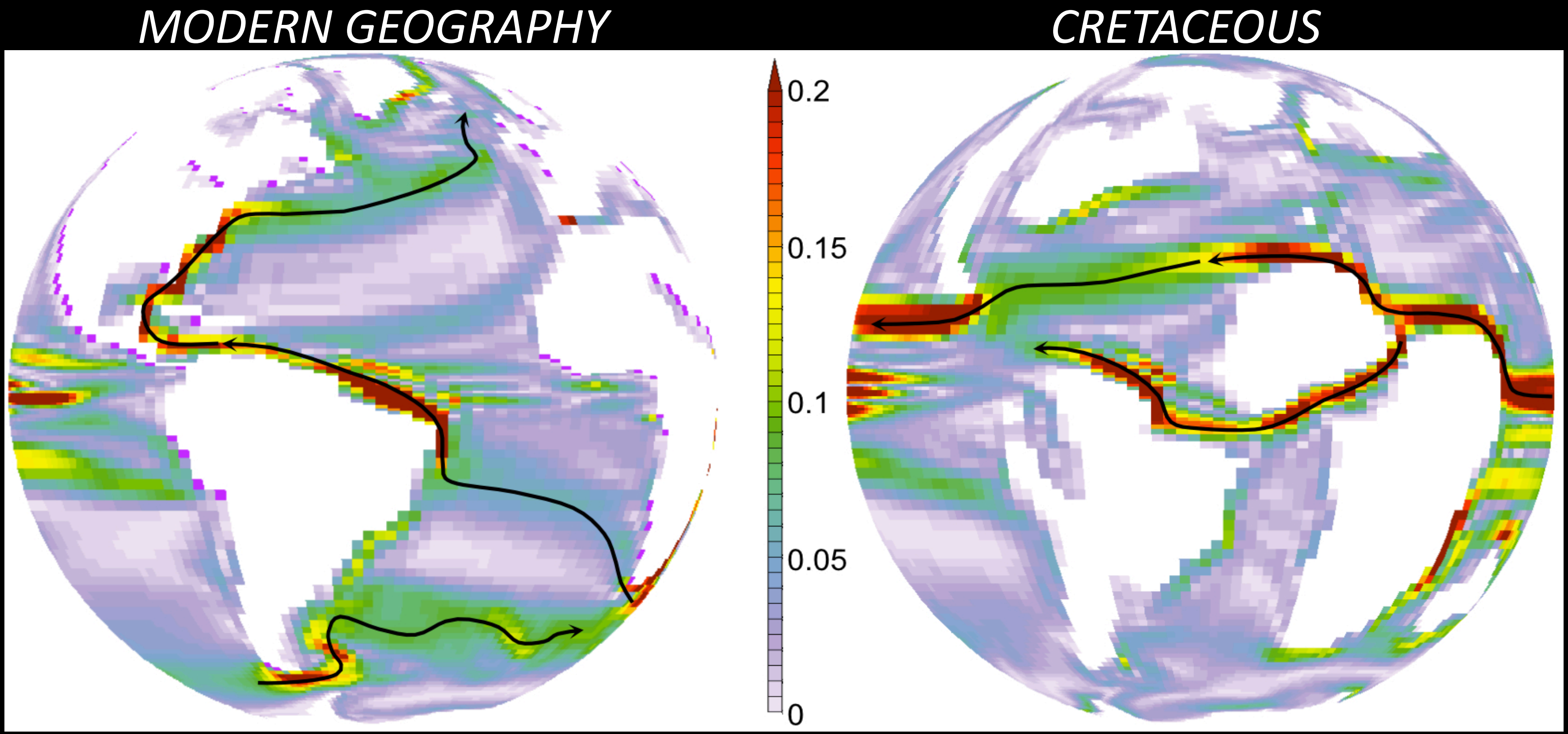
CENOMANIAN-TURONIAN PALEOGEOGRAPHY (90 MA)
→ EQUATORIAL OCEANIC CONNECTION

→ CircumEquatorial surface current

→ Enhanced intensity of surface circulation (cf also Hotinski & Toggweiler, 2003)



Intensity of surface currents (Sv)

