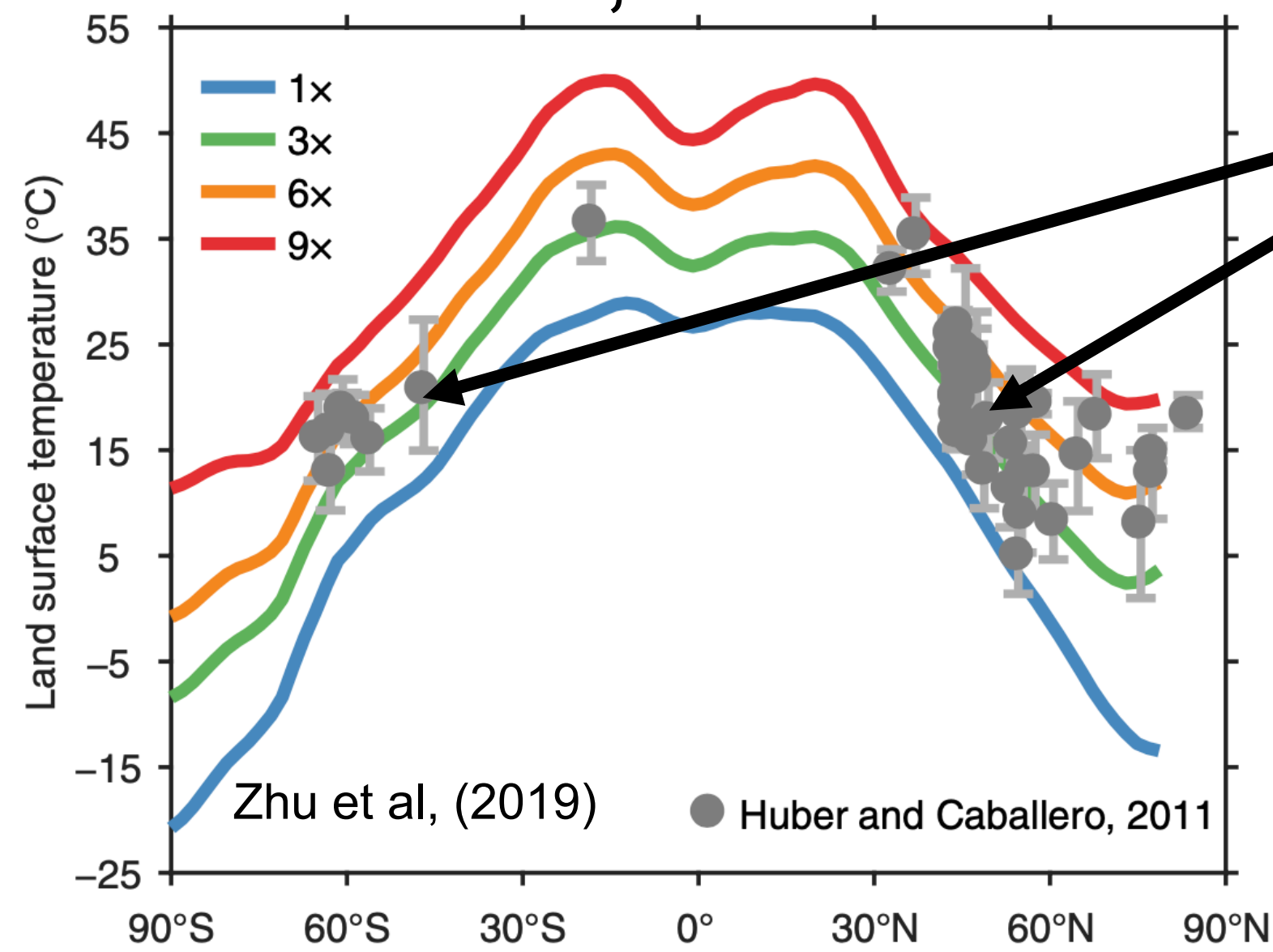# Investigating the role of subtropical stratocumulus break-up in a warm climate using cloud-locking in CESM2
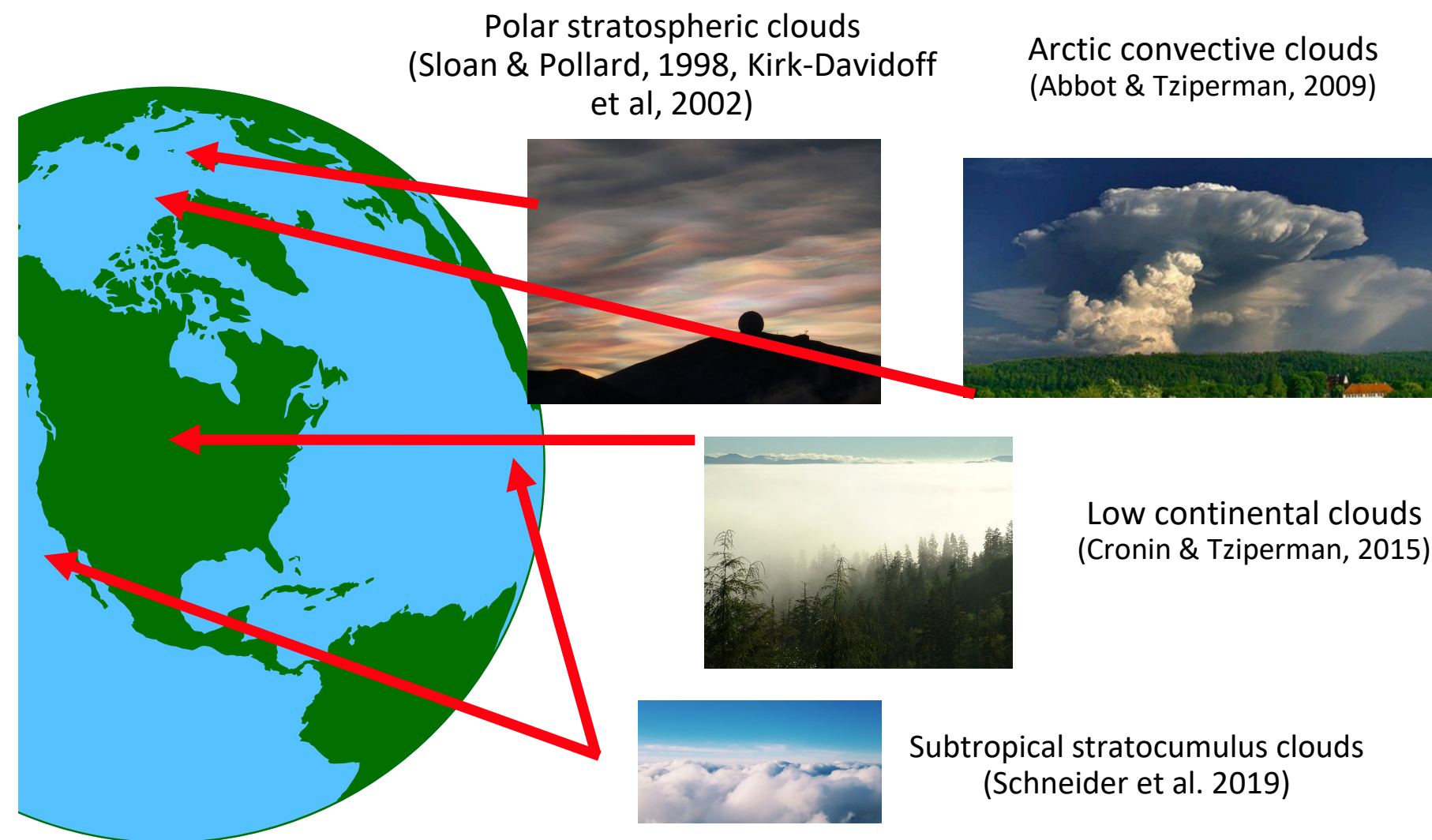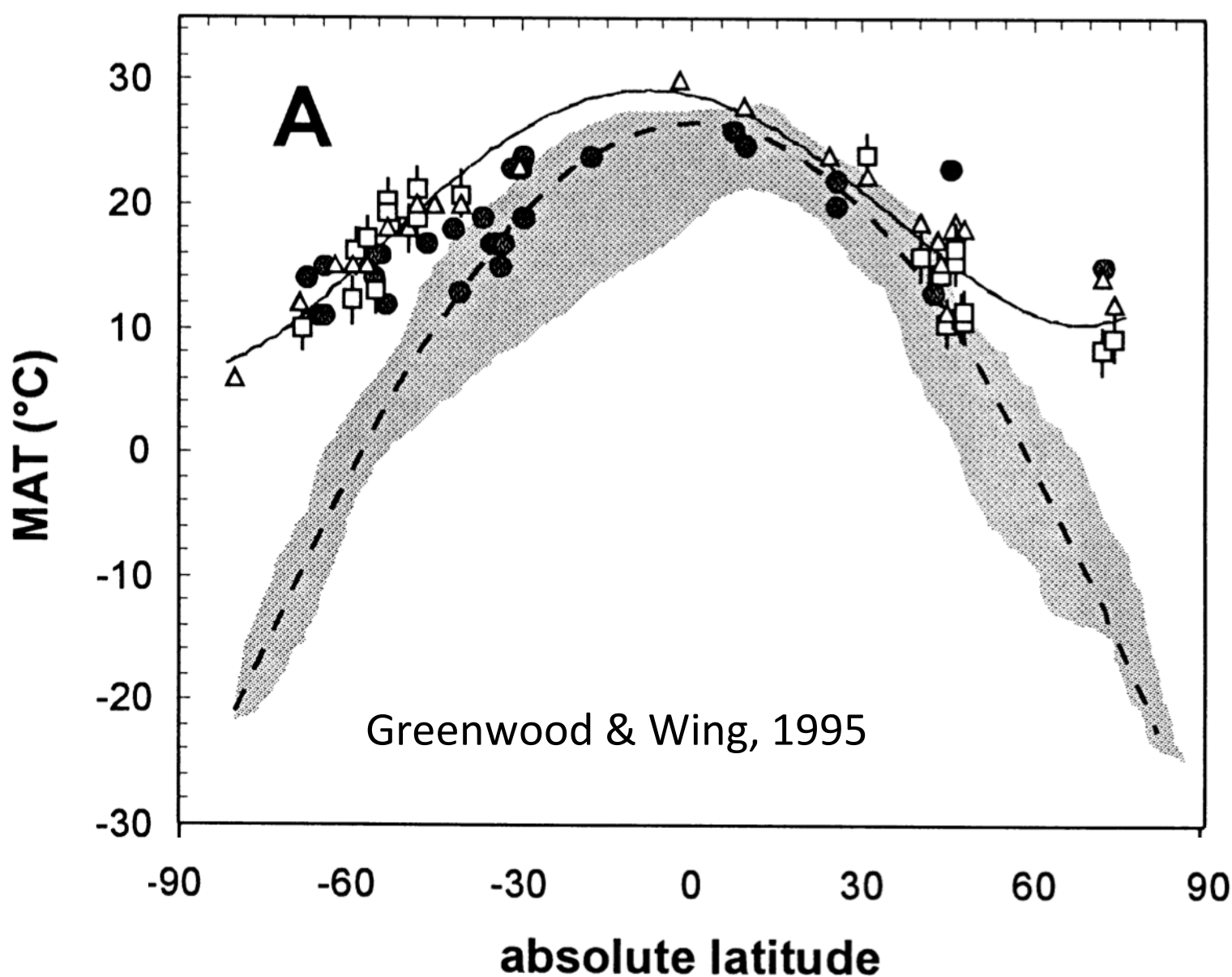
Andrea Salazar, Brian Medeiros, Jiang Zhu, Eli Tziperman
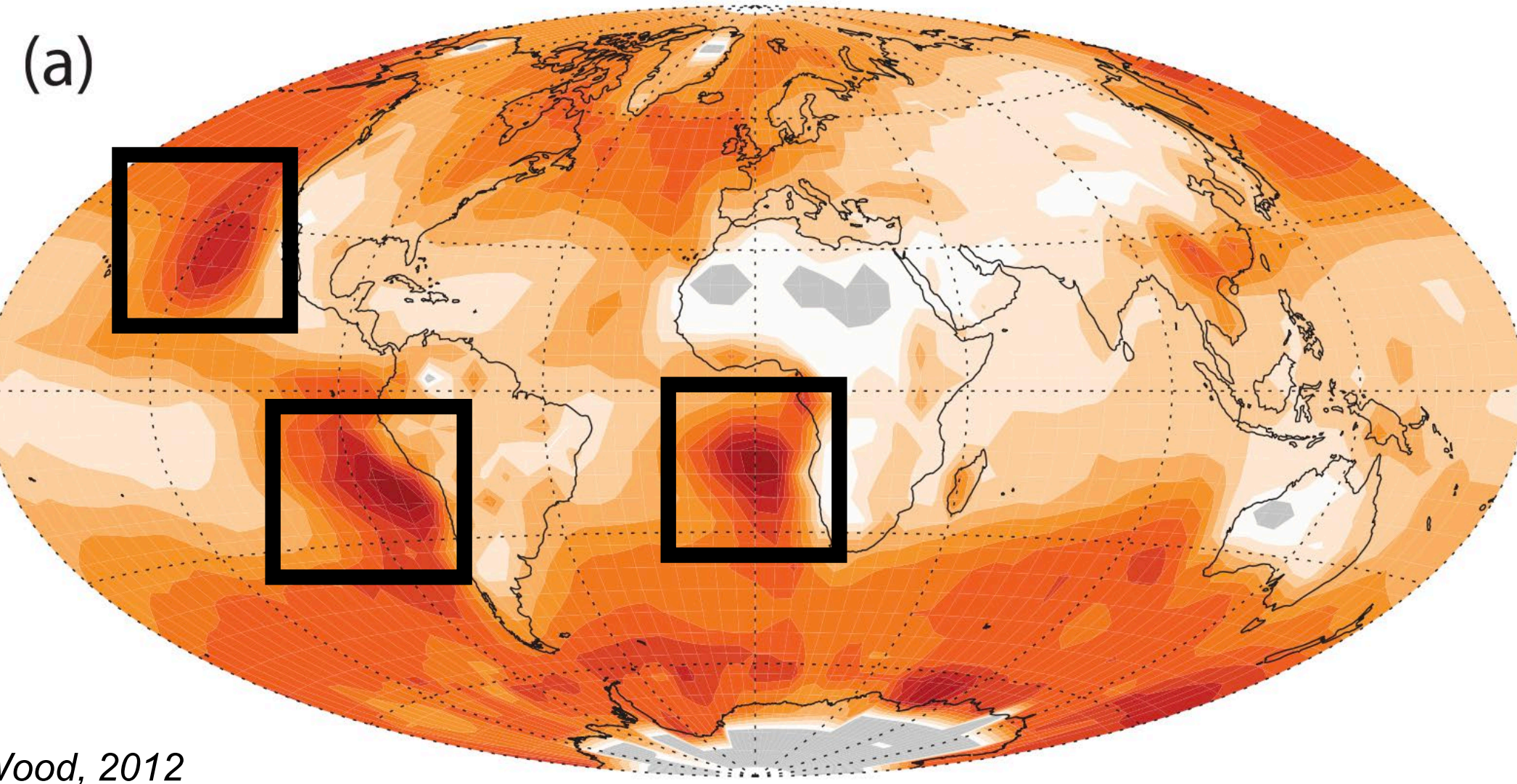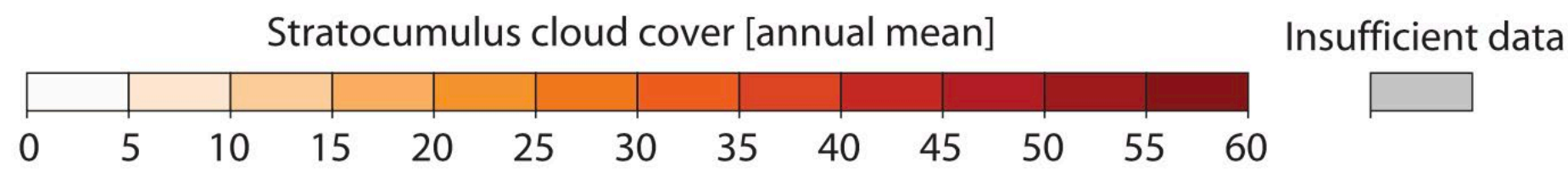
NOAA

~50 Ma, 3-8xCO2

Zhu et al, (2019)   ● Huber and Caballero, 2011

Fossil evidence for frost-intolerant species at high latitudes!
Requires no minimum temperatures below freezing.

