The relationship between condensate lifetime and precipitating efficiency and their response to sea surface warming

Hassan Beydoun[1], Aaron Donahue[1], Nadir Jeevanjee[2], Pater Caldwell[1]
[1]Lawrence Livermore National Lab
[2]Geophysical Fluid Dynamics Lab

October 27, 2024

LLNL-PRES-870893
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Lawrence Livermore National Laboratory

Precipitating efficiency is a key metric connecting microphysics to its large scale environment

Precipitating efficiency is defined as:

$$\varepsilon = \frac{Precipitation}{Total\ condesned\ water} = \frac{P}{P+E}$$

P: Precipitation rate
E: Hydrometeor evaporation rate

Where P is the mean tropical precipitation rate and E is the mean re-evaporation of condensate

1. Romps (2014) – PE can modulate the environment RH in the tropics
2. PE can modulate convective mass flux when radiative cooling is constrained – Jeevanjee and Zhou (2022) and Emanuel (2019)
3. Zhao et al. (2016) cmip spread in climate sensitivity can be reproduced by tuning a single model's deep convection ε.

ε may encapsulate micro2macro interactions especially in the deep tropics!

The inverse cloud lifetime as a proxy for PE?

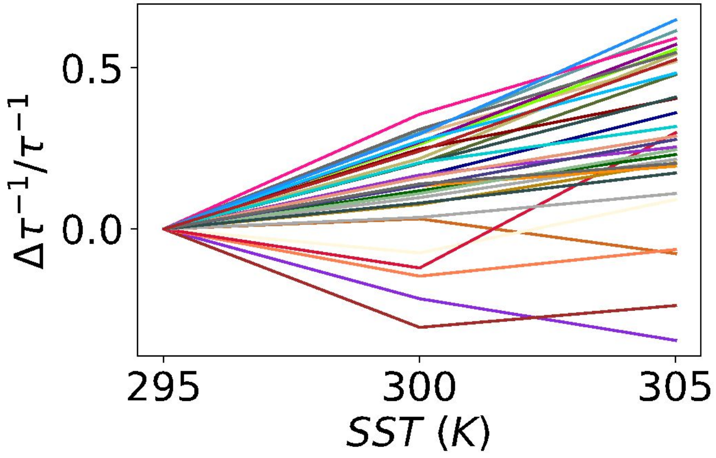
$$\varepsilon = \frac{P}{P+E}$$

Precipitating efficiency is difficult to measure and not widely available from CRM model output. An alternative that has been proposed is (Li et al., 2022):

$$\tau^{-1} = \frac{Precipitation}{Total\ condesned\ water\ path} = \frac{P}{TWP}$$

τ^{-1} is easy to measure from observations and standard model output

Remarkably, 32 out of 36 RCEMIP models predict an increase in τ^{-1} with SST (Li et al. , 2023):



Does a τ^{-1} increase indicate a ε increase? And what processes are responsible for the τ^{-1} increase?

Relationship between ε and lifetime and their constituent processes

$$\varepsilon = \frac{P}{P+E} = \frac{\frac{P}{TWP}}{\frac{P}{TWP} + \frac{E}{TWP}} = \frac{\tau^{-1}}{\tau^{-1} + \tau_e{}^{-1}}$$

Here, $\tau_e{}^{-1}$ can be thought of as the inverse evaporation timescale

This equation shows that $\varepsilon = \mathrm{f}(\tau^{-1}, \tau_e{}^{-1})$ and while the former can be measured, the latter is more elusive.

How do τ^{-1} and $\tau_e{}^{-1}$ relate to microphysical inverse timescales?

$$P = Precip\ Production\ - Precip\ Evaporation$$

$$E = Cloud\ Evaporation + Precip\ Evaporation$$

$$\tau^{-1} = \frac{\tau_a{}^{-1}\tau_{sed}{}^{-1}}{\tau_a{}^{-1} + \tau_{sed}{}^{-1} + \tau_{pe}{}^{-1}}$$

$$\tau_e{}^{-1} = (1 - f_p)\tau_{ce}{}^{-1} + f_p\tau_{pe}{}^{-1}$$

$$f_p = \frac{\tau_a{}^{-1}}{\tau_a{}^{-1} + \tau_{sed}{}^{-1} + \tau_{pe}{}^{-1}}$$