(Annual Mean, 0 to 80 meters of water depth)

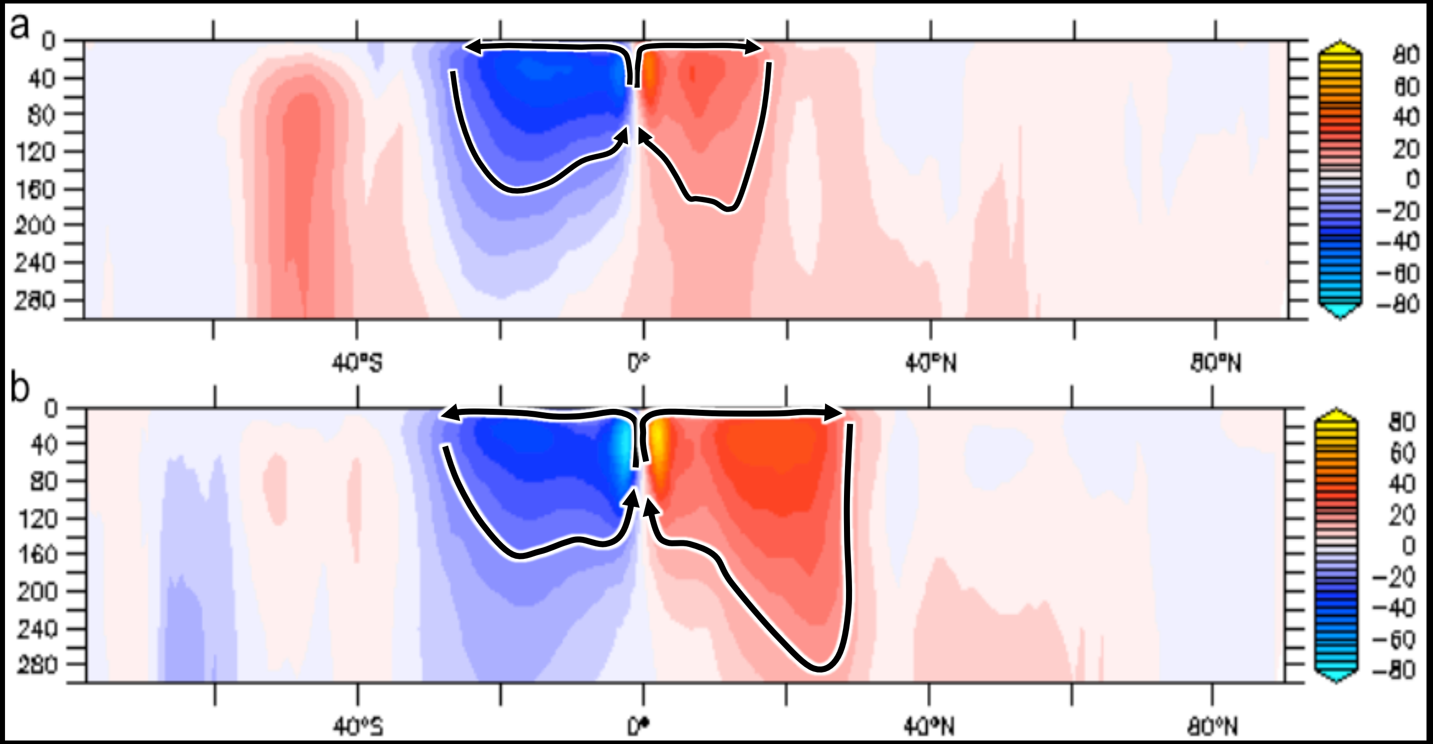
CENOMANIAN-TURONIAN PALEOGEOGRAPHY (90 MA)
→ EQUATORIAL OCEANIC CONNECTION

MODERN GEOGRAPHY

Surface meridionnal streamfunction

CRETACEOUS

Latitude



Water Depth (m)

Intensity (Sv)

