Using A-Train observations to evaluate East Pacific cloud occurrence and radiative effects in the Community Atmosphere Model

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CloudSat/CALIPSO Science Program Review

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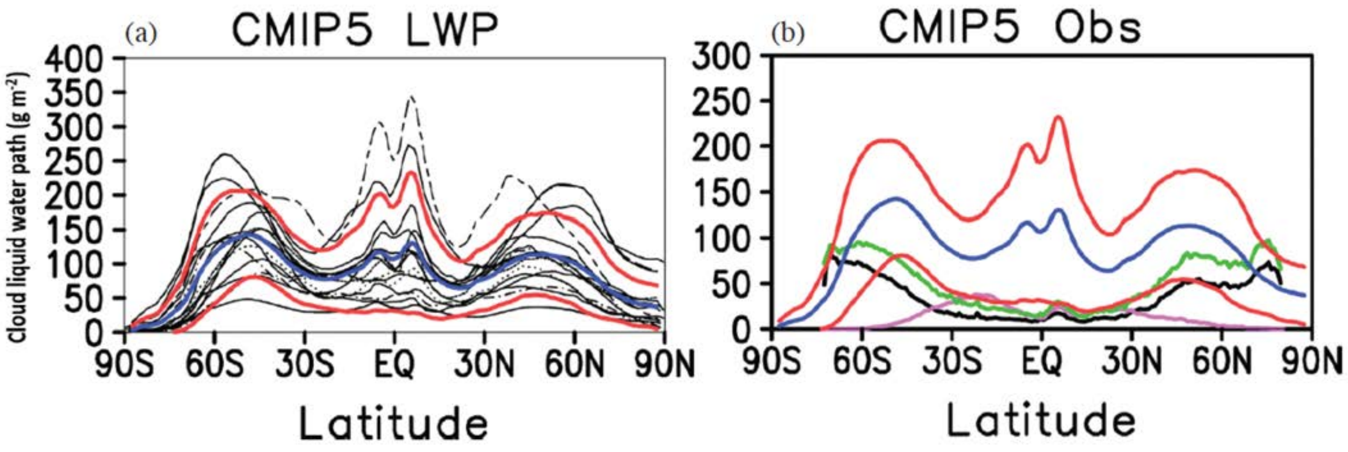
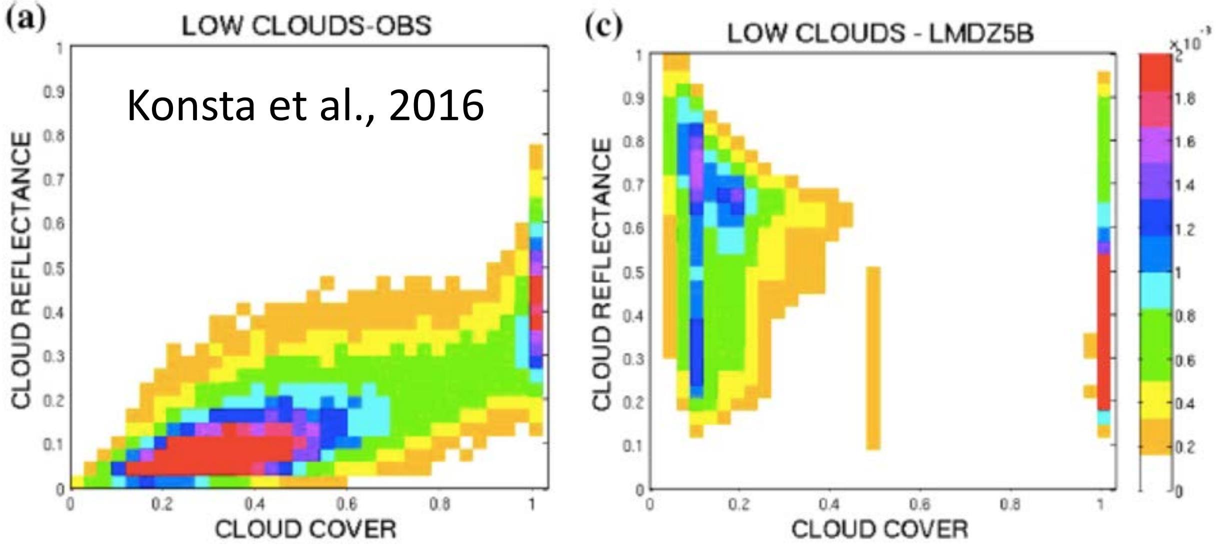
Motivation: Low clouds in GCMs



Annual mean Liquid Water Path (LWP) overestimated by factors of 2-10 compared to observations globally (Li et al., 2018)