Polar stratospheric clouds
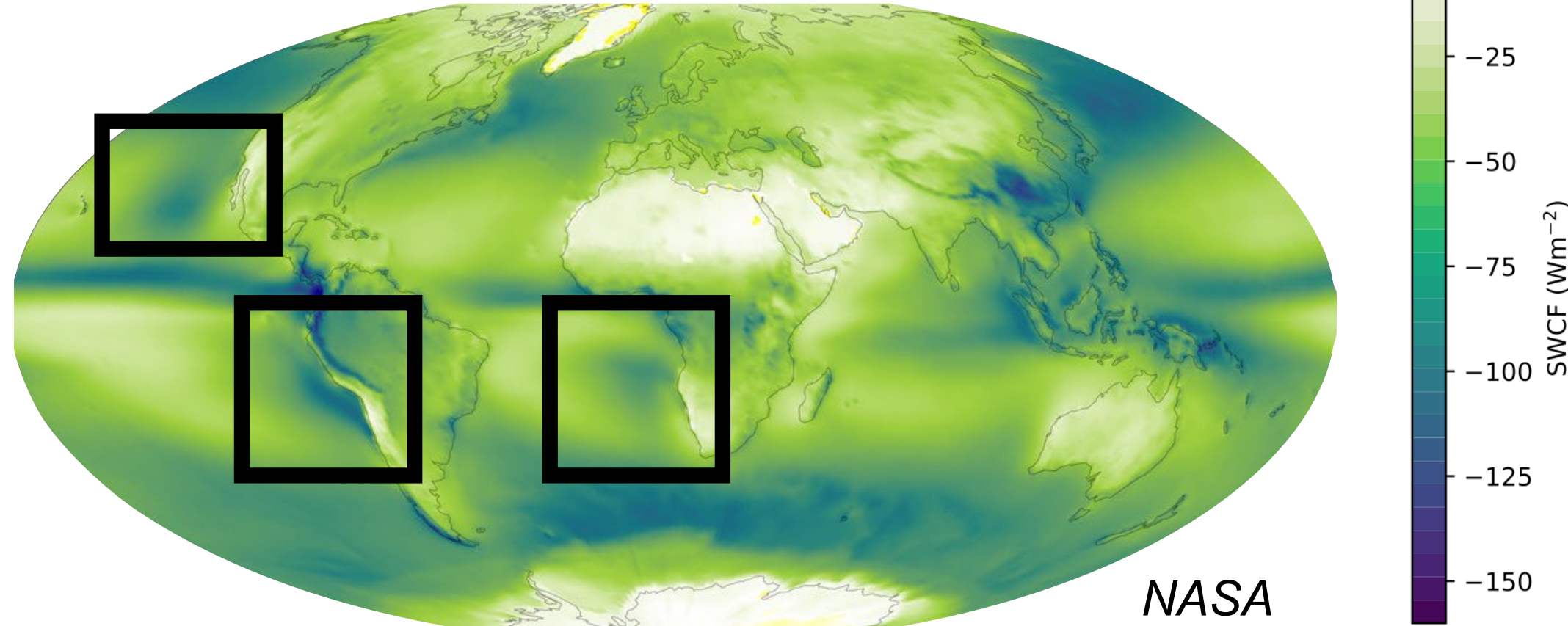(Sloan & Pollard, 1998, Kirk-Davidoff et al, 2002)

Arctic convective clouds
(Abbot & Tziperman, 2009)

Low continental clouds
(Cronin & Tziperman, 2015)

Subtropical stratocumulus clouds
(Schneider et al. 2019)

Greenwood & Wing, 1995

Can cloud feedbacks missing from current GCMs provide additional warming mechanisms?

(a)

Wood, 2012

Stratocumulus cloud cover [annual mean]   Insufficient data
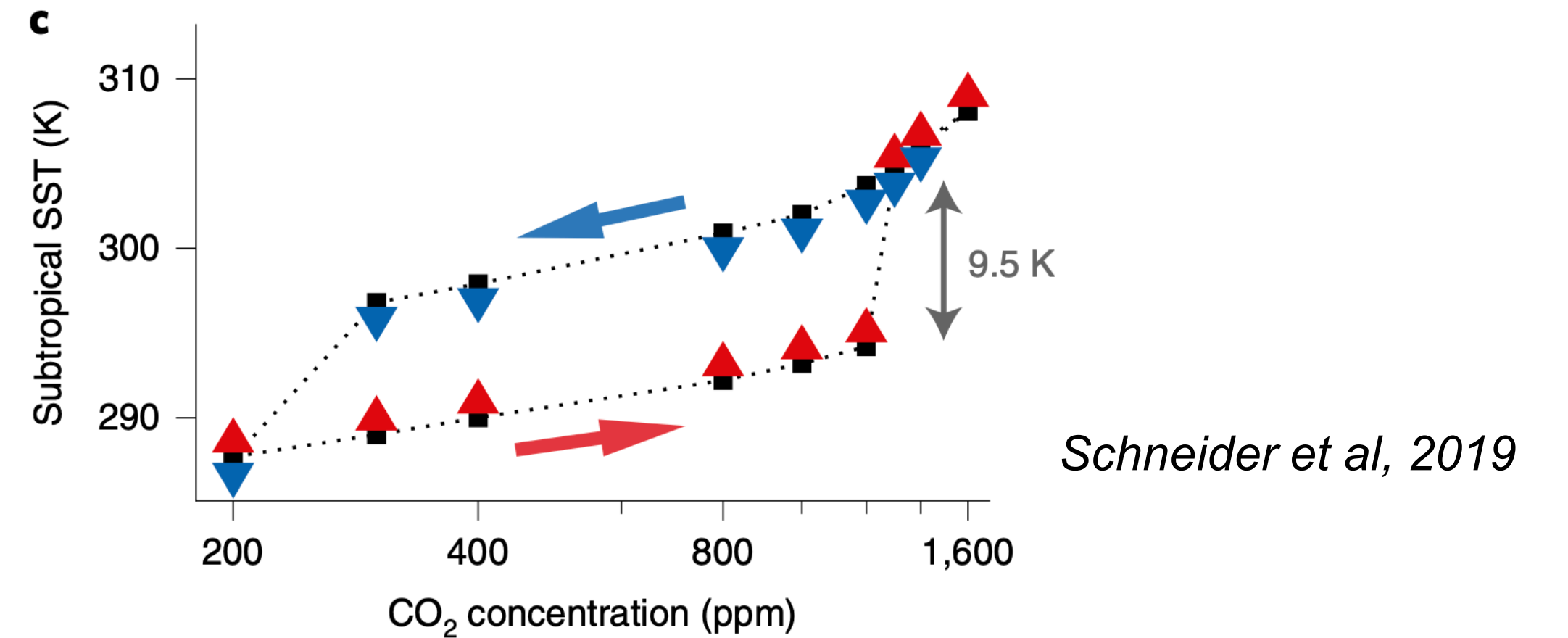
0 5 10 15 20 25 30 35 40 45 50 55 60

SWCF from CERES

NASA

Subtropical stratocumulus cover **~6.5% of Earth's surface and provide up to -100** Wm^{-2} **of SWCF** where they occur
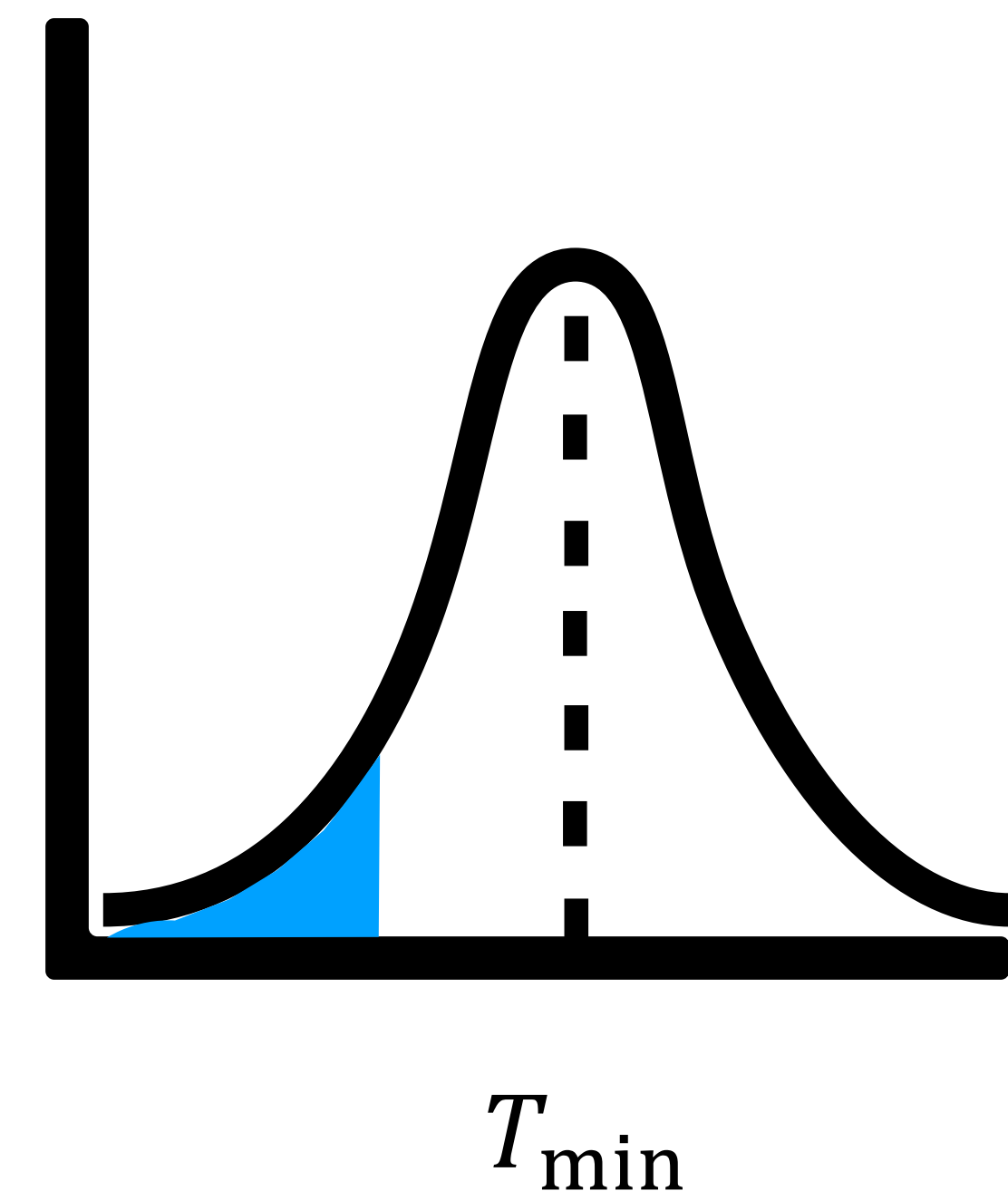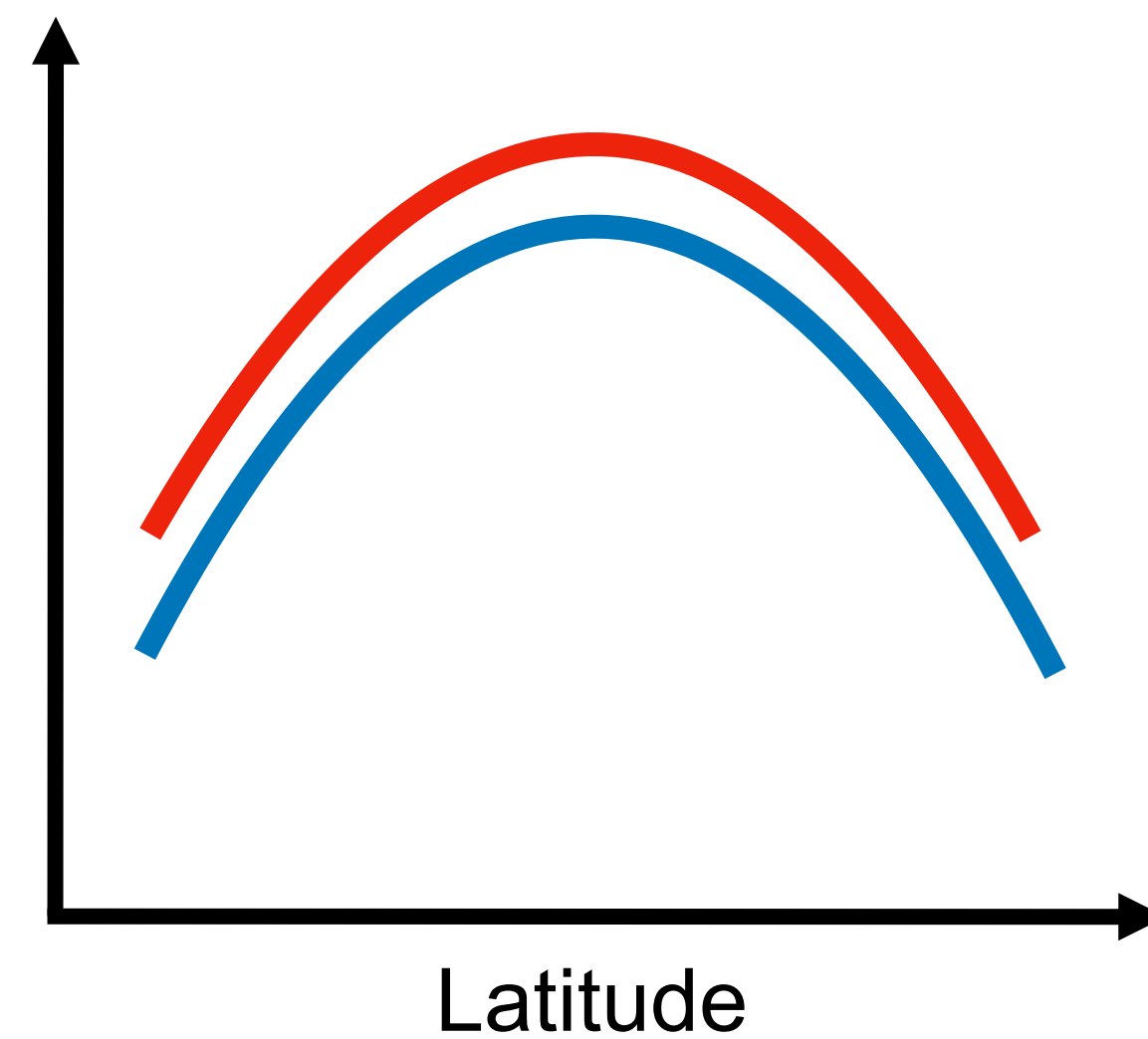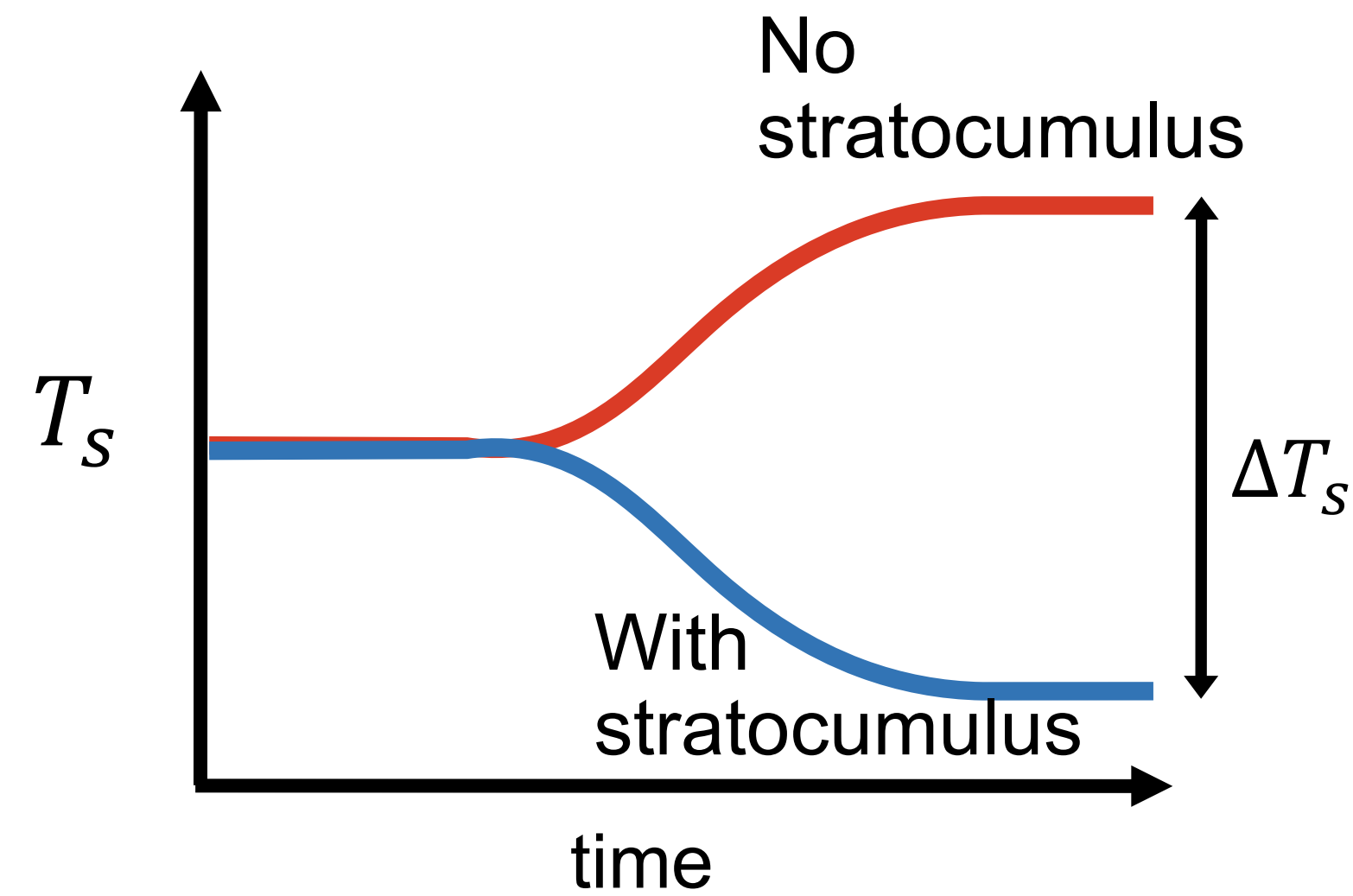

