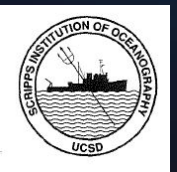
Investigating high cloud response to aerosols in a Perturbed Parameter Ensemble

Brandon Duran, Nicholas Lutsko, Casey Wall, Daniel McCoy



2025 CESM Workshop
June 9 2025

PPE Overview

CAM6.3

19 Parameters

- Aerosols
- Microphysics

162 parameter sets for simulation using Latin Hypercube Sampling

Almost all parameter ranges inherited from Eidhammer et al. (2024)

Parameters
micro_mg_accre_enhan_fact
micro_mg_autocon_fact
micro_mg_autocon_lwp_exp
micro_mg_autocon_nd_exp
micro_mg_berg_eff_factor
micro_mg_dcs
micro_mg_effi_factor
micro_mg_homog_size
micro_mg_iaccr_factor
micro_mg_max_nicons
micro_mg_vtrmi_factor
seasalt_emis_scale
microp_aero_npccn_scale
microp_aero_wsub_min
microp_aero_wsub_scale
microp_aero_wsubi_min
microp_aero_wsubi_scale
dust_emis_fact
Sol_facti_cloud_borne

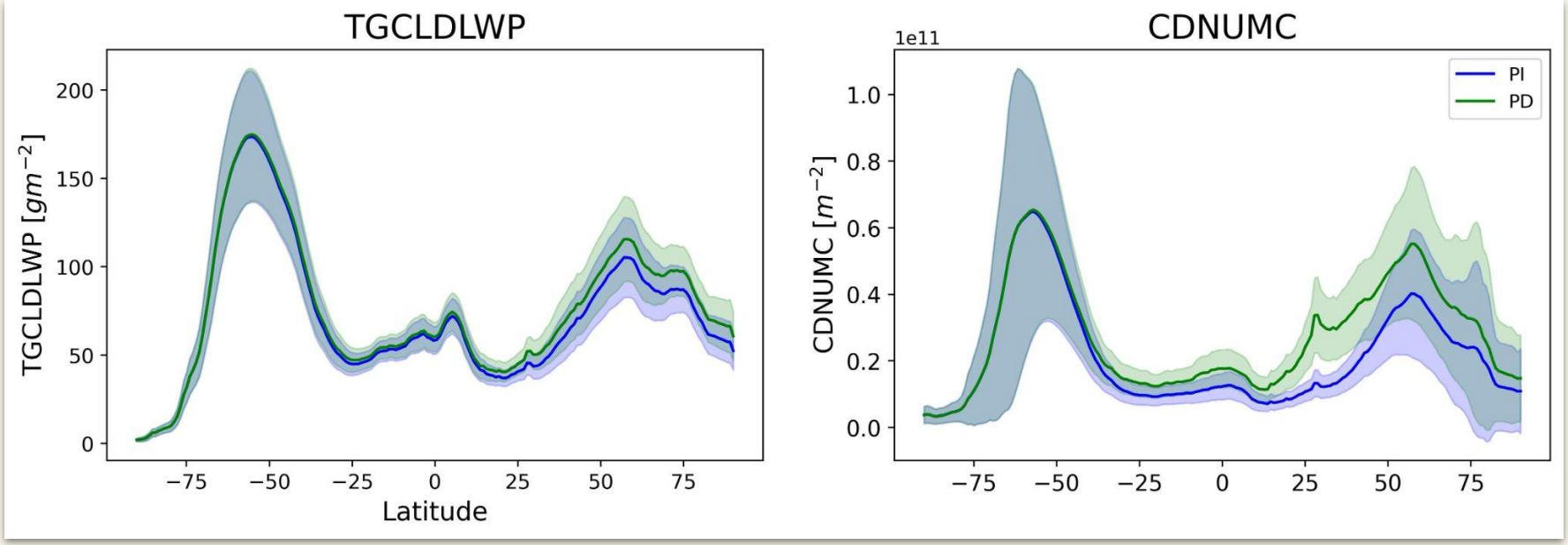
New parameter
Modified parameter range

Experiment Setup

Two types of simulation (2 years), all fixed SST:

- **PI:** preindustrial (1850) aerosol emissions
- **PD:** present day forcing & SSTs (2010)

Winds nudged to MERRA2 reanalysis over 2010-2011 period



How to diagnose ERFaci

Double-call (Ghan, 2013)

Uses extra aerosol-free radiative fluxes under clear- and all-sky conditions

APRP (Taylor et al., 2007)

Simplified 1-layer model of the atmosphere

Partition cloud changes into amount, scattering, and absorbing components

MODIS cloud radiative kernel (Duran et al., 2025)

Uses MODIS satellite simulator output and cloud radiative kernels

Phase-distinction enables separation of liquid and ice cloud changes!

How to diagnose ERFaci

Double-call (Ghan, 2013)

Uses extra aerosol-free radiative fluxes under clear- and all-sky conditions

APRP (Taylor et al., 2007)

Simplified 1-layer model of the atmosphere

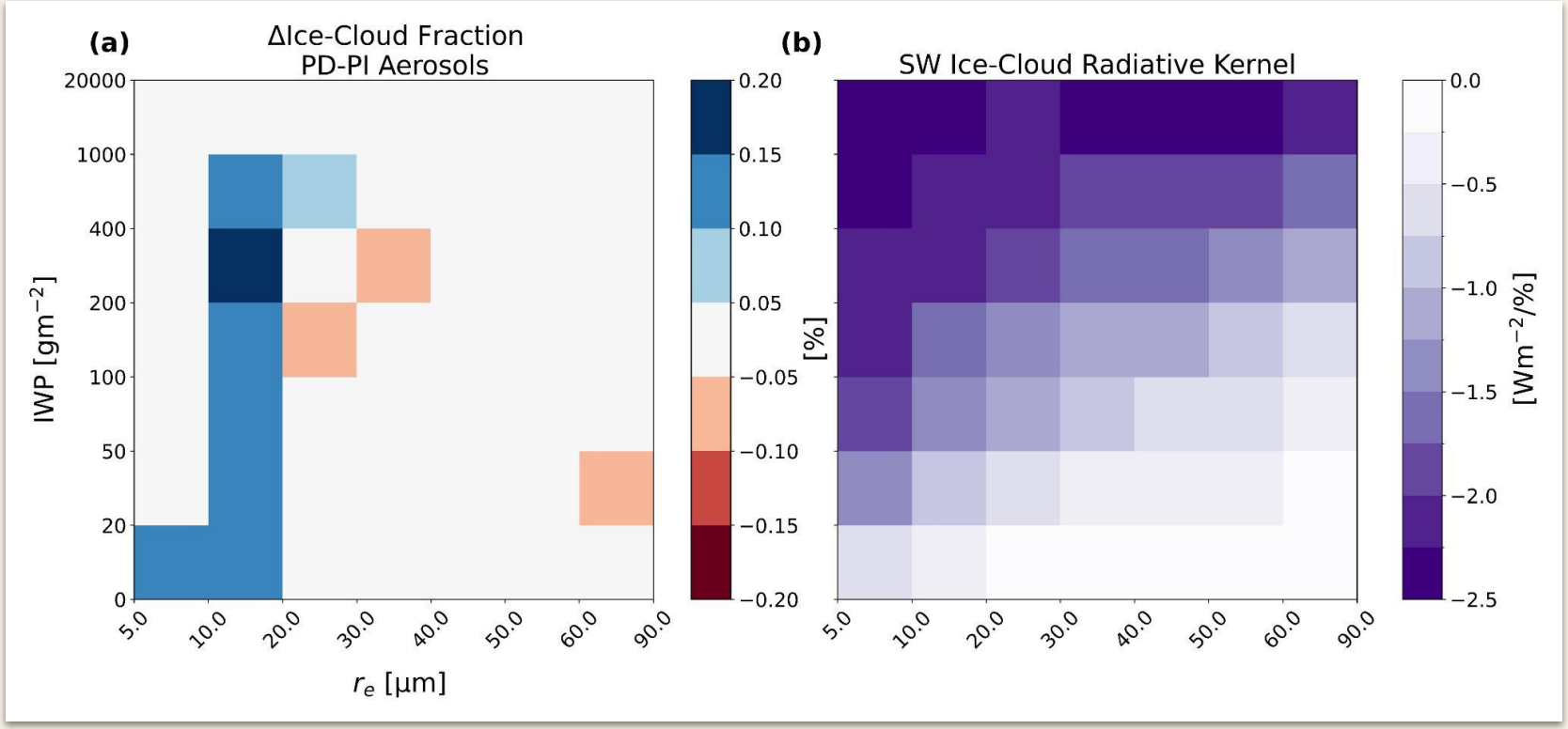
Partition cloud changes into amount, scattering, and absorbing components

