Quantifying the response of anvil cloud fraction to sea surface warming in SCREAM-RCE

Hassan Beydoun[1], Peter Caldwell[1], Walter Hannah[1], and Aaron Donahue[1]
[1]Lawrence Livermore National Laboratory, Livermore, CA

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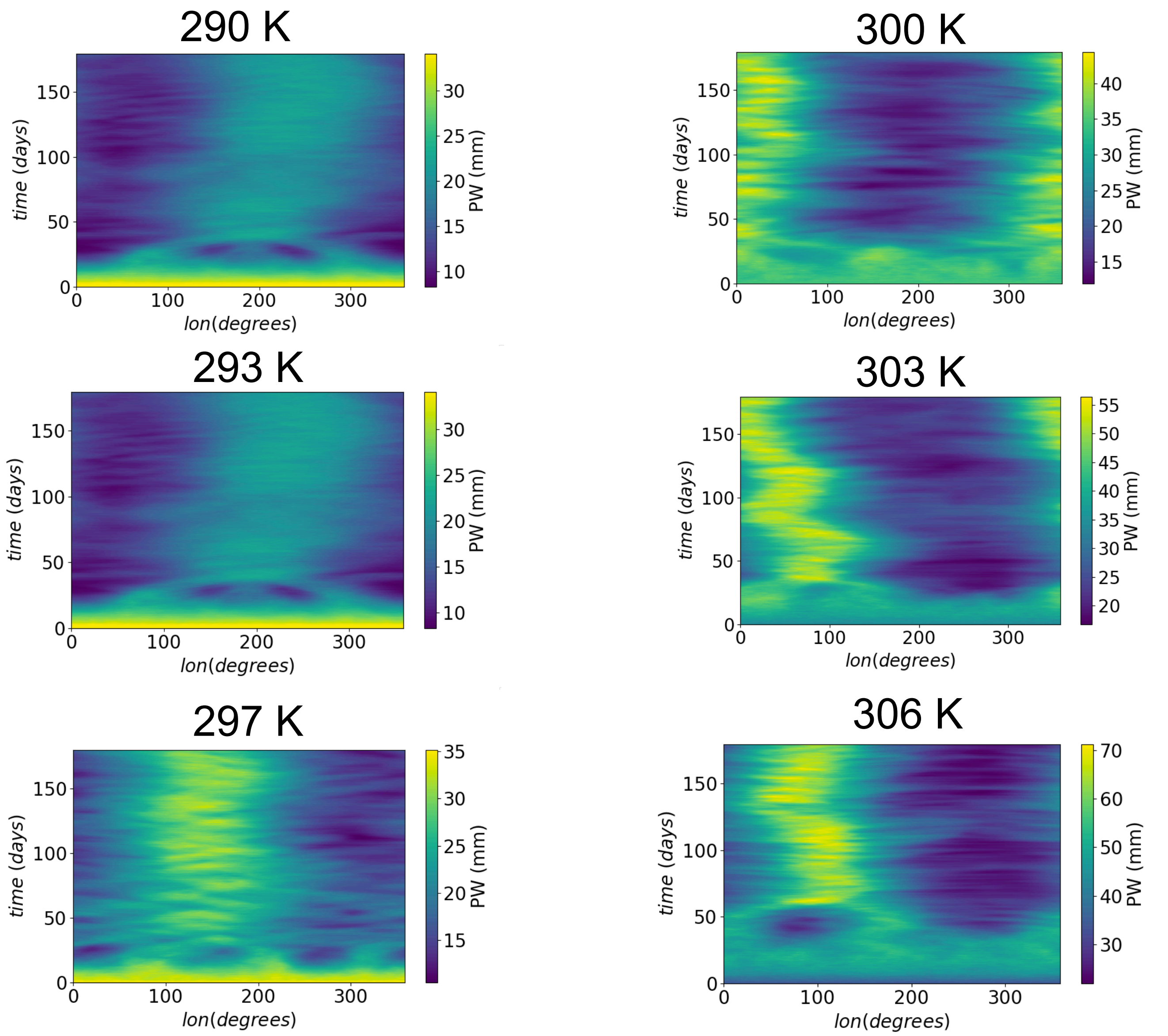
SCREAM in RCE mode

- SCREAM-RCE: Simple Cloud Resolving Atmospheric Model is run on a 20x reduced size planet with a uniform SST and a dx of 3 km.