$\tau_a{}^{-1}$: inverse time scale for cloud to rain conversion

$\tau_{sed}{}^{-1}$: inverse time scale for precip sedimentation

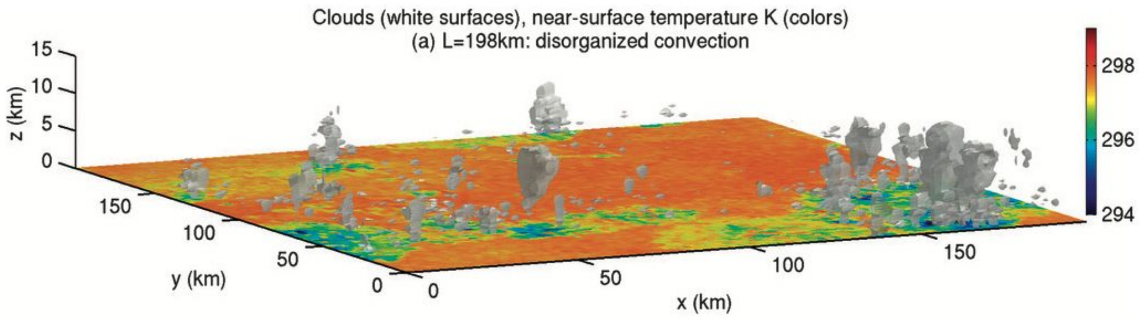
$\tau_{pe}{}^{-1}$: inverse time scale for precip evaporation

$\tau_{ce}{}^{-1}$: inverse time scale for cloud evaporation

f_p : fraction of condensate in precip phase

RCE simulations

- Unaggregated small domain RCE simulations. 100 km x 100 km domain with 1 km resolution
- In house SCREAM simulations with SST range of 290 K to 310K
- SAM simulations from Lutsko and Cronin (2018) – three ensemble members with different mp schemes
- Minimal recipe simulations from Jeevanjee and Zhou (2021) with the GFDL model – two ensemble members with and without accretion



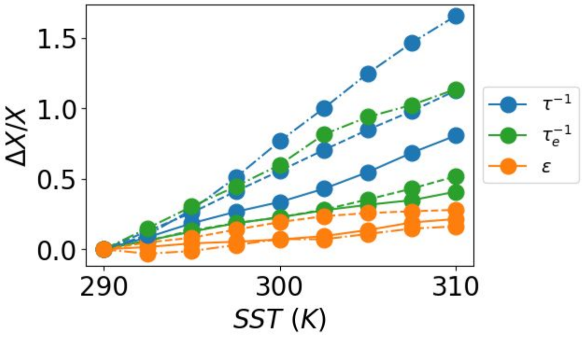
3D contour plot of an RCE simulation from Muller and Held (2014)

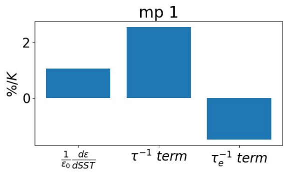
- For all simulation pairs, we use domain mean averages and apply the chain rule on each term within the four previously derived equations to understand SST trends.

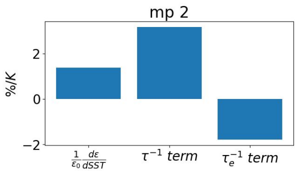
ε breakdown

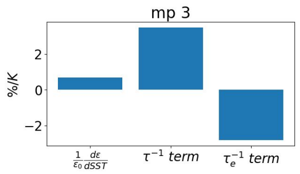
$$\varepsilon = \frac{\tau^{-1}}{\tau^{-1} + {\tau_e}^{-1}}$$

SAM



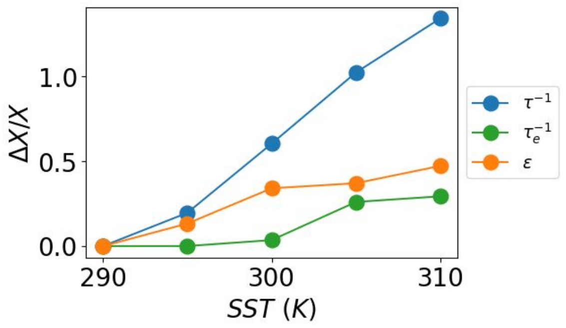


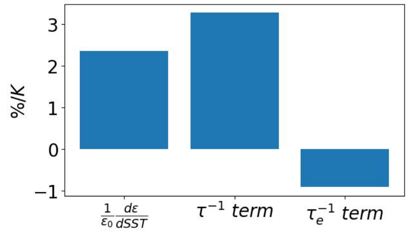




τ^{-1} increase drives ε increase for all mp schemes.