MODIS cloud radiative kernel (Duran et al., 2025)

Uses MODIS satellite simulator output and cloud radiative kernels

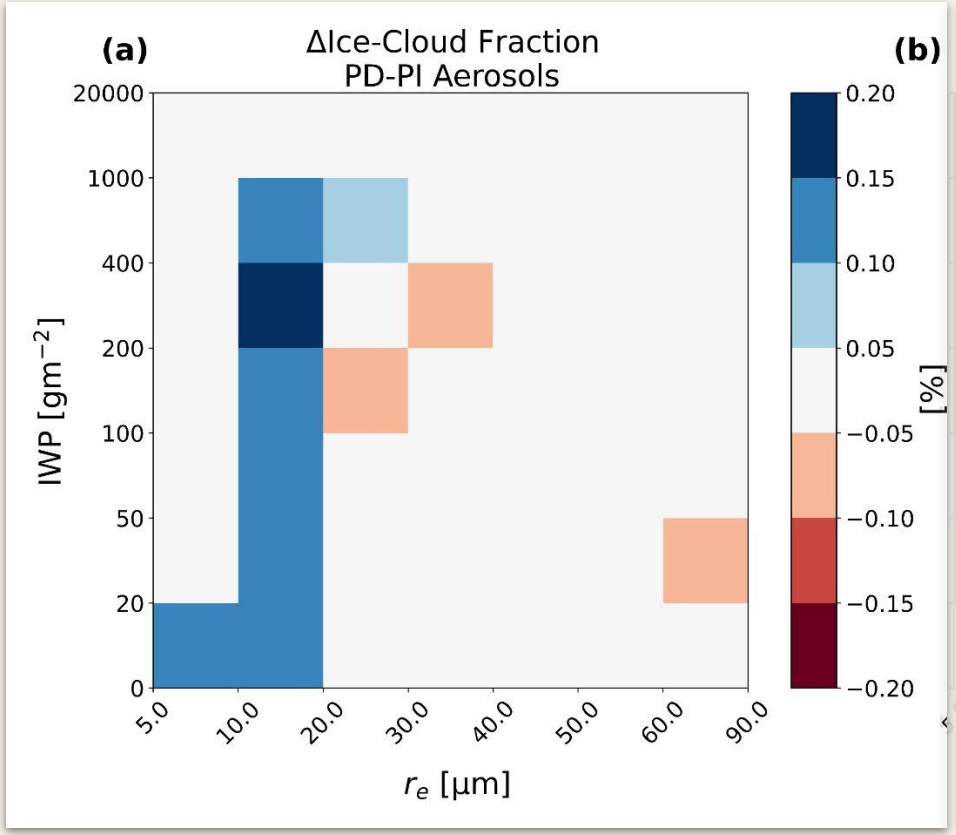
Phase-distinction enables separation of liquid and ice cloud changes!

New MODIS CRK method for diagnosing ERFaci



Radiative kernels quantify changes to TOA radiative fluxes in response to a climate forcing

New MODIS CRK method for diagnosing ERFaci



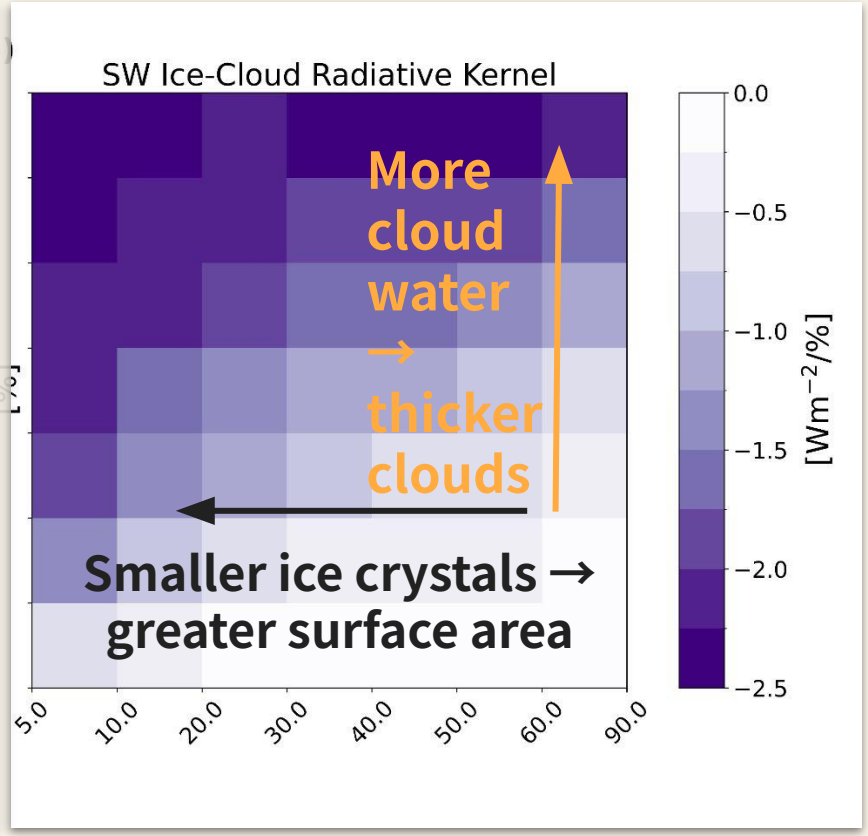
GCM output from the MODIS satellite simulator