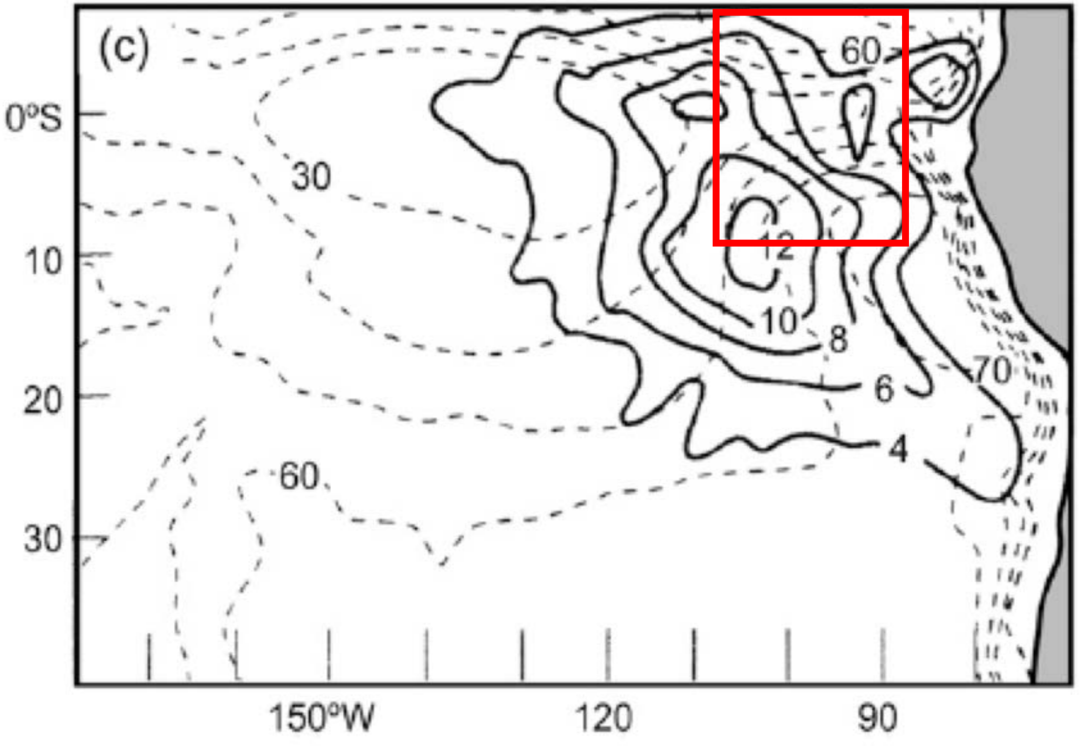
Konsta et al., 2016

“Too few, too bright” low cloud problem
(Nam et al., 2012 and many others)

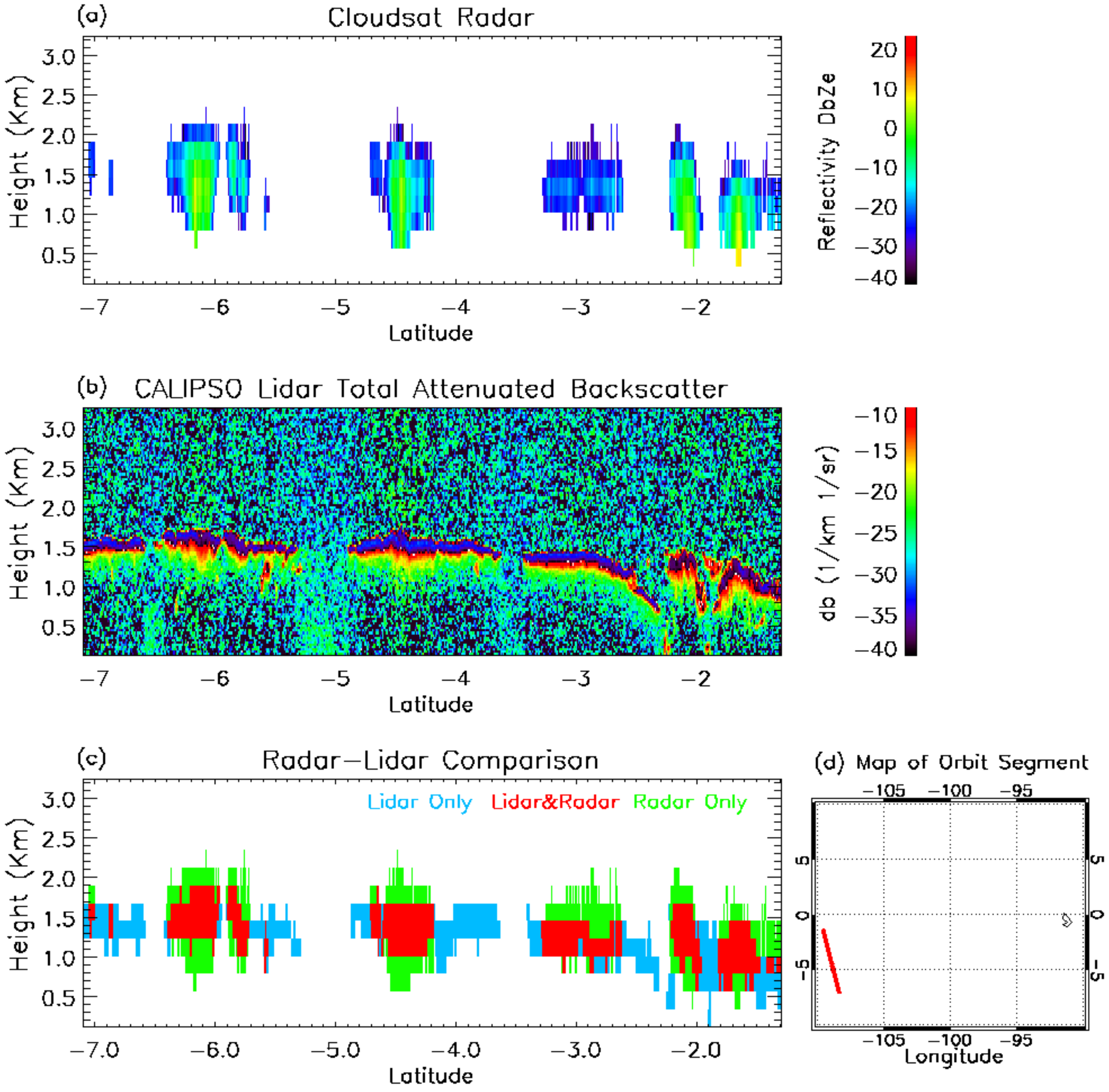
The amplitude of the low-level cloud feedback depends on the cloud radiative effect (Brient and Bony, 2012). An error in the latter may impact the former.