Schneider et al, 2019

$$6.5\% \times 100 \, Wm^{-2} \times 1.2 \, K(Wm^{-2})^{-1} \approx$$
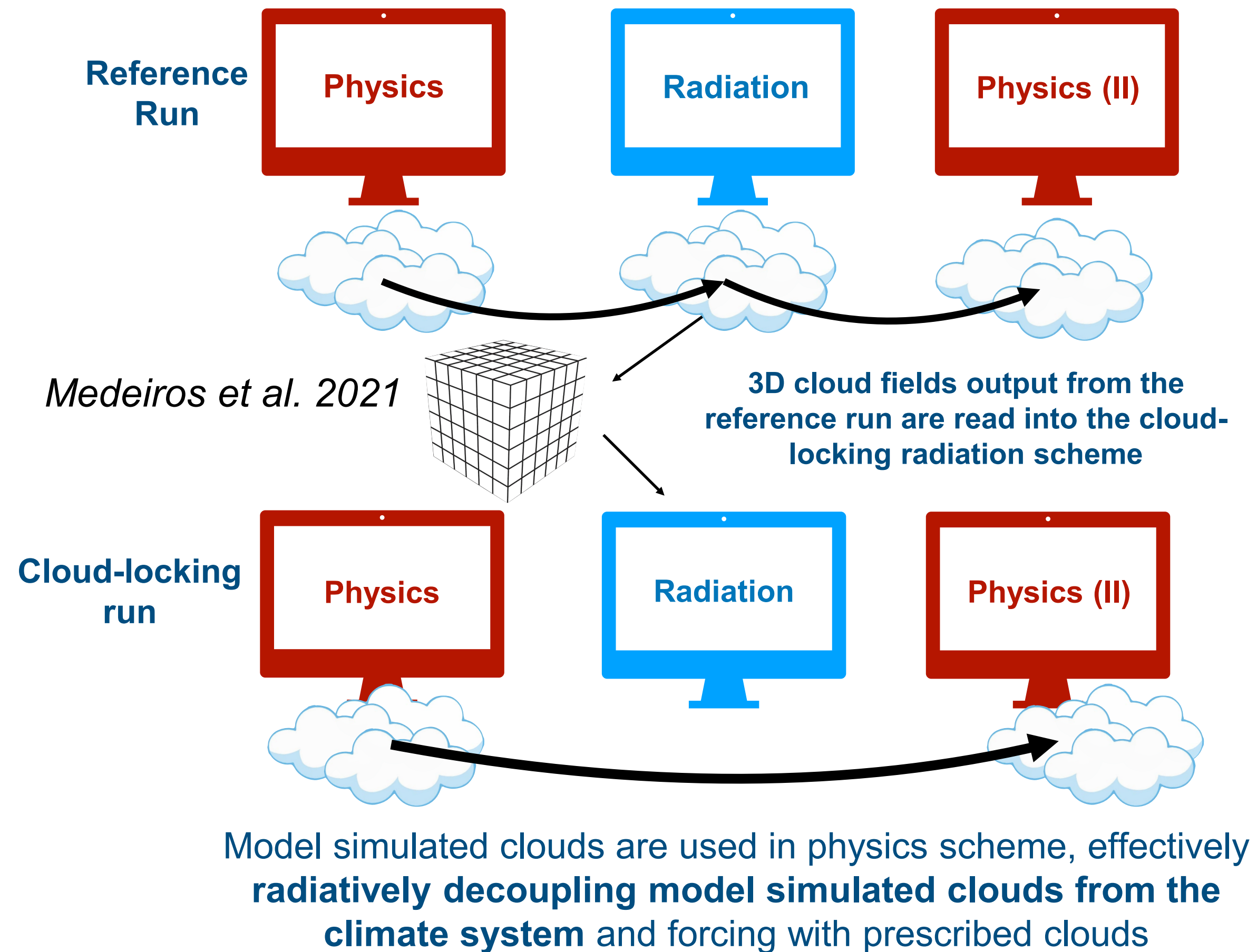
8 K of global average warming!

Motivating questions of this study:

How much global warming does an abrupt break-up of subtropical stratocumulus induce? How much warming is transported to higher latitudes?

Can stratocumulus cloud break-up mitigate below freezing days in continental interiors?

Standard Cloud Locking in CAM6:

Reference Run

Physics → Radiation → Physics (II)

Medeiros et al. 2021

3D cloud fields output from the reference run are read into the cloud-locking radiation scheme

Cloud-locking run

Physics → Radiation → Physics (II)

Model simulated clouds are used in physics scheme, effectively **radiatively decoupling model simulated clouds from the climate system** and forcing with prescribed clouds

** user can also perform *regional* cloud-locking where reference run clouds are only input in certain regions

Middlemas et al. 2020
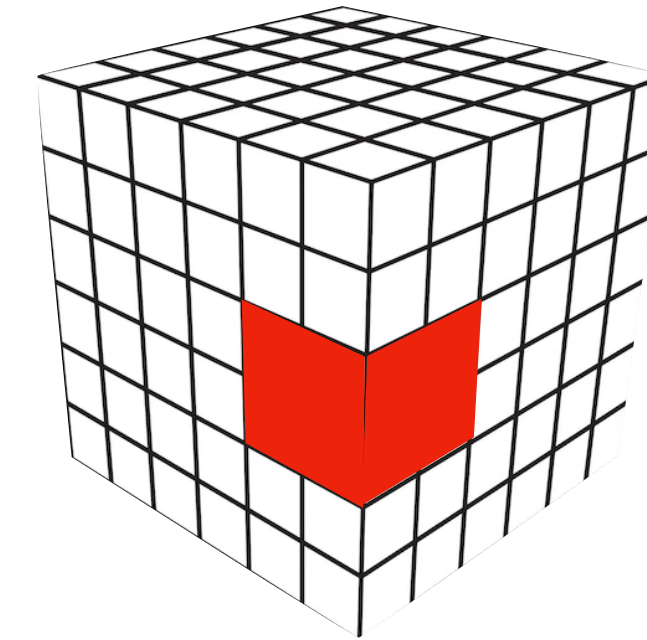
Radiation scheme in CAM6 requires 9 3D cloud variables prescribed every two hours:

- **CLD**: grid box cloud fraction
- **CLDFSNOW**: cloud fraction adjusted for snow
- **ICLWP**: in cloud liquid water path
- **ICIWP**: in cloud ice water path
- **ICSWP**: in cloud snow water path
- **DES**: effective snow diameter
- **DEI**: effective ice diameter
- **MU**: microphysical parameter
- **LAMBDAC**: microphysical parameter

Four cloud-locking runs (2 degree, full coupled):
- **8xCO2 locked-strato:** *high CO2 with prescribed stratocumulus*
- **8xCO2 locked-nostrato:** *high CO2 with stratocumulus removed (CLD = ICLWP = 0)*
- **1xCO2 locked-strato:** *PI CO2 with prescribed stratocumulus*
- **1xCO2 locked-nostrato:** *high CO2 with stratocumulus removed (CLD = ICLWP = 0)*
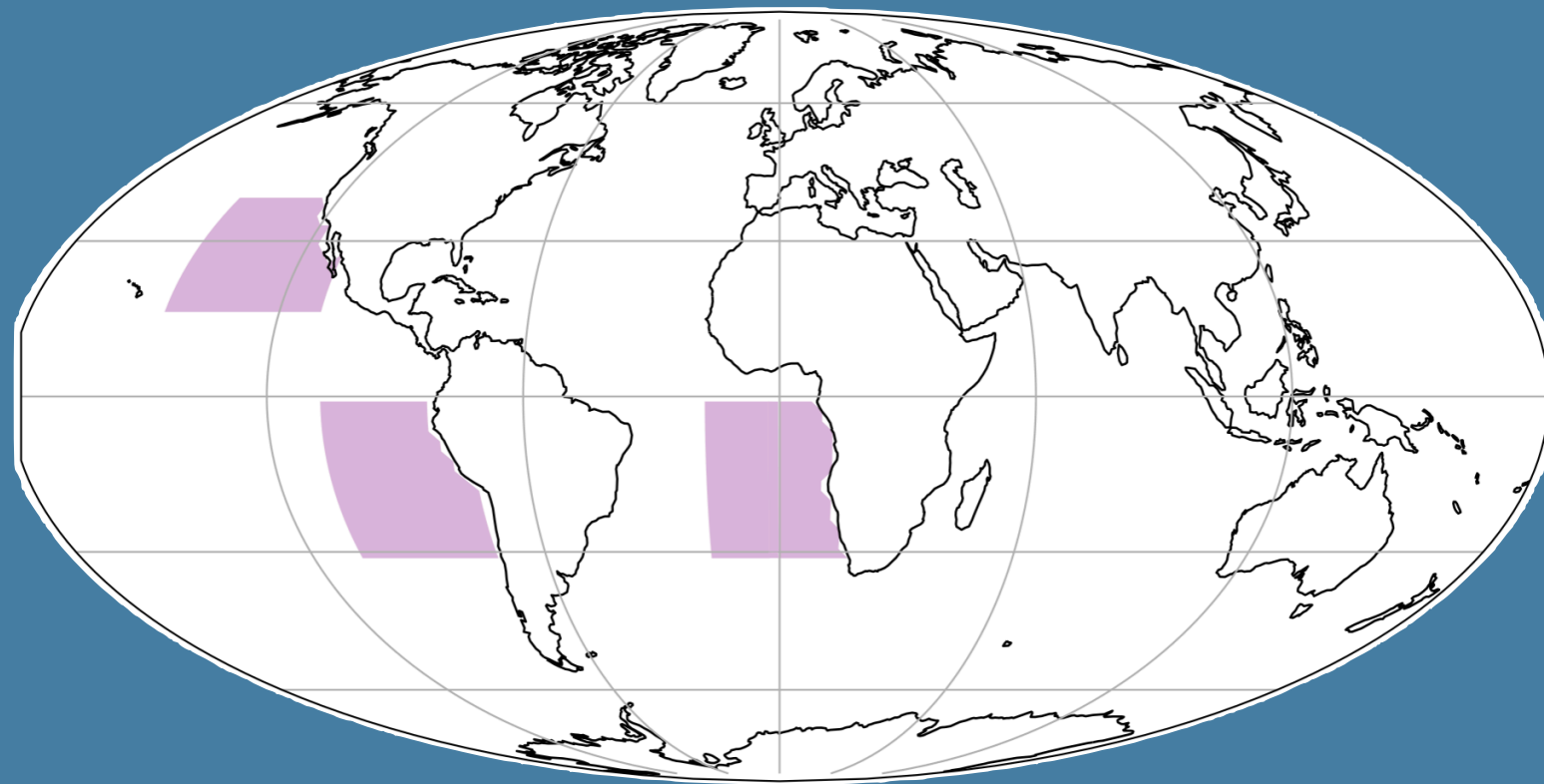

Annual Mean SWCF in $1xCO_2$ stratolocked
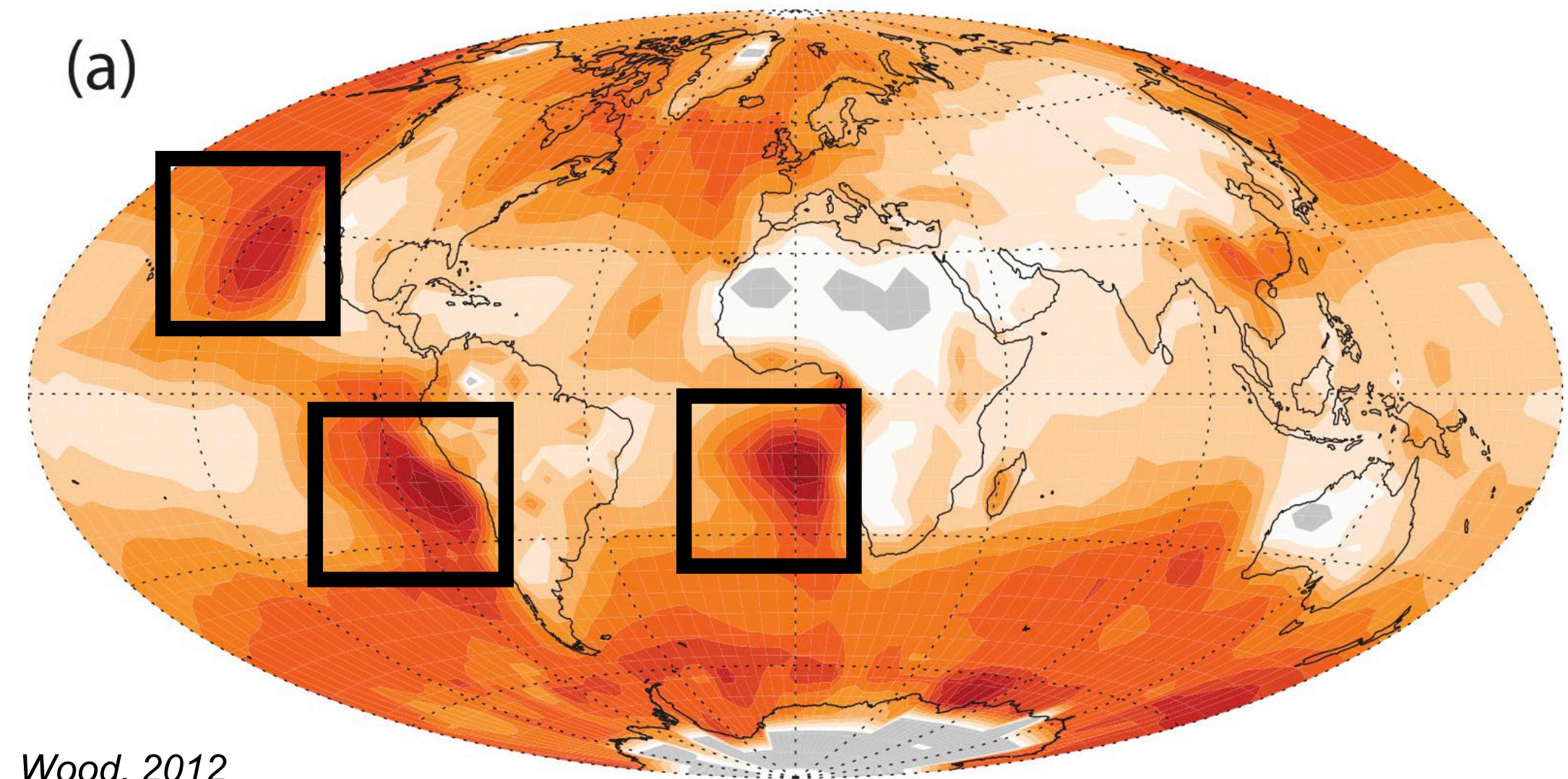