Cloud fraction partitioned by cloud droplet effective radius (r_e) and ice water path (*IWP*)

New MODIS CRK method for diagnosing ERFaci

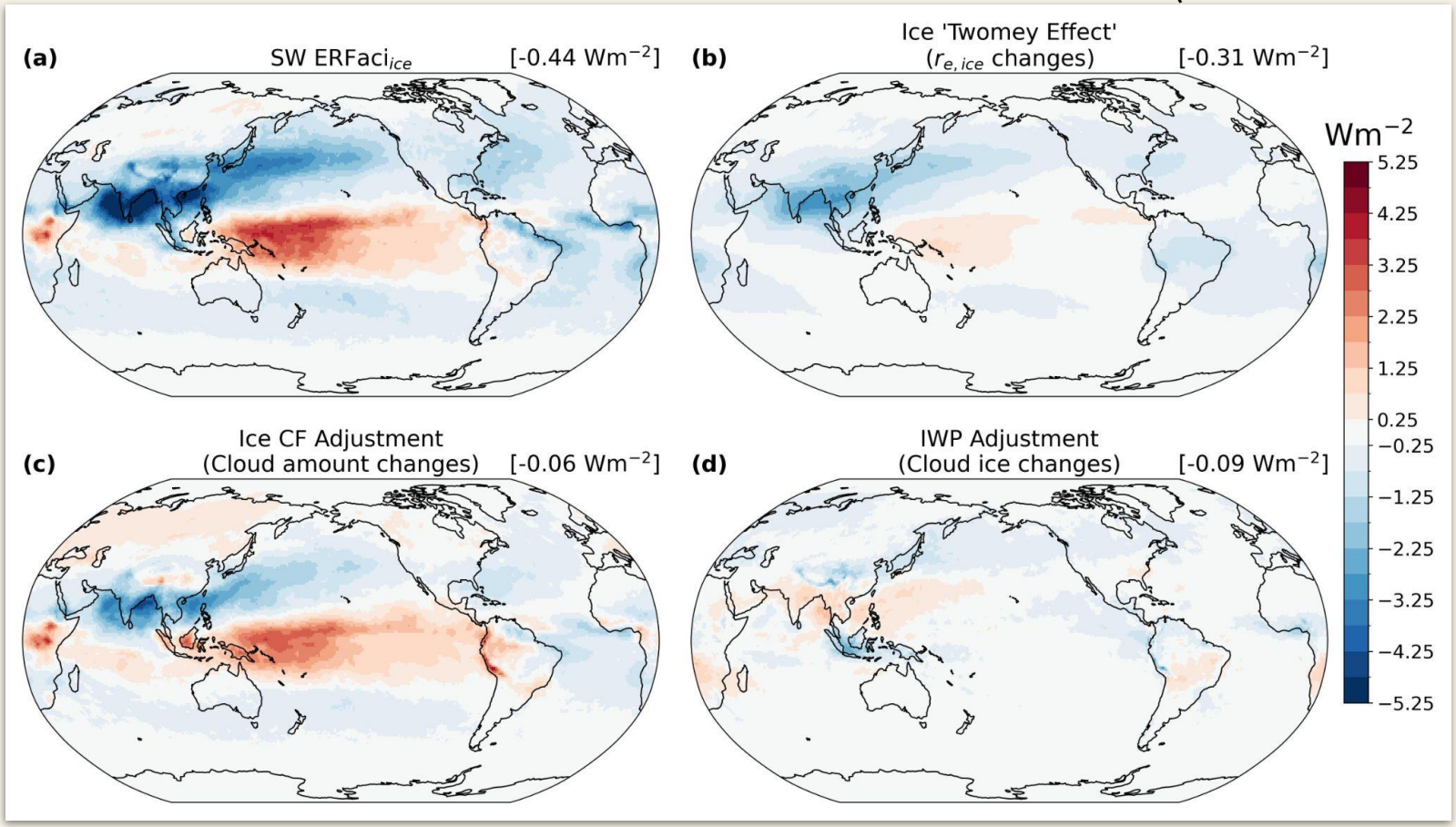
Generated offline using a radiative transfer model