East Pacific Low Clouds

June through September, 2007-2008
[10S to 10N, 90W to 110W]



(Wood, 2012)



Methods

CloudSat and CALIPSO (CC)

- Overpass time ~1:30a/p
- Footprint 1.4 x 1.7 km

Cloud layers identified from 2B-Geoprof-LIDAR (Mace and Zhang, 2014)

↓

Liquid microphysics from some combination of A-Train measurements

↓

T and Q from ECMWF-AUX (Partain, 2007)

CAM5 2005-2008 climate run

- 3hrly output (sampled at overpass time)
- Grid box 1.9° x 2.5°

Apply downscaling to create subcolumns from grid box cloud fraction profile

↓

Model cloud water contents and sizes

↓

Model T and Q

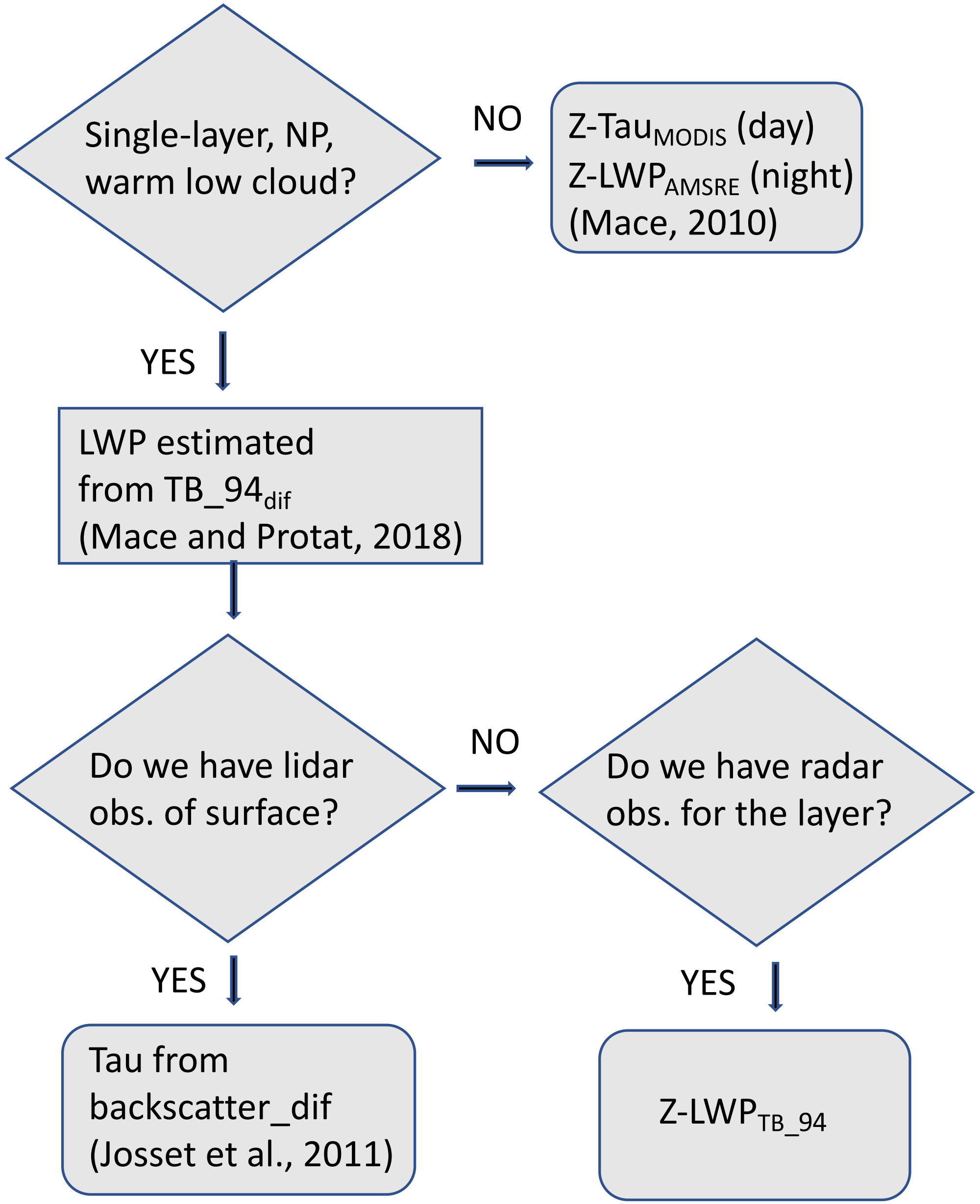
↓

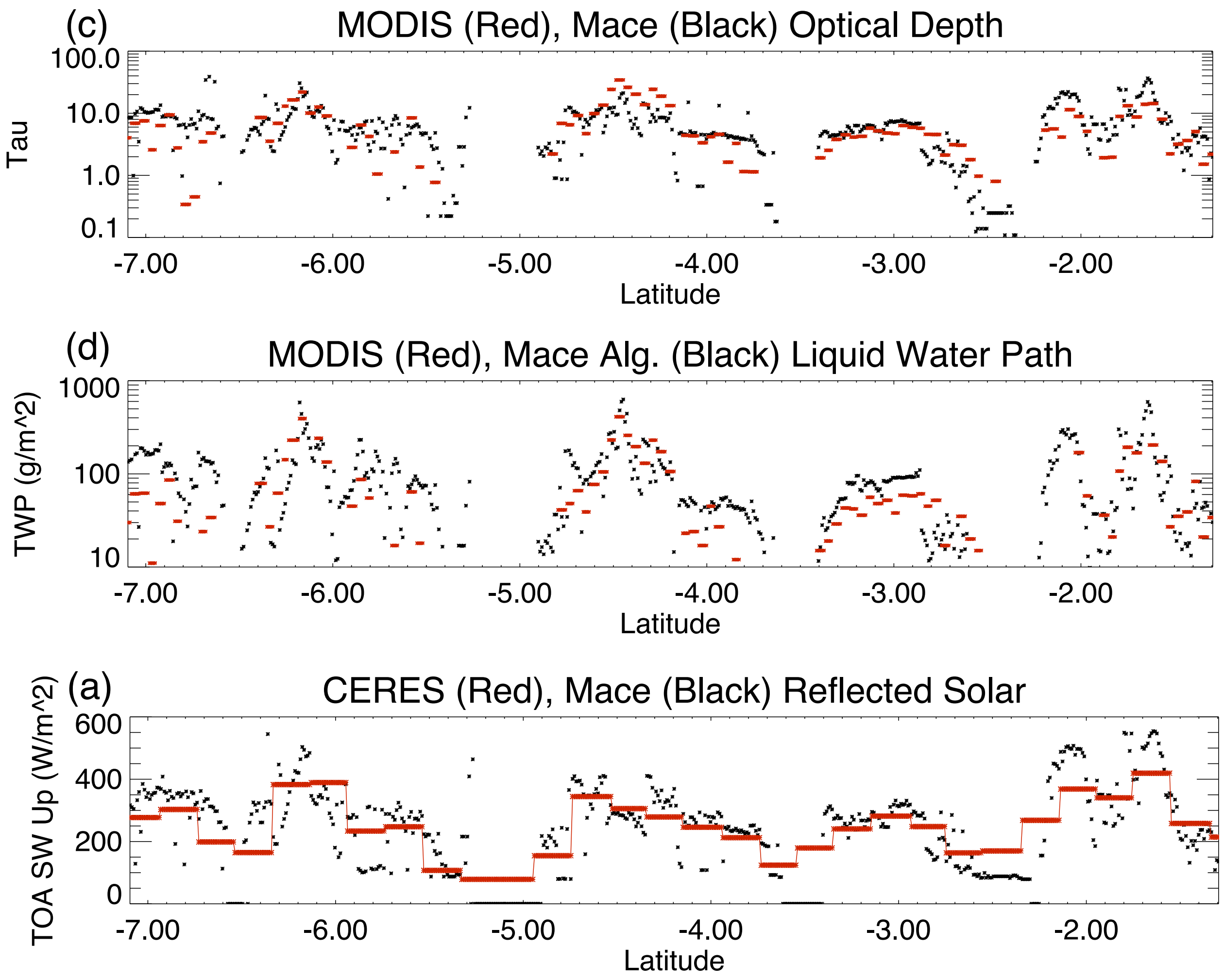
Calculate radiative properties (ω, τ, g) using parameterizations for ice cloud (Fu 1996; Fu et al. 1998) and liquid cloud (Slingo 1989; Kiehl et al. 1998)

↓

Run two-stream radiative transfer model that uses the k-distribution method and correlated-k assumptions (Toon et al. 1989; Kato et al., 2001; Mlawer et al. 1997)