SCREAM

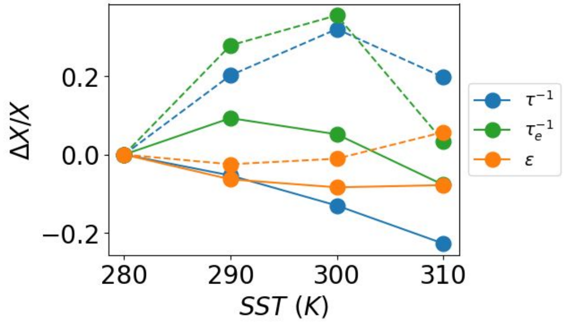


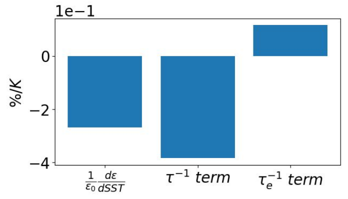


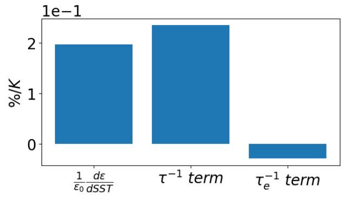
τ^{-1} increase drives ε increase

SAM and SCREAM agree that τ^{-1} increase drives ε increase however increase in ${\tau_e}^{-1}$ modulates ε change

GDFL-minimal





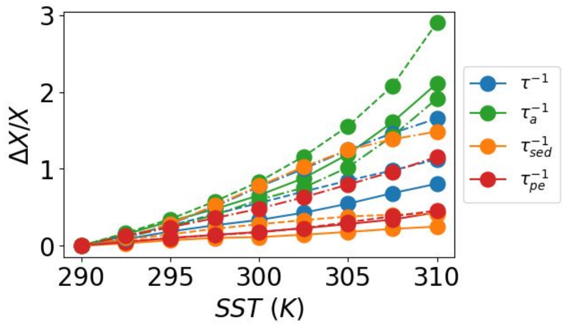


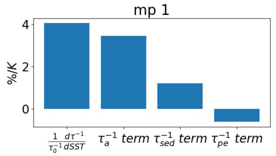
No ε change

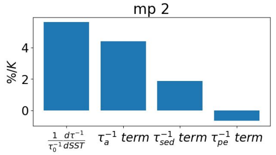
τ^{-1} breakdown

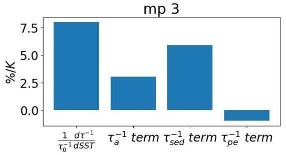
$$\tau^{-1} = \frac{{\tau_a}^{-1}{\tau_{sed}}^{-1}}{{\tau_a}^{-1} + {\tau_{sed}}^{-1} + {\tau_{pe}}^{-1}}$$

SAM



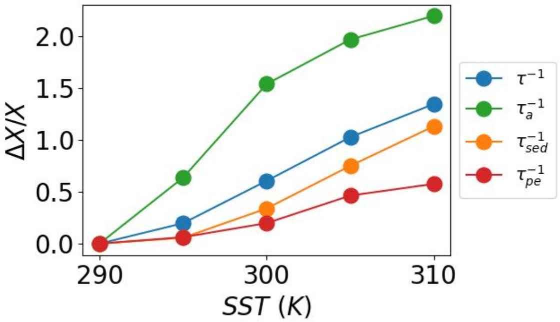


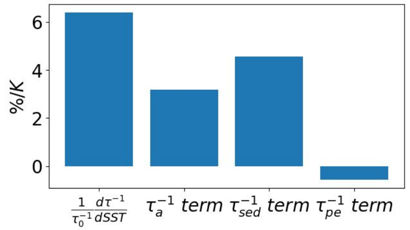




τ^{-1} increase driven by ${\tau_a}^{-1}$ and ${\tau_{sed}}^{-1}$

SCREAM

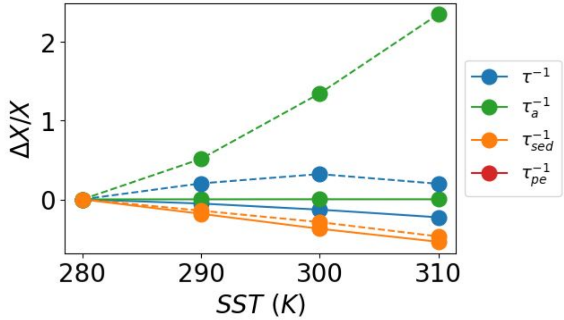


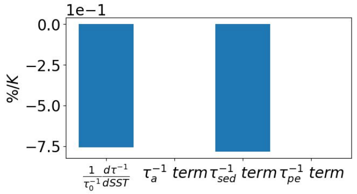


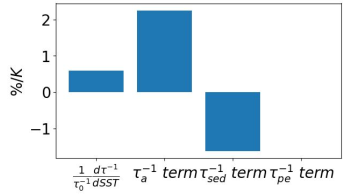
τ^{-1} increase driven by ${\tau_a}^{-1}$ and ${\tau_{sed}}^{-1}$

