Simulation of the Eocene hothouse climate using CESM2

Jiang Zhu

NCAR/CGD

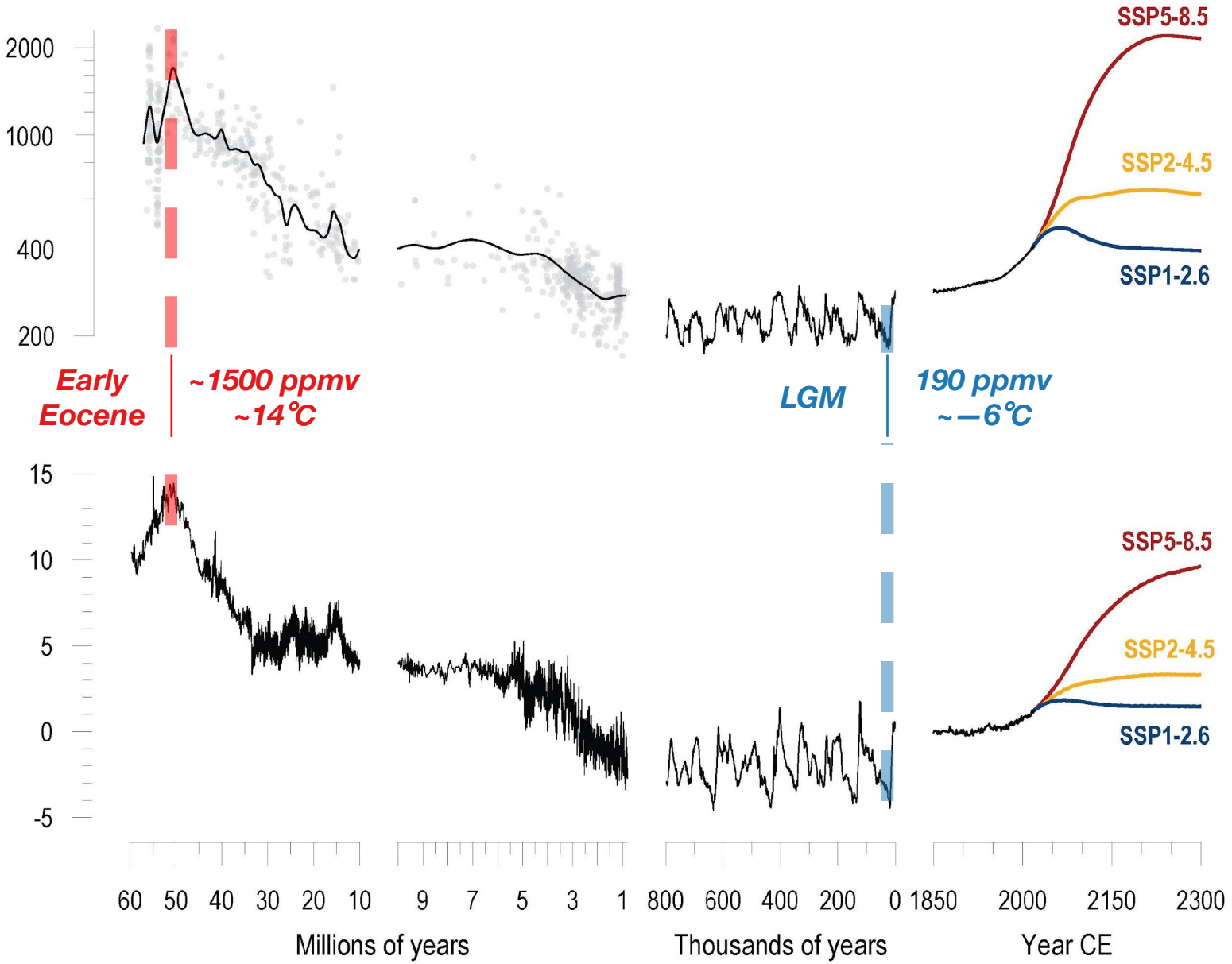
Collaborators: B. Otto-Bliesner, E. Brady, Zhun Guo,
V. Larson, B. Medeiros

