High-CO_2 World

Motivating Questions

1. Are projections of

drying/browning for a high CO_2 future
compatible with lush plant fossil record

from the early Eocene?

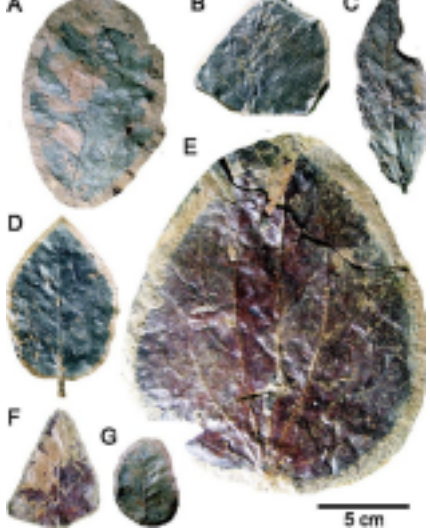
2. How can we improve model-proxy agreement for early Eocene precipitation?

Early Eocene Arctic rainforest

American Museum of Natural History (© AMNH/D. Finnin)

My approach: dynamic vegetation modeling

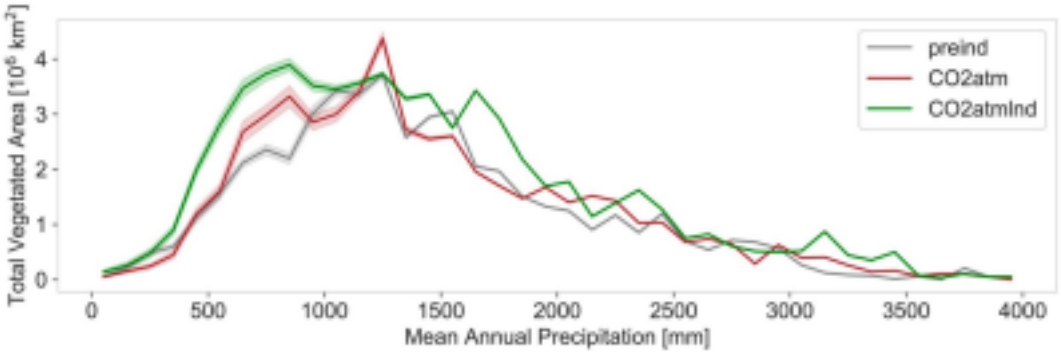
- Precipitation proxies for early Eocene are based on plant fossils
- Modeling with dynamic vegetation allows for direct comparison with plant fossil record
- Understudied area
- Climate-vegetation feedbacks



Fossil leaves from the Eocene Arctic
(Greenwood et al, 2010)

Climate-vegetation feedbacks

- CO_2 fertilization
- Transpiration
- Albedo CO_2 fertilization→ increased water use efficiency → vegetation expands in arid regions



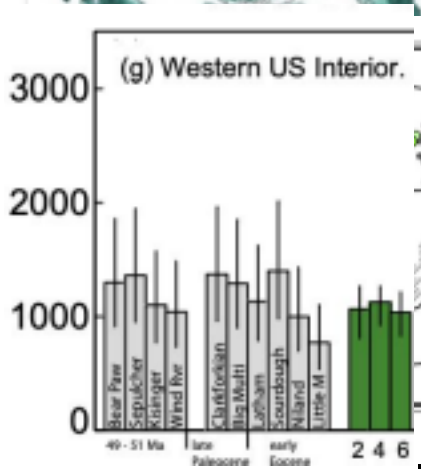
Kowalczyk & Lee (2022)

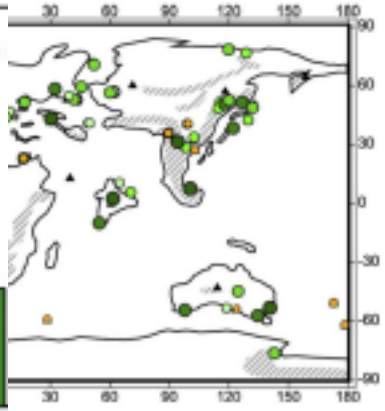
Part 1: North America – wetter past, drier future?