$$\partial TOA_{SW}/\partial CF$$

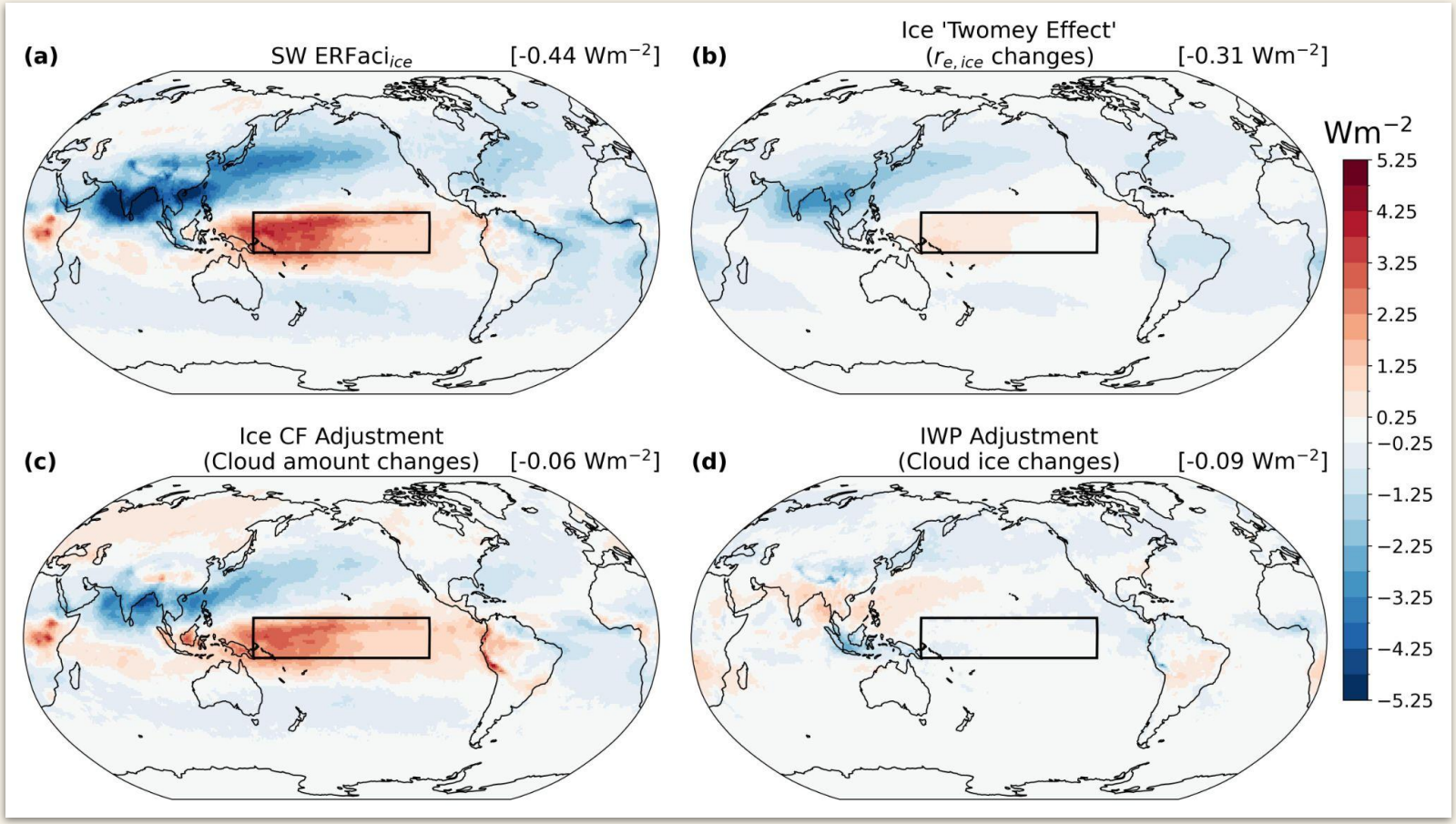


ERFaci from ice clouds

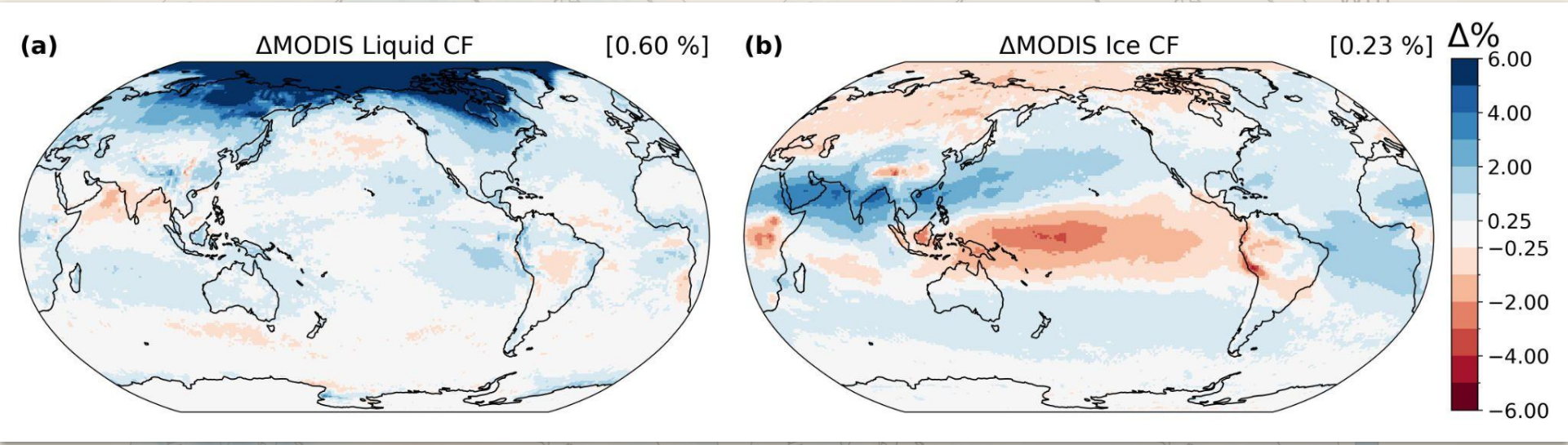
(Ensemble mean)



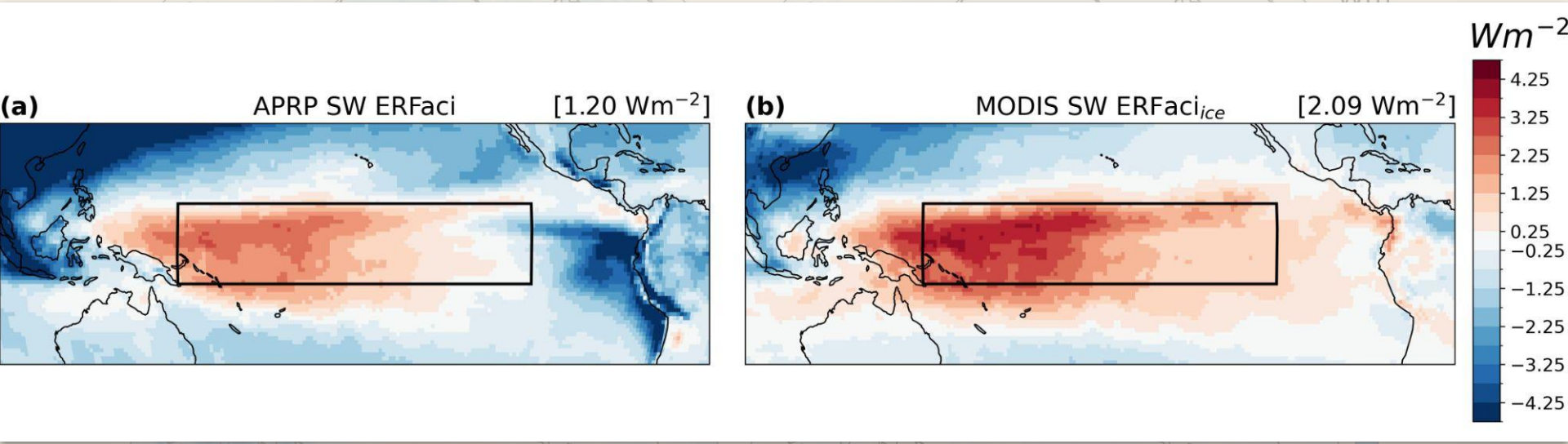
Ice cloud response to aerosols is heterogeneous!



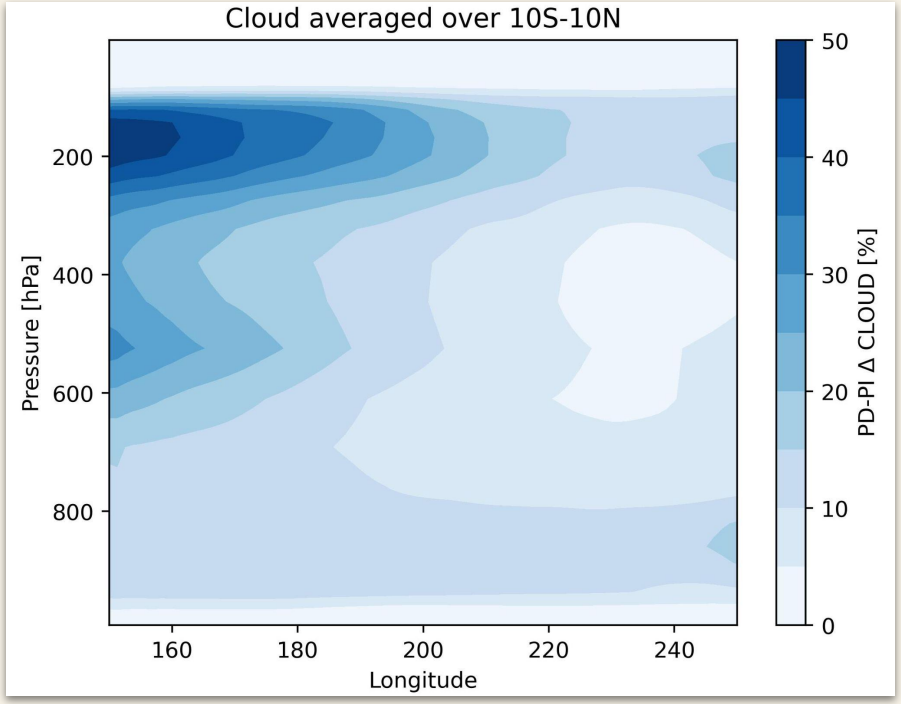
(whereas aerosols induce much more broad increases in liquid clouds)