This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

Cenozoic extreme climates help assess climate sensitivity in models

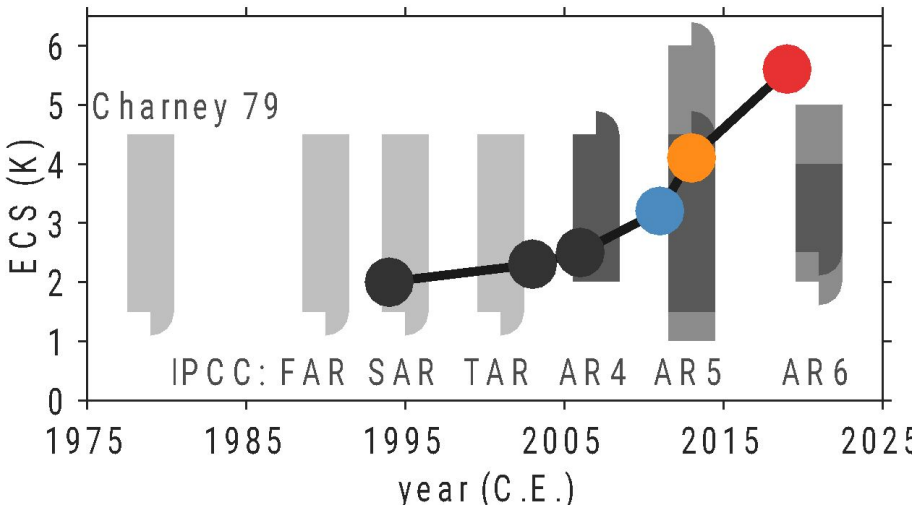
CO_2

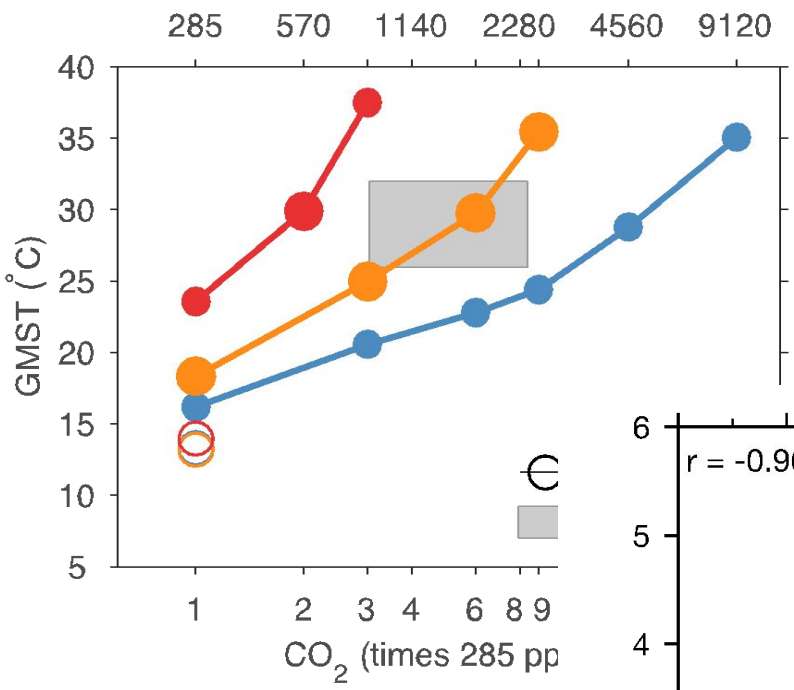
ΔT
(Global surface temperature change)



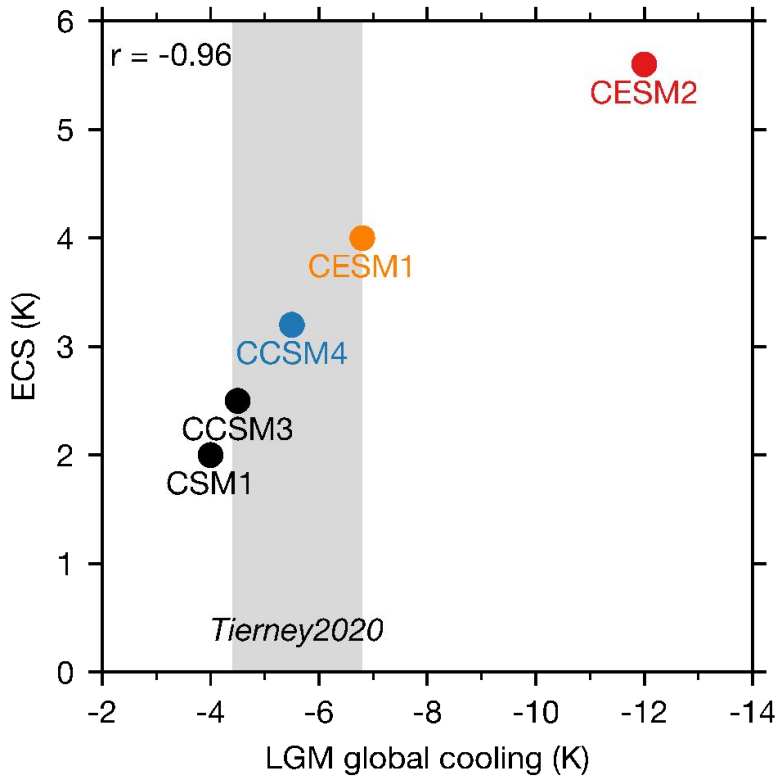
Modified after IPCC AR6 Figure TS.1

CESM2 with a high ECS overestimates ΔT for Eocene & LGM





Eocene



LGM

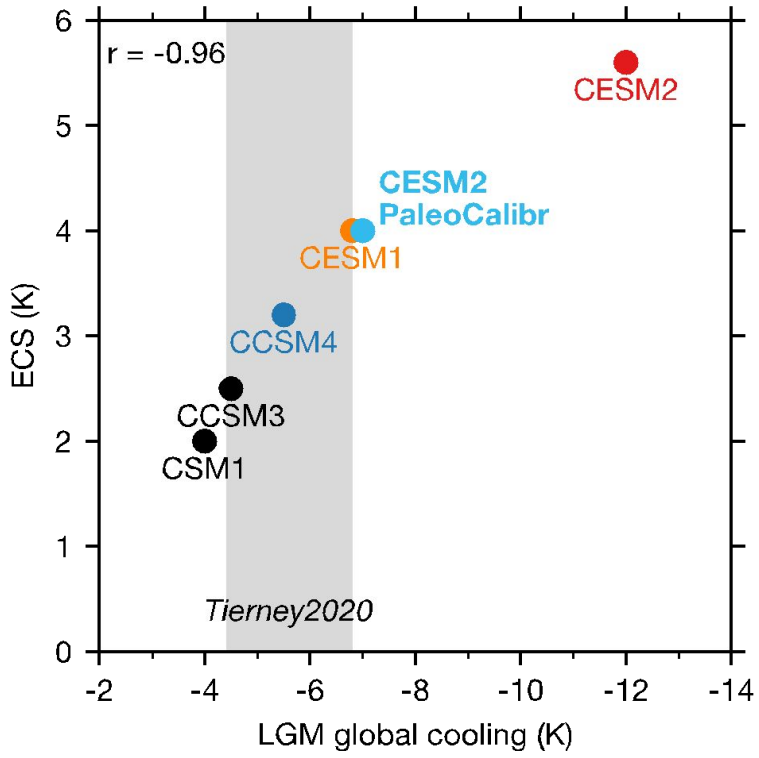
Zhu, Poulsen, Tierney, 2019, Sci. Adv.
Zhu, Poulsen, Otto-Bliesner, 2020, Nat. Clim. Change.
Zhu et al., 2021, GRL

