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Can day length explain the latitudinal limit to Eocene coral reef expansion?

A simple model study of coral calcification

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Motivation

- The latitudinal extent of tropical coral reefs is often assumed to be temperature controlled.
- **But**, during early Eocene, with water temperatures at mid and high latitudes 10-20°C warmer than today, coral reef distribution no longer reflects this tropical temperature range (Fig. 1)

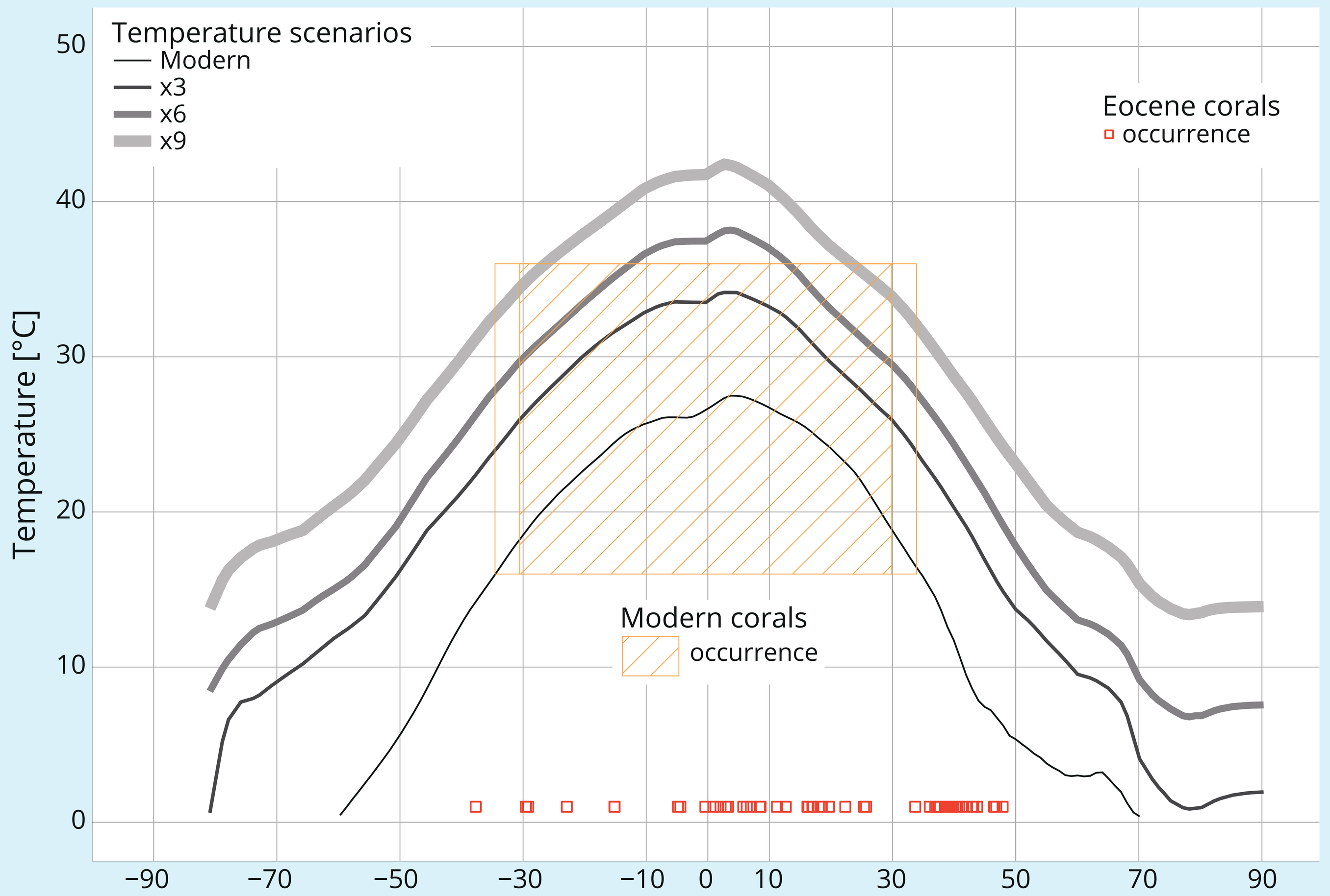


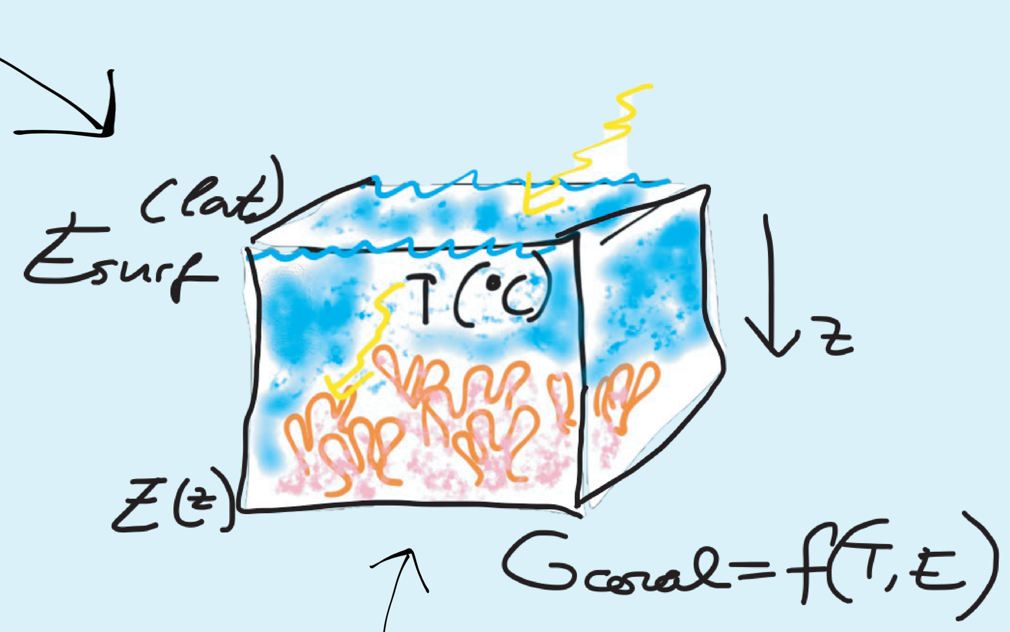
Figure 1: Eocene and modern temperature reconstructions[1,2], plotted together with modern and Eocene coral occurrences[3]

We hypothesize that for the Early Eocene:

→ Light intensity and especially winter day-length becomes the limiting factor to poleward expansion.

Approach

- We developed a simple mathematical model to explore the effect of latitudinally dependent light and temperature conditions (Fig.1) on coral calcification.