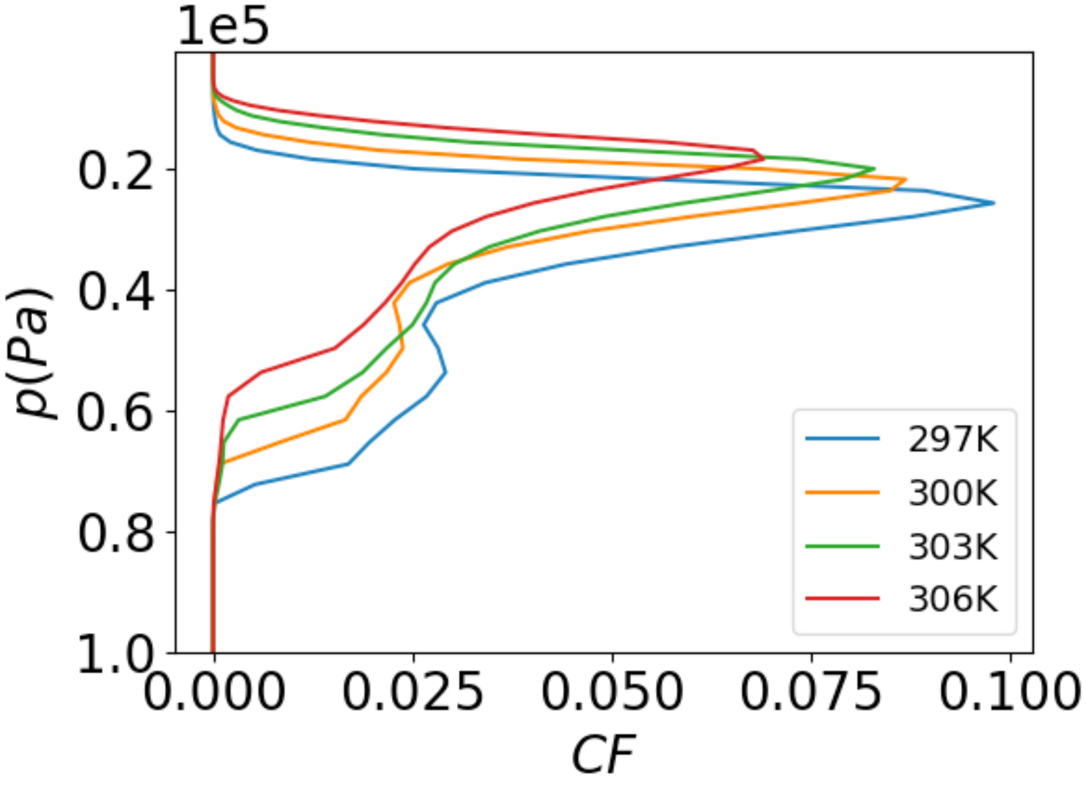
- We focus on upper level clouds.

- SCREAM-RCE is a “boutique” version of SCREAM that allows speedy diagnosing of the developing model as well as idealized science experiments (e.g., looking at upper level clouds).