A-Train Liquid Cloud Microphysical Retrieval



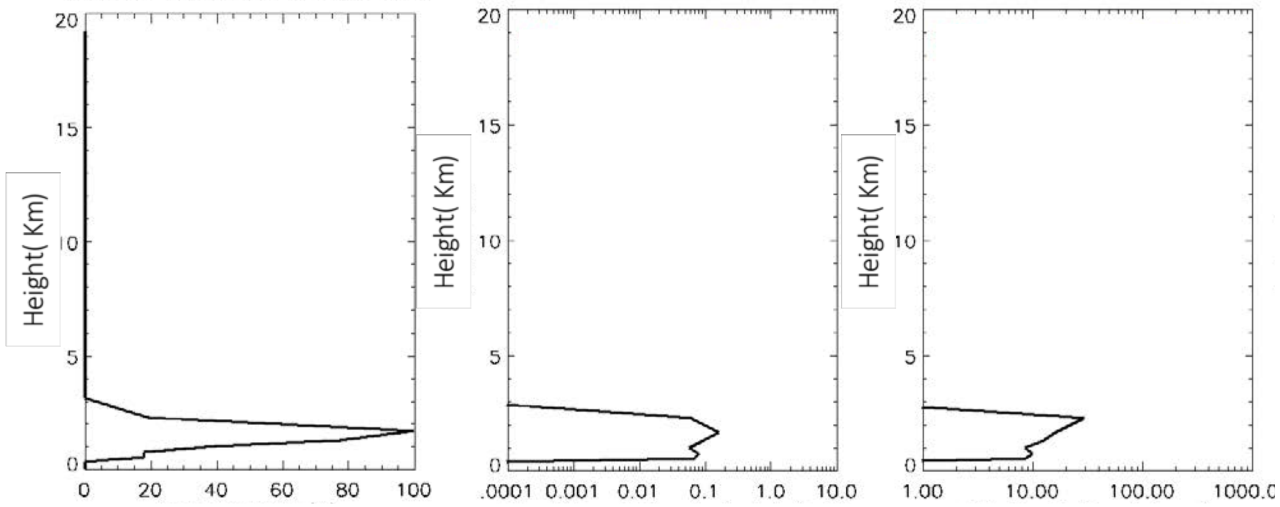


Creating Model Subcolumns

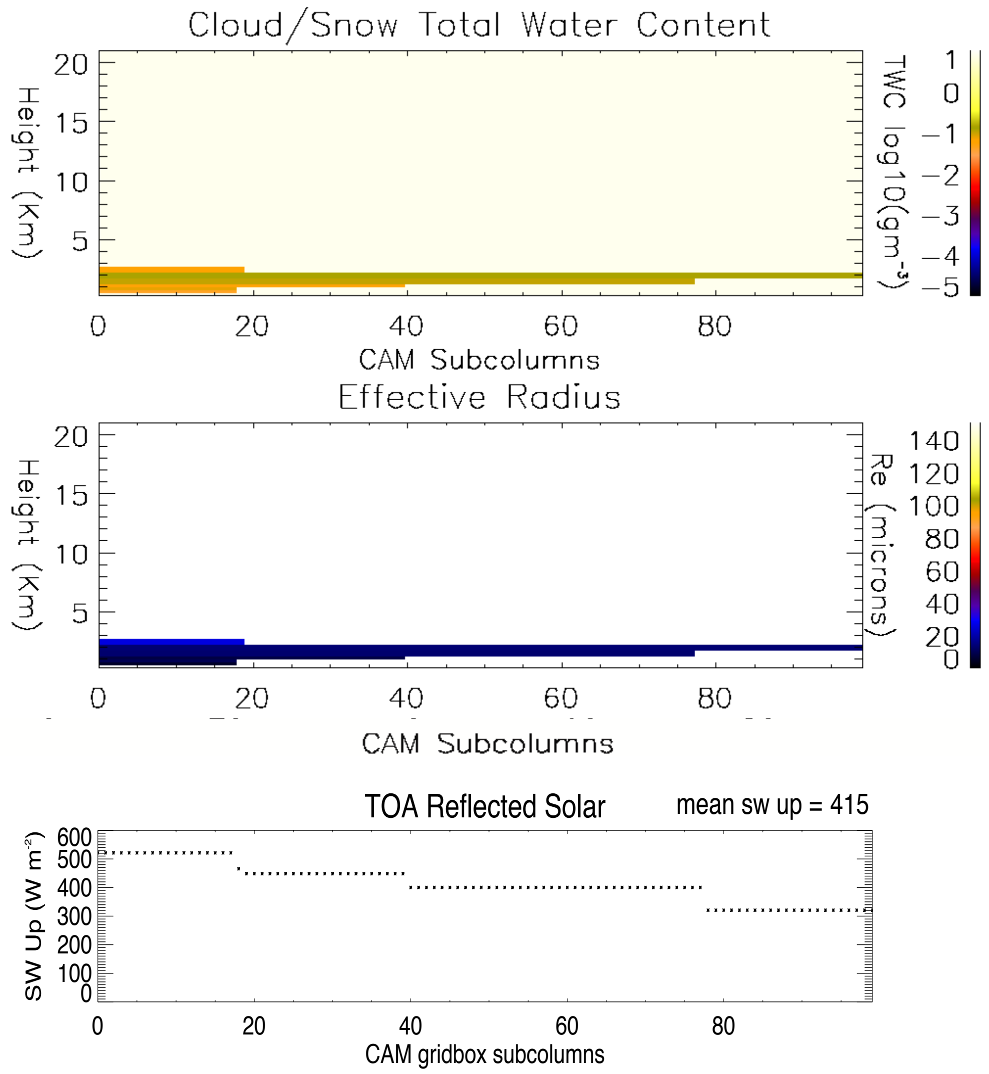
Maximum random overlap assumption to create 100 subcolums within each grid box (Jacob and Klein, 1999)

Clear-sky: Net TOA Solar = 1118 W m^{-2} Net TOA LW = 288 W m^{-2}

All-Sky: Net TOA Solar = 730W m^{-2} Net TOA LW = 276 W m^{-2}



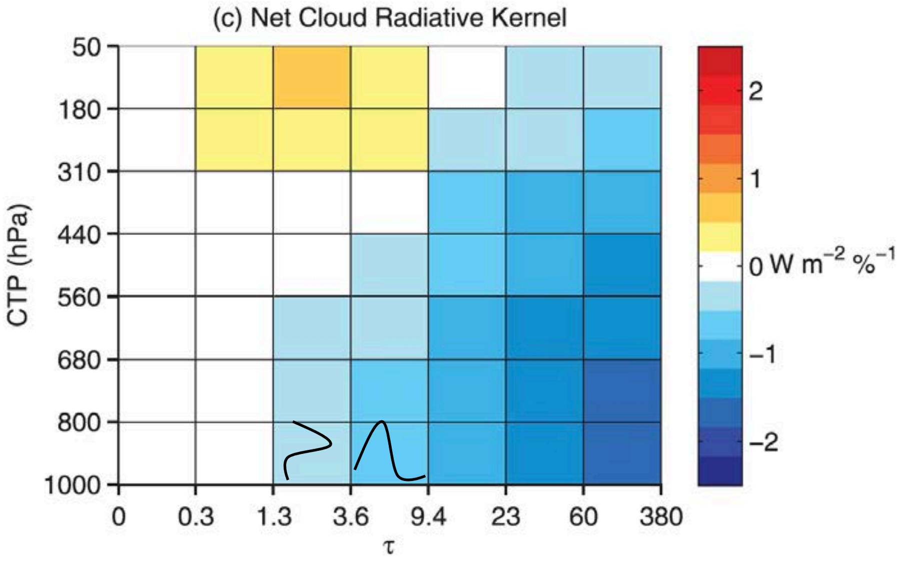
Cloud Fraction (%) Water Content (g m^{-3}) Effective Radius (μm)