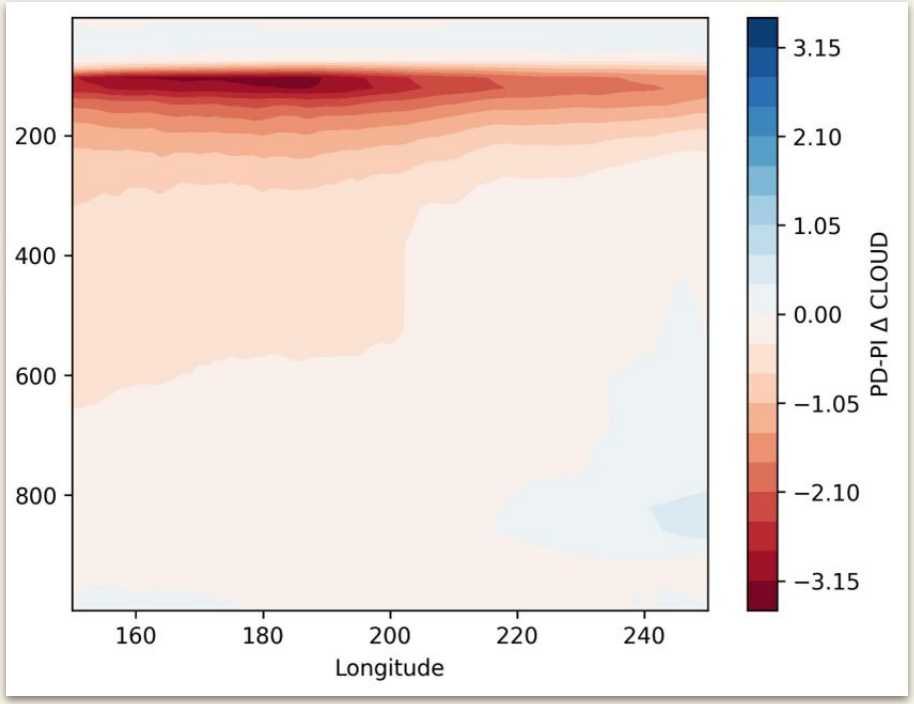


Warming effect is robust across ERFaci estimates (magnitude differs across methods)



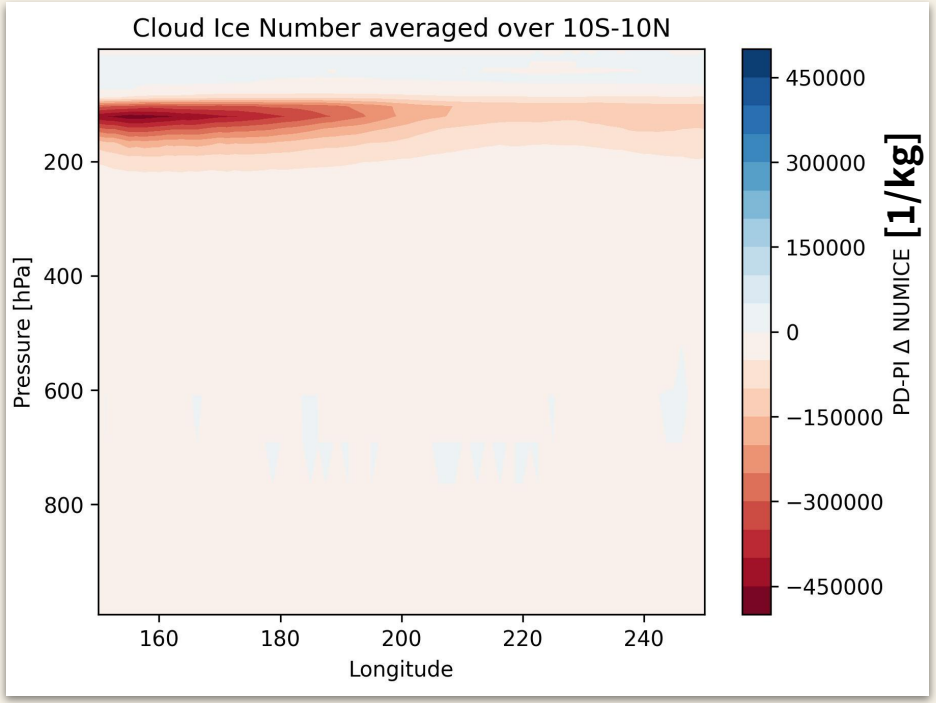
Tropical Ice Cloud Response - Micro or Macro?

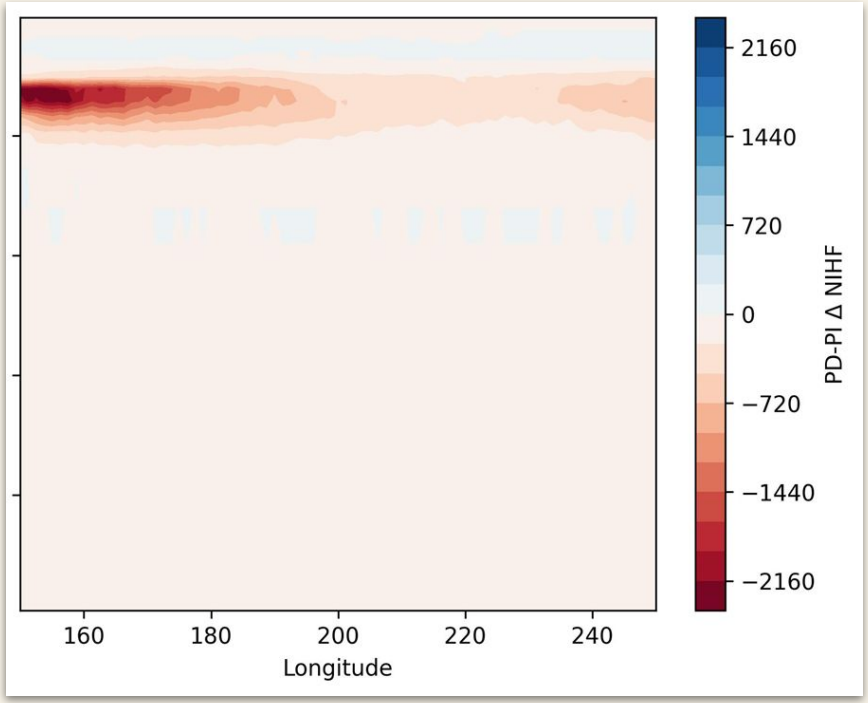




Cloud loss confined to upper troposphere (150-250E)