Anvil cloud fraction in SCREAM and the Bony et al. (2016) argument

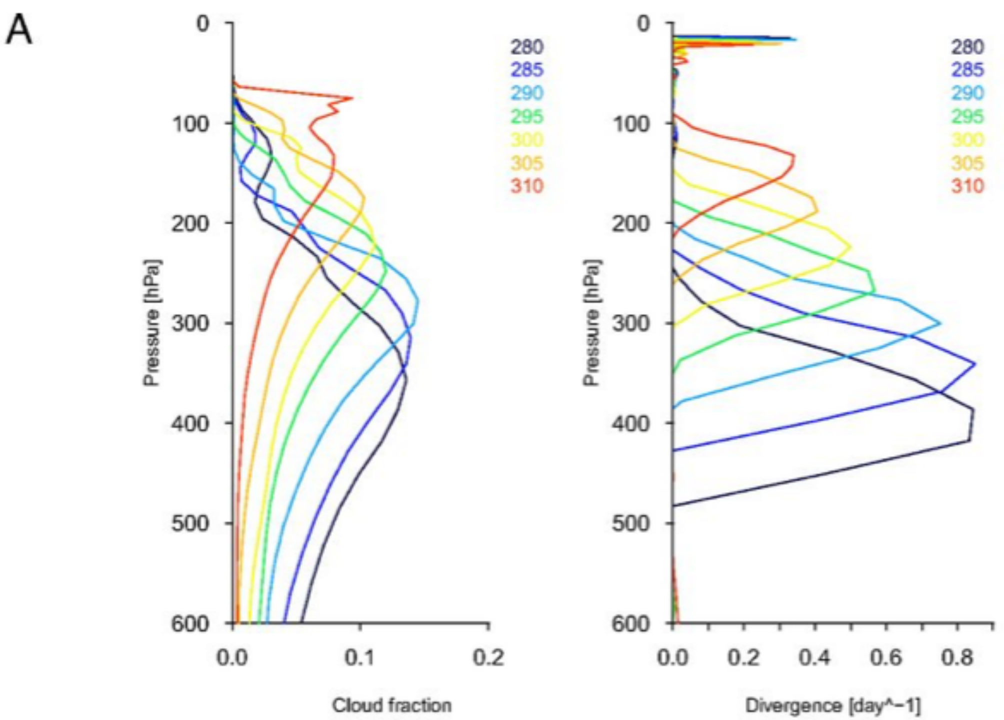
SCREAM-RCE



CF is fraction of domain covered by cloud mixing ratio greater than 10^{-5} kg/kg

Bony et al. (2016)
" As the climate warms, the clouds rise and remain at nearly the same temperature, but find themselves in a more stable atmosphere; this enhanced stability reduces the convective outflow in the upper troposphere and decreases the anvil cloud fraction."

From Bony et al. (2016):



Decomposing contributions to cloud fraction

Over non-convective cloudy grid cells, mass balance along a vertical level dictates that:

$$\sum_{N_c} \frac{\partial q_i}{\partial t}_{adv} = \sum_{N_c} \frac{\partial q_i}{\partial t}_{sink} = N_c \overline{\frac{\partial q_i}{\partial t}_{sink}}$$

$$CF = \frac{N_c}{N_{tot}} = \frac{1}{N_{tot}} \frac{\sum_{N_c} \frac{\partial q_i}{\partial t}_{adv}}{\overline{\frac{\partial q_i}{\partial t}_{sink}}} \propto \frac{all - cell\ average\ ice\ source}{cloud\ averaged\ ice\ sink}$$

Next, define cloud normalized horizontal and vertical gross divergences:

$$V_h = \frac{1}{N_{tot}} \frac{\sum_{N_c} \frac{\partial q_i}{\partial t}_{adv}}{\bar{q_i}} \qquad V_v = \frac{\overline{\frac{\partial q_i}{\partial t}_{sink}}}{\bar{q_i}}$$

$$\Longrightarrow CF = \frac{V_h}{V_v}$$

Note that the Bony et al. argument asserts that V_h decreases with mean stability and modulates the CF response to warming.