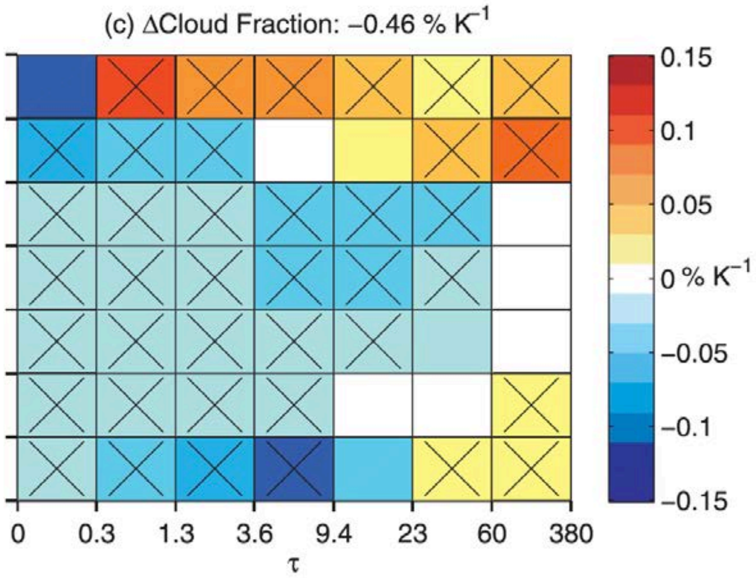


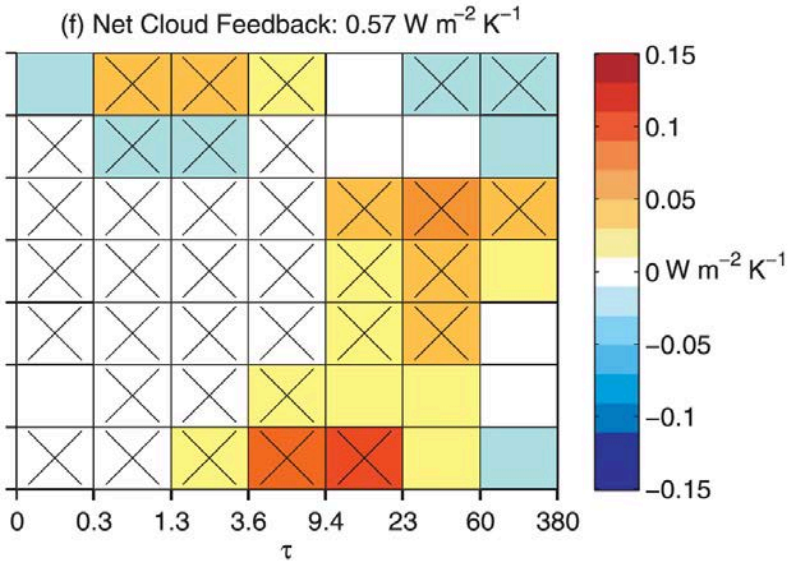
Example Grid Box June 1, 2007 at 21Z

Latitude: 6.63, Longitude: -107.5

Cloud Radiative Kernel Method for Cloud Feedbacks
(Zelinka et al., 2012a)







Sensitivity of TOA fluxes to perturbations in cloud fraction

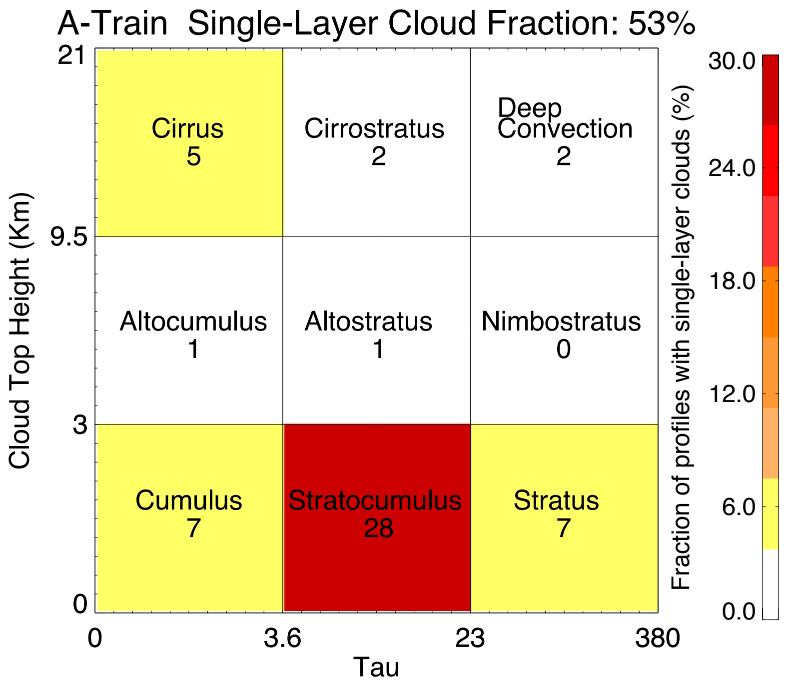
$$K \equiv \frac{\partial R}{\partial C}$$

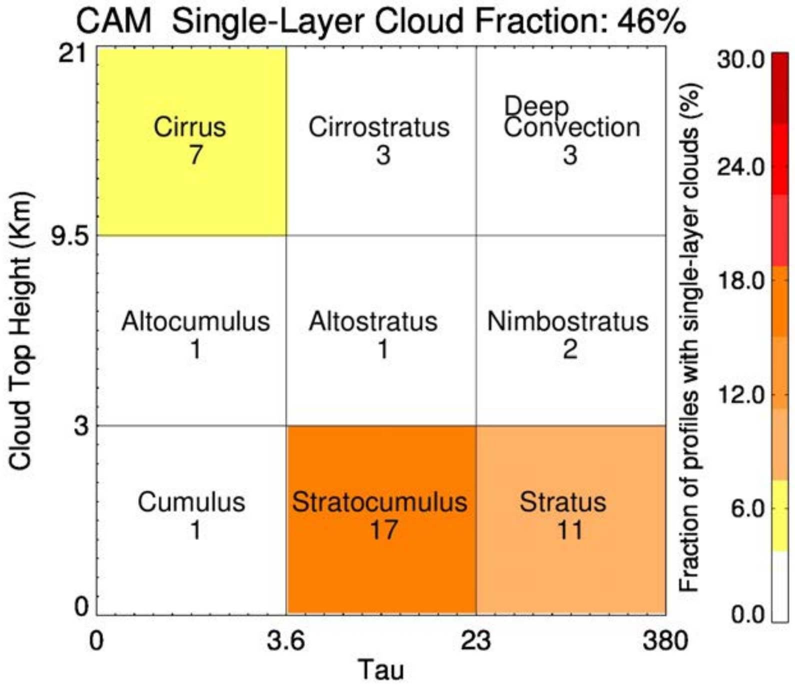
Contribution of each cloud type to change in TOA radiation associated with climate change