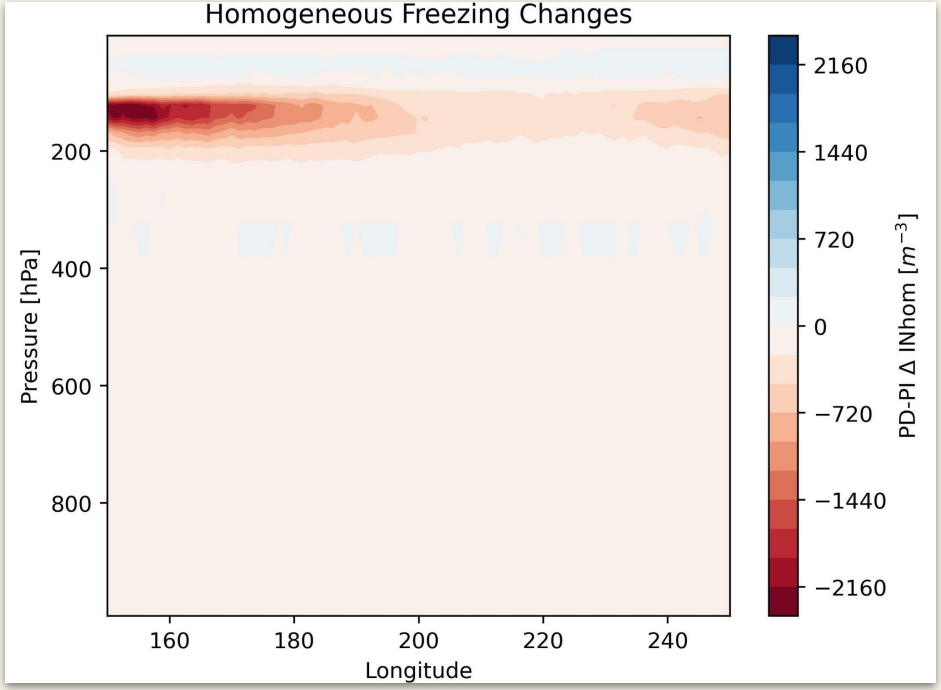
Tropical Ice Cloud Response - Micro or Macro?

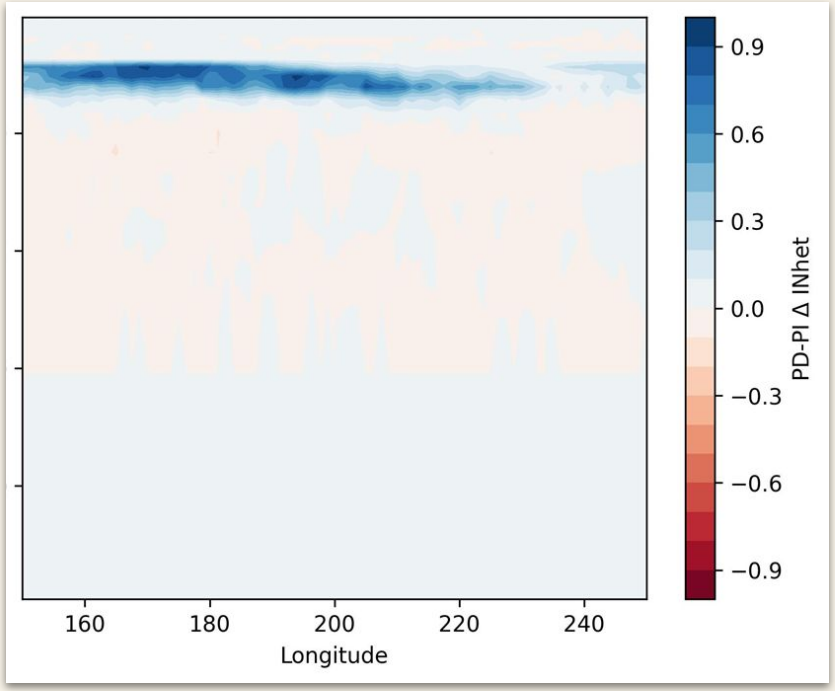




Strong decrease in cloud ice number, associated with diminished homogeneous nucleation

Tropical Ice Cloud Response - Micro or Macro?





Increase in heterogeneous nucleation reflective of intensified competition between homogeneous and heterogeneous nucleation?

Conclusions & paths forward

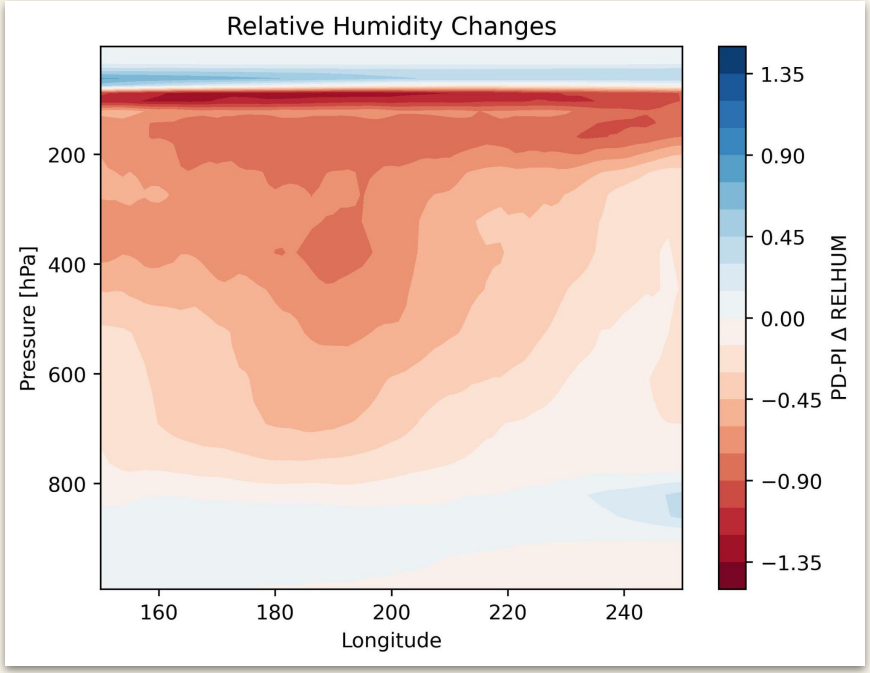
Default CAM6 $ERFaci_{ice}$ (-0.3 Wm^{-2}) is substantially weaker than $ERFaci_{liq}$ (-1.5 Wm^{-2})