CENOMANIAN-TURONIAN PALEOGEOGRAPHY (90 MA)
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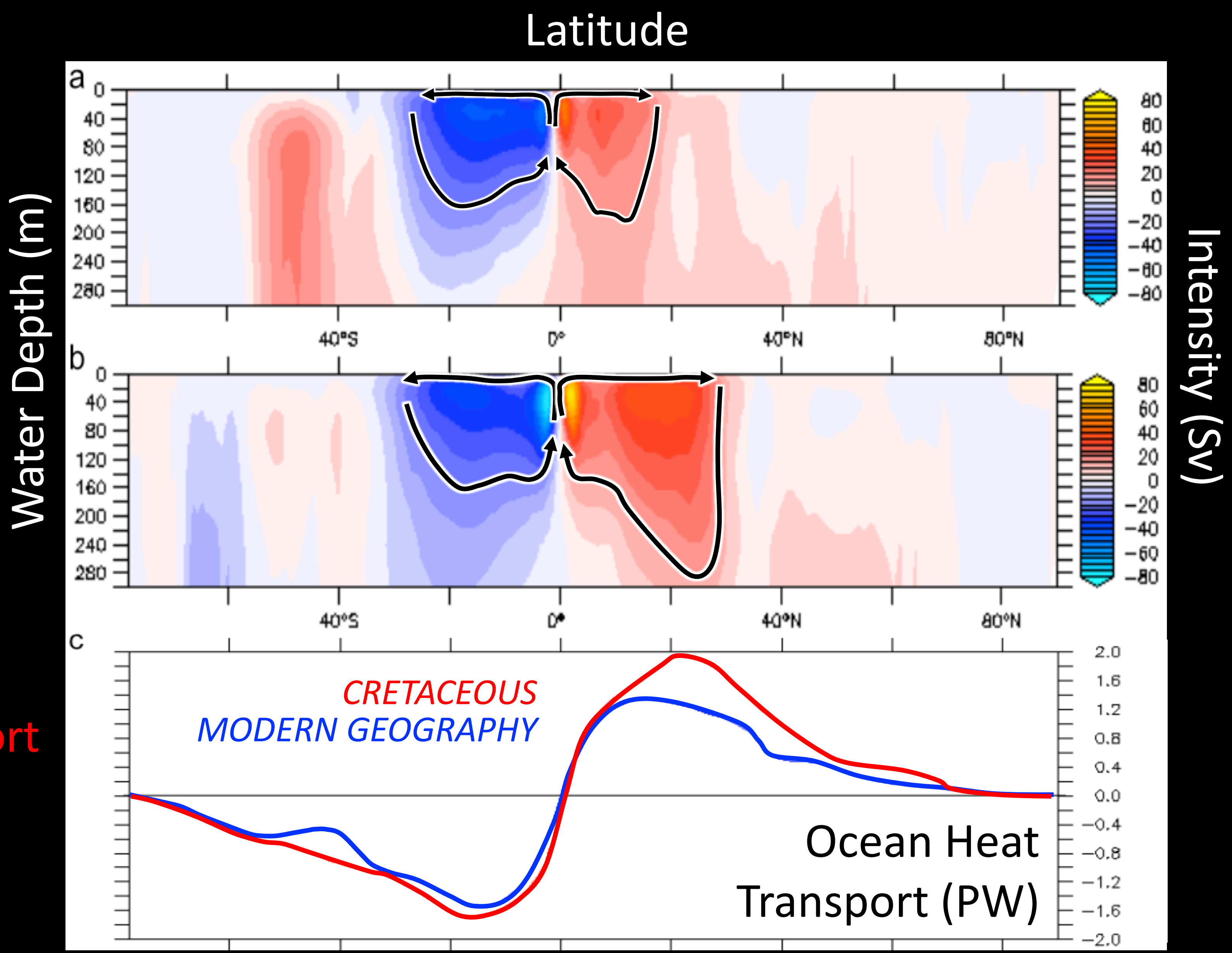
MODERN GEOGRAPHY

Surface meridionnal streamfunction

CRETACEOUS



→ Enhanced ocean heat transport (cf also Hotinski & Toggweiler, 2003)

CENOMANIAN-TURONIAN PALEOGEOGRAPHY (90 MA)

→ INCREASED OCEANIC HEAT TRANSPORT

→ Enhanced moisture injection into the upper troposphere

→ Increased high-latitude cloudiness

→ Enhanced greenhouse effect

(cf also Rose & Ferreira, 2013 – Herweijer et al., 2005)

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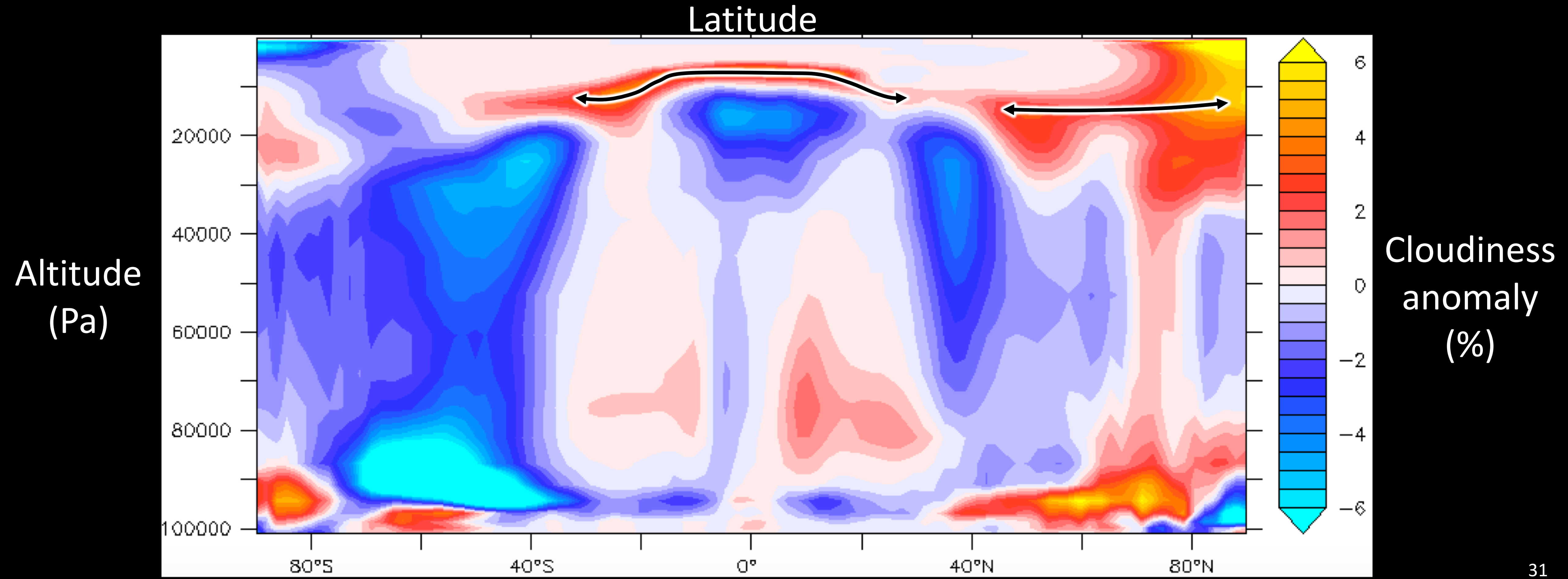