- All other environmental parameters are kept constant

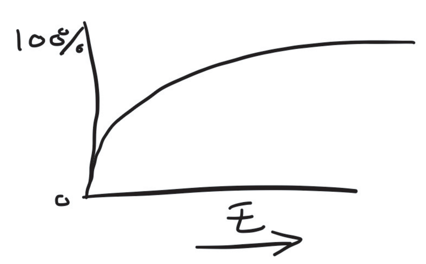


Model details

- G_{coral} = yearly calcification potential
- Temperature unlimiting when $16 < T < 36$
- Daily average light (E) unlimiting when $E > E_{saturation}$

$$G_{coral} = 100\%$$

- When $E < E_{saturation}$, G_{coral} decreases following a Monod-dependence



- When $E < E_{lim}$, day is considered 'dark' and G_{coral} for entire year is 0

$$G_{coral} = 0\%$$

Model results

- Low pCO_2 world (Fig 2A, B): calcification at mid- and high latitudes is limited by temperature (too cold)
- High pCO_2 world (Fig 2C, D):
  - calcification at low latitudes is limited by temperature (too warm)
  - and at high latitudes limited by number of dark days (too much darkness)
- Latitudinal extent of Eocene coral reefs (Fig. 2E) can be simulated with minimum required daily-irradiance (E_{lim}) of 105 μmol m^{-2} s^{-1} (Fig. 2C, D)
- In highest pCO_2 scenario, model suggests NO latitudinal range exists where both temperature and light are favorable (Fig. 2D)