Annual Mean SWCF in $1xCO_2$ nostrato

SWCF (Wm^{-2})
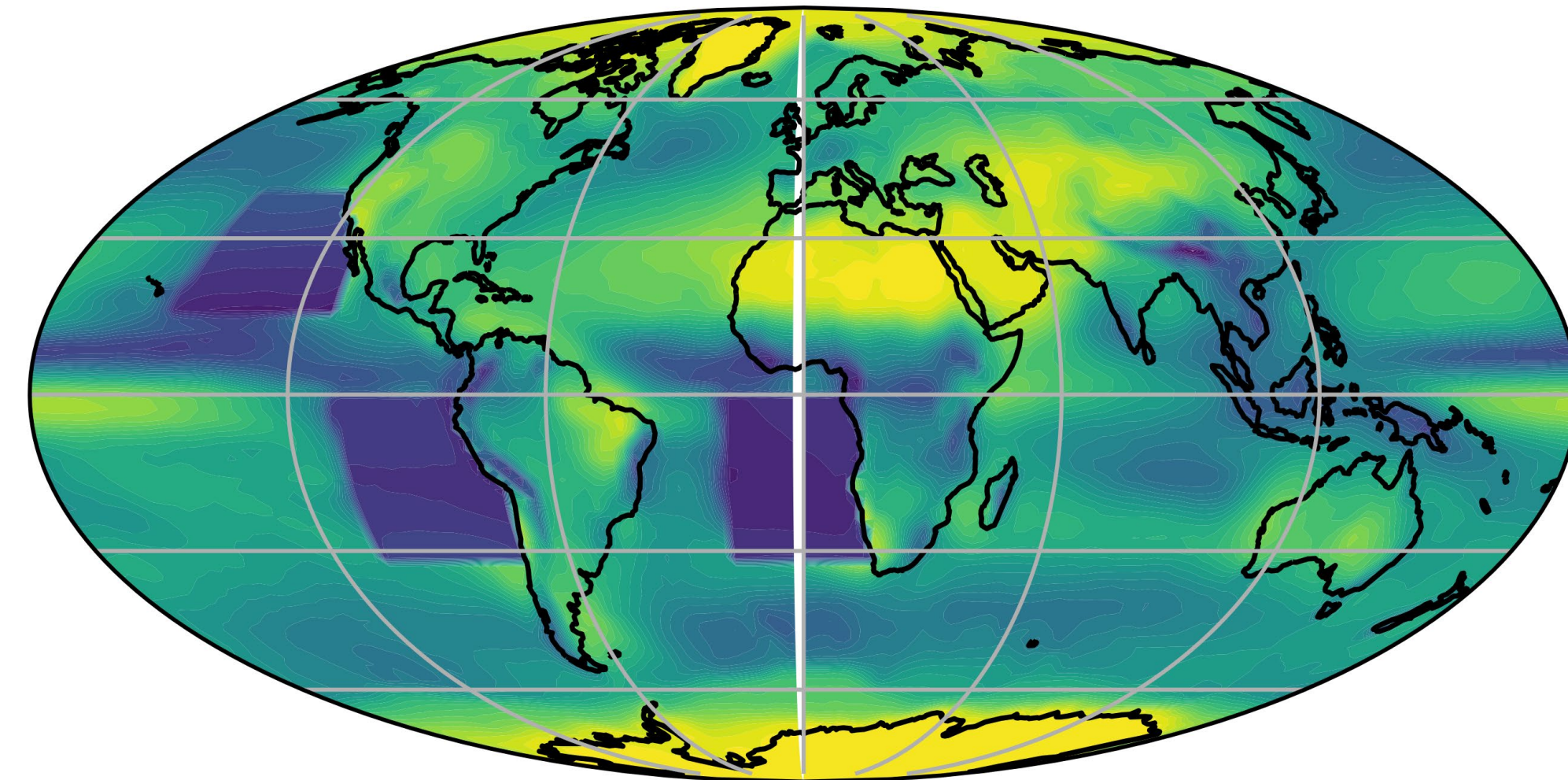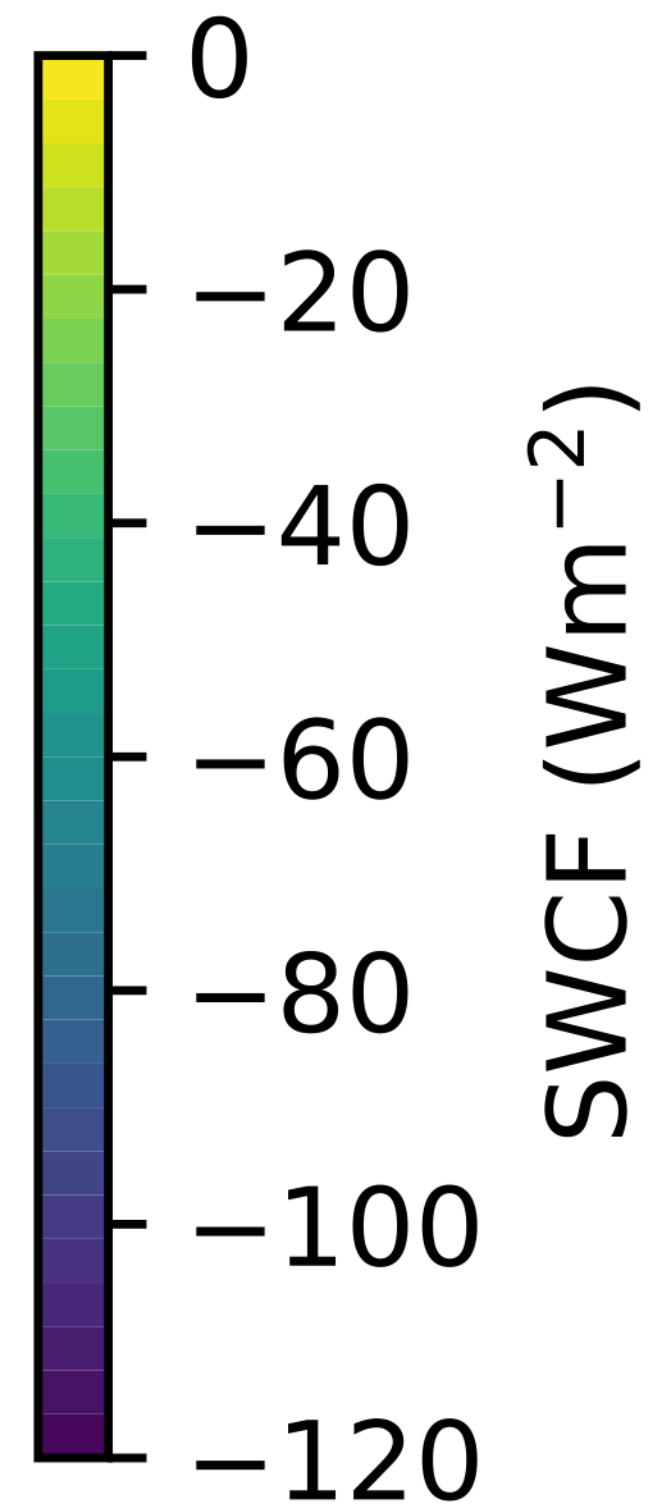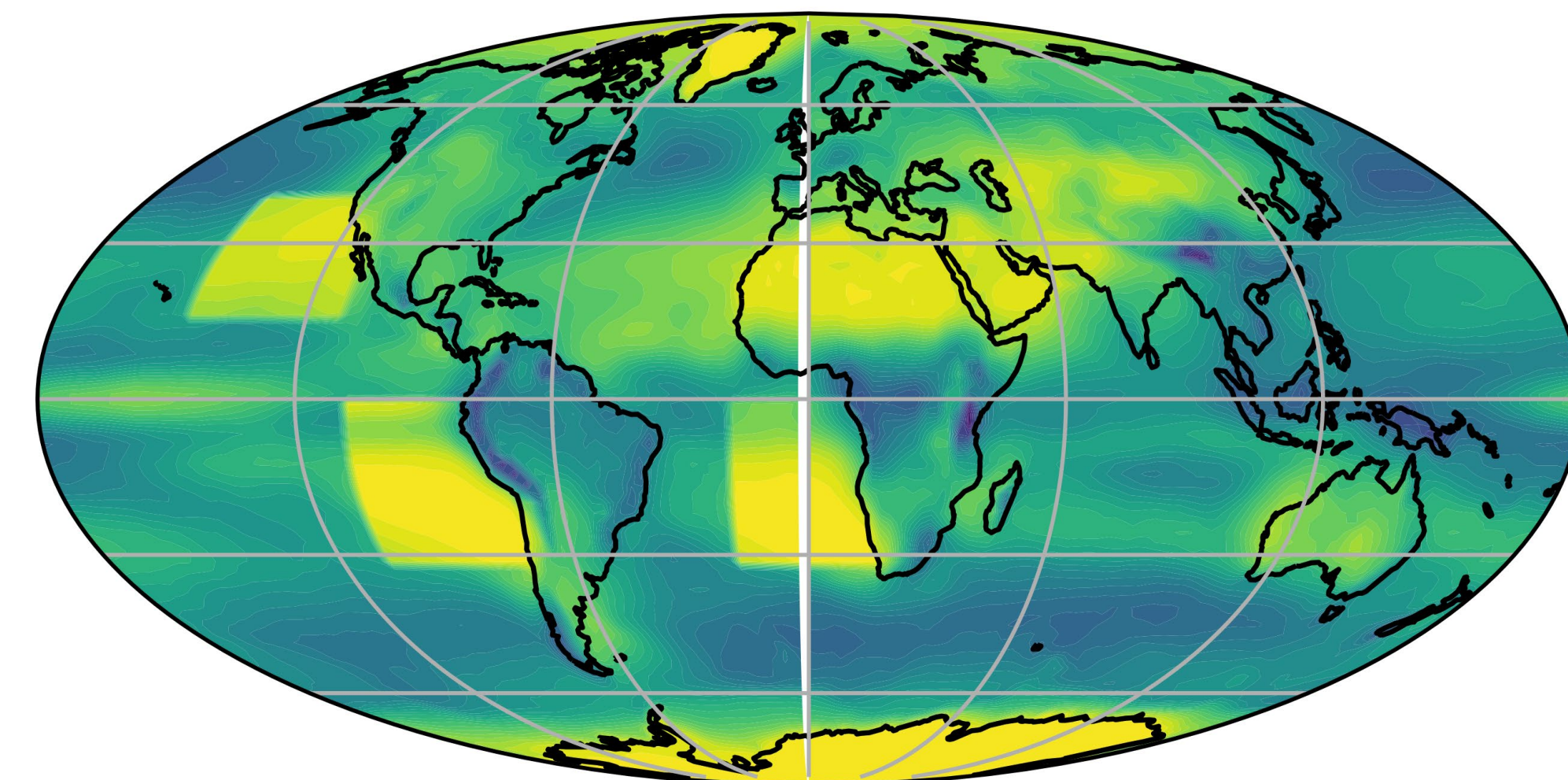
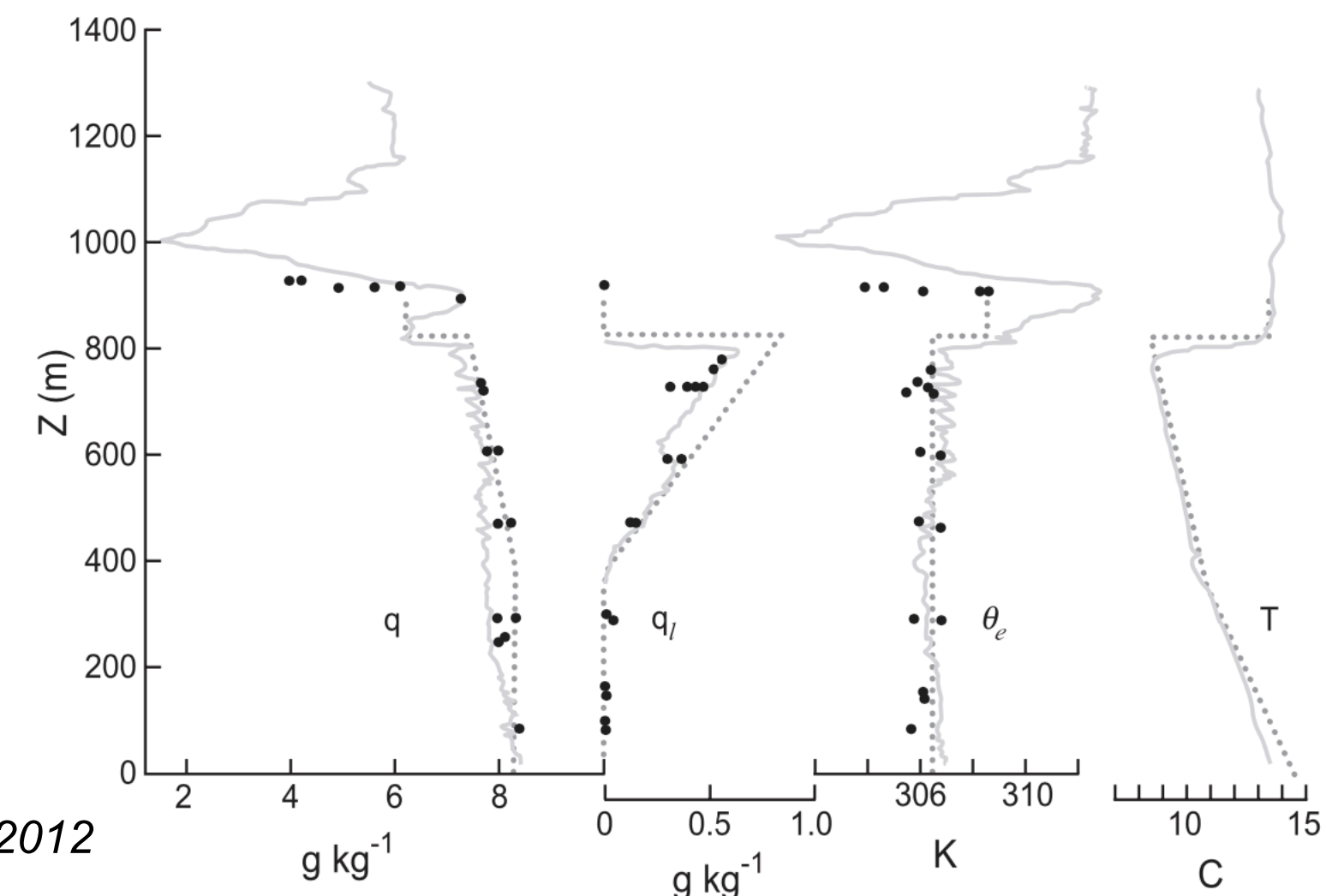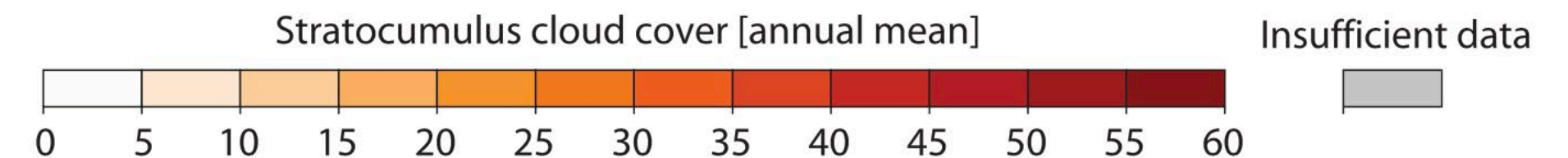# Synthetic Regional Cloud-Locking

Define cloud-locking region

Centered on SEP, NEP, SEA stratocumulus regions, only over ocean, covers ~6.5% of Earth's surface

Only in bottom 10 model layers of the atmosphere (up to ~700 hPa).


(a)

Wood, 2012

Stratocumulus cloud cover [annual mean]

0   5   10   15   20   25   30   35   40   45   50   55   60

Insufficient data

Wood, 2012

Synthetic Regional Cloud-Locking

Liquid phase low clouds!

- **CLD**: grid box cloud fraction
- **CLDFSNOW:** cloud fraction adjusted for snow
- **ICLWP:** in cloud liquid water path
- **ICIWP:** in cloud ice water path
- **ICSWP:** in cloud snow water path
- **DES:** effective snow diameter
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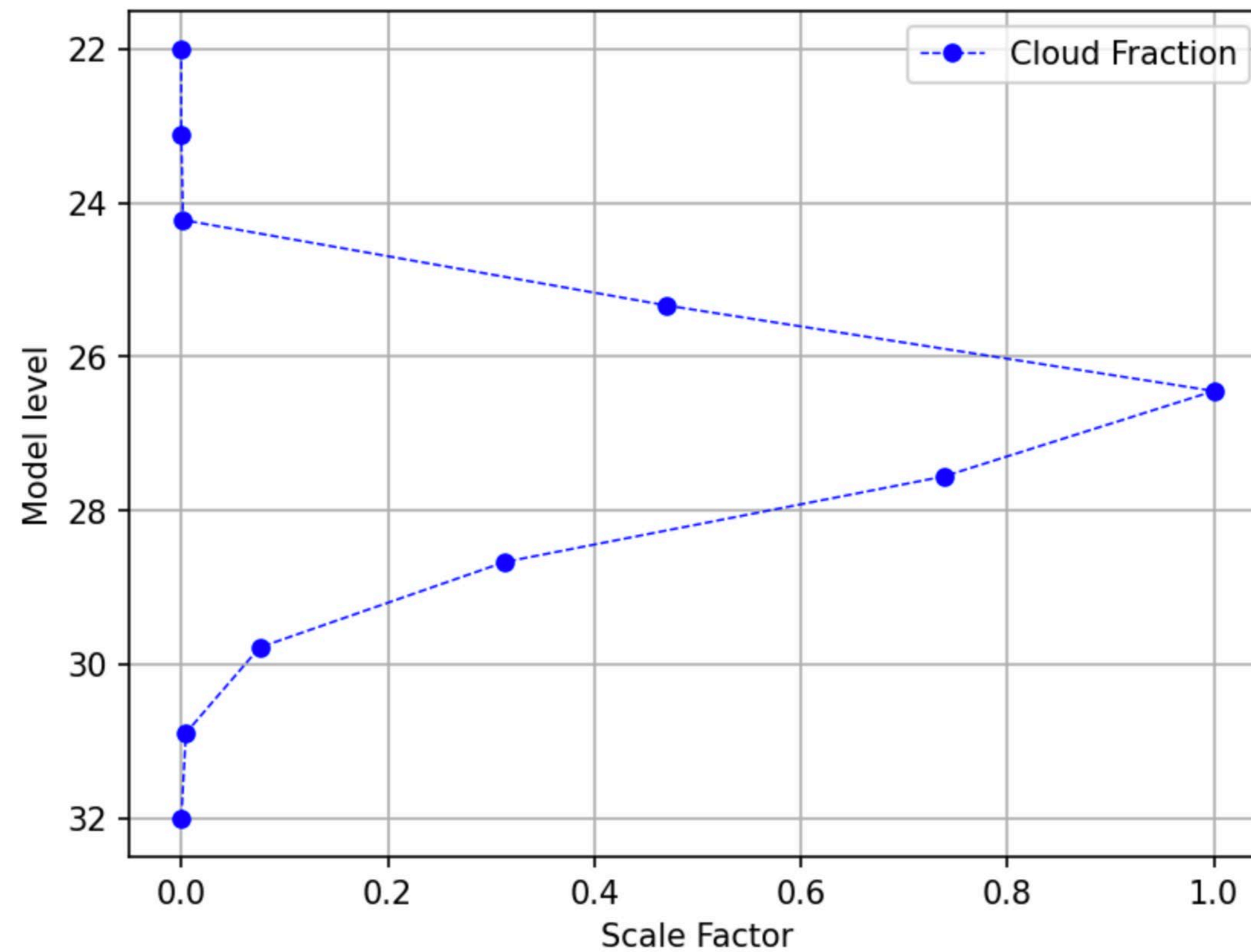- **MU:** microphysical parameter
- **LAMBDAC:** microphysical parameter