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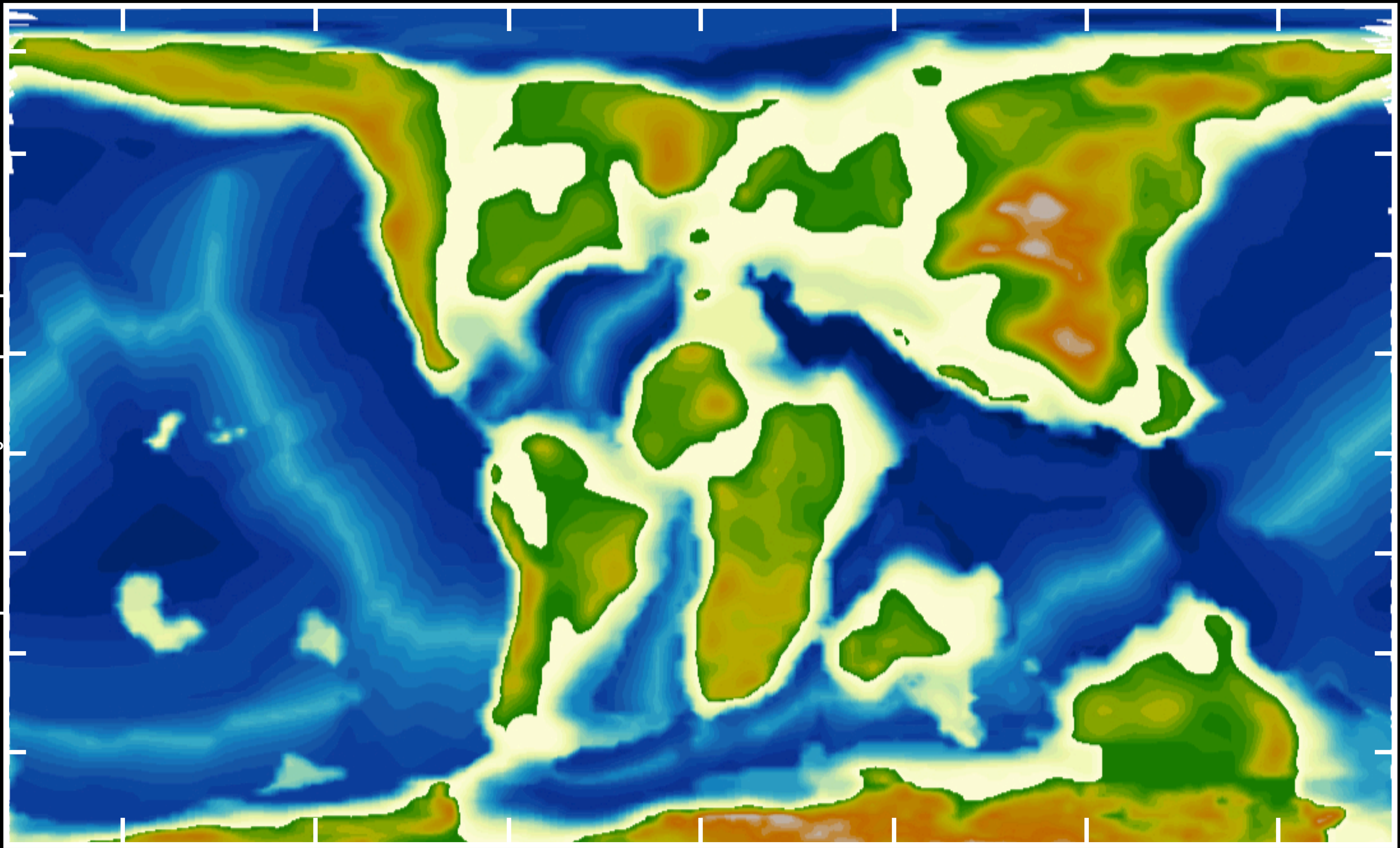