Tropical ice clouds loss may be governed by competition between homogeneous and heterogeneous ice nucleation…

But targeted simulations needed to explore relevance of micro- and macro-physical controls on ice cloud response

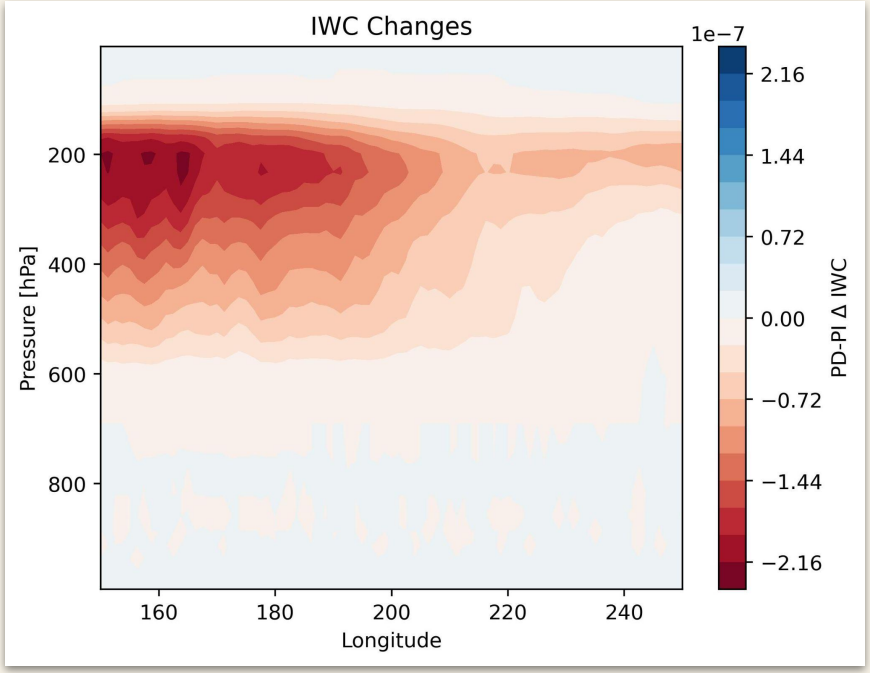
bmduran@ucsd.edu

Tropical Ice Cloud Response - Micro or Macro?



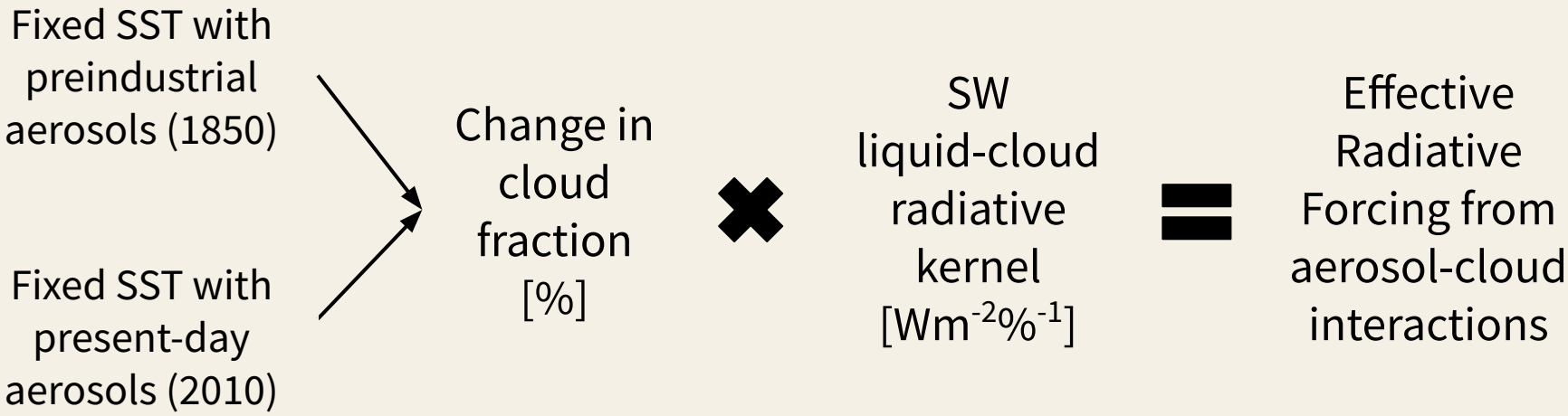
Some evidence of drying in the tropical upper troposphere → changes in the vertical transport of water vapor?

Tropical Ice Cloud Response - Micro or Macro?