- Widespread summer drying projected for the future, and MAP decrease in

southwest

ssil evidence for lushly forested interior, high MAP





ΔJJA precip 2100 RCP 8.5

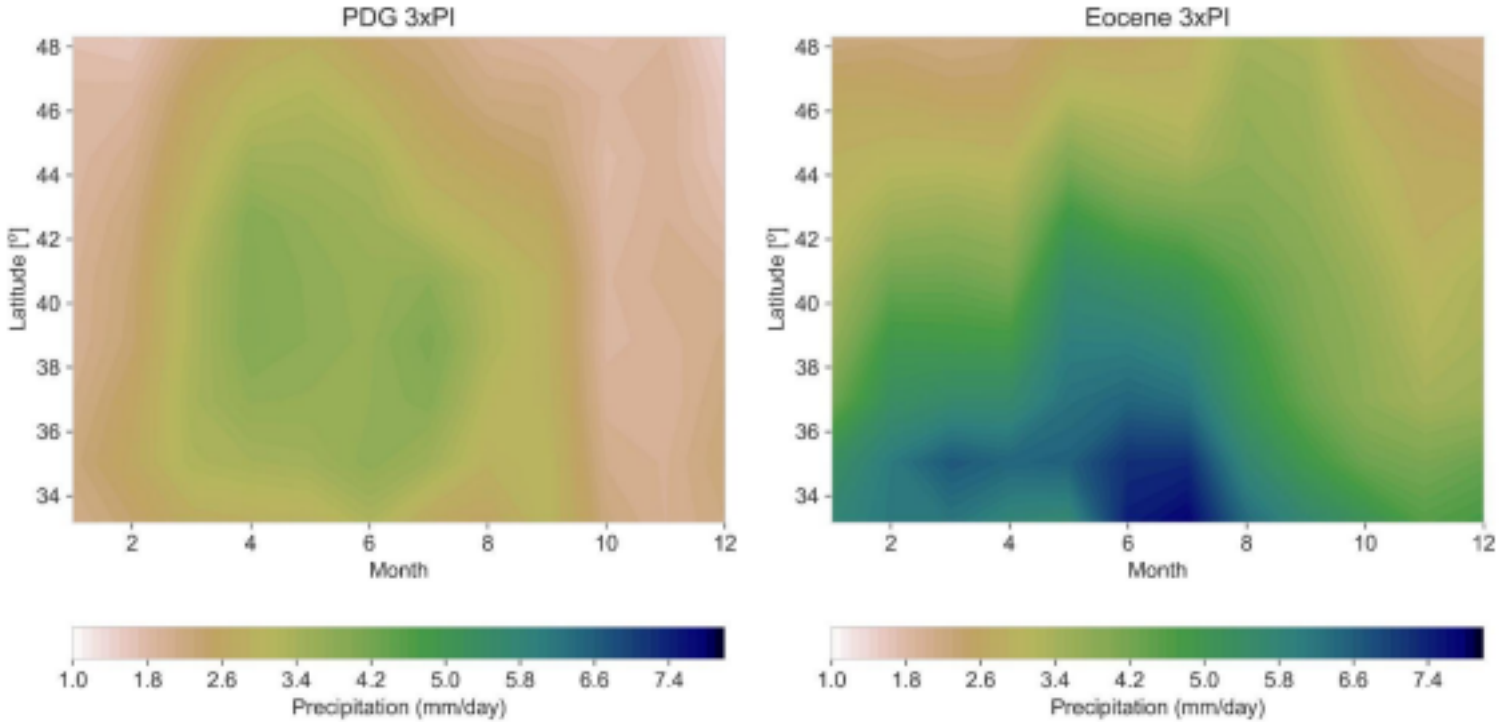
MAP (mm)

Carmichael et al. (2016)

Utescher & Mosbrugger (2007)

Wang & Kotamarthi (2015)