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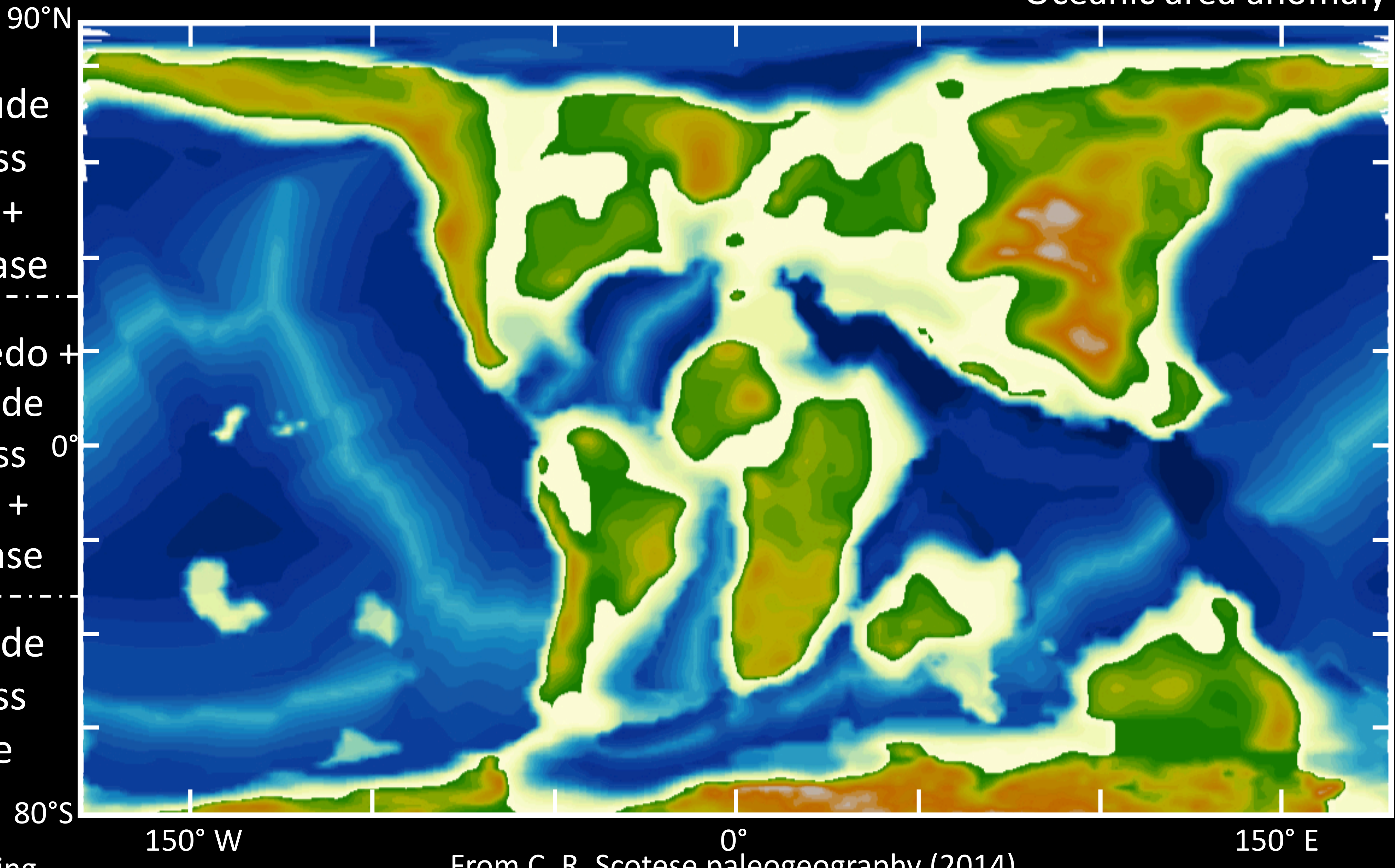

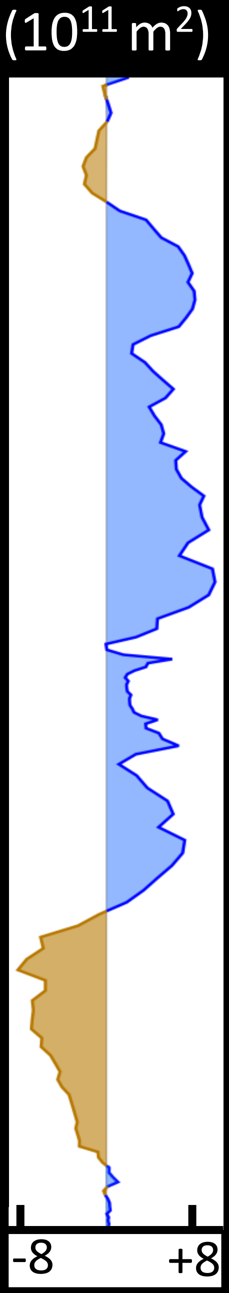

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CONCLUSIONS

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  - The ocean/continent proportion

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  Not that much (2.6°C)

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- As strong as a doubling of $p\mathrm{CO}_2$ (~4.5°C here) ?

  Not that much (2.6°C)

CONCLUSIONS

- Paleogeography has an impact on climate, driven by specific features :
  - The configuration of equatorial gateways
  - The ocean/continent proportion

- Negligible role?

  Not here (but dependant on specific geographic features)

- Only regional role?