A paleoclimate-calibrated CESM2 was developed

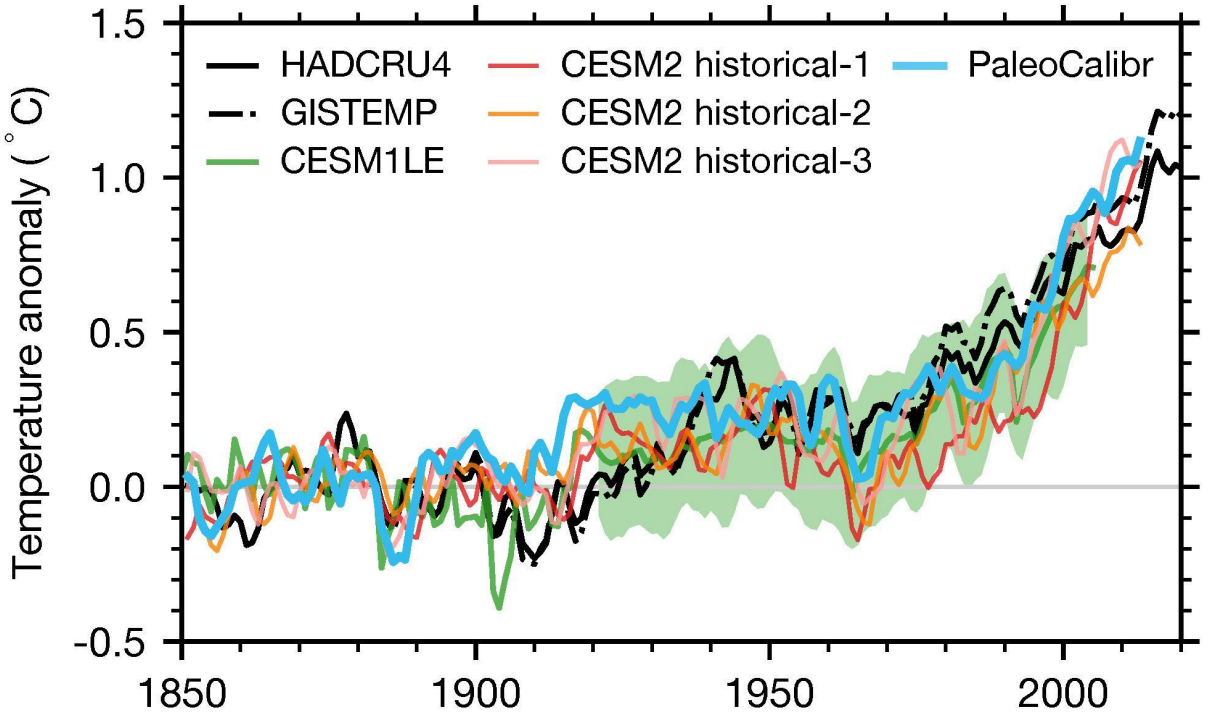
PaleoCalibr = 1. ***Remove an unphysical limiter*** on cloud ice number (one line of code change)

2. ***Decrease the microphysical timestep*** (one parameter change; Δt: 600s → 75s)