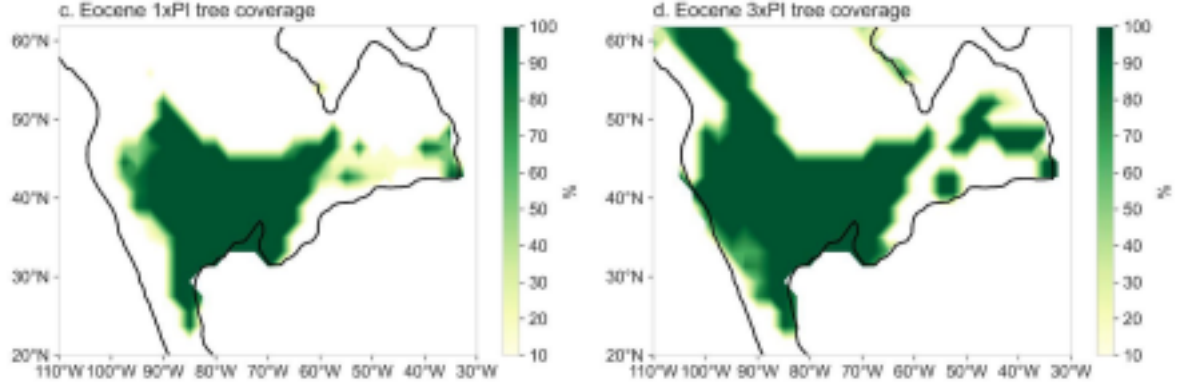
North American summer monsoon in early Eocene



present-day geography early Eocene modeled precipitation under 3xPI CO_2

(Kowalczyk et al, i

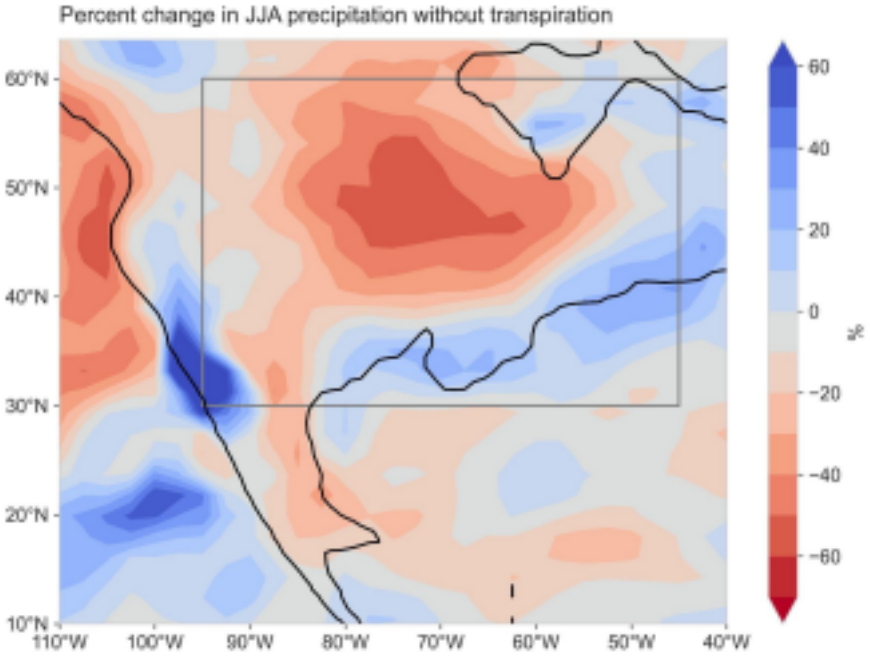
Mo esponse to

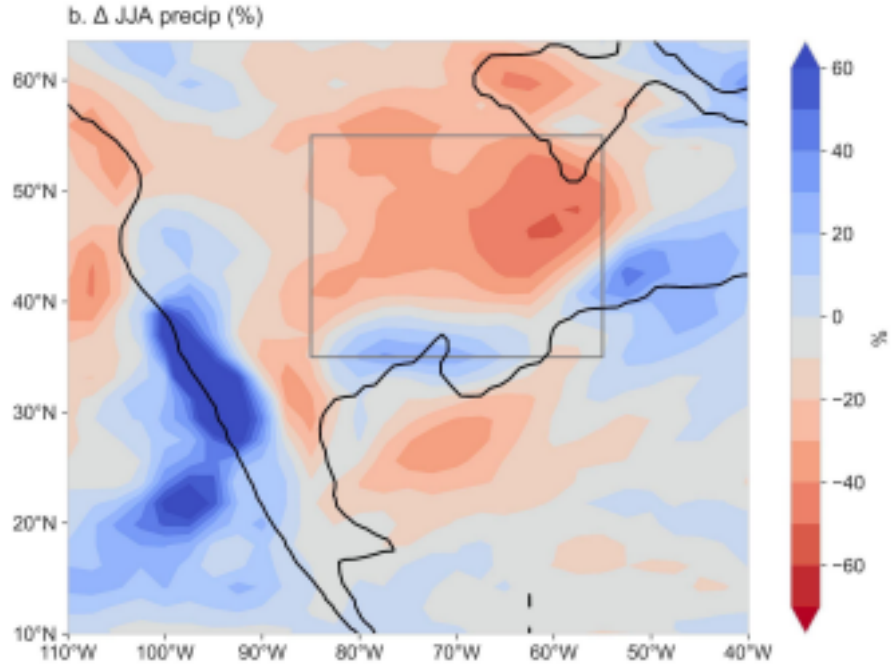


(Kowalczyk et al, in review)

Greater forest coverage in early Eocene increases summer rainfall via transpiration

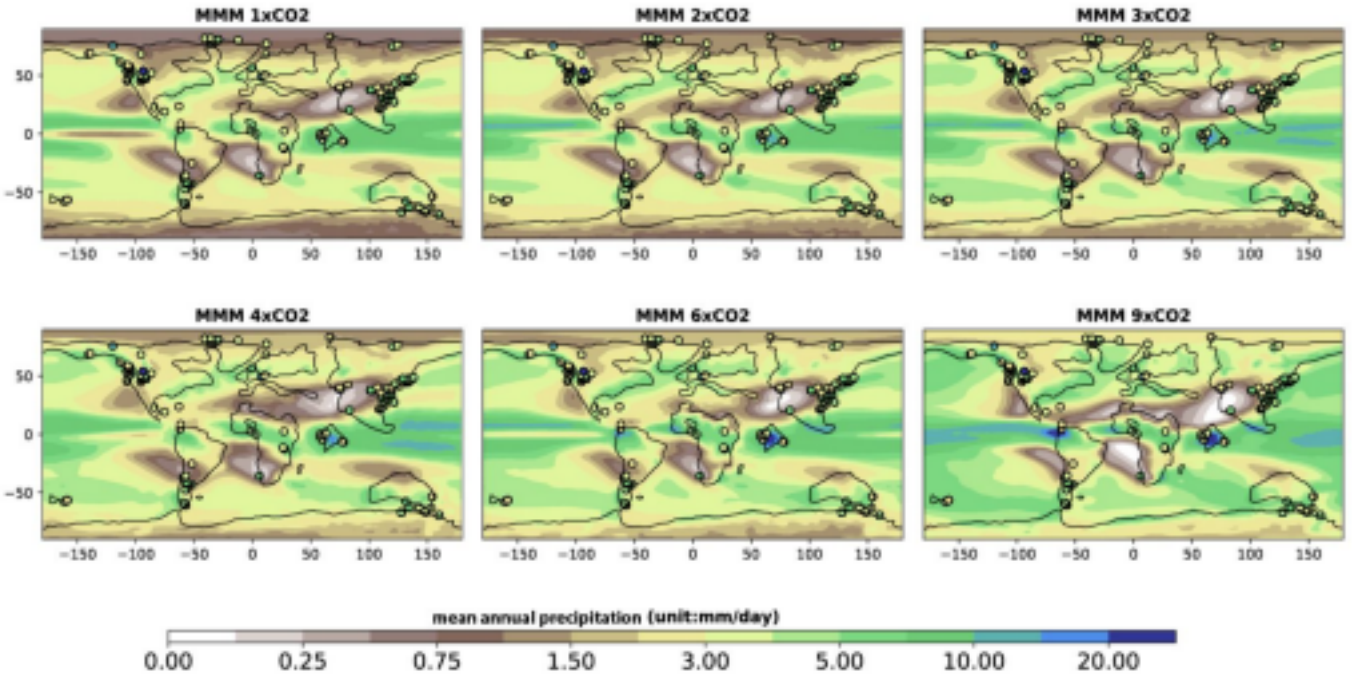
% change in summer rainfall if transpiration is set to zero in box


Percent change in JJA precipitation without transpiration
60°N
50°N
40°N
30°N
20°N
10°N
110°W
100°W
90°W
80°W
70°W
60°W
50°W
40°W
60
40
20
0
−20
−40
−60
%



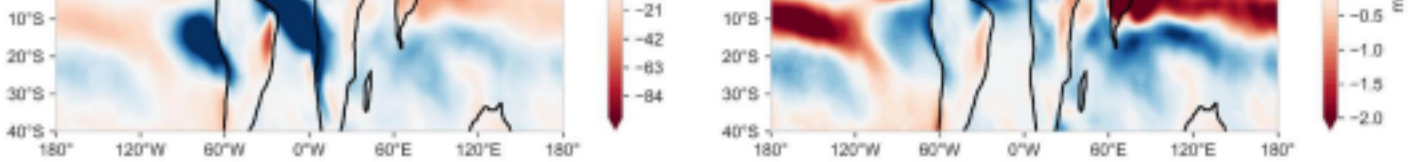
(Kowalczyk et al, in review)

Part 2: Can orbital precession help explain model-proxy rainfall discrepancy?



DeepMIP modeled precipitation compared to proxy data (Cramwinckel et al., 2022)

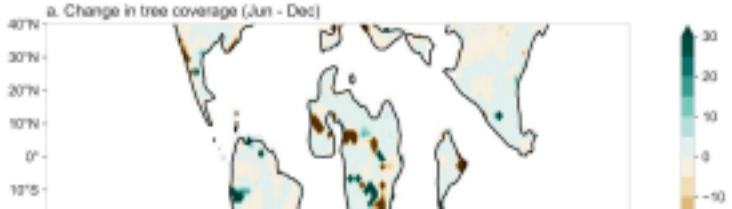
Precession can change MAP by up to 7 cm/year but does not resolve model-proxy mismatch over western Asia



(Kowalczyk et al, in prep)

With June perihelion, shrubland expands by > 10%

Trees + shrubs



Dec

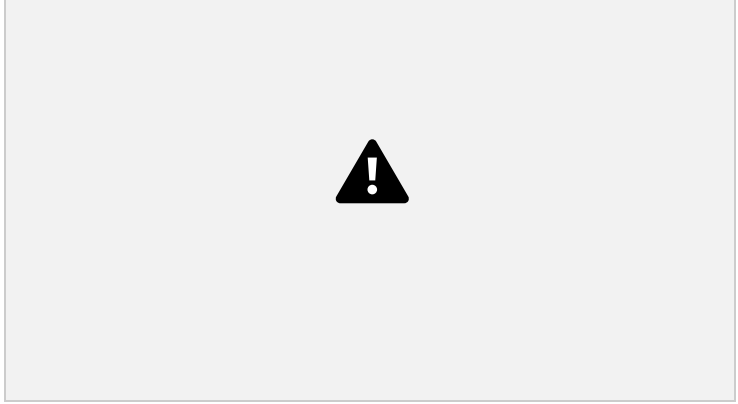
Jun

Δ trees Δ shrubs

Δ (Jun - Dec)

(Kowalczyk et al, in prep)