Define temporal variation in cloud parameters

Ghate, 2009

Wood, 2012
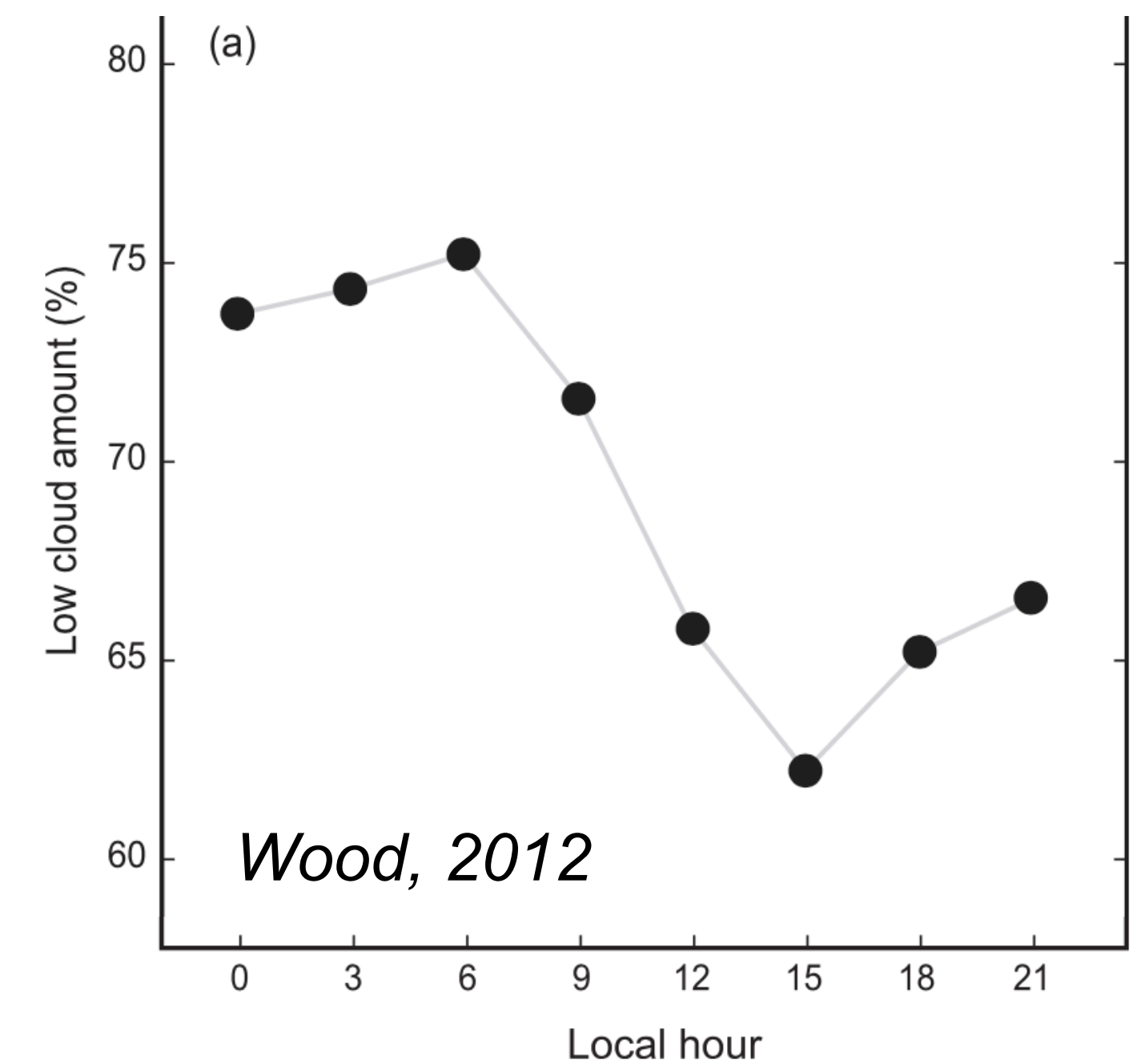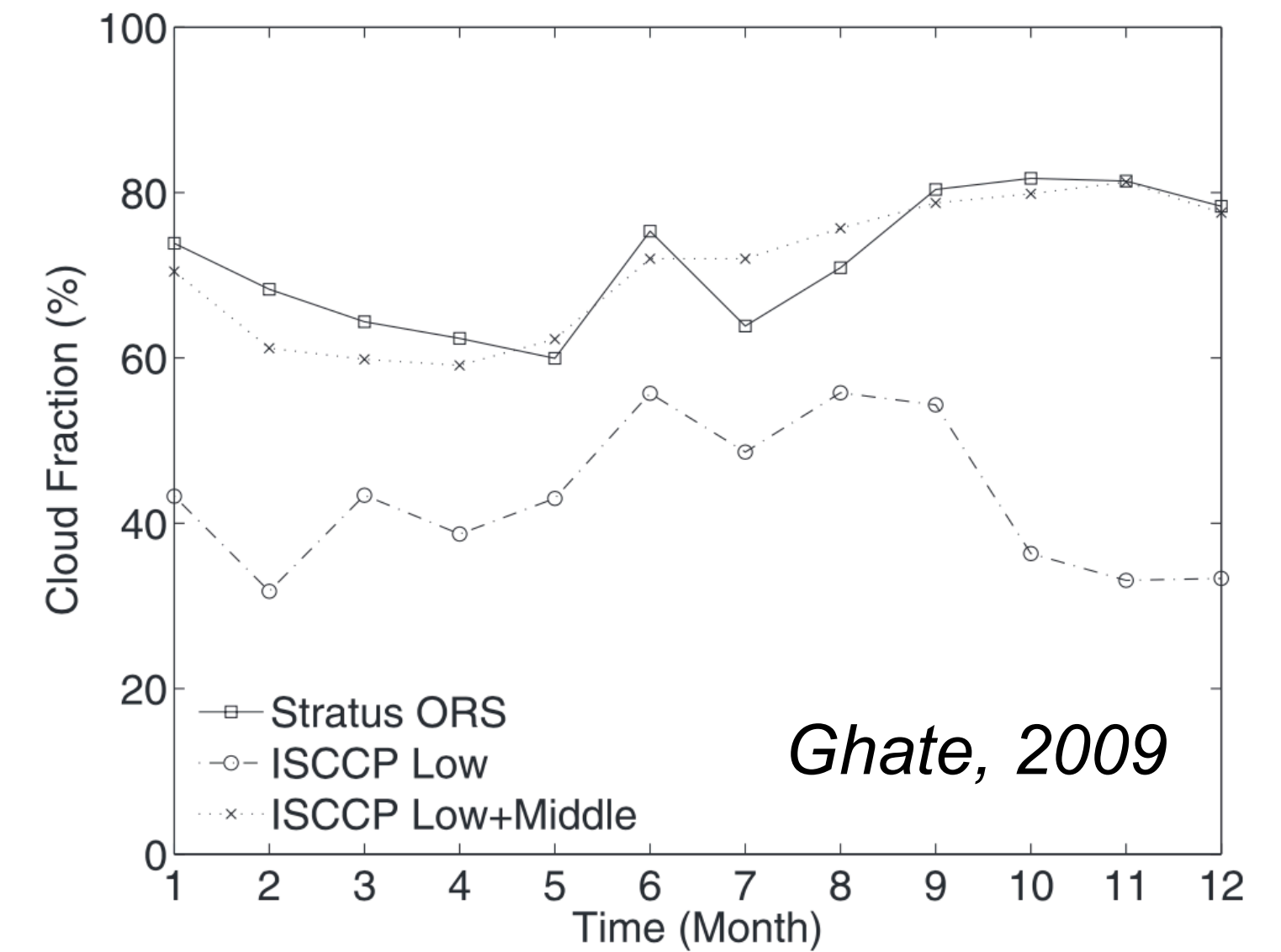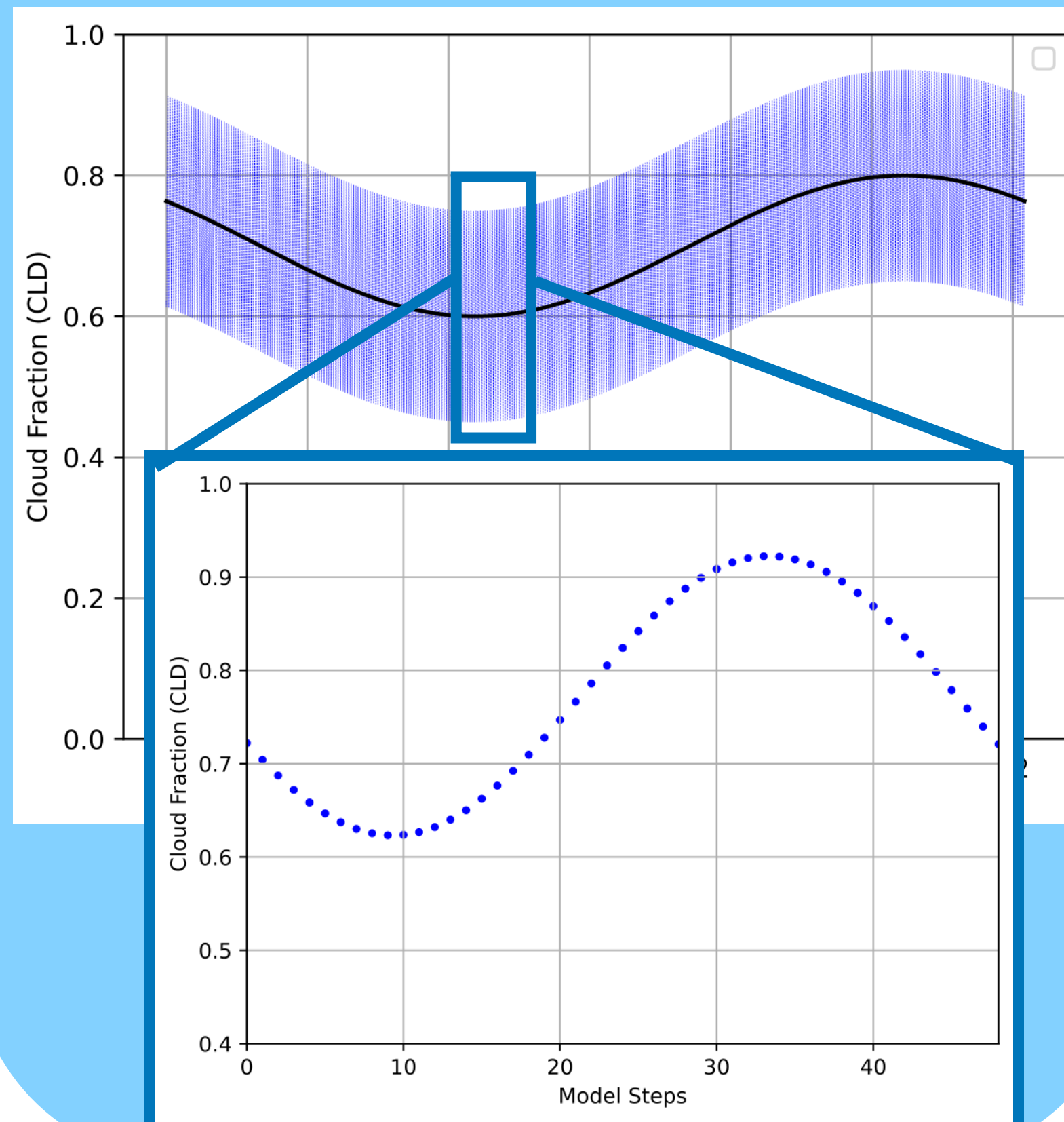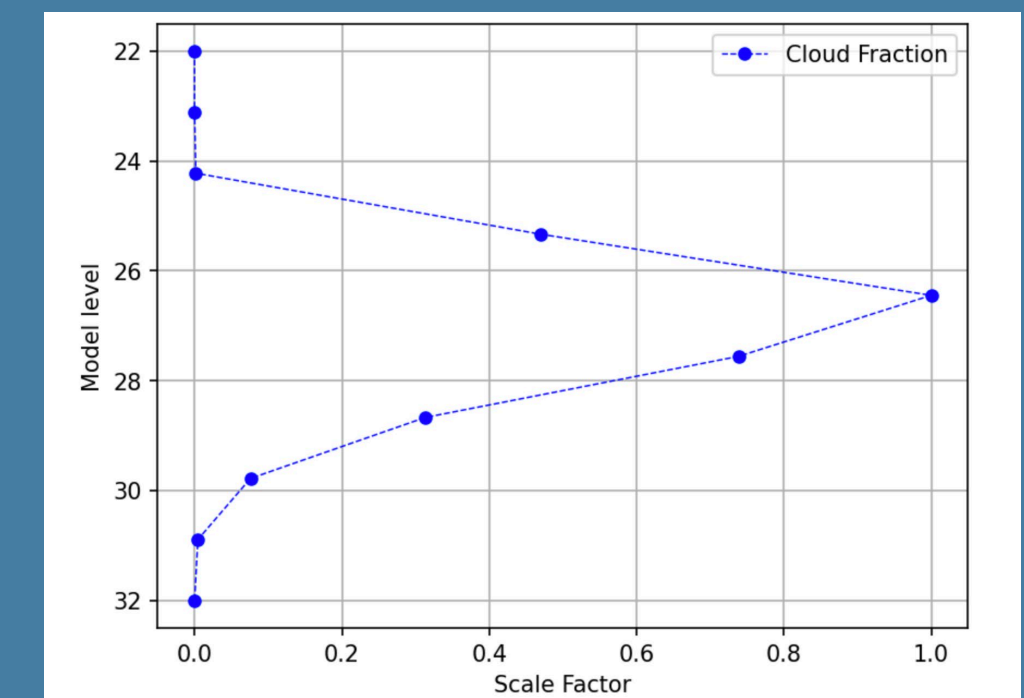
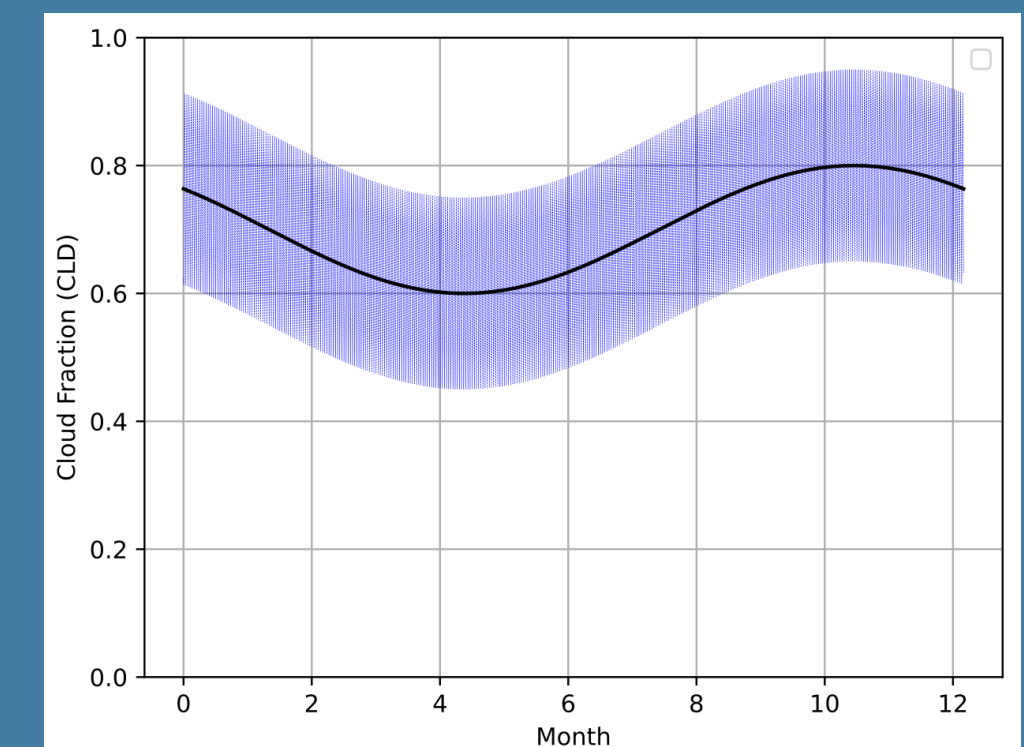# Synthetic Regional Cloud-Locking

Normalized vertical profile of CLD and ICLWP from CAM6 piControl

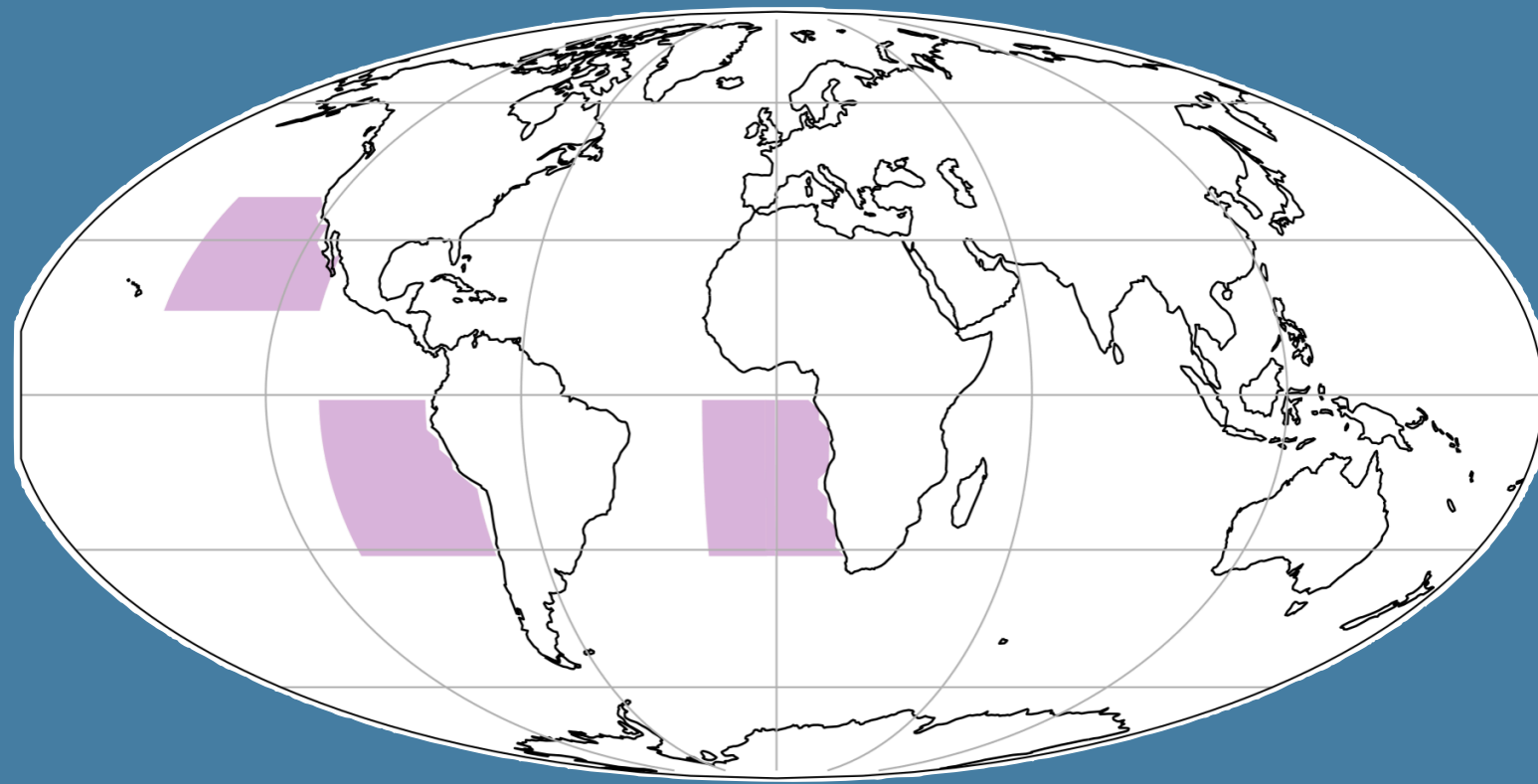**Define vertical variation in cloud parameters**