$$\Delta R = K \Delta C. \qquad f = \frac{\Delta R}{\Delta \overline{T_s}}.$$

<u>Modify the method by making two changes</u>

1. Create data-based kernels, derived from populations of observed and modeled single-layer clouds
2. Evaluate present-day clouds





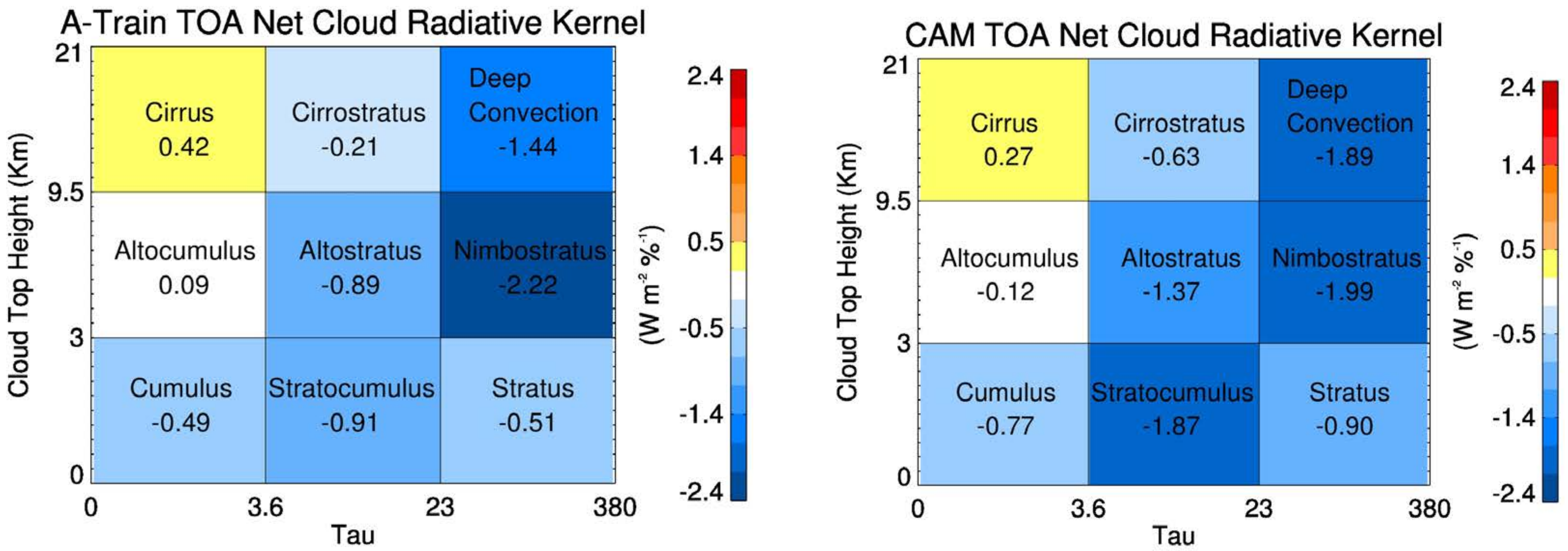
East Pacific: Single-Layer Cloud Fraction Histogram (C)

- Too few single-layer low clouds in the model (29% for the CAM5 vs. 42% for CC)
- Cumulus and Stratocumulus are underpredicted in the model by about half (18% for the CAM5 vs. 35% for CC).

NP Low Cloud Microphysics	CloudSat/CALIPSO	CAM5
Mean Optical Depth	13	21
Mean Liquid Water Path	110 g m^{-2}	115 g m^{-2}
Mean Effective Radius	13 µm	9 µm

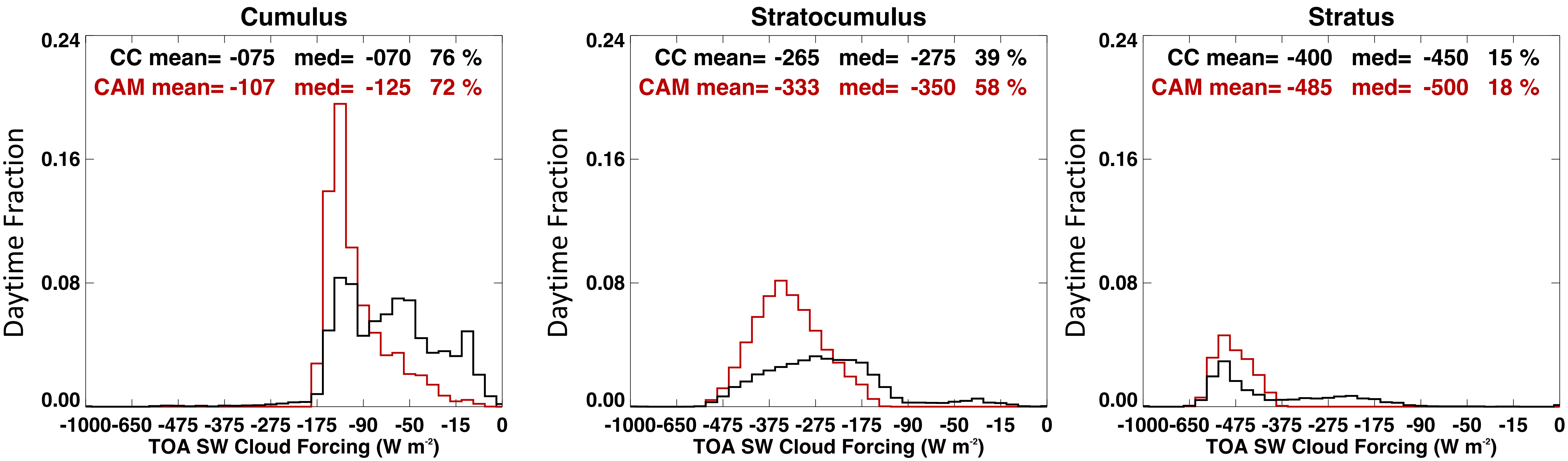
- Cloud-fraction-normalized LWP is larger for CAM5