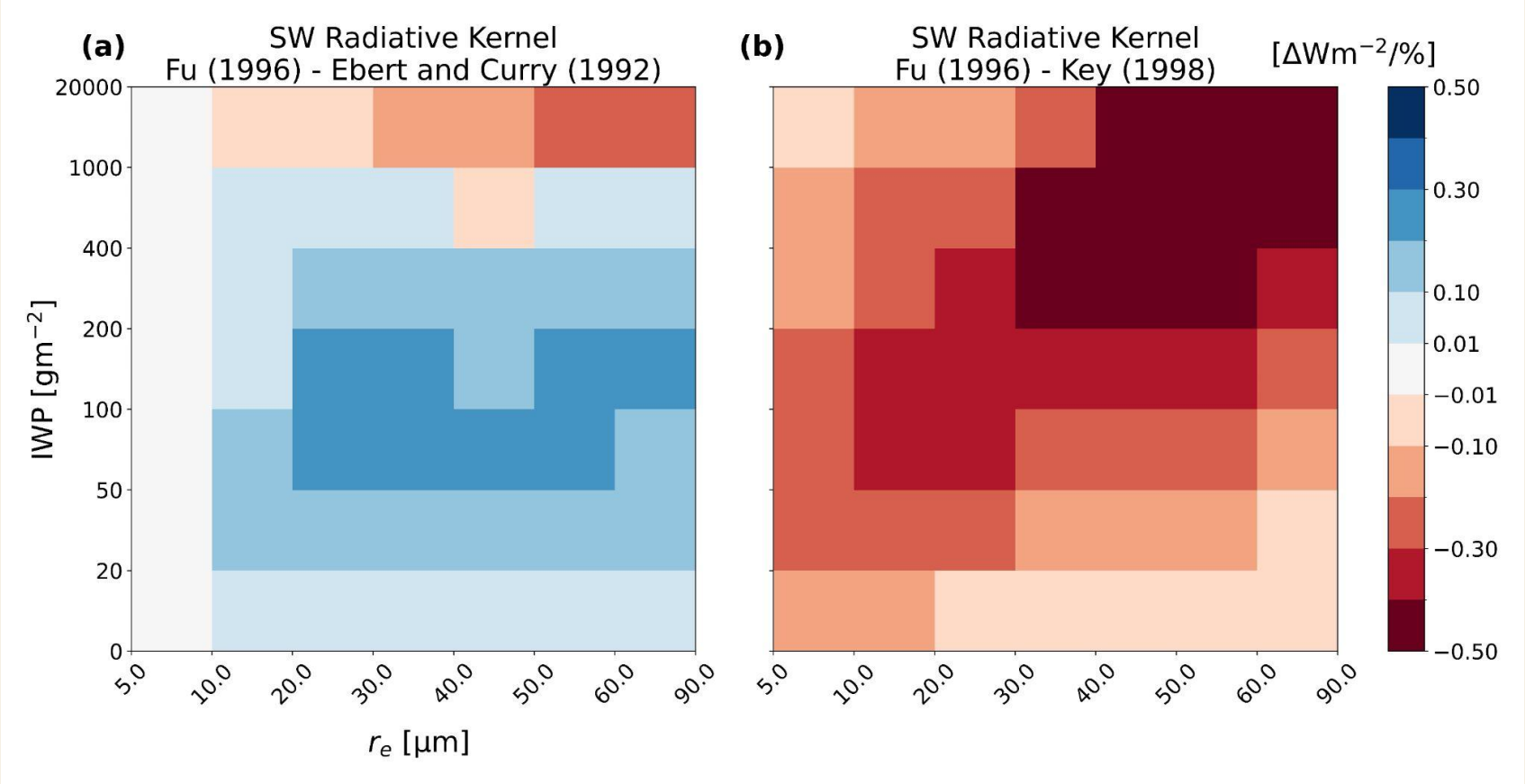


Decreases in IWC

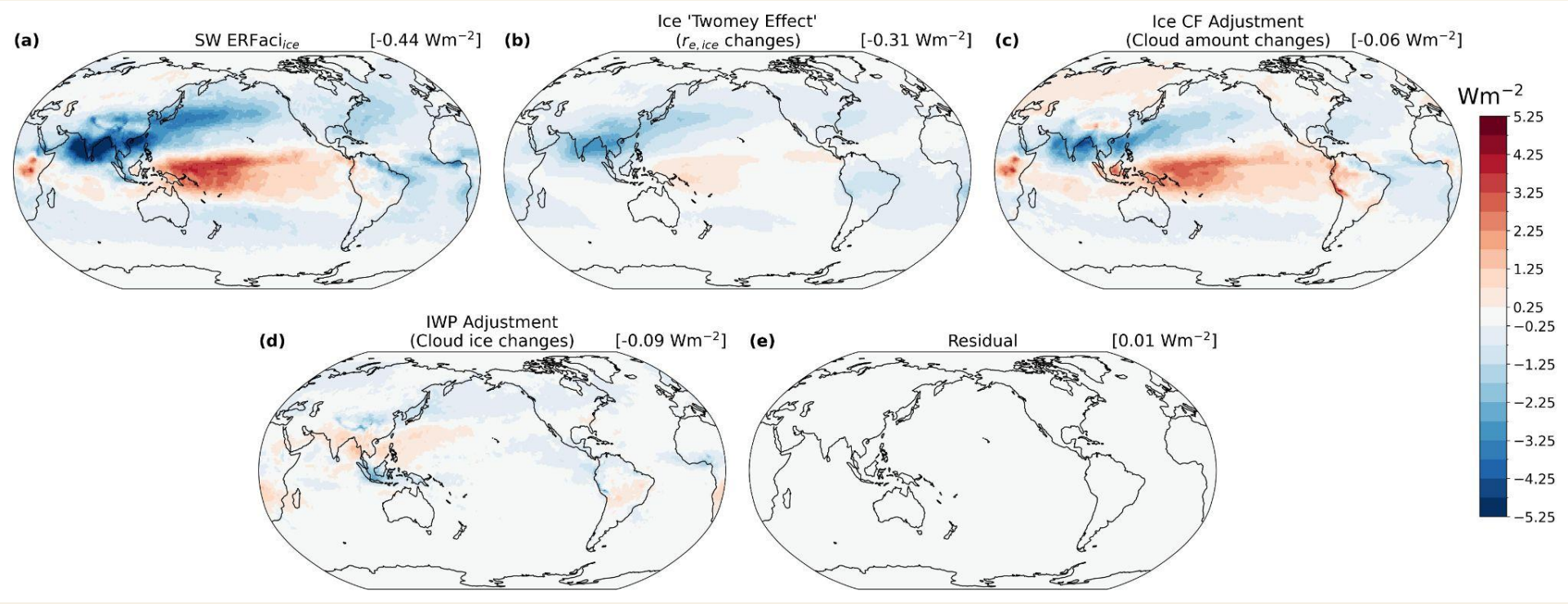
SW ERFaci diagnosis



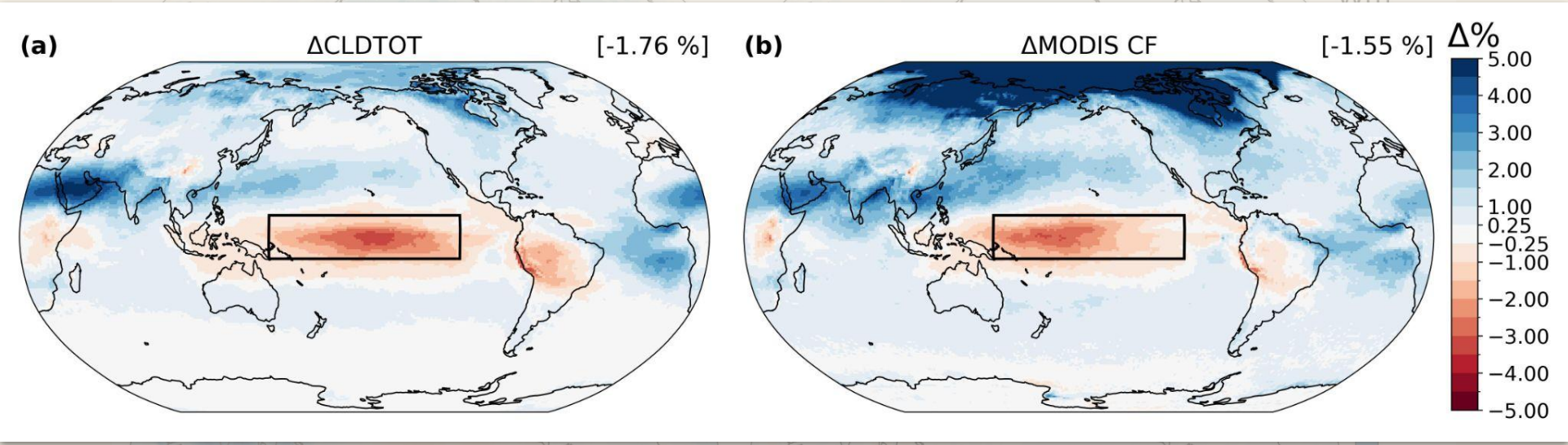
Ice crystal shape parameterization matters!



Residual for our decomposition is small!



Satellite simulator cloud changes don't always line up with model-native cloud changes



This is an inherent limitation of cloud radiative kernel methods

(whereas aerosols induce