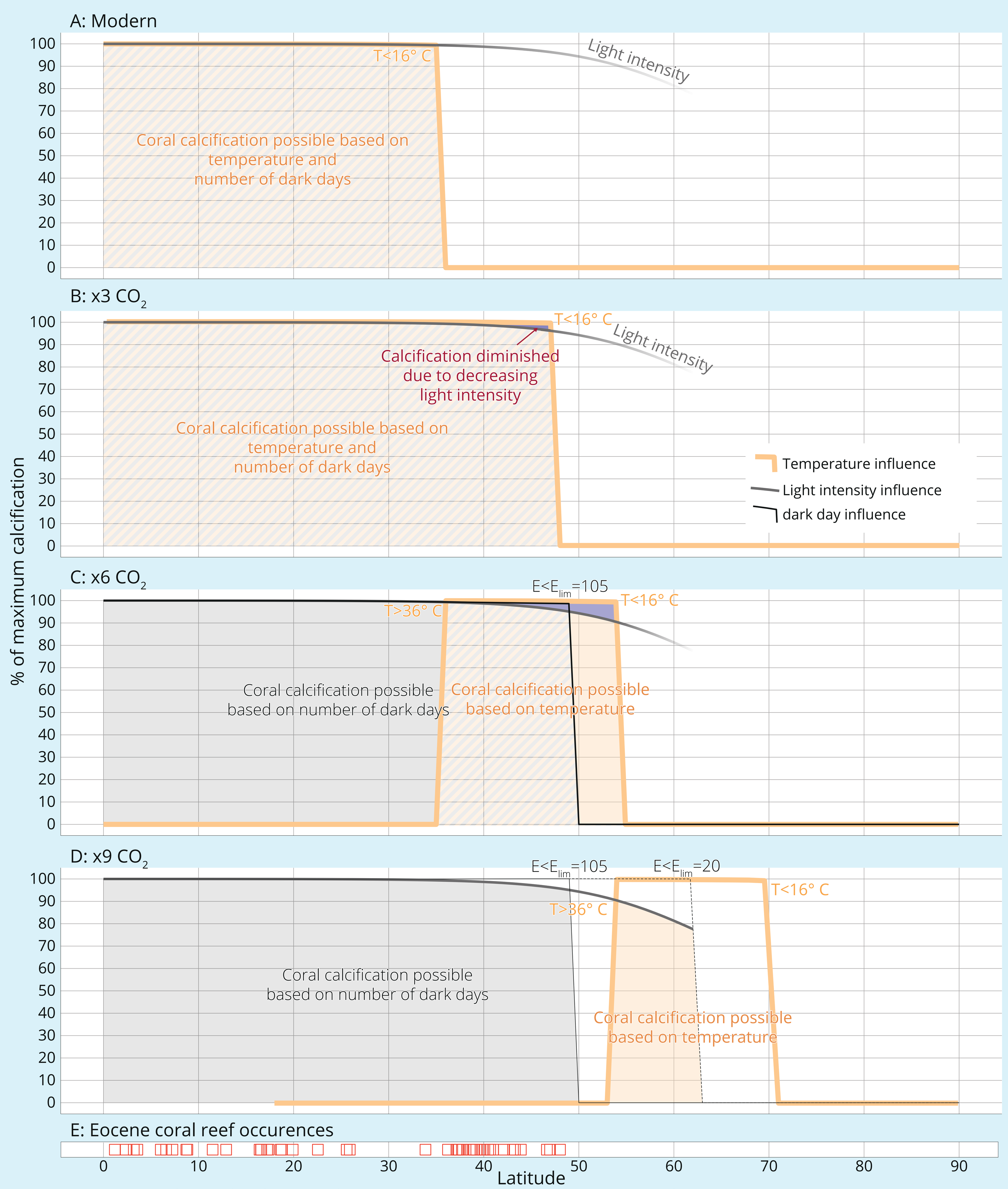


Figure 2: Model results for the four temperature scenarios (panels A, B, C, D) together with Eocene coral reef occurrences (panel E)

Discussion: what about aragonite saturation state?