East Pacific: Cloud Radiative Kernels (K) [$Wm^{-2}K^{-1}$]



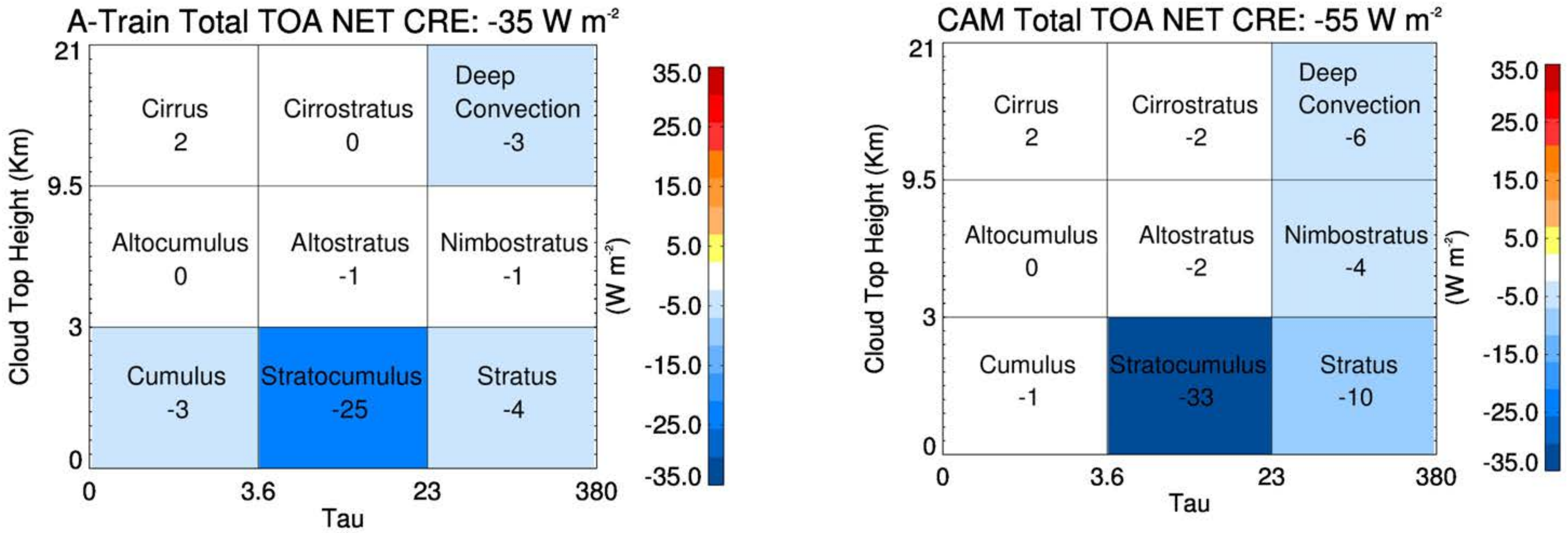
- Cooling increasing with increasing cloud-type optical depth (exception: Stratus, more on this later)
- Sensitivity of the radiation to low clouds is stronger in the model
- Stratocumulus - cooling is a factor of two larger in the model

East Pacific: Daytime SW Cloud Radiative Effects



- Stratus occur mostly at nighttime overpass, explaining smaller than expected cooling in kernel
- Relatively good agreement, in terms of the magnitude and ranges of SW forcing for cloud types
- However CAM5 low clouds tend to be brighter across all low cloud types
- Greater fraction of daytime Stratocumulus in model, which contributes to stronger cooling in kernel

East Pacific: Cloud Radiative Effects (R = C * K)



- Stratocumulus responsible for majority of cooling in model and observations, a result of compensating errors in CAM5
- Net CRE for Low Clouds is larger for CAM5 (-44 W m^{-2}) compared to A-train (-32 W m^{-2})
- Larger cooling in the model is weighted towards more optically thick clouds

Conclusions for East Pacific Low Clouds in CAM5

1. Evidence of “too few, too bright” low cloud bias in CAM5
2. Microphysics: for CAM5 the CF-normalized LWP larger, Re tends to be smaller
3. CAM5 produces a larger magnitude of CRE cooling which is accomplished by a narrower range of clouds
4. Stratocumulus: stronger cooling in model kernel implies overly sensitive tropical low cloud feedback
5. Discrepancies are somewhat expected, given the diagnostic treatment of cumulus. Suggests low cloud predictions from this generation of models remain uncertain. Improvements in CAM6?

Berry, E., G. G. Mace, and A. Gettelman, 2019: Using A-train observations to evaluate East Pacific cloud occurrence and radiative effects in the Community Atmosphere Model, J. Clim., in review.