N_c: total number of cloudy grid cells

N_{tot}: number of grid cells along a vertical slab

CF: Cloud fraction

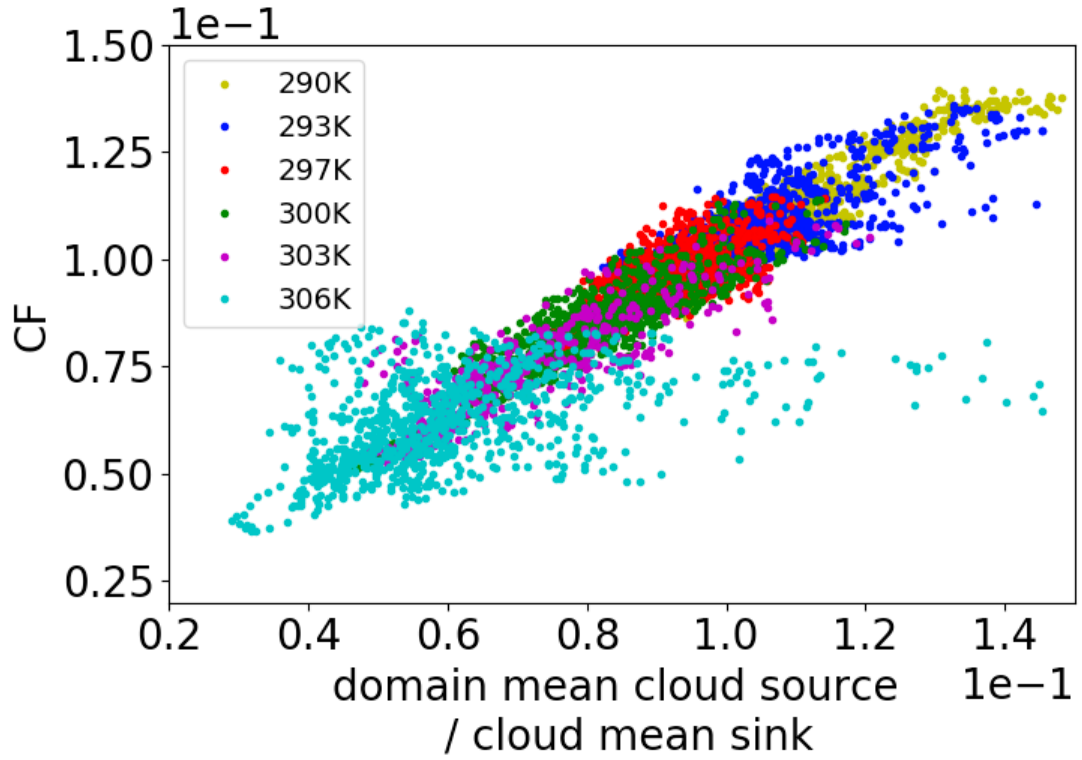
$\frac{\partial q_i}{\partial t}_{adv}$: cloud advective tendency