X

We can write the temporal variation analytically and hard code the synthetic clouds in, which avoids having to read in files every radiation time-step and saves computation time
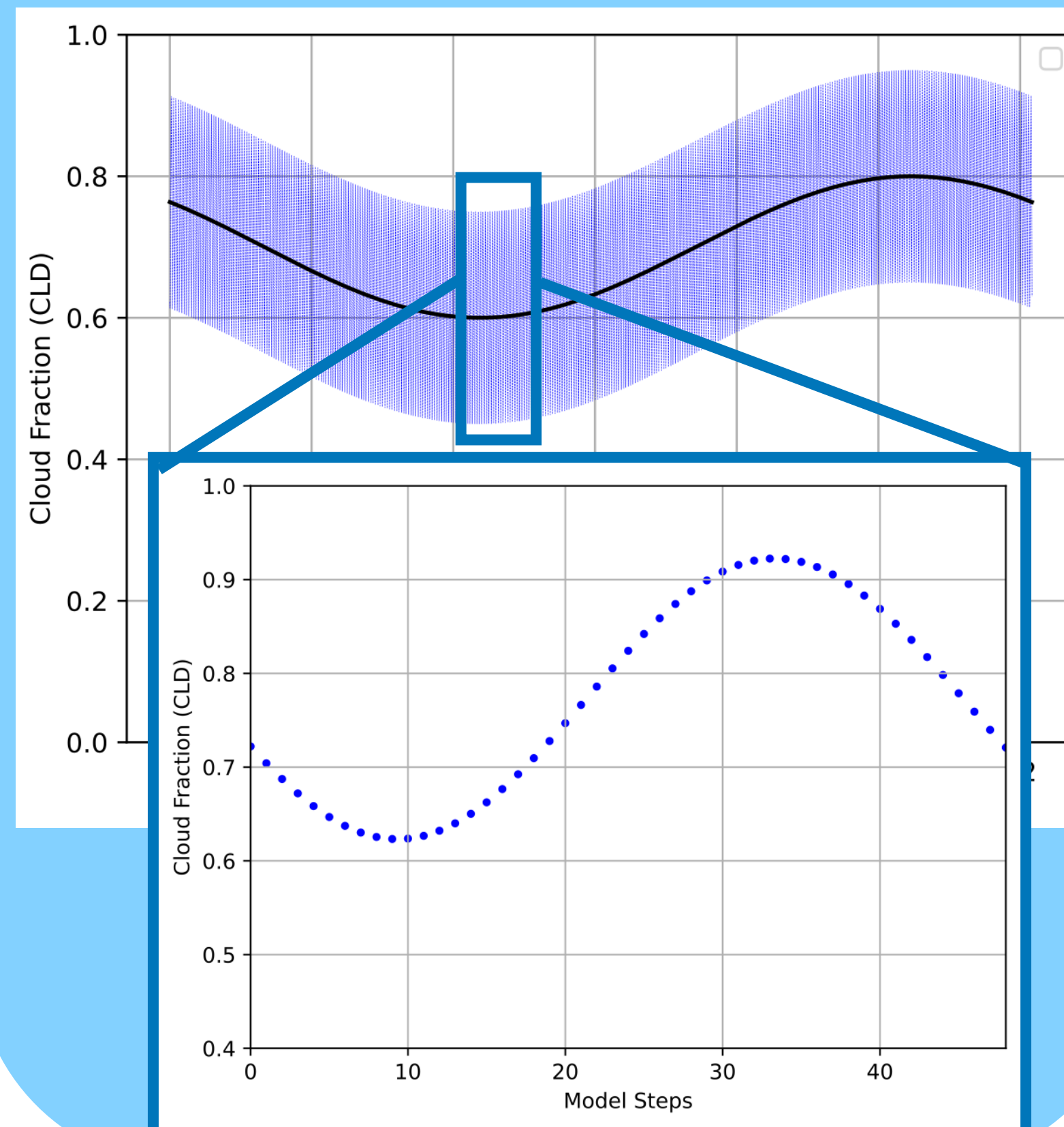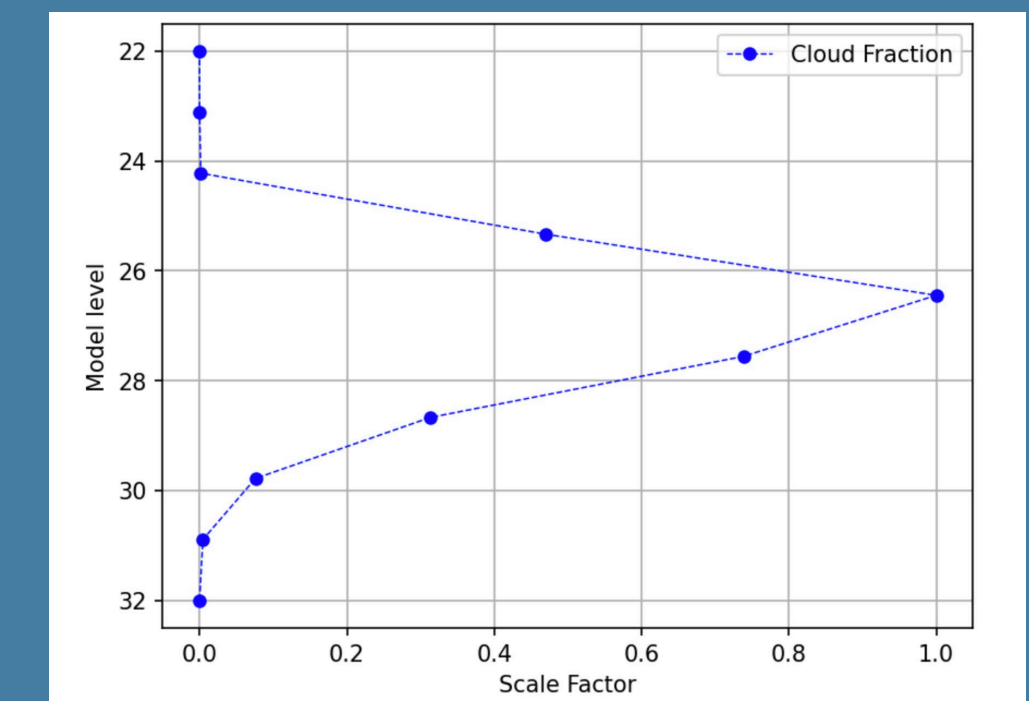
Define cloud-locking region

Centered on SEP, NEP, SEA stratocumulus regions, only over ocean, covers ~6.5% of Earth's surface

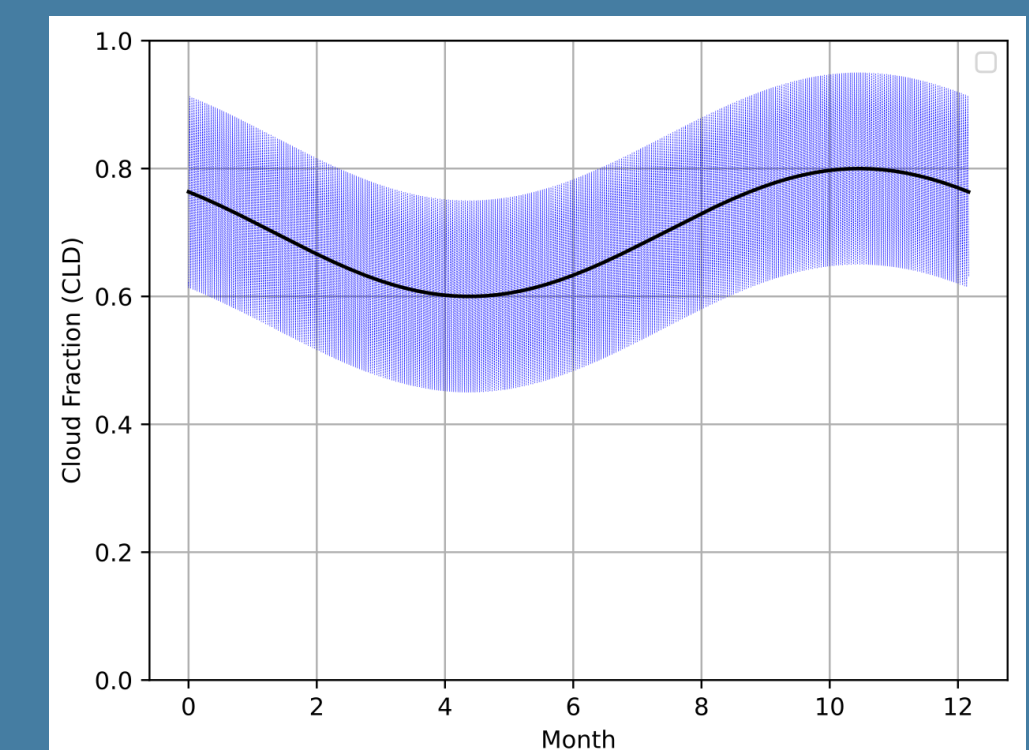Only in bottom 10 model layers of the atmosphere (up to ~700 hPa).

Define temporal variation in cloud parameters
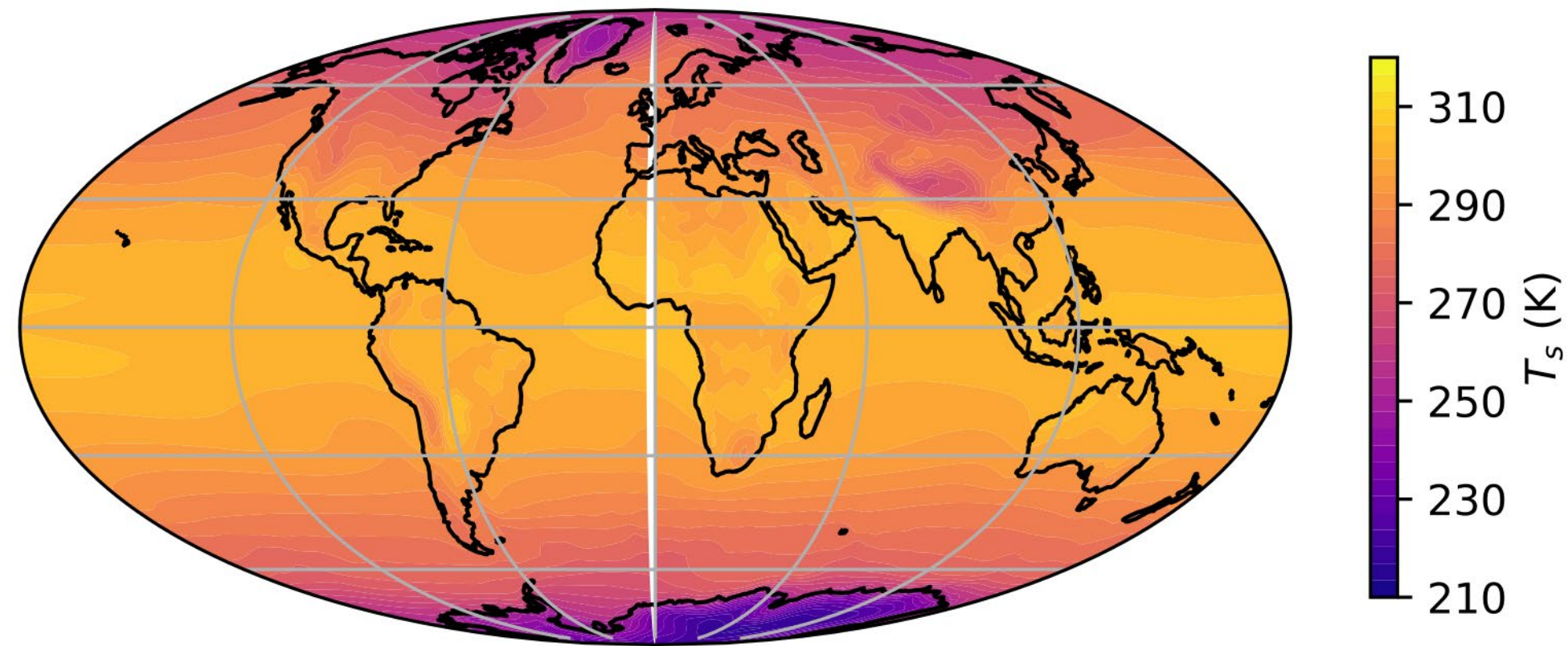

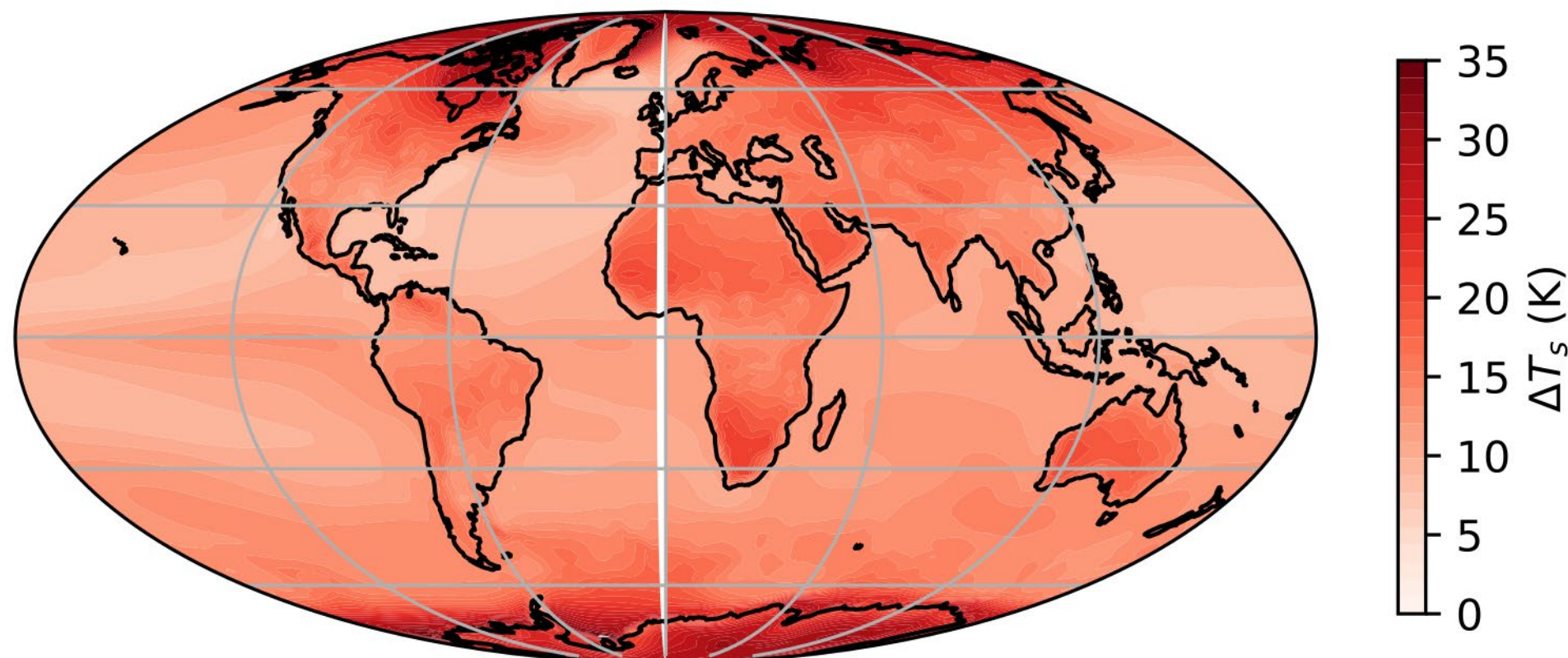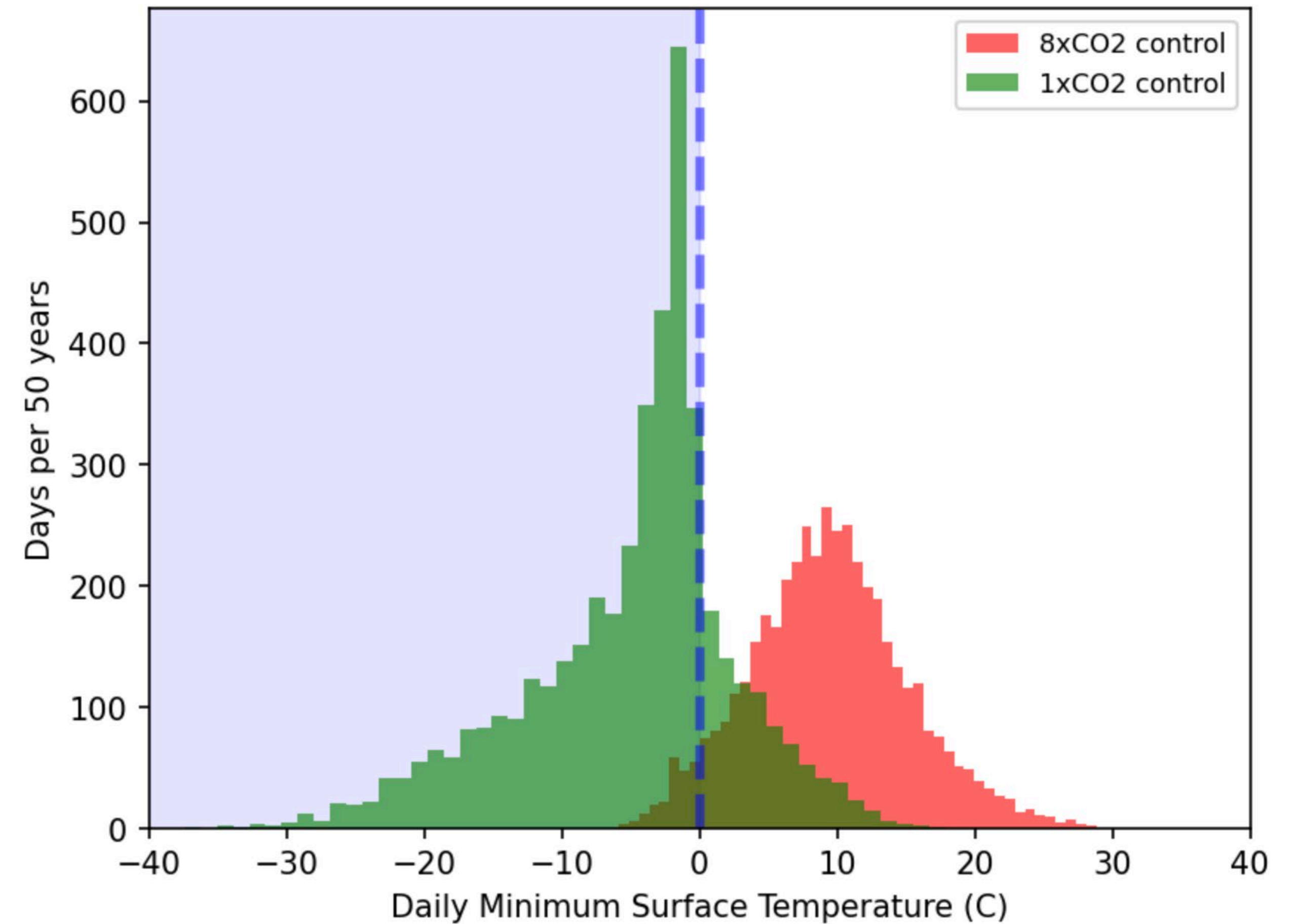## Define vertical variation in cloud parameters


X

8xCO2 Spin-up using PaleoCalibr (Zhu et al. 2022)

* removes an inappropriate cap on ice particle number and decreases microphysics time-step

$$\overline{T_s} = 29.2\,C$$

A

Annual Mean T_s in 8xCO$_2$ Control

B

Annual Mean T_s in 8xCO$_2$ Control - 1xCO$_2$ Control

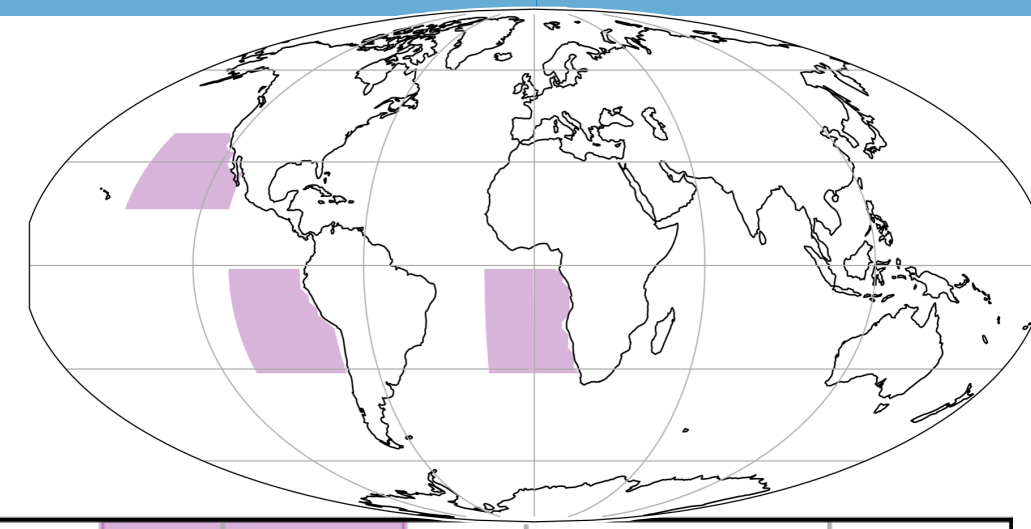
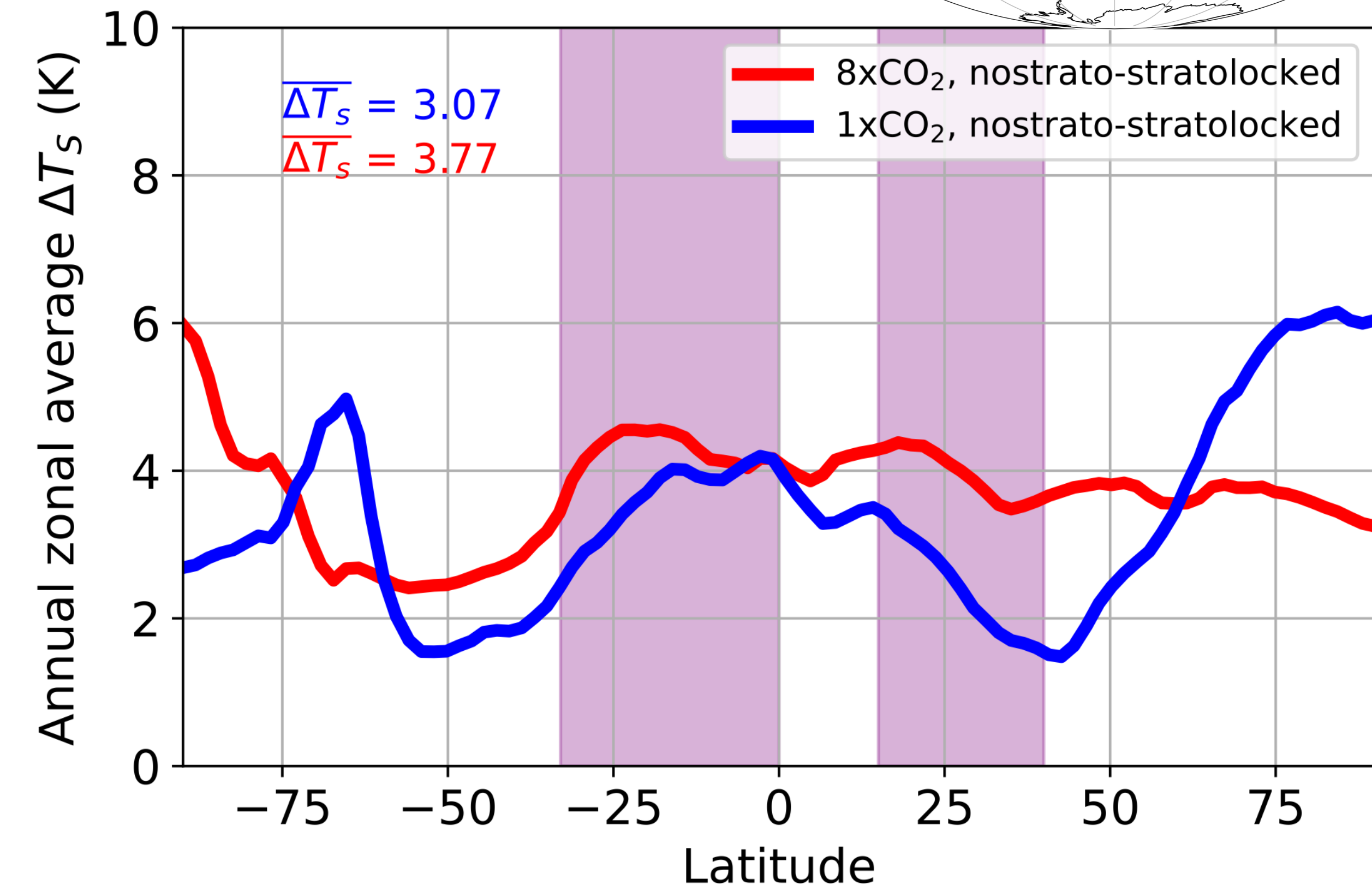Daily Minimum DJF Surface Temperature in Northern US over 50 years

Daily Minimum DJF Surface Temperature in Northern US over 50 years, 8xCO$_2$
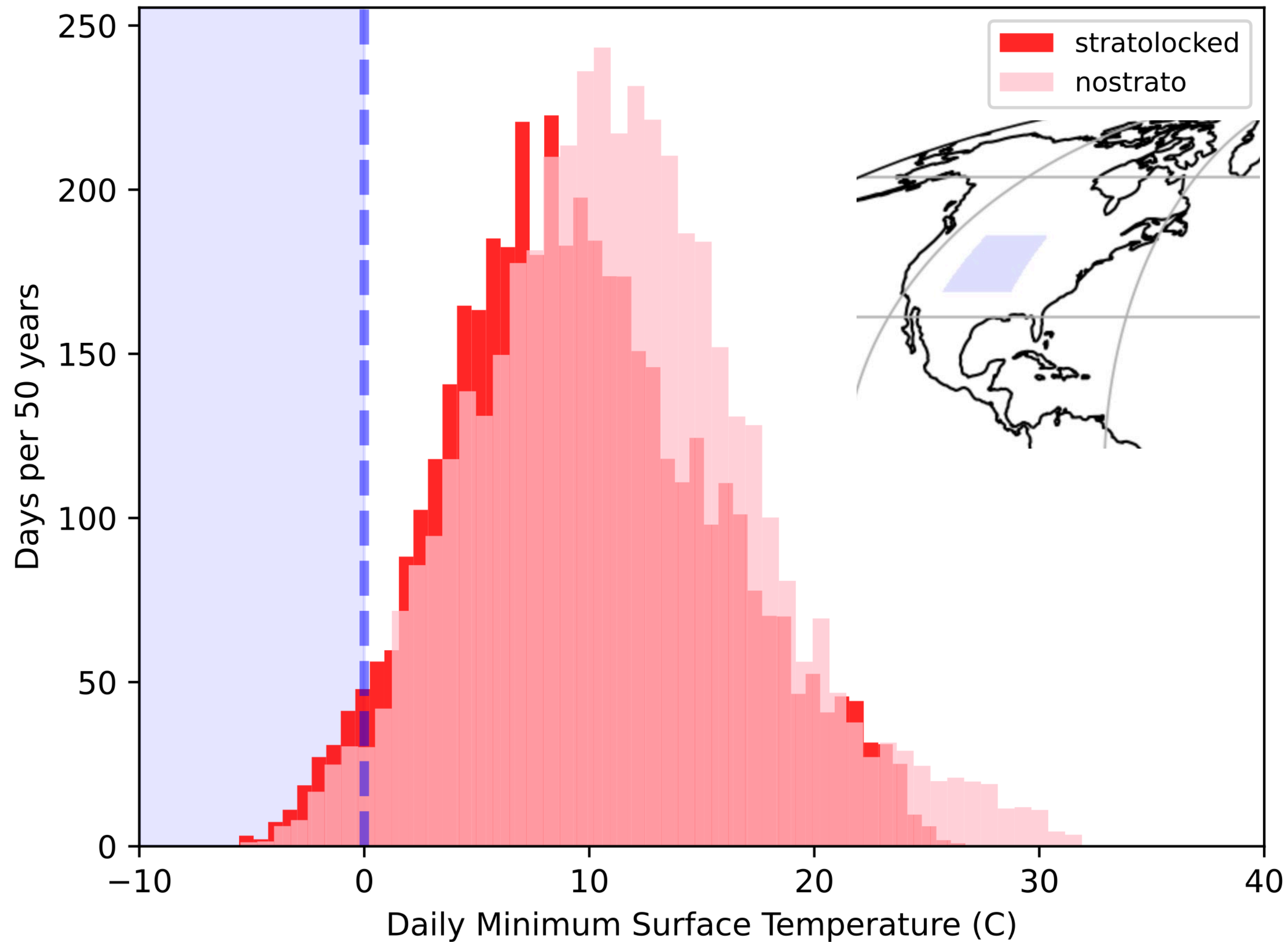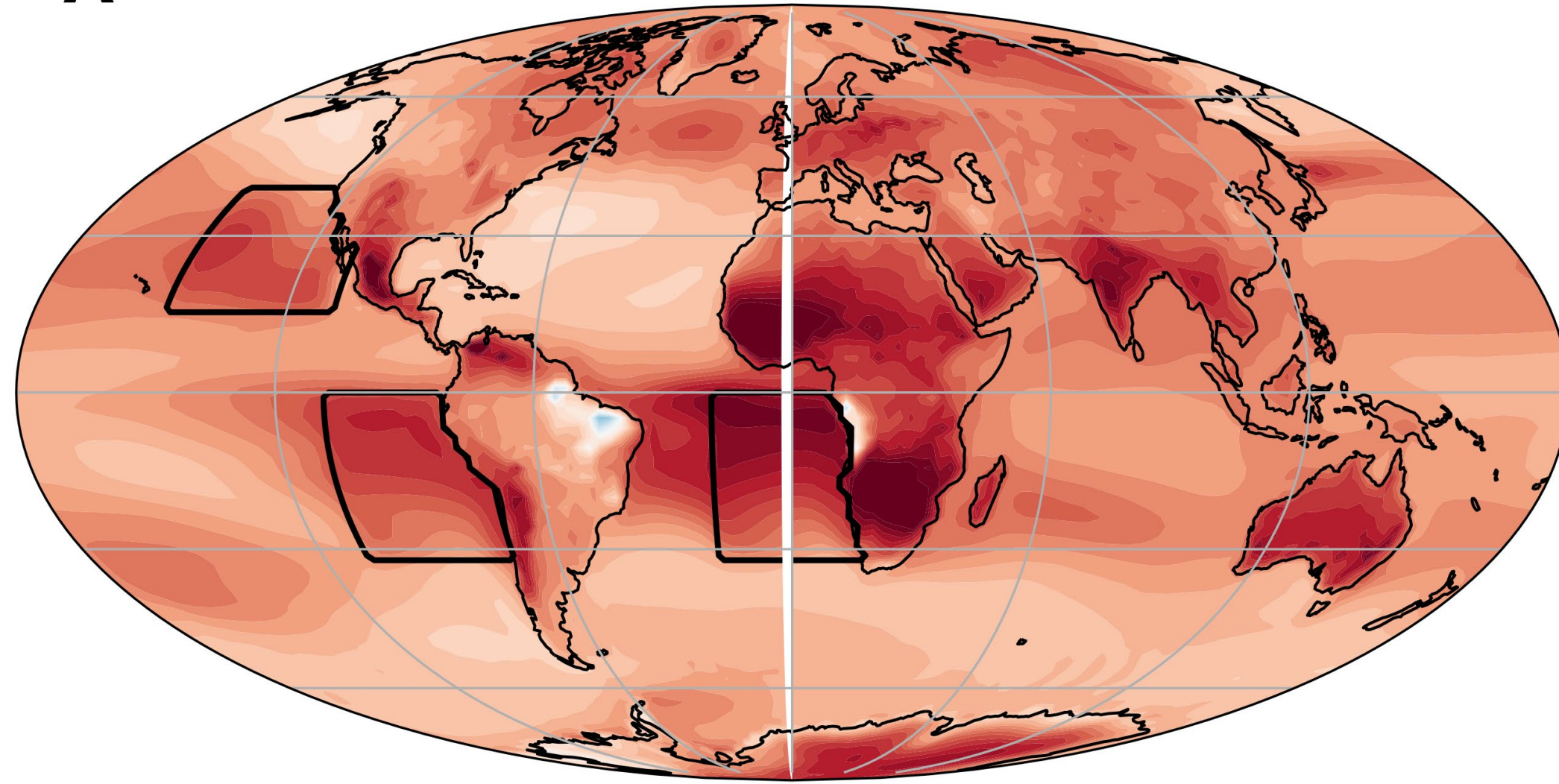
At 8xCO2 with no subtropical stratocumulus, there are still many below freezing days in the continental interior.

Annual Mean SWCF in 1xCO$_2$ stratolocked
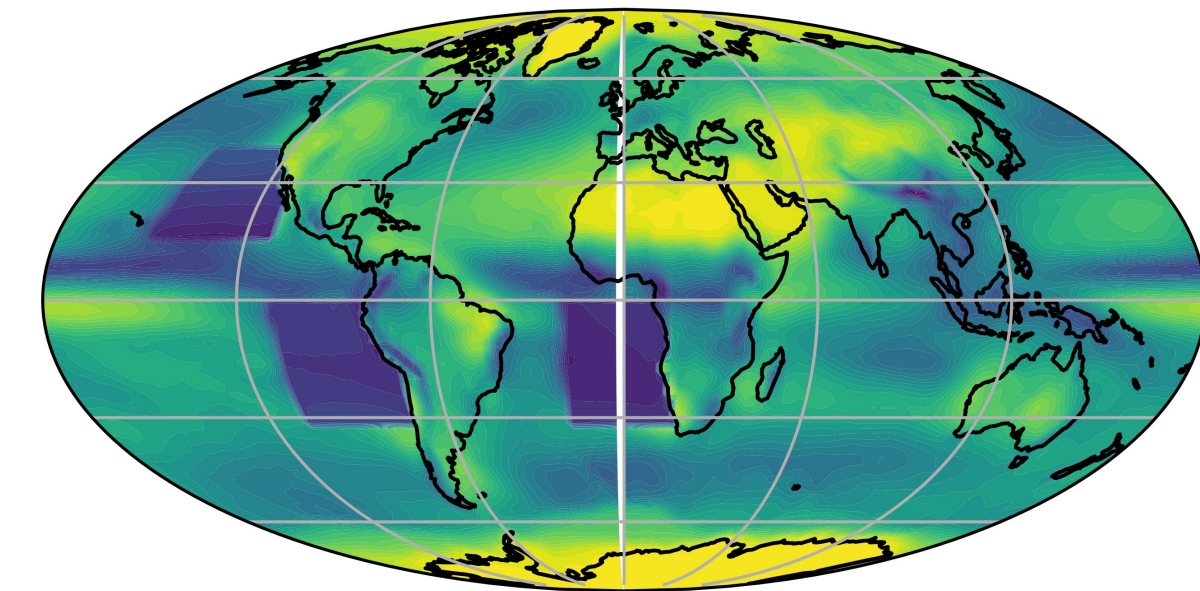
Annual Mean SWCF in 1xCO$_2$ nostrato
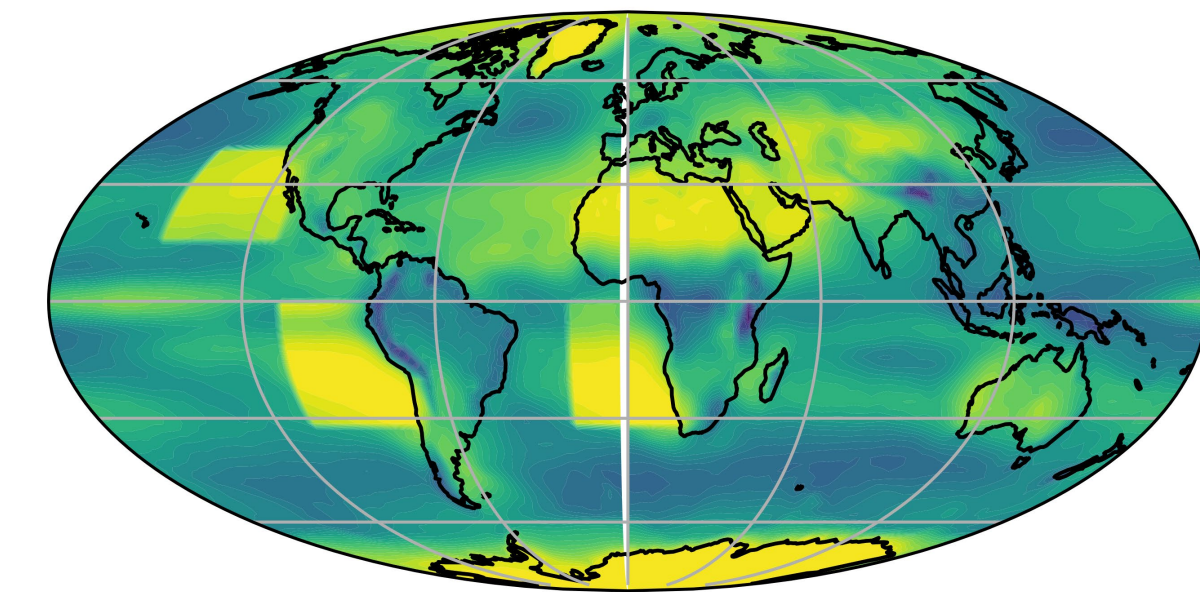
A

Global

A

Annual Mean T_s in 8xCO_2 (nostrato - stratolocked)
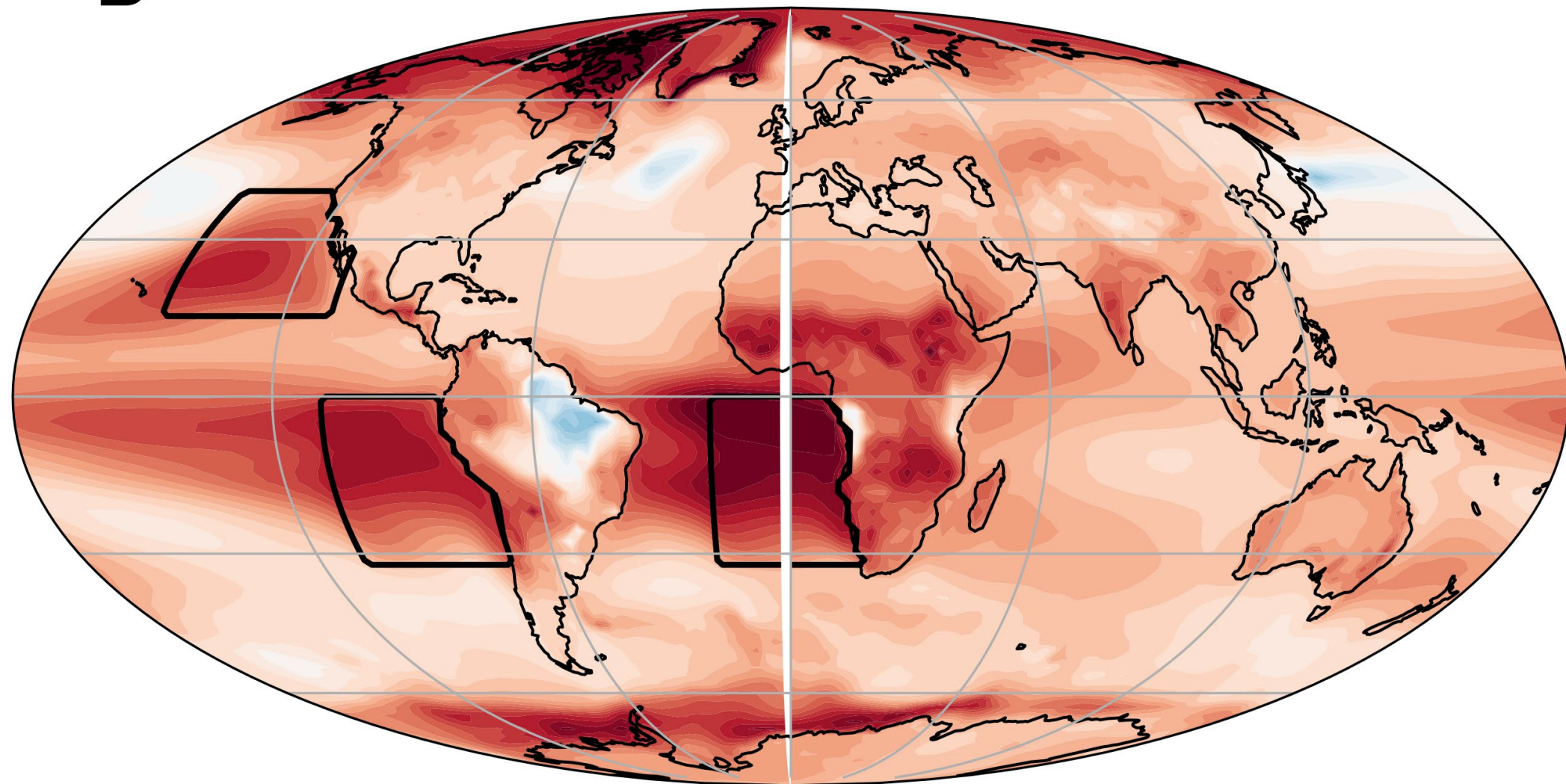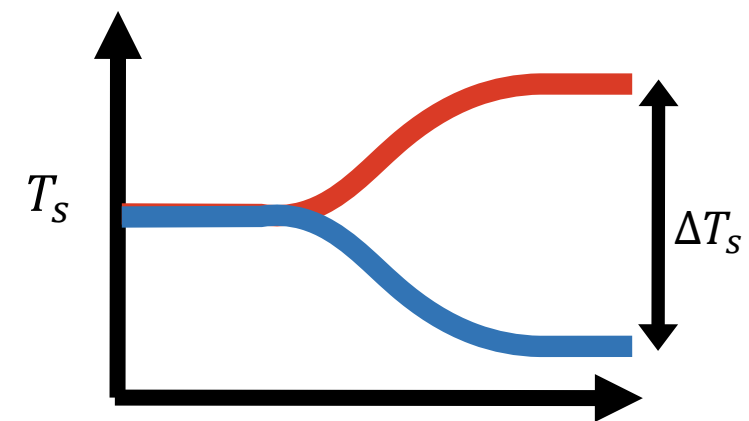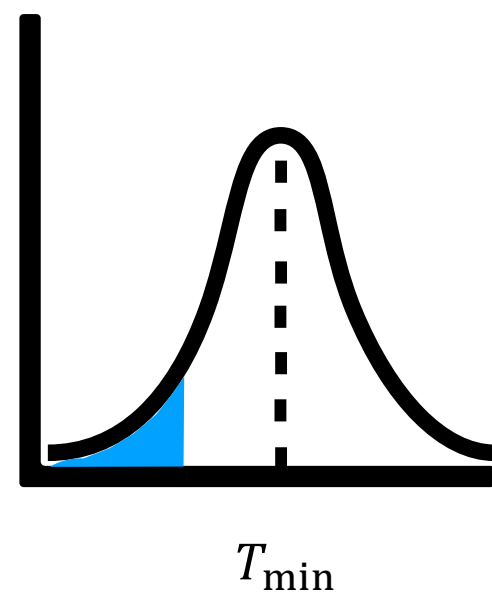
B

Annual Mean T_s in 1xCO_2 (nostrato - stratolocked)

ΔT_s (K)
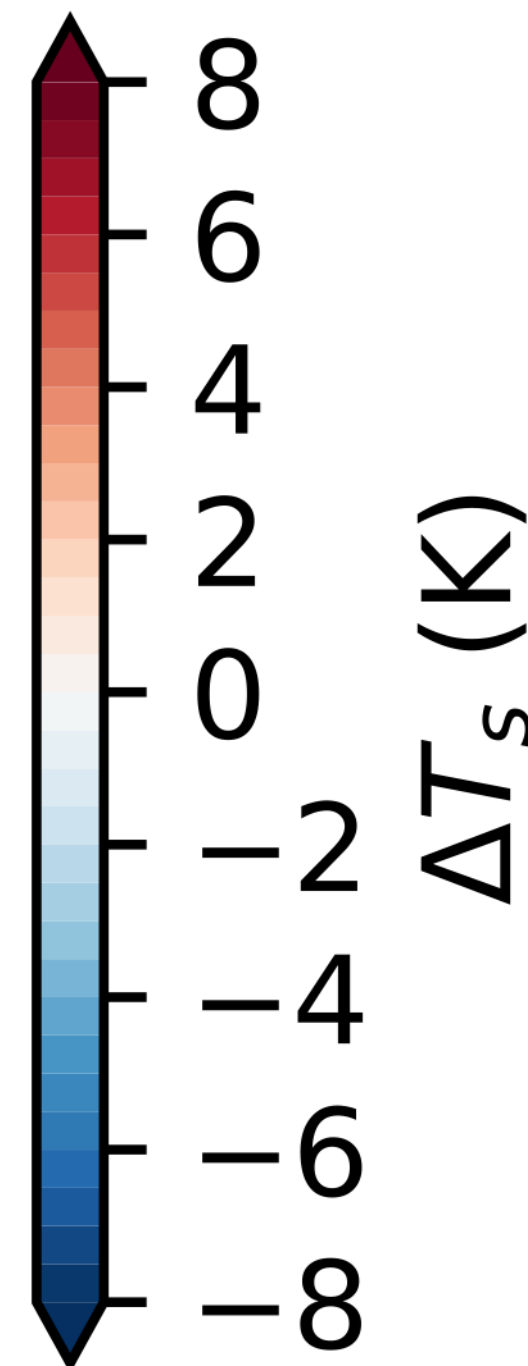
Most of the **warming is isolated to the lower latitudes**, and only 4 K of global average warming is observed
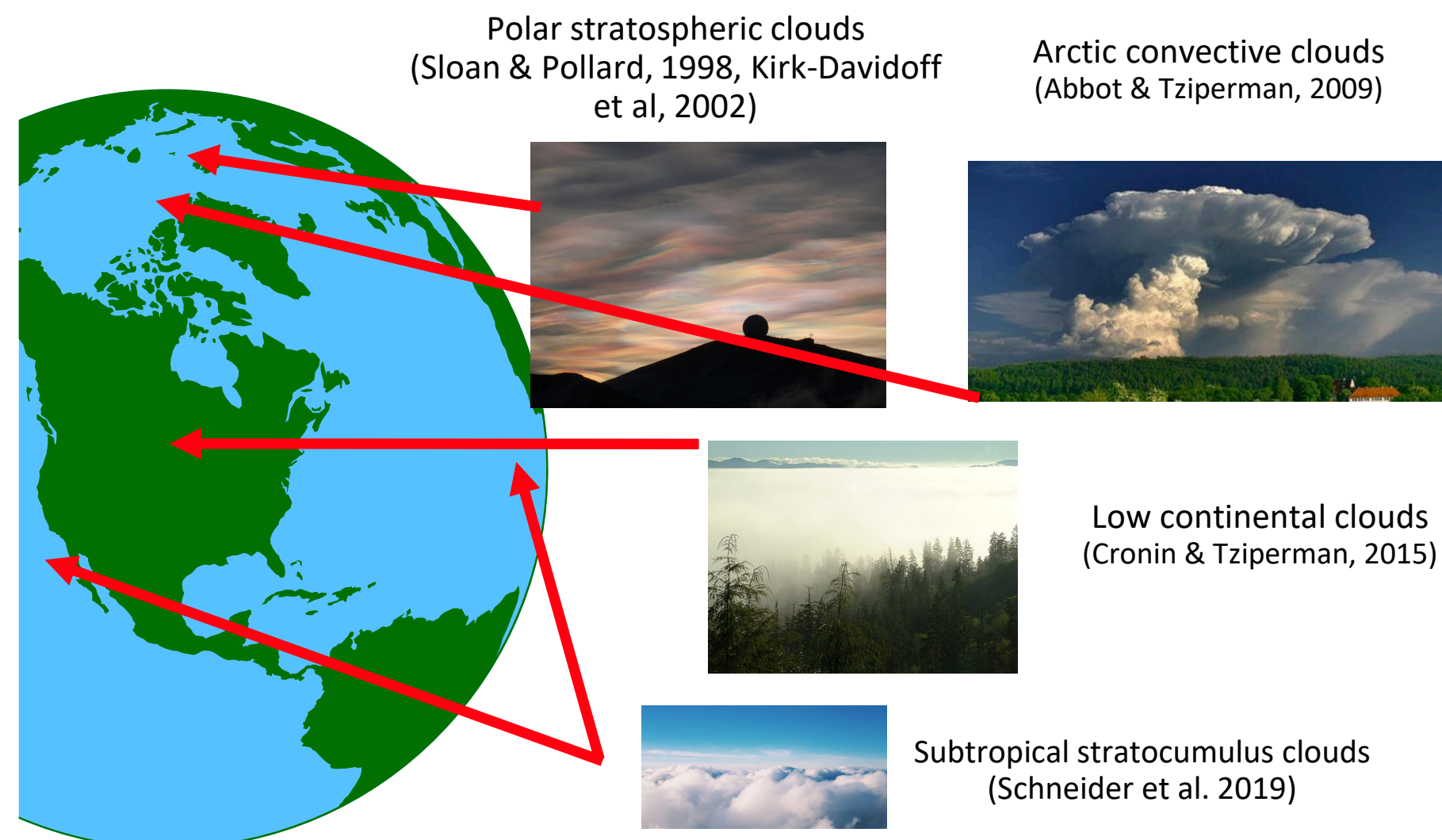
Even in the most dramatic case (100 Wm-2 forcing over 6.5% of Earth's surface), a **subtropical stratocumulus break-up causes up to 4 K global averaged warming**.

T_{min}

In an 8xCO2 scenario, **a complete removal of subtropical stratocumulus cannot on its own mitigate below-freezing days in the continental interior**

Polar stratospheric clouds
(Sloan & Pollard, 1998, Kirk-Davidoff et al, 2002)

Arctic convective clouds
(Abbot & Tziperman, 2009)

Low continental clouds
(Cronin & Tziperman, 2015)

Subtropical stratocumulus clouds
(Schneider et al. 2019)

Future work: apply synthetic cloud-locking to many proposed cloud feedbacks to explore if a combination of feedbacks can warm continental interiors