  Regional controls, but global impact

- As strong as a doubling of pCO_2 (~4.5°C here) ?

  Not that much (2.6°C)

Thank you for your attention !

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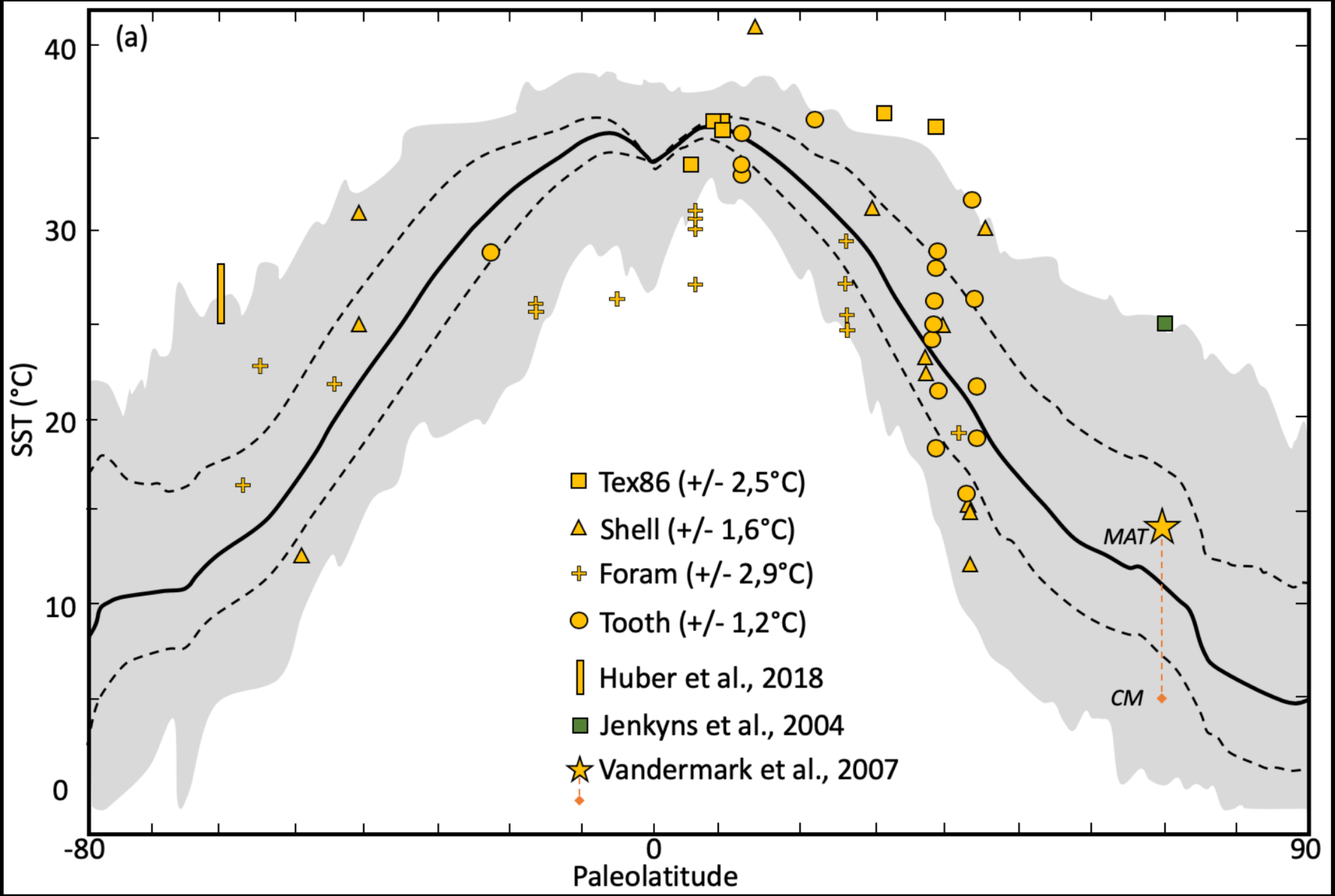
MORE

4X-CRETACEOUS SIMULATION - RESULTS



CENOMANIAN-TURONIAN PALEOGEOGRAPHY (90 MA)