LGM global cooling vs ECS

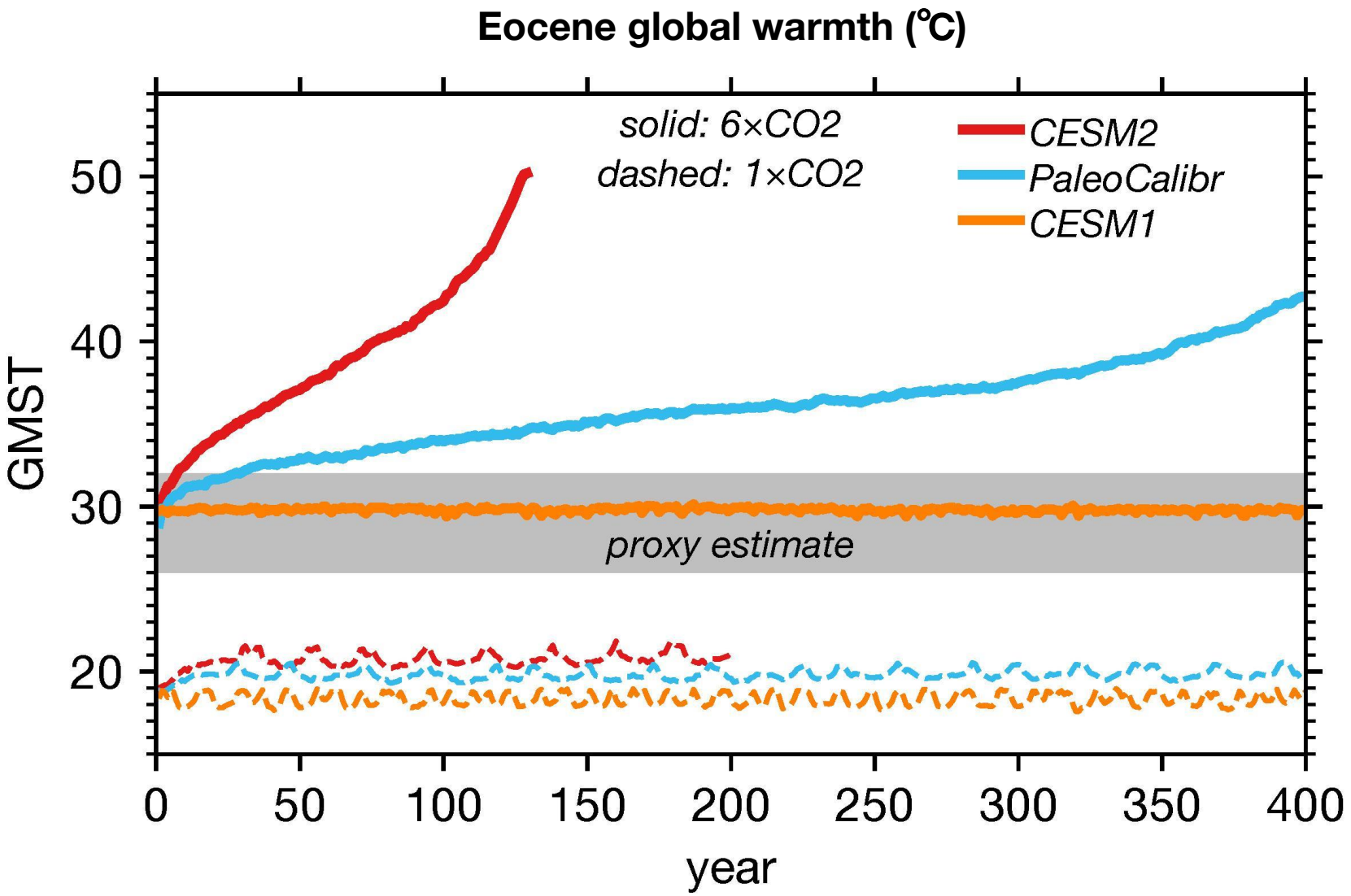


Historical warming



Zhu et al., 2022, JAMES

Can CESM2-PaleoCalibr simulate the early Eocene?



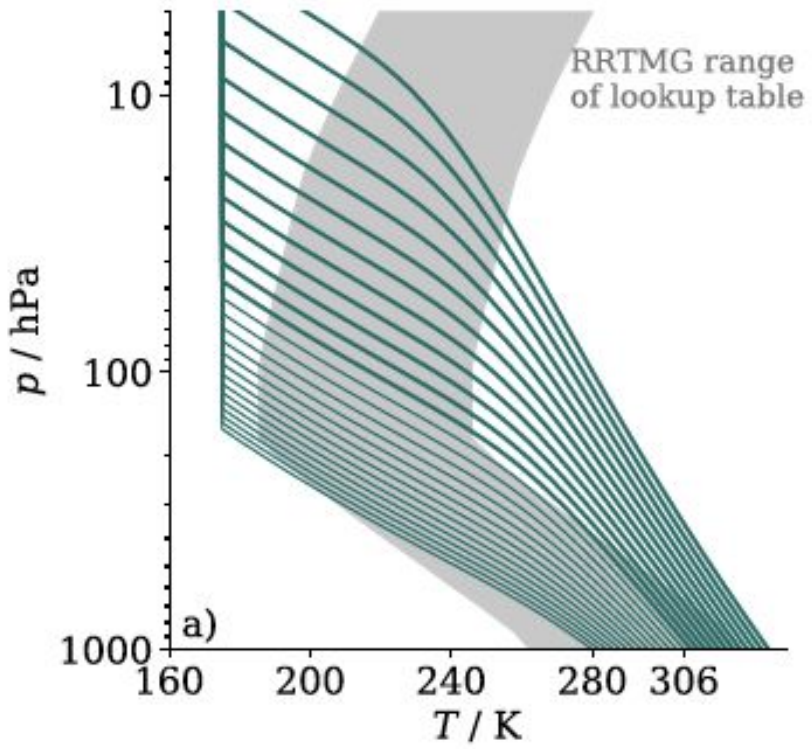
Zhu et al., in prep.

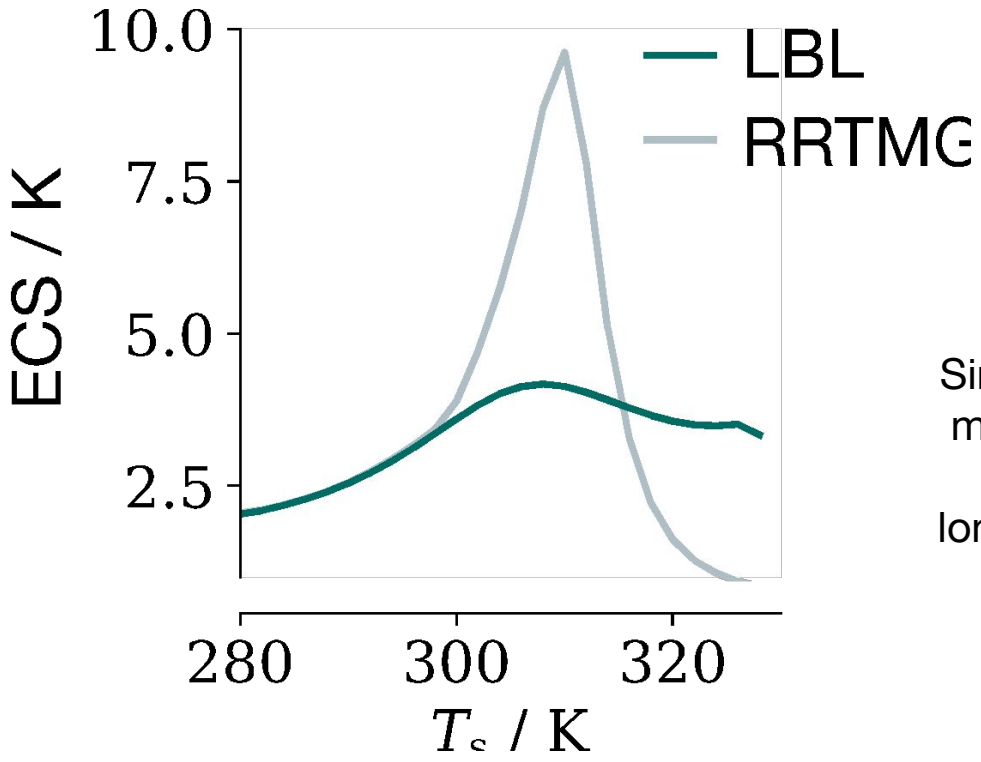
Hypothesis: problems in radiation (RRTMG)?

Kluft et al. (2021) *(see also Popp et al. 2014; Seeley & Jeevanjee, 2021)*

- lookup tables are out of bounds

→ Unrealistic, amplified ECS increase with warming

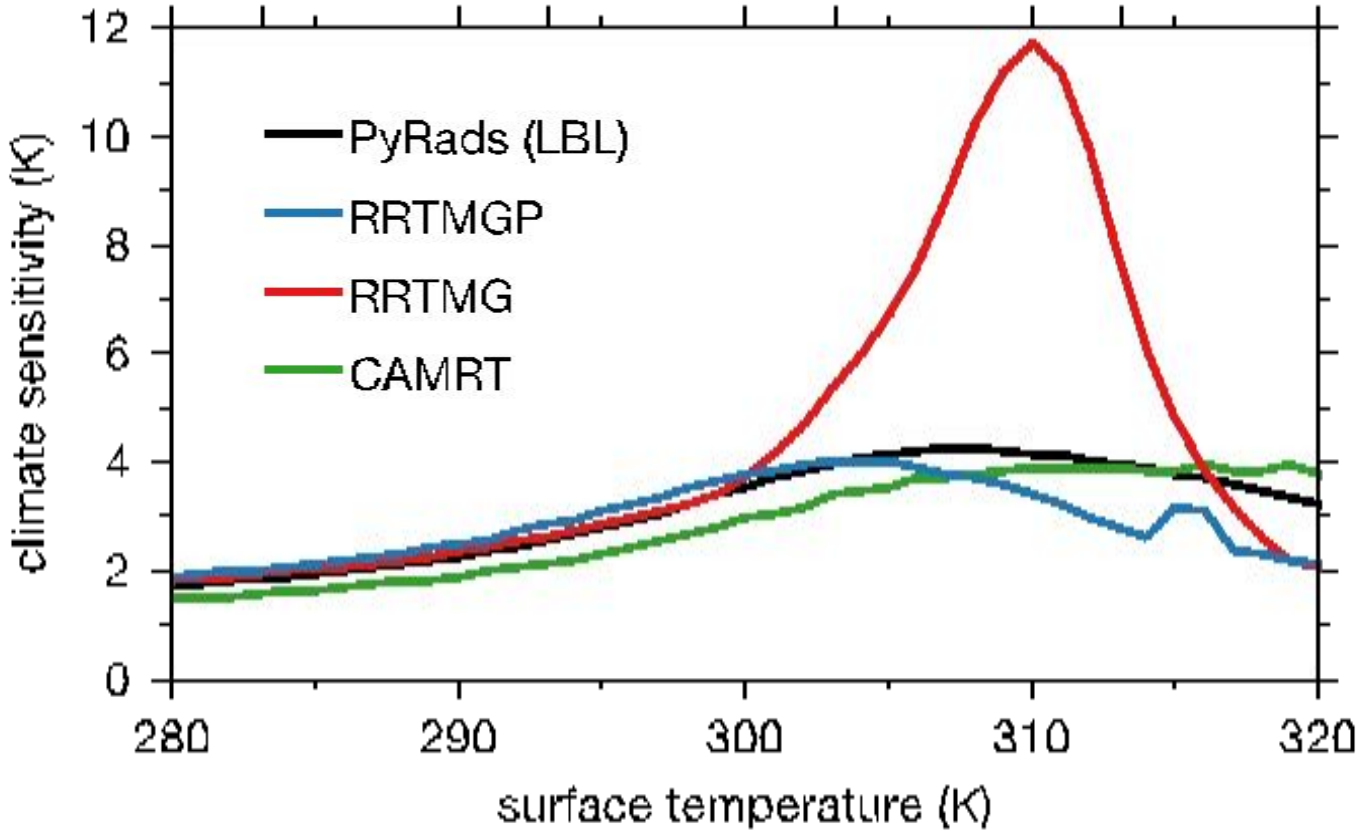




Single column
moist adiabat
RH = 80%
longwave only
PI CO2

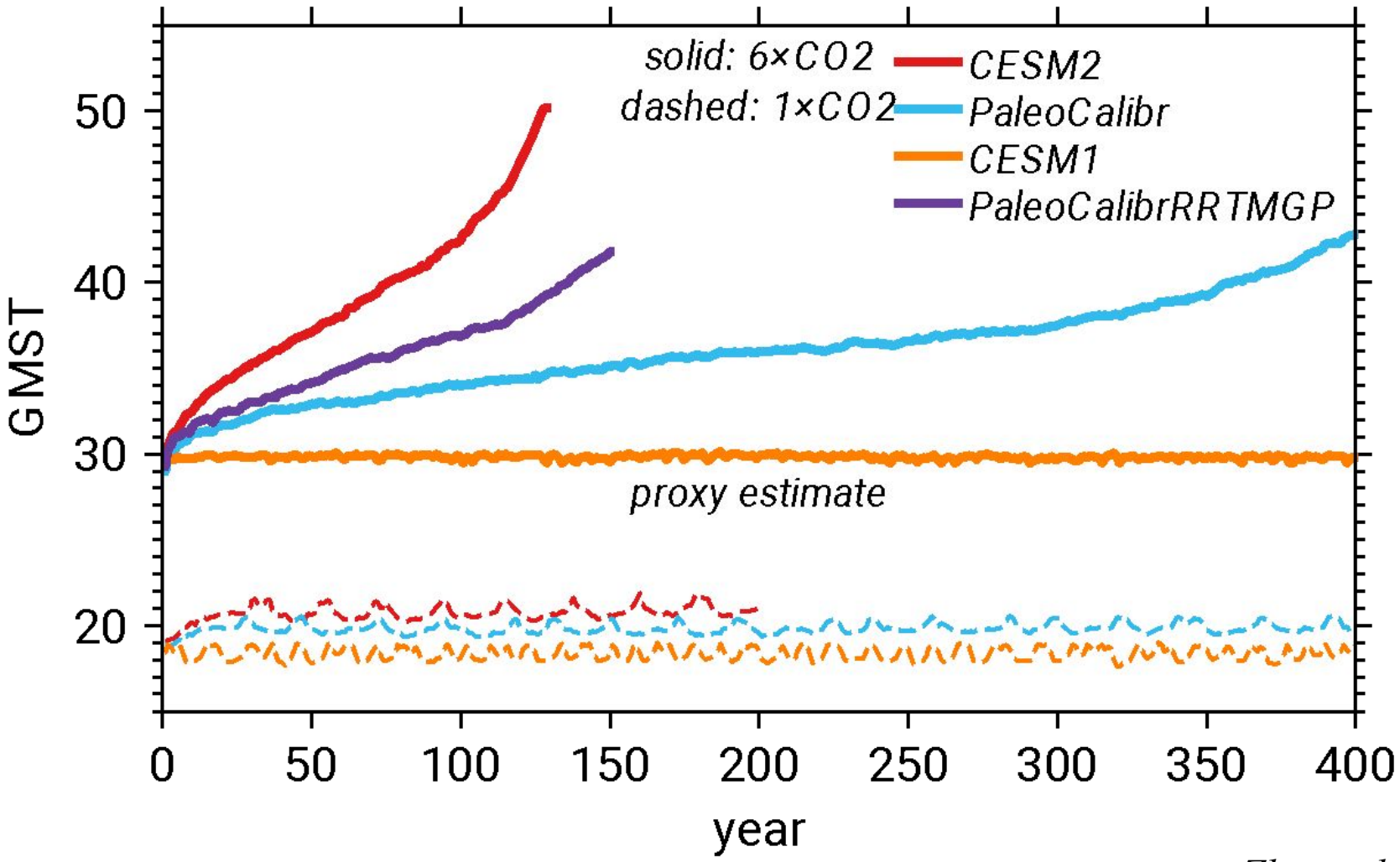
RTE+RRTMGP has a much wider lookup table *(Pincus et al., 2019)*

Benchmark radiation schemes using PyRads (line-by-line)



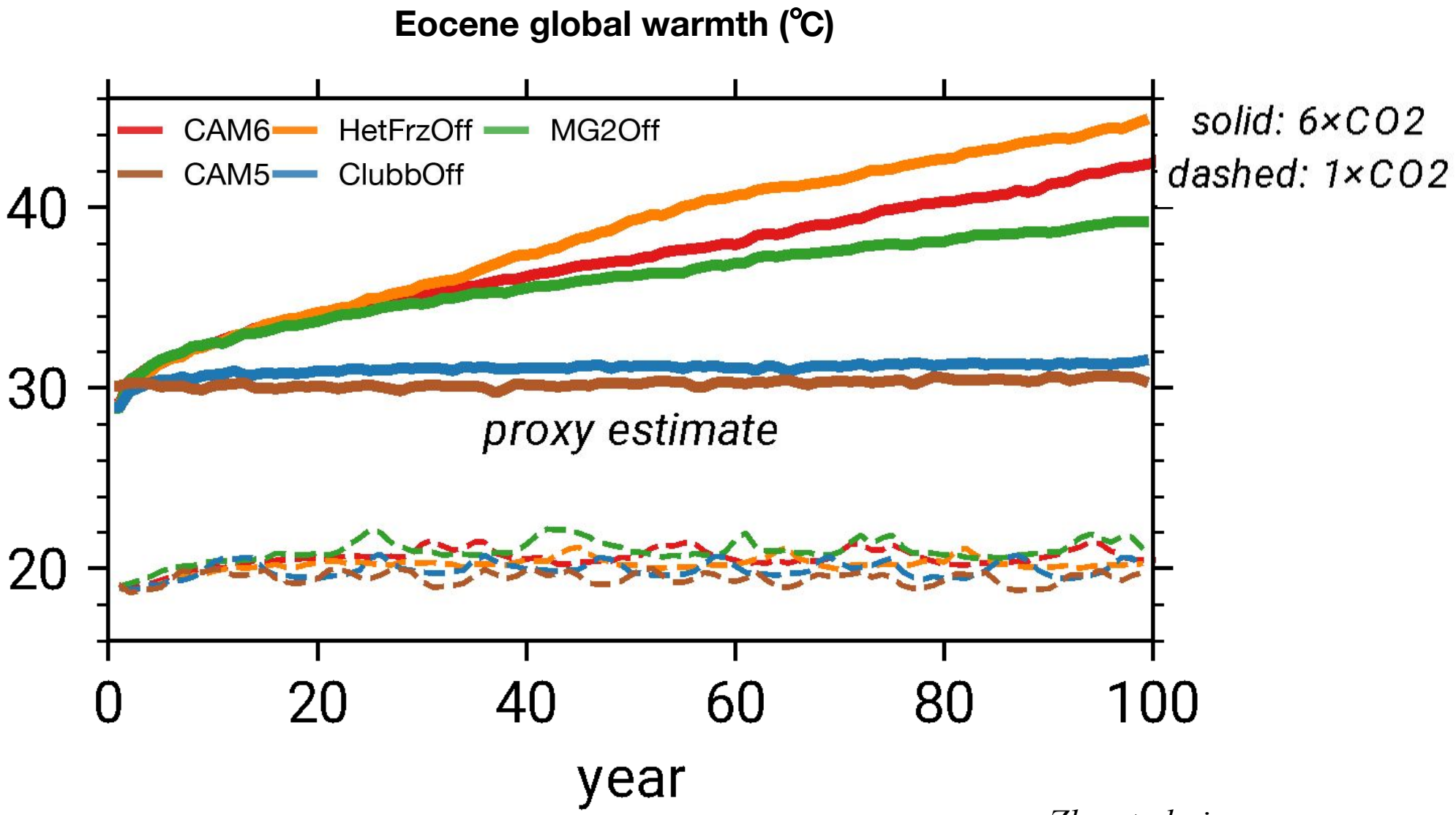
Zhu et al., in prep.

New radiation (RTE+RRTMGP) does not help with the runaway



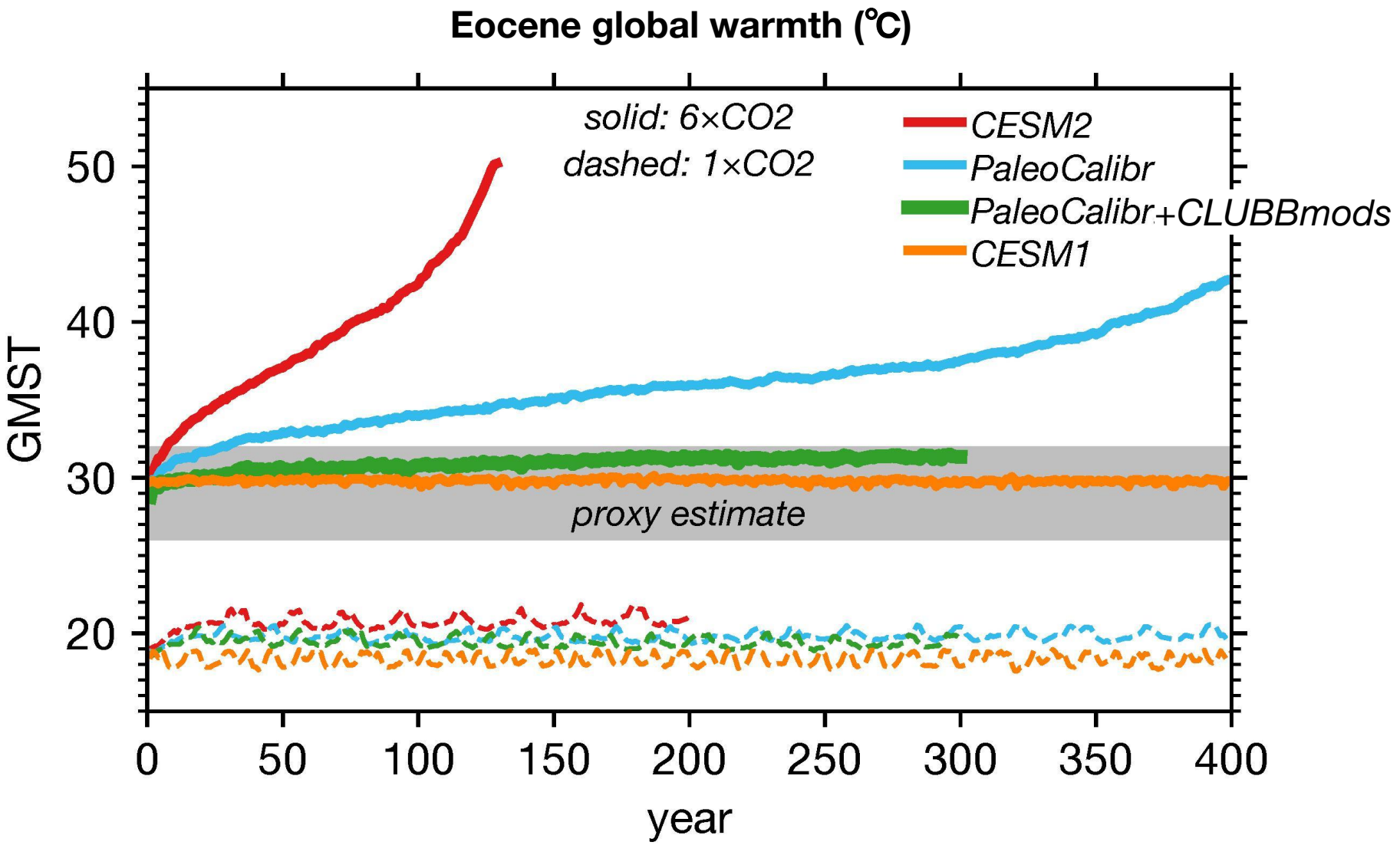
Zhu et al., in prep.

Testing individual schemes: turbulence & shallow convection (CLUBB)?



Zhu et al., in prep.

PaleoCalibr+CLUBBmods = PaleoCalibr + *CLUBB_C8* × *1.2* + minimal tuning



Zhu et al., in prep.

Hypothesis: larger CLUBB_C8 delays/weakens the disappearing of low clouds

CLUBB_C8 damps the 3rd moment of vertical velocity and promotes stratocumulus

$$\frac{\partial \overline{w'^3}}{\partial t} = \underbrace{-\overline{w}\frac{\partial \overline{w'^3}}{\partial z}}_{ma} \underbrace{-\frac{1}{\rho_s}\frac{\partial \rho_s \overline{w'^4}}{\partial z}}_{ta} \underbrace{+3\frac{\overline{w'^2}}{\rho_s}\frac{\partial \rho_s \overline{w'^2}}{\partial z}}_{tp} \underbrace{-3\overline{w'^3}\frac{\partial \overline{w}}{\partial z}}_{ac} \underbrace{+\frac{3g}{\theta_{vs}}\overline{w'^2\theta'_v}}_{bp1}$$

$$\underbrace{-C_{15}K_m\frac{\partial}{\partial z}\left(\frac{g}{\theta_{vs}}\overline{w'\theta'_v} - \overline{u'w'}\frac{\partial \overline{u}}{\partial z} - \overline{v'w'}\frac{\partial \overline{v}}{\partial z}\right)}_{bp2}$$

$$\underbrace{-\frac{C_8}{\tau}\overline{w'^3}}_{pr1} \underbrace{-C_{11}\left(-3\overline{w'^3}\frac{\partial \overline{w}}{\partial z} + \frac{3g}{\theta_{vs}}\overline{w'^2\theta'_v}\right)}_{pr2}$$

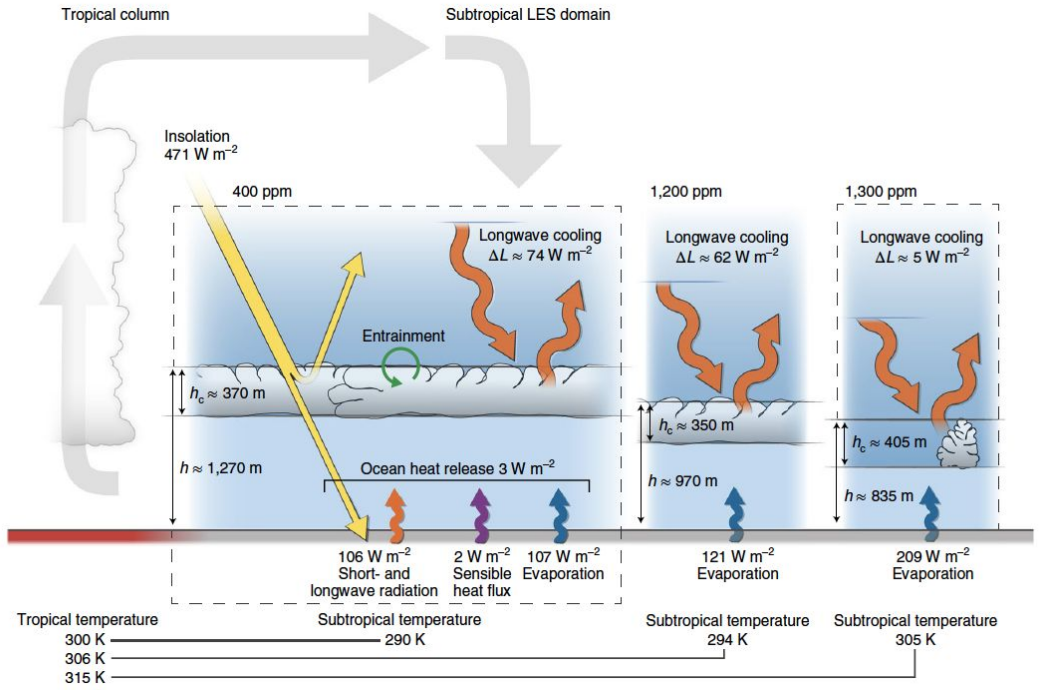
$$\underbrace{+\frac{\partial}{\partial z}\left[\left(K_{w8}+\nu_8\right)\frac{\partial}{\partial z}\overline{w'^3}\right]}_{dp1}$$

$$+\left.\frac{\partial \overline{w'^3}}{\partial t}\right|_{\text{cl}}$$

Larson, 2017

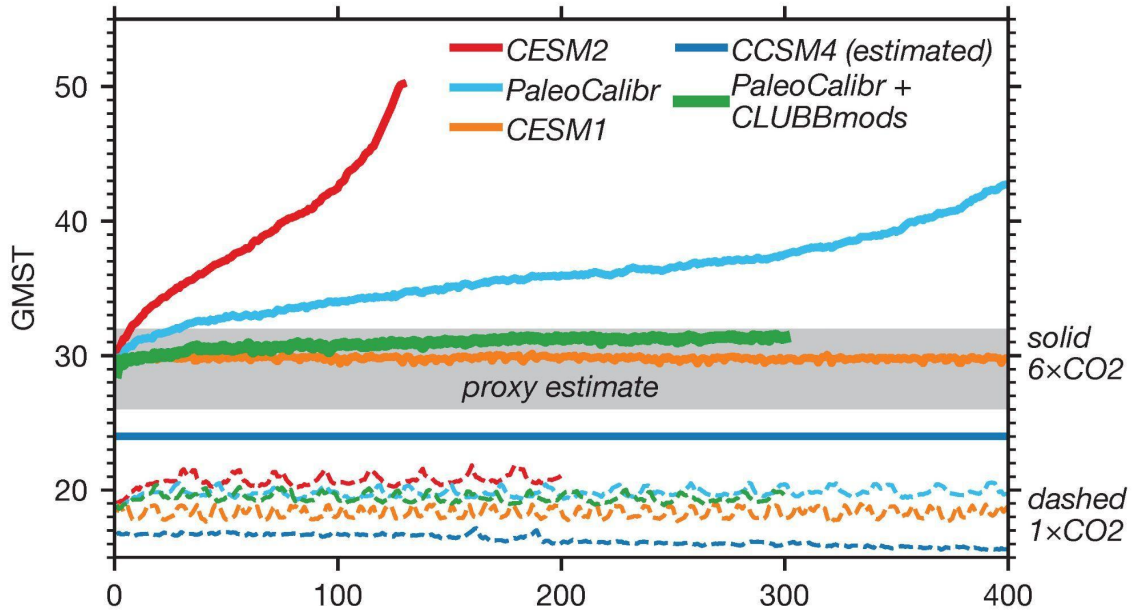
Possible climate transitions from breakup of stratocumulus decks under greenhouse warming

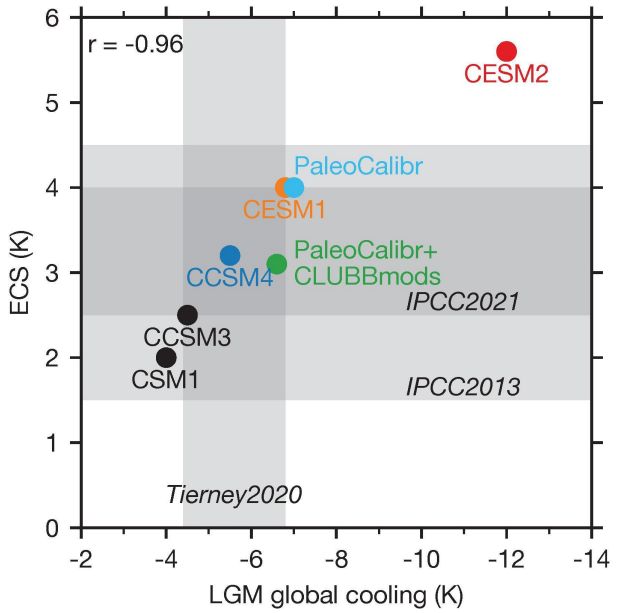
Tapio Schneider[1,2*], Colleen M. Kaul[1] and Kyle G. Pressel[1]



Summary

- **CESM2 *runs away* under realistic Eocene conditions**
- PaleoCalibr improves but not good enough
- Moist turbulence scheme (***CLUBB***) ***likely has a too strong drying effect on low clouds*** under warming, leading to the runaway
- ***CLUBBmods stabilizes Eocene & lowers ECS***





Runaway in coupled CESM Eocene simulations