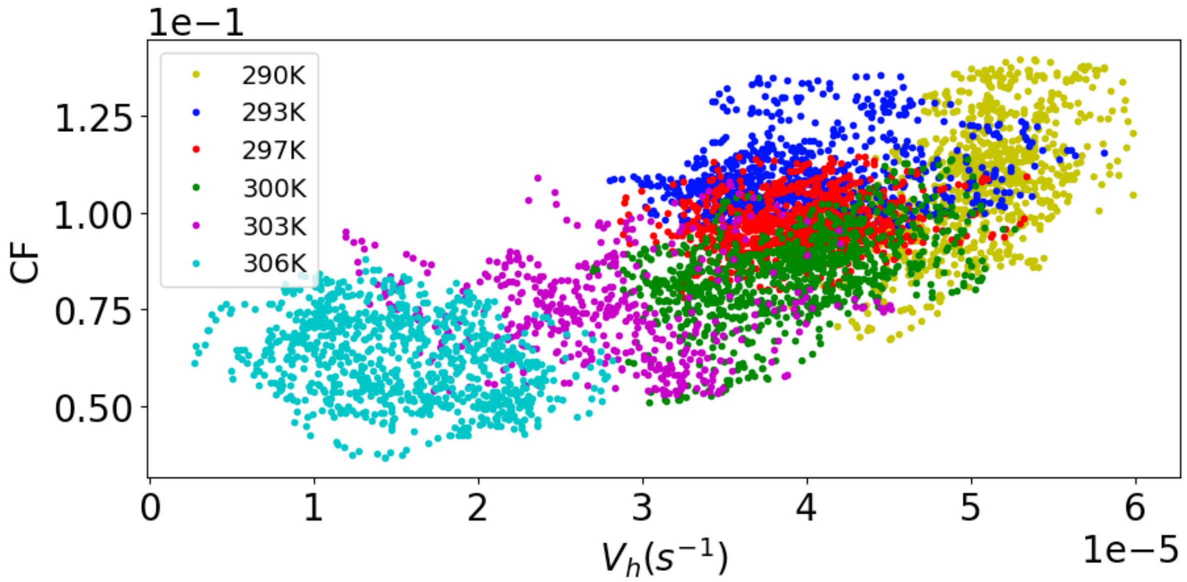
$\frac{\partial q_i}{\partial t}_{sink}$: cloud removal tendency

V_h: Bulk cloud detrainment rate

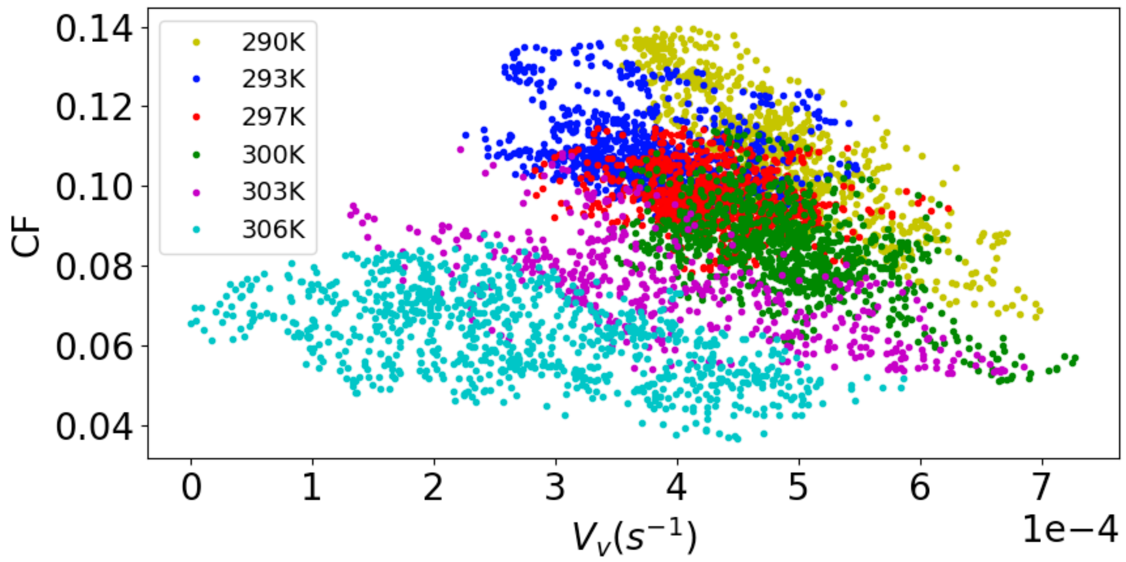
V_v: Mean cloud removal velocity

Results





Overall, V_h is a stronger modulator for the reduction in CF across the entire SST range However, does V_h scale with large scale divergence? Stay tuned for paper!



In all plots, we exploit model internal variability to generate a larger data set.

Left hand plot: cloud fraction can be reliably predicted as the ratio of horizontally summed advection divided by mean ice sink.