- Coral calcification also depends on aragonite saturation state[4,5]
- Aragonite saturation increases with temperature (Fig. 3) but decreases with pCO_2
- Our assumption that undersaturation is not controlling latitudinal extent of Eocene coral reefs only holds for a high temperature and high alkalinity ocean

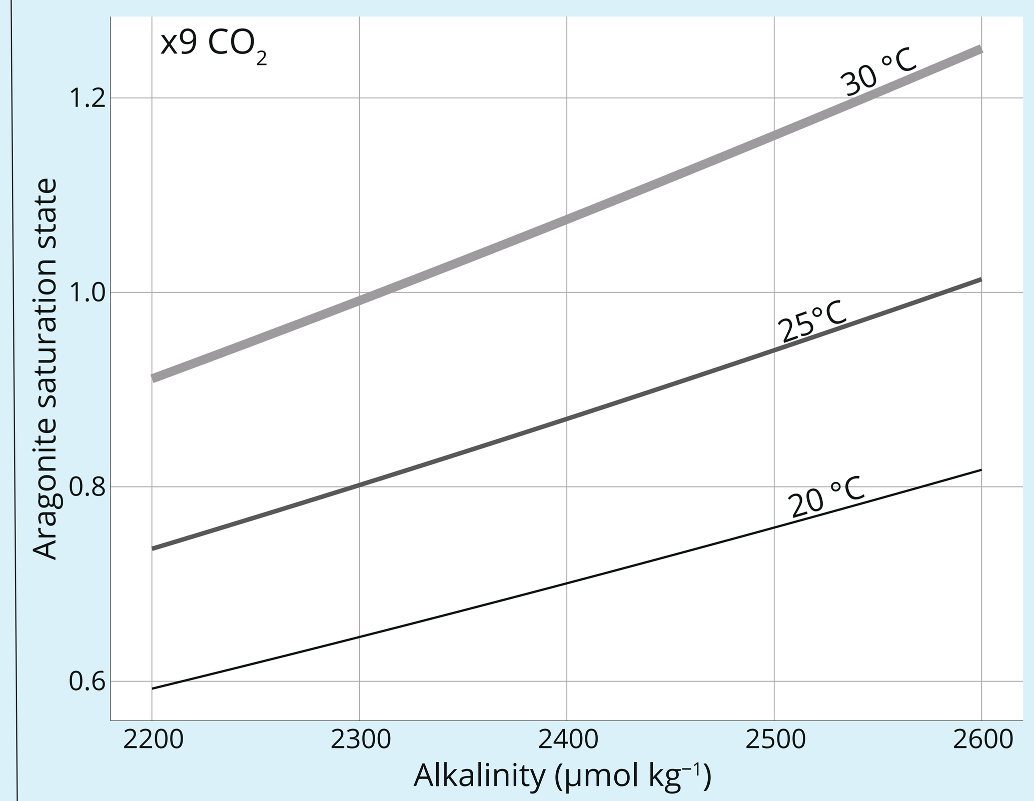


Figure 3: Aragonite saturation state dependence on temperature and alkalinity, in a high CO_2 world

Take home

Our model allows us to form and test simple hypotheses:

→ Winter day-length can determine latitudinal limit of corals during warm climate of the Eocene

→ Current temperature tolerance might not apply to Eocene corals[6]

→ Coral tolerance to darkness not a well-established metric: results provide a hypothetical limitation

References
1. Zhu et al., 2019
2. Locarniniet al., 2019
3. Kiessling and Krause, 2022.
4. Muir et al., 2015
5. Kleypas et al., 1999
6. Zamagni et al., 2012

Code available on Github:

For more illustrations: https://www.instagram.com/kruijtanne/

Abstract
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EGU European Geosciences Union

NESSC Netherlands Earth System Science Centre