SAM and SCREAM agreement: clouds become denser and rain drops fall faster

GDFL-minimal





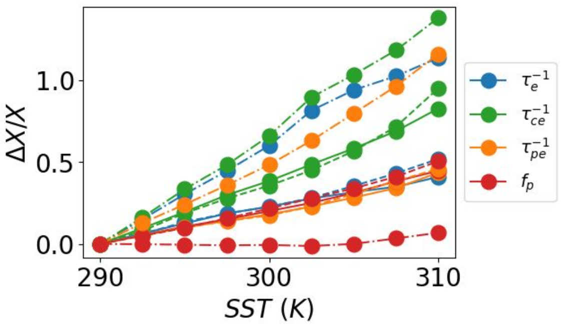


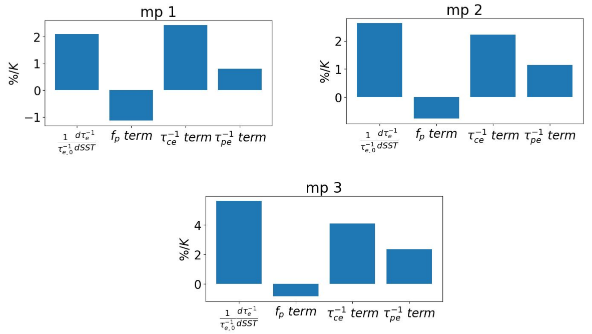
Minimal recipe predicts decrease in ${\tau_{sed}}^{-1}$ as clouds move upwards

$\tau_e{}^{-1}$ breakdown

$$\tau_e{}^{-1} = (1 - f_p)\tau_{ce}{}^{-1} + f_p\tau_{pe}{}^{-1}$$

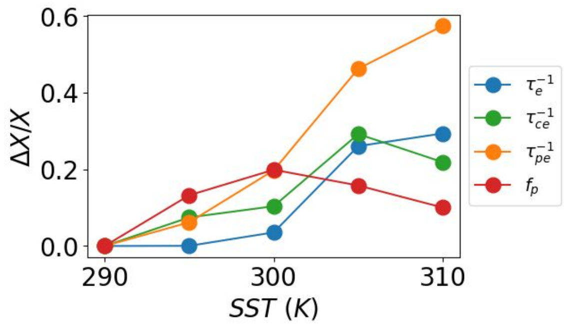
SAM

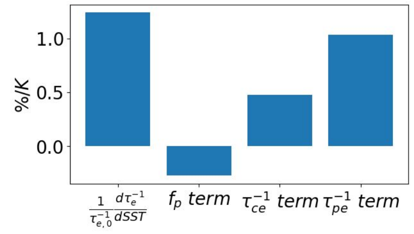




$\tau_e{}^{-1}$ increase driven by $\tau_{ce}{}^{-1}$ and $\tau_{pe}{}^{-1}$

SCREAM

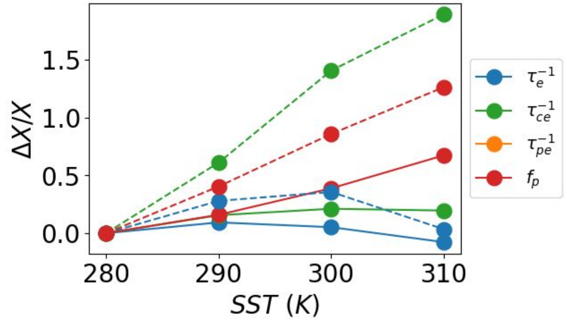


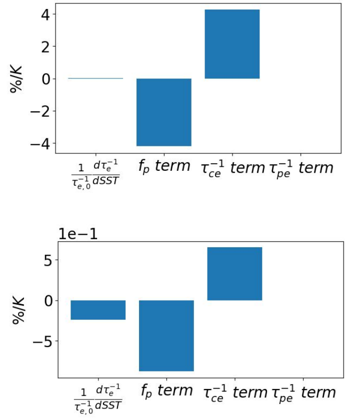


$\tau_e{}^{-1}$ increase driven by $\tau_{ce}{}^{-1}$ and $\tau_{pe}{}^{-1}$

SAM and SCREAM agreement: clouds and rain drops evaporate quicker likely due to increased saturation deficit