Global plant fossil record is integrated over orbital cycles

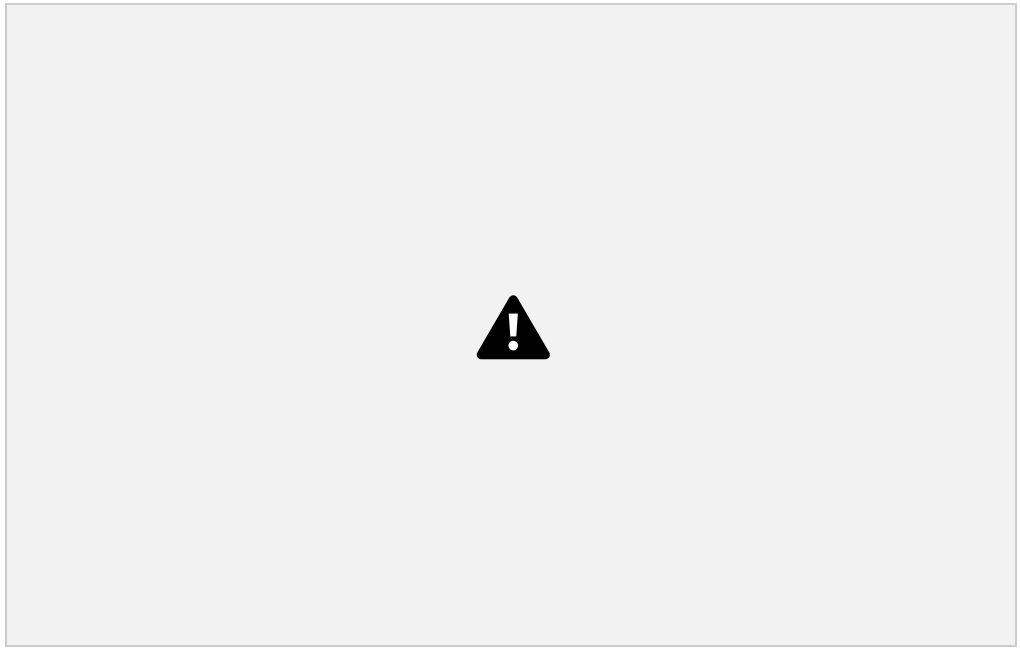


Combine results from December and June perihelion simulations

(Kowalczyk et al, in prep)

Using single orbital configuration biases climate and underestimates vegetation coverage

with December perihelion: combined results from Dec & Jun perihelion:

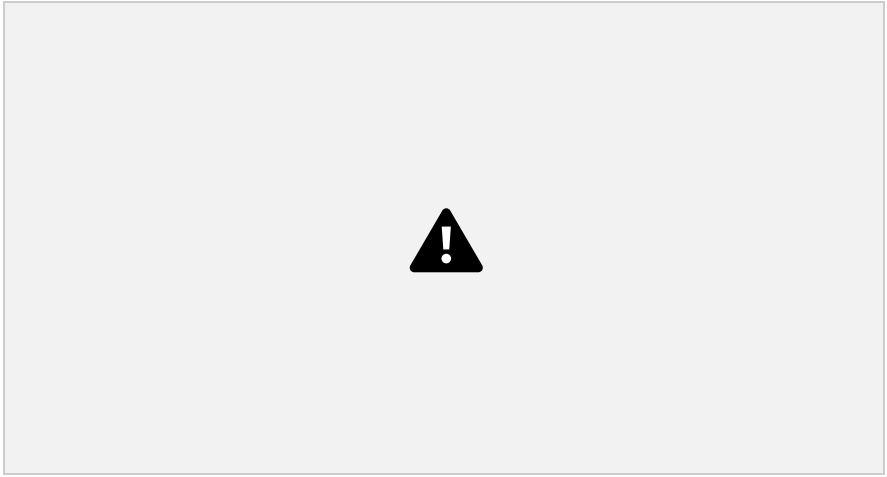


(Kowalczyk et al, in prep)

Combined results compare better to fossil record, but still too cold and dry at high latitudes and too dry in some subtropical areas

combined results from Dec & Jun perihelion:

fossil compilation:



“a more or less dense forest cover is indicated for most of the Eocene localities”

Utescher & Mosbrugger (2007)

(Kowalczyk et al, in prep)

Summary

- CO_2 fertilization shifts climate - vegetation relationship

Vegetation affects climate through transpiration and albedo

- Transpiration feedback may have been crucial to maintaining North

American summer monsoon in early Eocene

- Combining vegetation modeling results from orbital precession end-members improves match to fossil record

- Model-fossil vegetation comparison suggests modeled climate still too cold and dry at high latitudes and too dry in some subtropical areas

extra slides

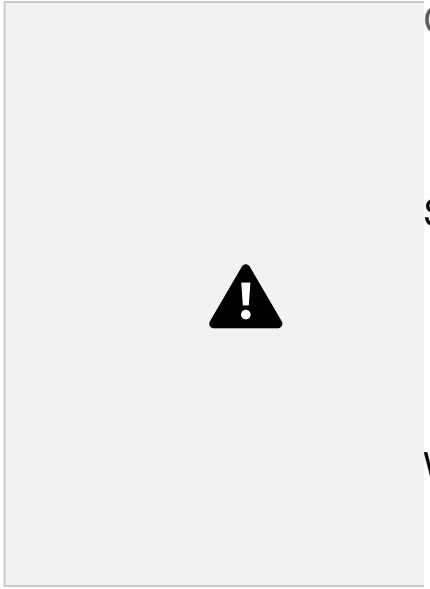
Vegetation feedbacks can be critical for tropical precipitation

Δ MAP relative to PI

Without green

North Africa: vegetation albedo feedback necessary to intensify monsoon during African Humid Period

Chandan & Peltier (2020)



Sahara

With green Sahara

CESM/CAM5: Cloud feedbacks reduce latitudinal temperature gradient

Positive feedback with new prognostic cloud microphysics:

Warming → more efficient conversion of cloud water into precipitation → reduced low cloud cover

Novel aspect of my research: dynamic vegetation model coupled to atmospheric model capable of producing early Eocene equable climate

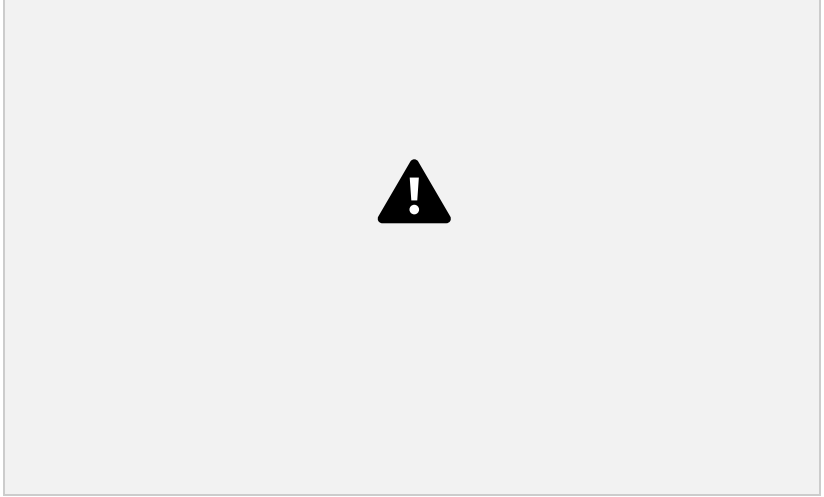
Zhu et al. (2019)

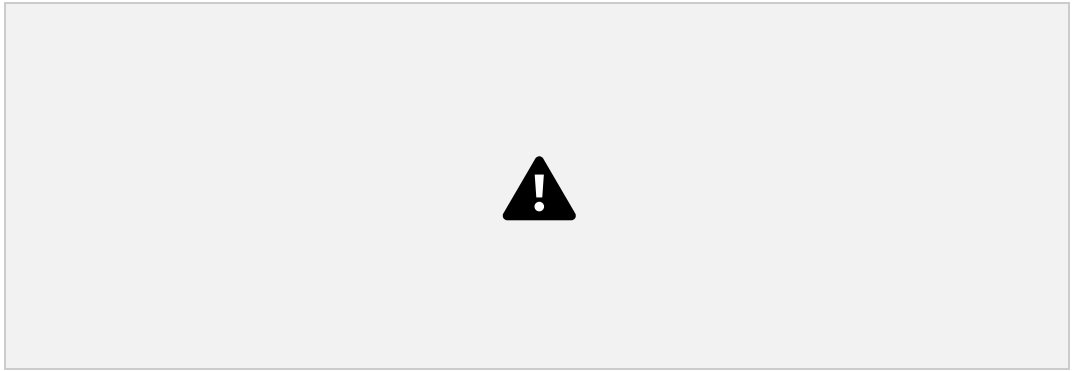
Observed greening in arid regions over past decades

Donohue et al. (2013)

CO_2 fertilization→ increased water use efficiency → vegetation expands in arid regions

High CO_2 expands where plants can grow





CO_2 fertilization increases vegetation in arid regions..

..and increases total vegetated area

Kowalczyk & Lee (2022)

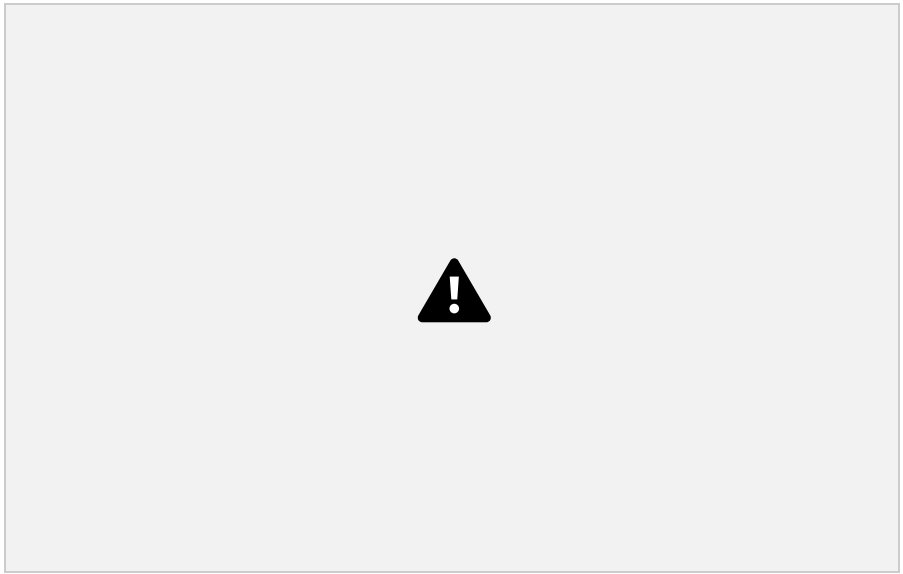
CO_2 fertilization shifts climate-vegetation relationships Kowalczyk &

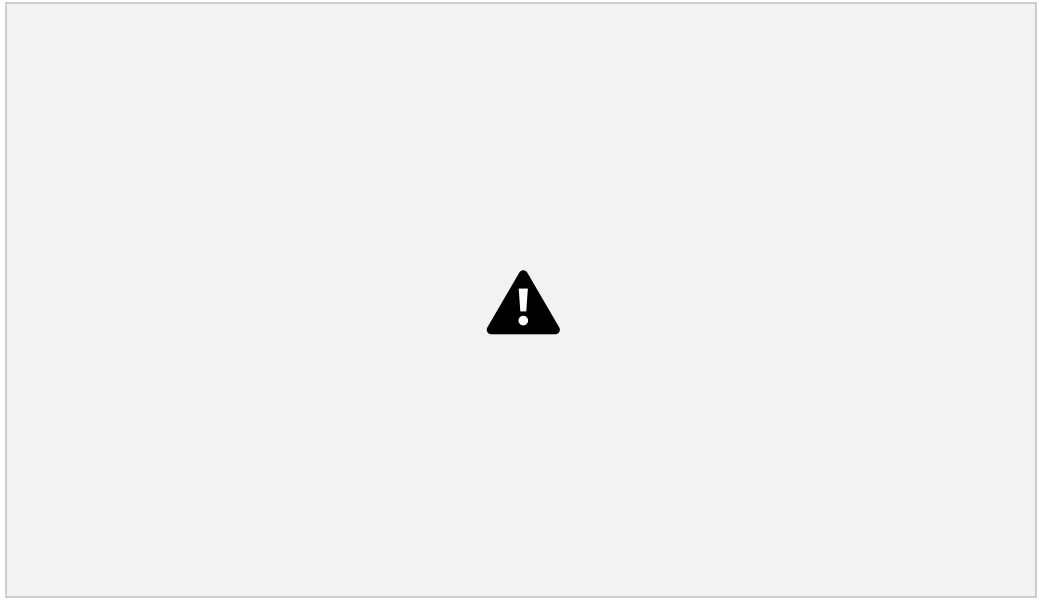
Lee (2022)

CAM5/CLM4 improves early Eocene vegetation modeling, especially in tropics

combined results from Dec & Jun perihelion:

previous results (Loptson et al, 2014):





Herold et al (2014)