GDFL-minimal



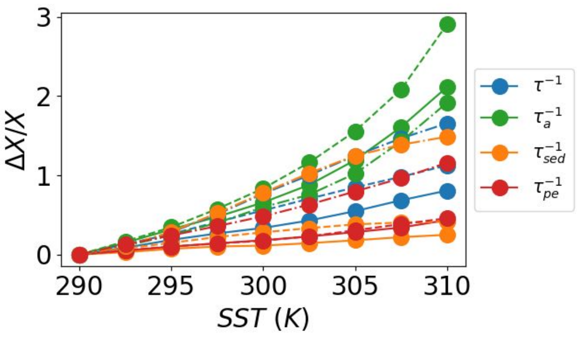


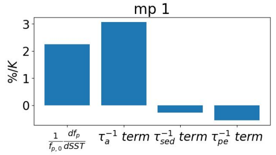
Minimal sees $\tau_{ce}{}^{-1}$ increase but f_p increase counteracts

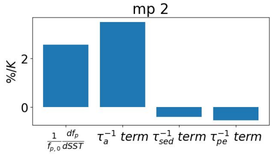
f_p breakdown

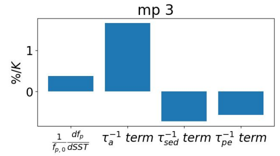
$$f_p = \frac{{\tau_a}^{-1}}{{\tau_a}^{-1} + {\tau_{sed}}^{-1} + {\tau_{pe}}^{-1}}$$

SAM



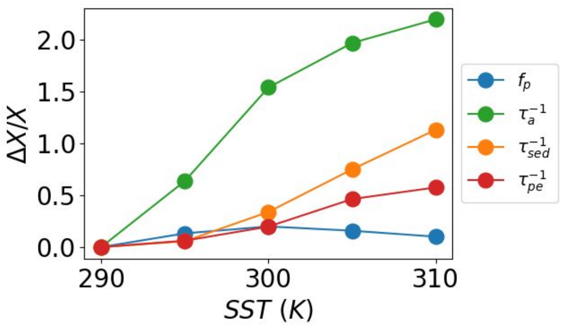


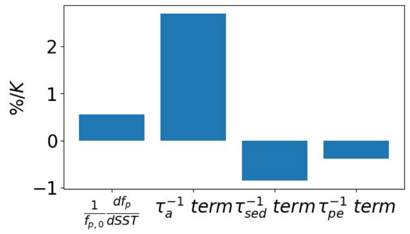




f_p increase driven by ${\tau_a}^{-1}$ increase

SCREAM

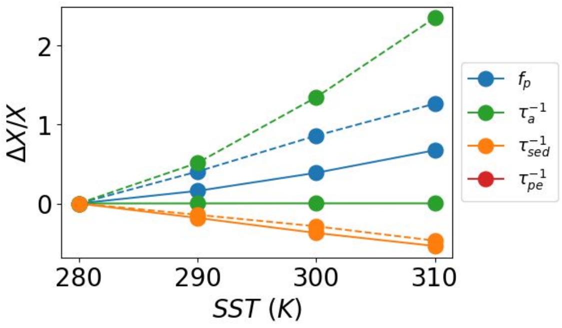


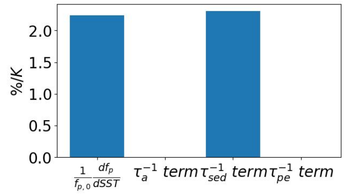


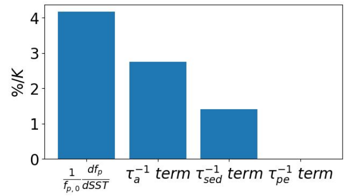
f_p increase driven by ${\tau_a}^{-1}$ increase

SAM and SCREAM agreement: f_p increases slightly as all terms increase

GDFL-minimal







f_p increases more substantially since ${\tau_{sed}}^{-1}$ decreases

Conclusions

- τ^{-1} is not a proxy for ε but a component of it. While τ^{-1} qualitatively drives the increase in ε, the scaling is quite different.
- τ^{-1} is still an interesting metric to examine and simulation results + diagnostic framework allow us to understand why its increasing with SST. Potential explanation for model consensus is that warmer atmospheres tend to convert clouds to rain more rapidly and create faster falling rain drops – consistent with intuition.
- Future work – as well as conversations at this meeting – should look into how best to leverage observations to affirm τ^{-1} trends.

Lawrence Livermore National Laboratory

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC