A process system approach for addressing climate change uncertainties

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NCAR U.S. DEPARTMENT OF ENERGY Office of Science ASR Atmospheric System Research NSF

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“How Can We Plan Future Process Observations to Reduce Climate Change Uncertainty?”

Climate Prediction Uncertainty: Southern Ocean Aerosol Cloud Interactions in CAM6

What can we do about it?

NCAR: Brian Medeiros, Trude Eidhammer, Sisi Chen, Isla Simpson, John Truesdale, Cecile Hannay, Justin Richling,Jesse Nusbaumer, Jon Petch, Charles G. Bardeen, Chris Kruse, Patrick Veres

PNNL: Susannah Burrows, Andrew Gettelman

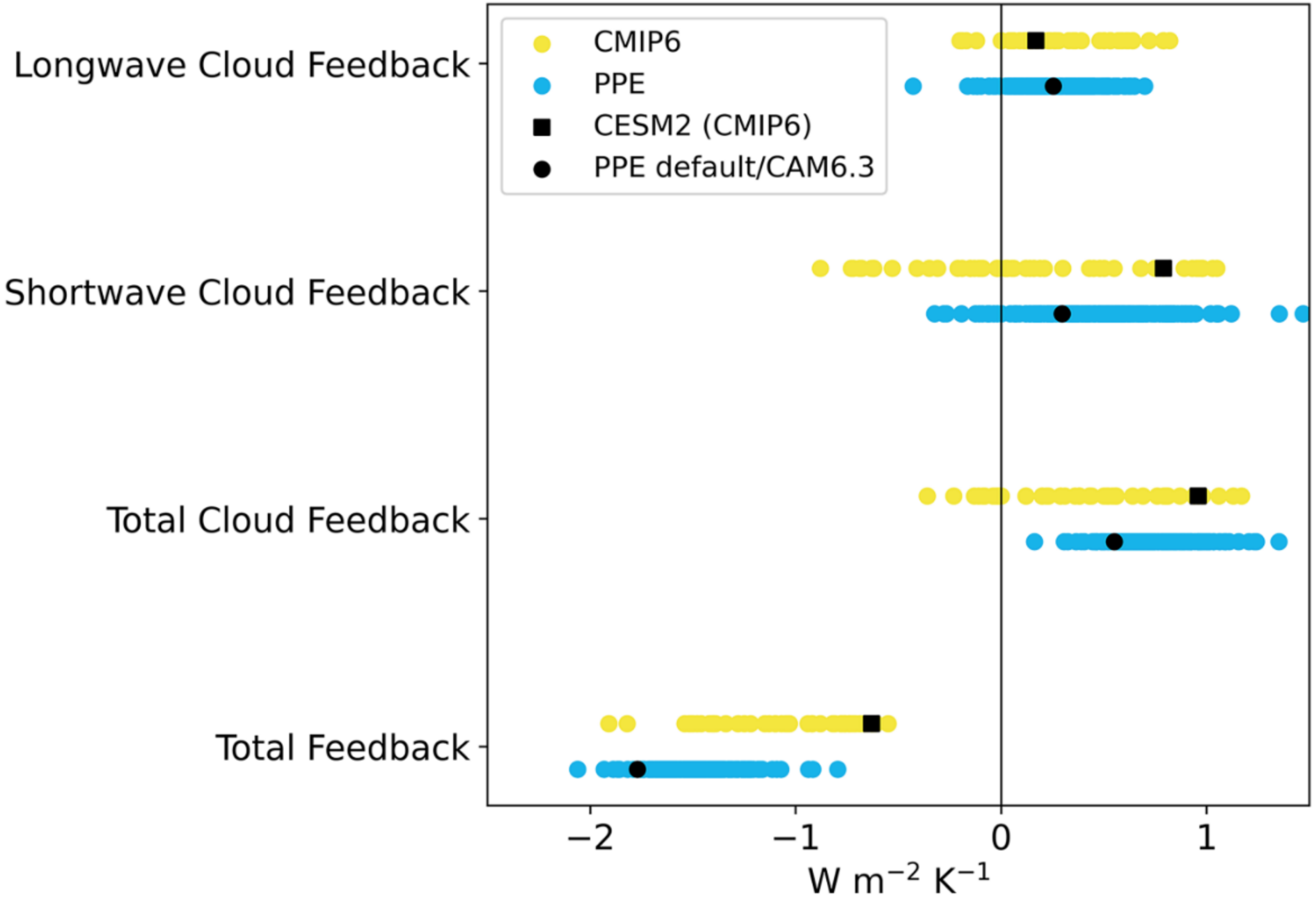
CSU: Paul J. DeMott, Sonia M. Kreidenweis, Jessie Creamean

CIWRO/OU: Greg McFarquhar, Qing Niu

Univ of Utah: Gerald (Jay) Mace

Australian Bureau of Meteorology: Alain Protat

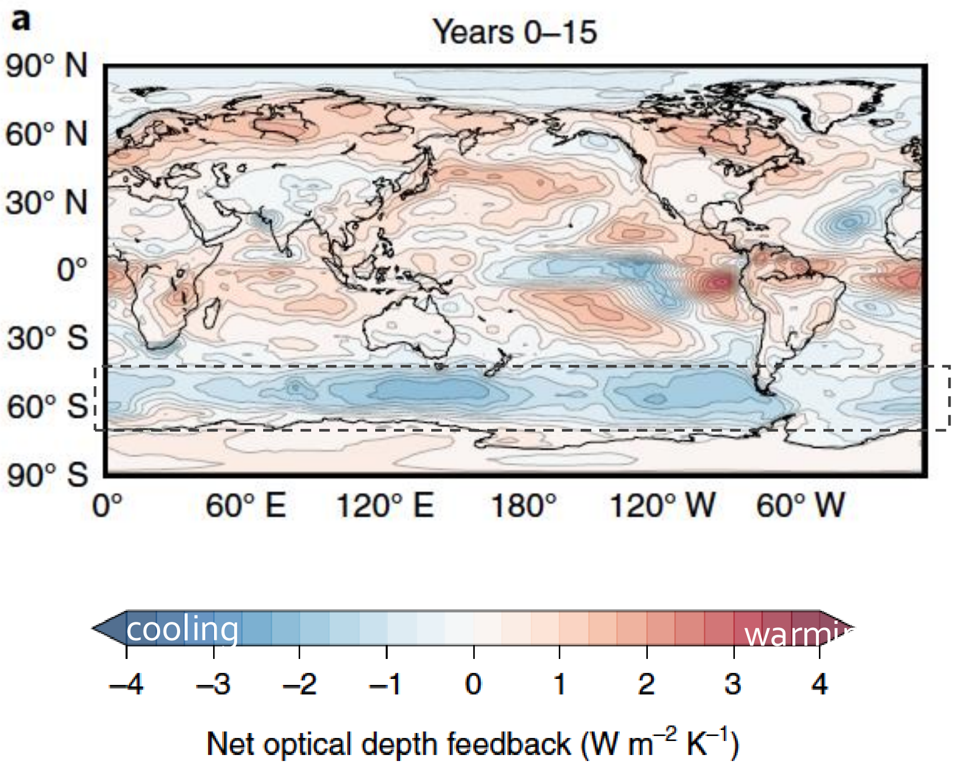
Parametric uncertainty is as large as structural variability across all CMIP models for cloud feedback predictions

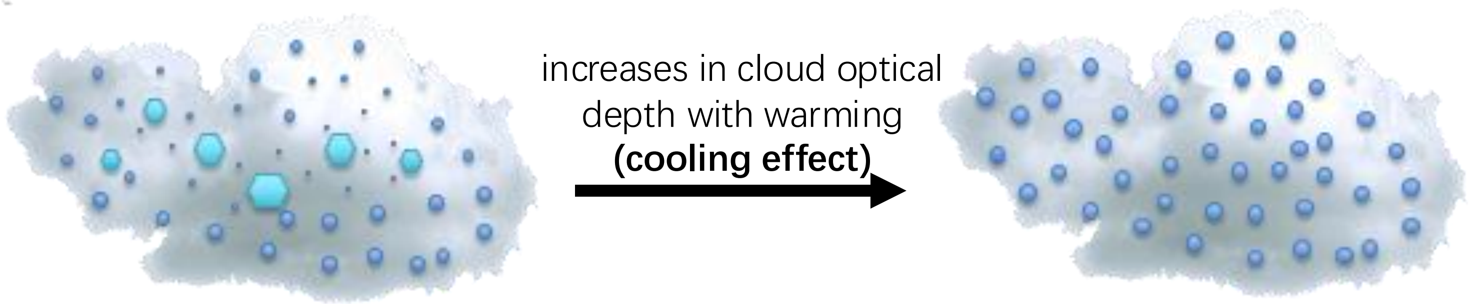


Perturbed Parameter Ensemble (PPE)
CAM6.3, 45 parameters

Duffy et al., 2023

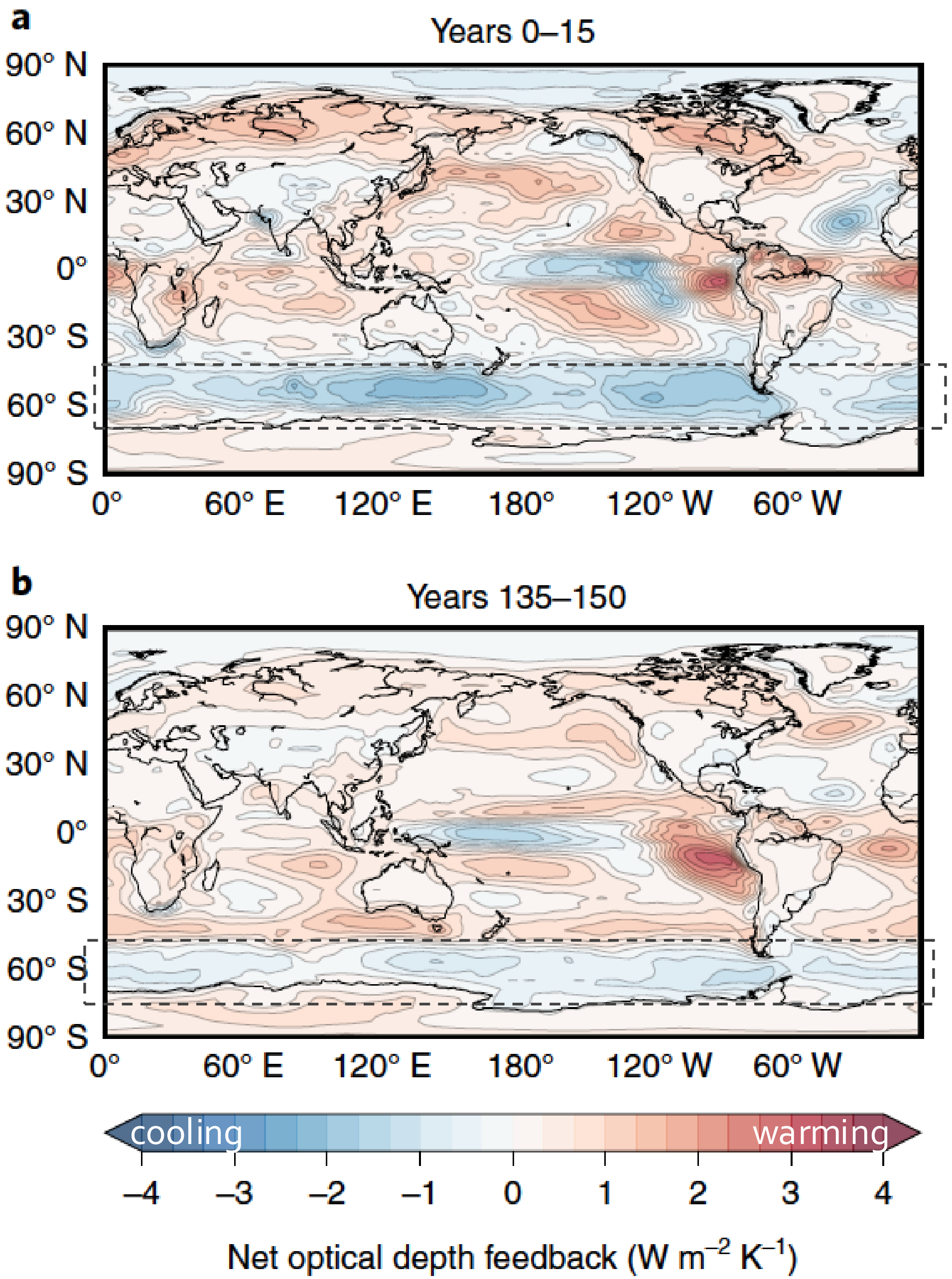
The Southern Ocean negative cloud phase feedback

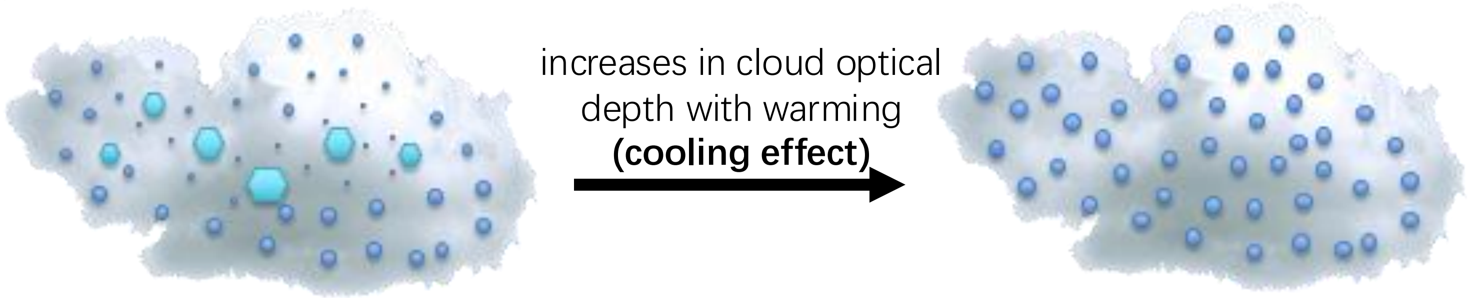




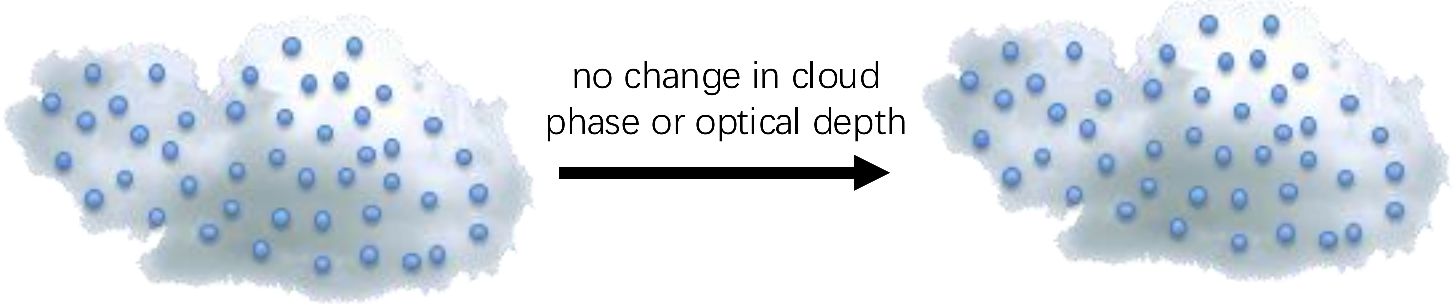
Bjordal et al., 2020

The Southern Ocean negative cloud phase feedback



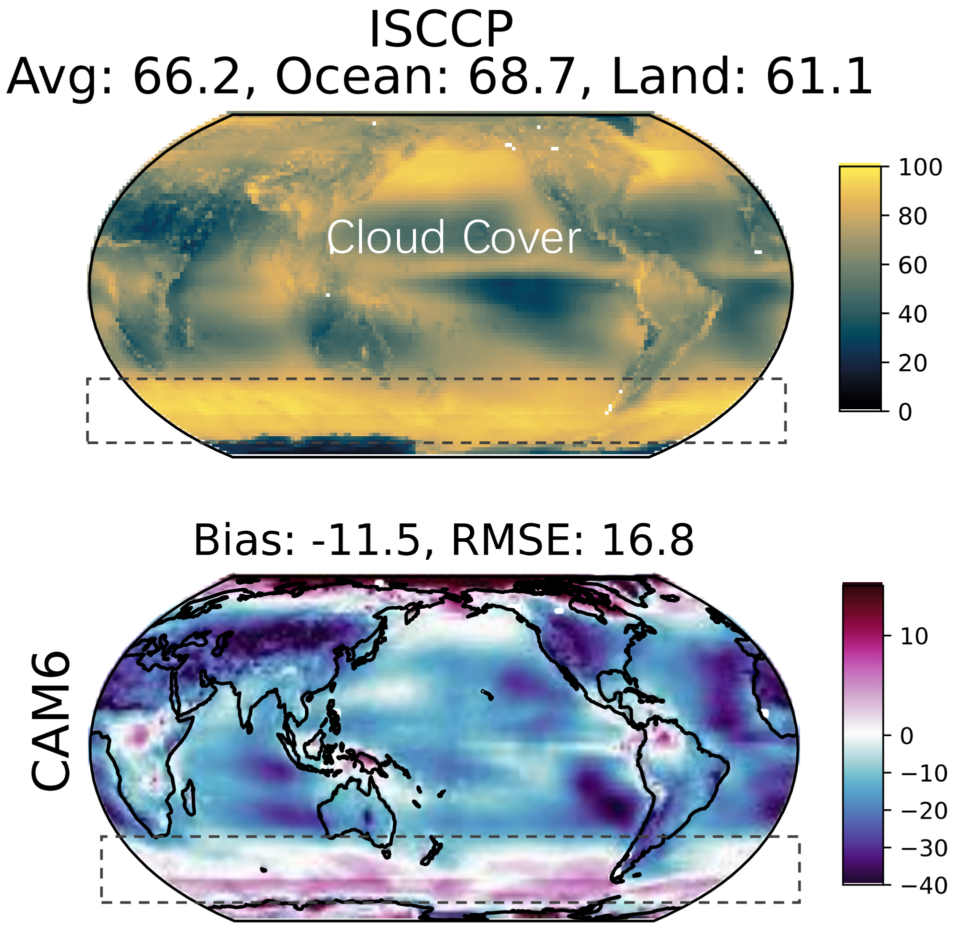


Future projections indicate a dampening of the cloud phase feedback

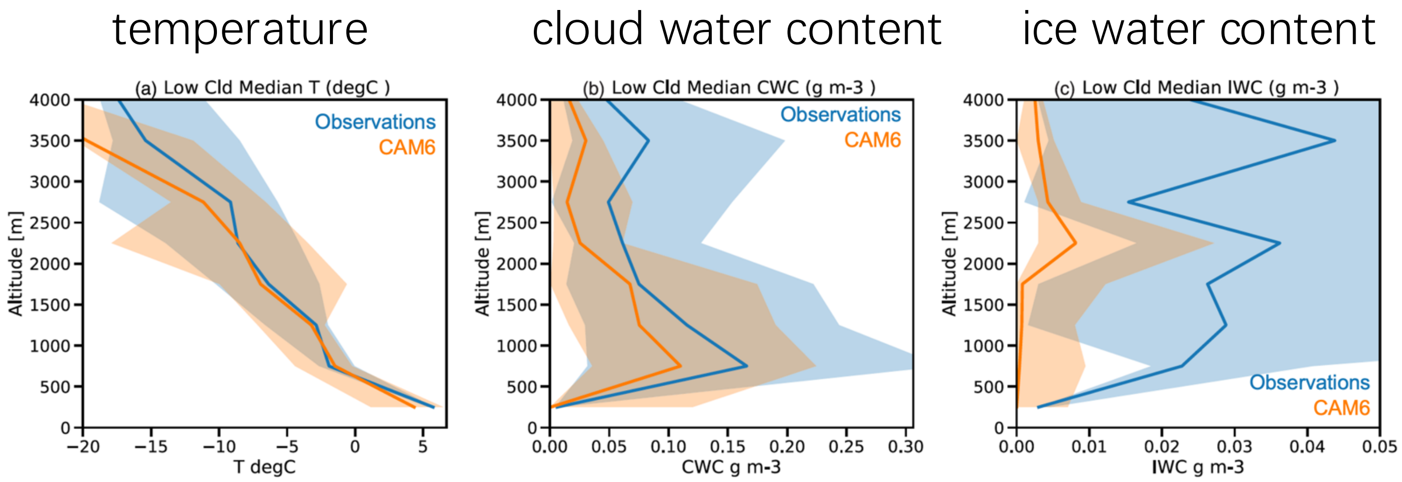


Bjordal et al., 2020

Continued challenges with simulating Southern Ocean clouds



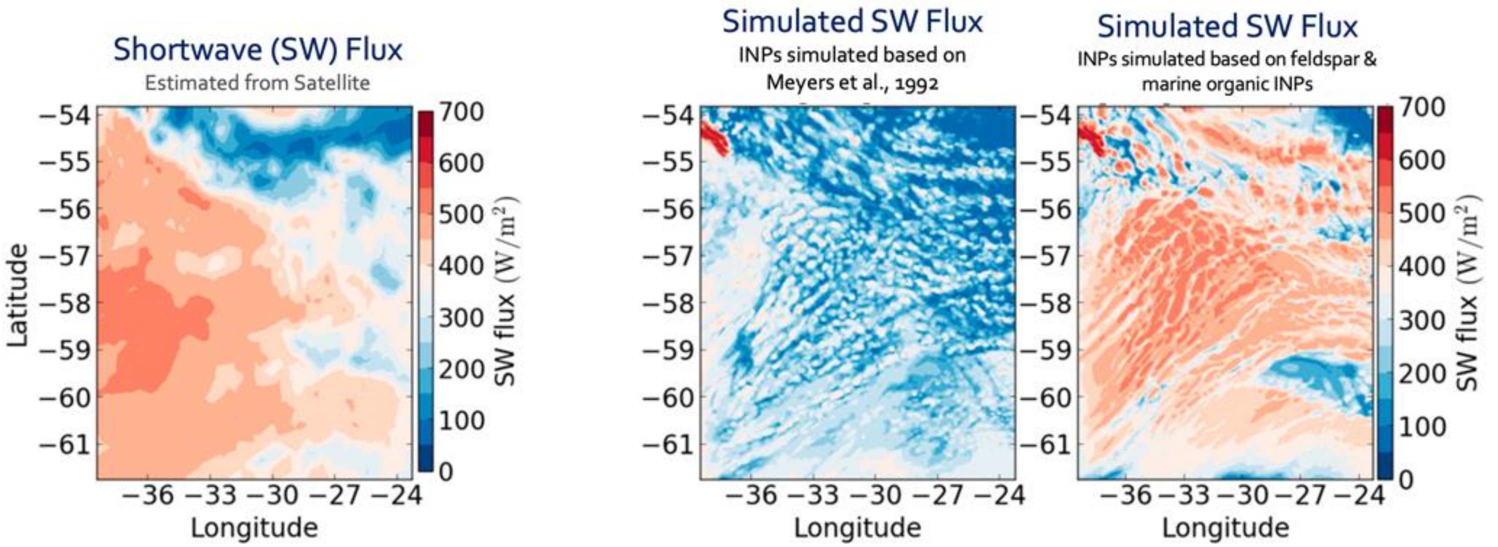
Medeiros et al., 2023



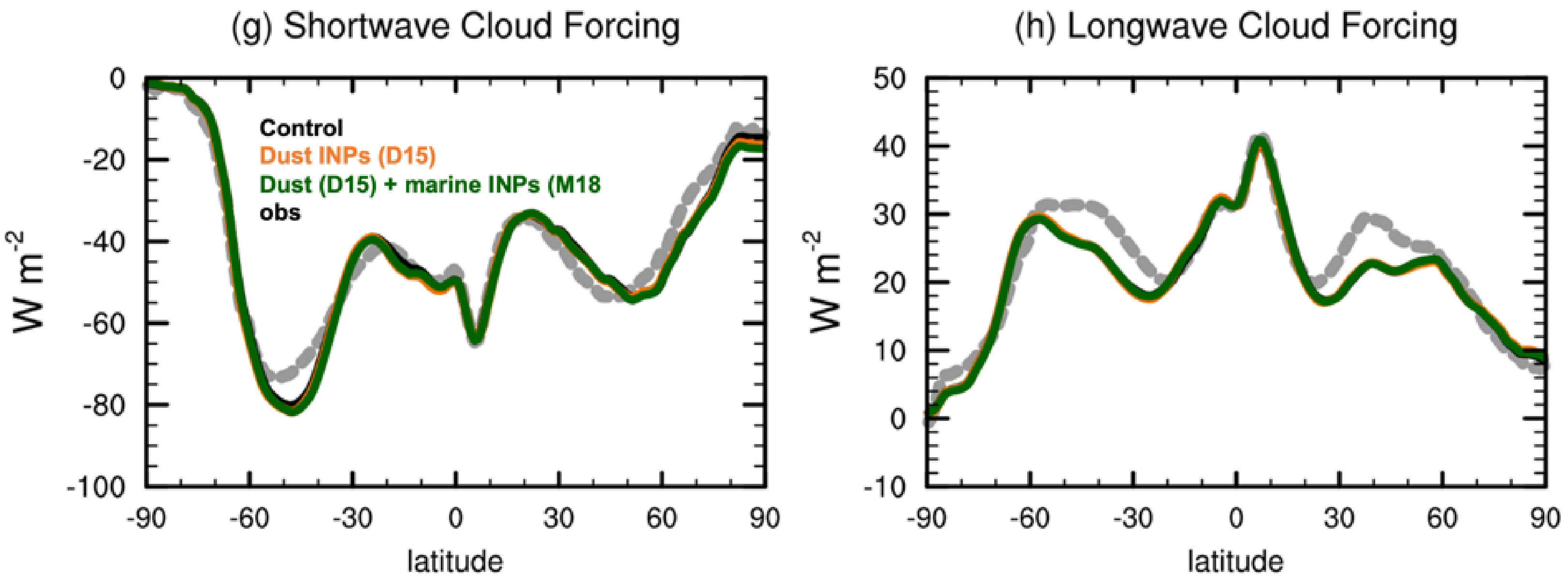
Gettelman et al., 2020

ISCCP = International Satellite Cloud Climatology Project
CAM6 = Community Atmosphere Model v6

Conflicting results regarding the importance of Ice Nucleation

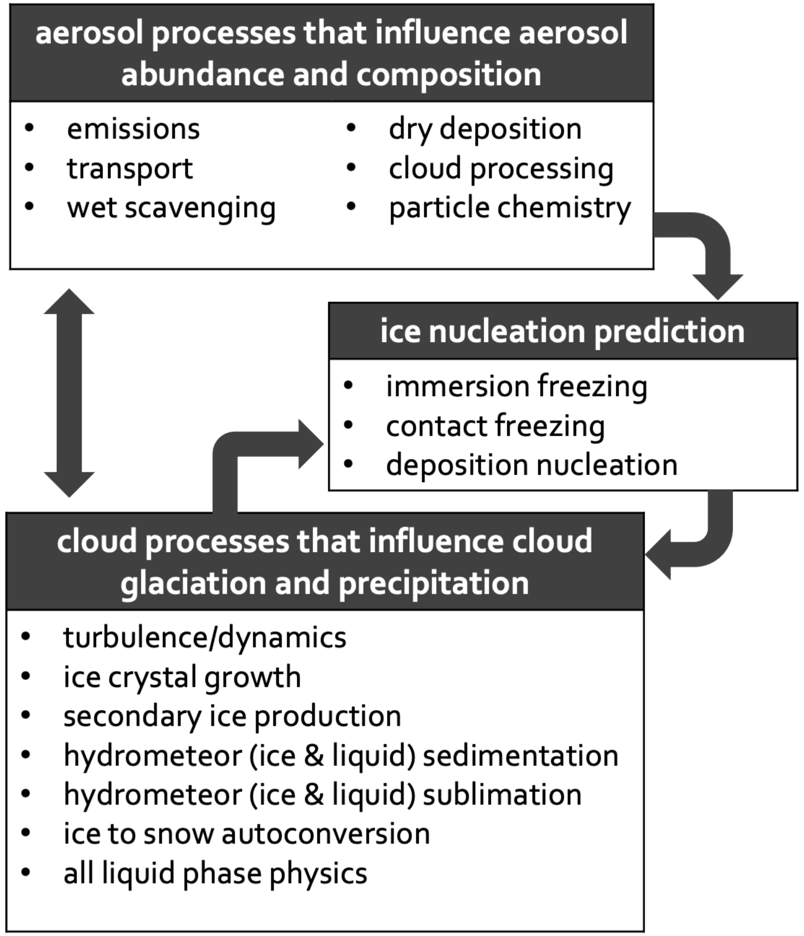


Vergara-Temprado et al., 2018



Zhao et al., 2021

Assessing the ice nucleation *process system* in CAM6



Burrows et al., 2022

D15M18

Mineral Dust INPs: DeMott et al. 2015 (D15)

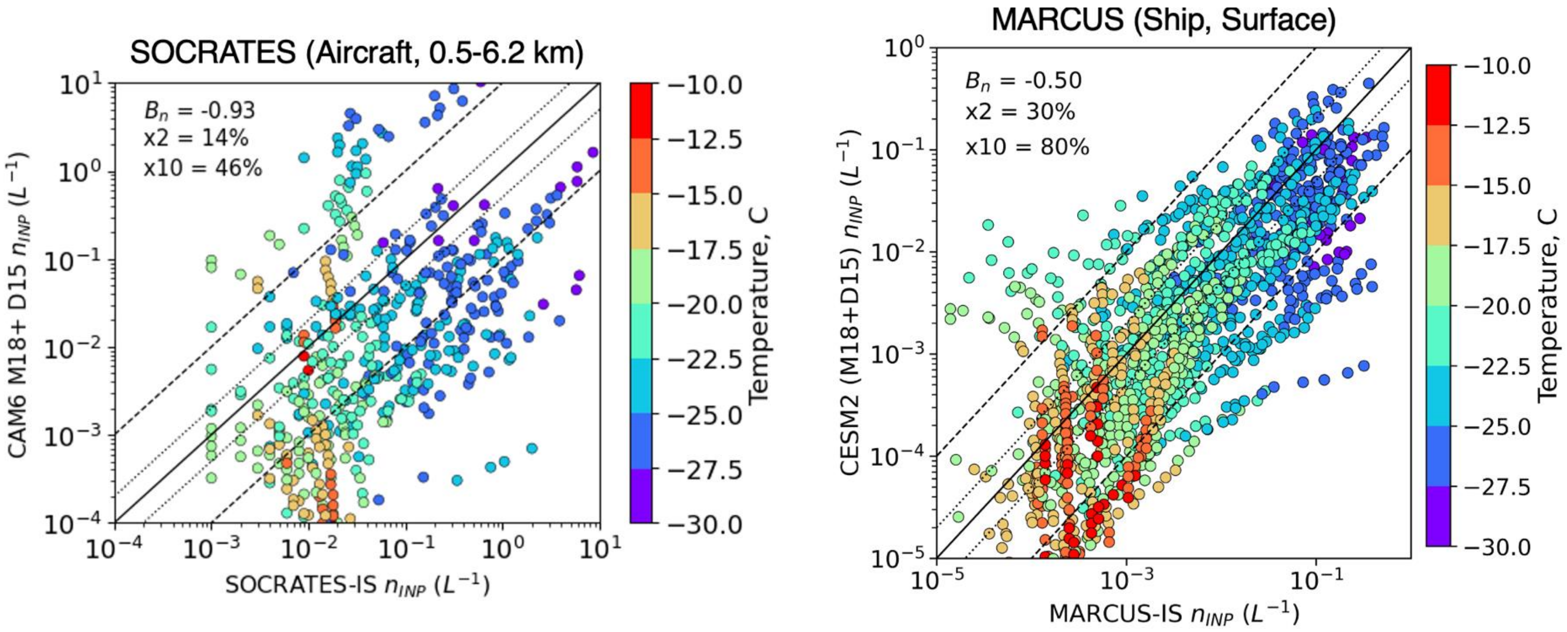
$$n_{INPs}(T) = f(T, \mathbf{n_{500nm,dust}})$$

Marine INPs: McCluskey et al. 2018 (M18)

IN-active molecules

$$n_{INPs}(T) = f(T, \mathbf{S_{seaspray}})$$

$$S_{seaspray} \approx \mathbf{S_{sea\ salt}}$$



McCluskey et al., 2023

What predictability skill do we need for INPs?

Coarse resolution: 2˚ latitude x 2˚ longitude; 32 levels to ~1 hPa

Temporal resolution: 30 minutes (2 year)

Specified dynamics free-running climate

MG2 two-moment cloud microphysics with modified ice nucleation

MAM6 - modal aerosol scheme

CLUBB - boundary layer dynamics scheme

Model Experiments:

Control

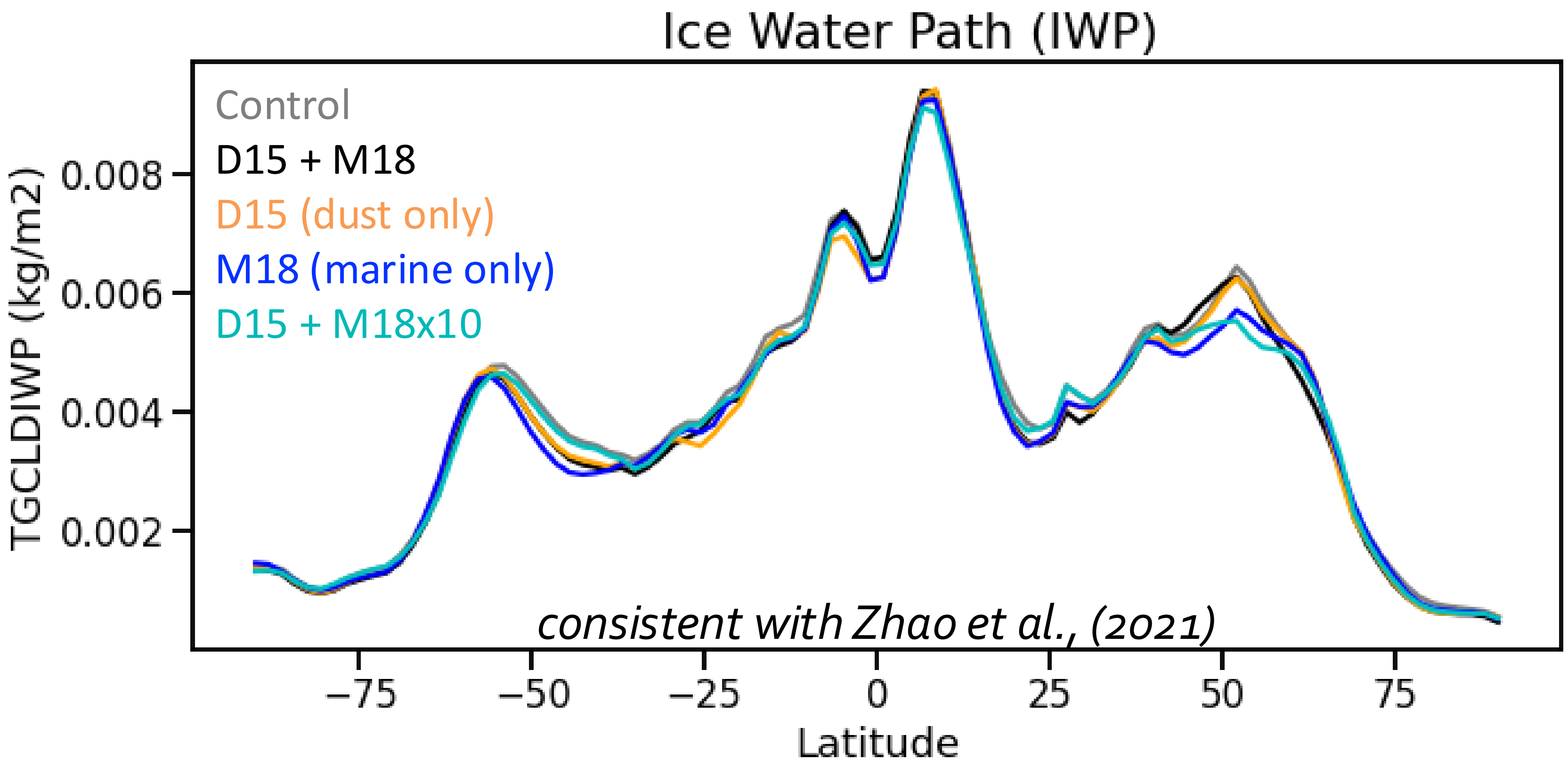
D15 + M18

D15 (dust only)

M18 (marine only)

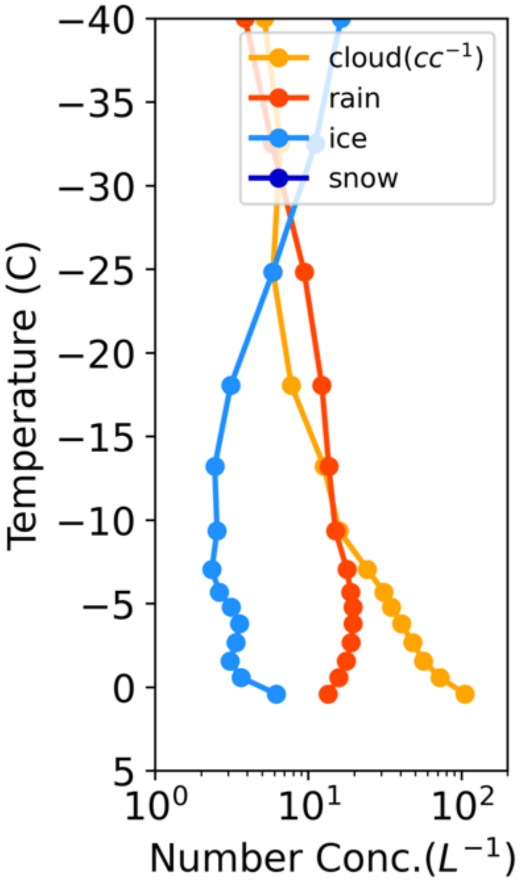
D15 + M18x10

No simulated change in ice water path, liquid water path, shortwave or longwave cloud radiative effects due to changes in ice nucleation



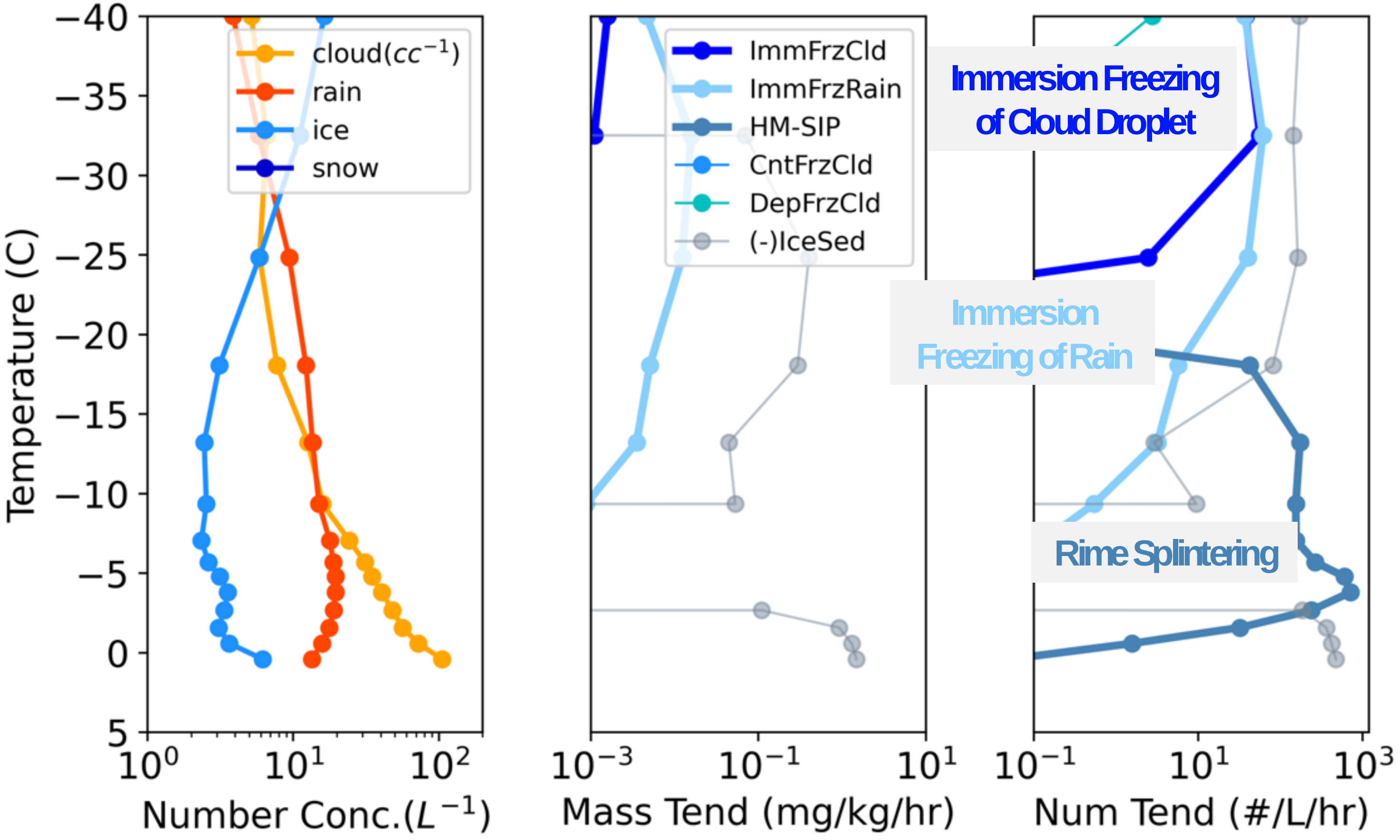
Coarse resolution: 2° latitude x 2° longitude; 32 levels to ~1 hPa
Temporal resolution: 30 minutes
free-running climate, 2 years

CAM6 microphysics tendencies reveal processes that dominate simulated ice formation in Southern Ocean clouds



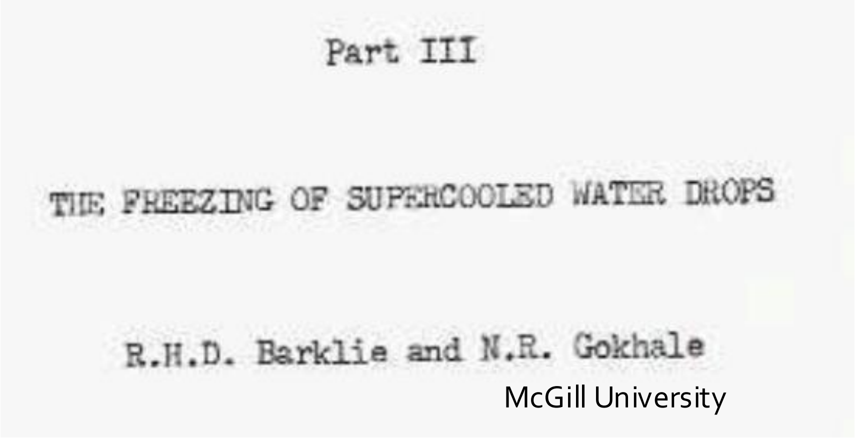
All clouds, DJF, SO region (-65<Lat<-50 and 80<Lon<165)

CAM6 microphysics tendencies reveal processes that dominate simulated ice formation in Southern Ocean clouds



All clouds, DJF, SO region (-65<Lat<-50 and 80<Lon<165)

Immersion Freezing of Rain

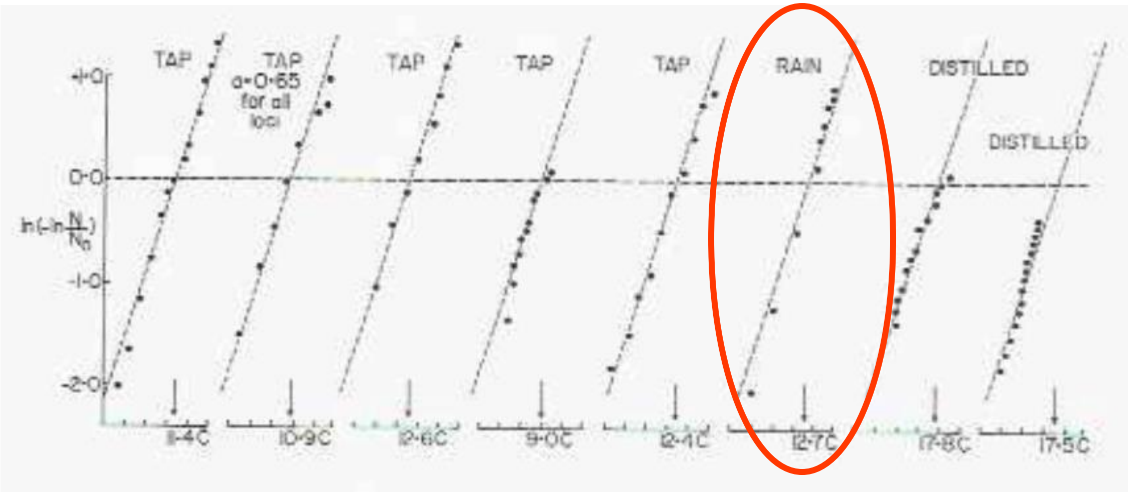


Part III

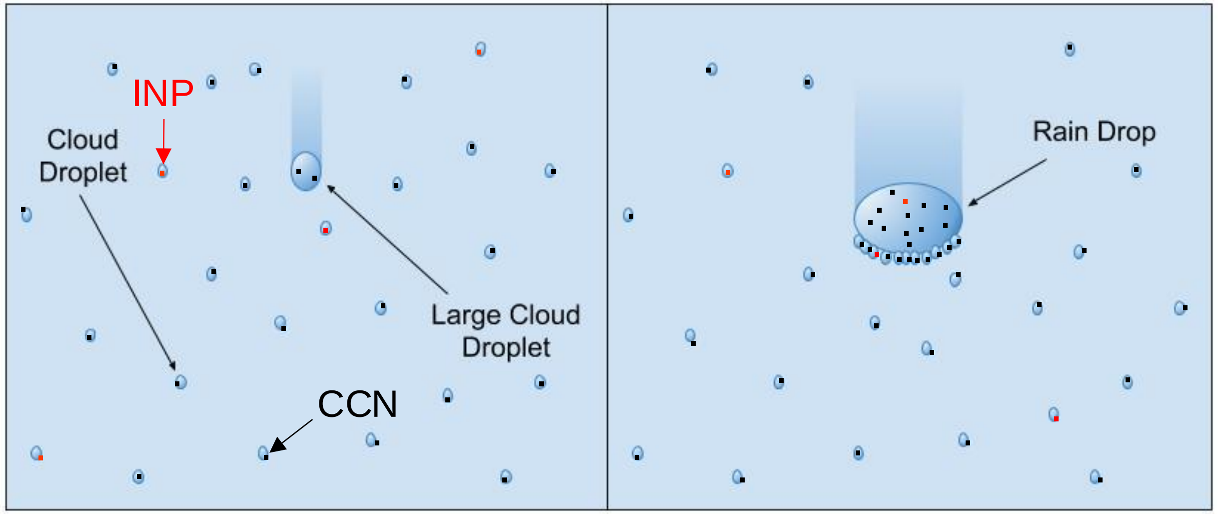
THE FREEZING OF SUPERCOOLED WATER DROPS

R.H.D. Barklie and N.R. Gokhale

McGill University



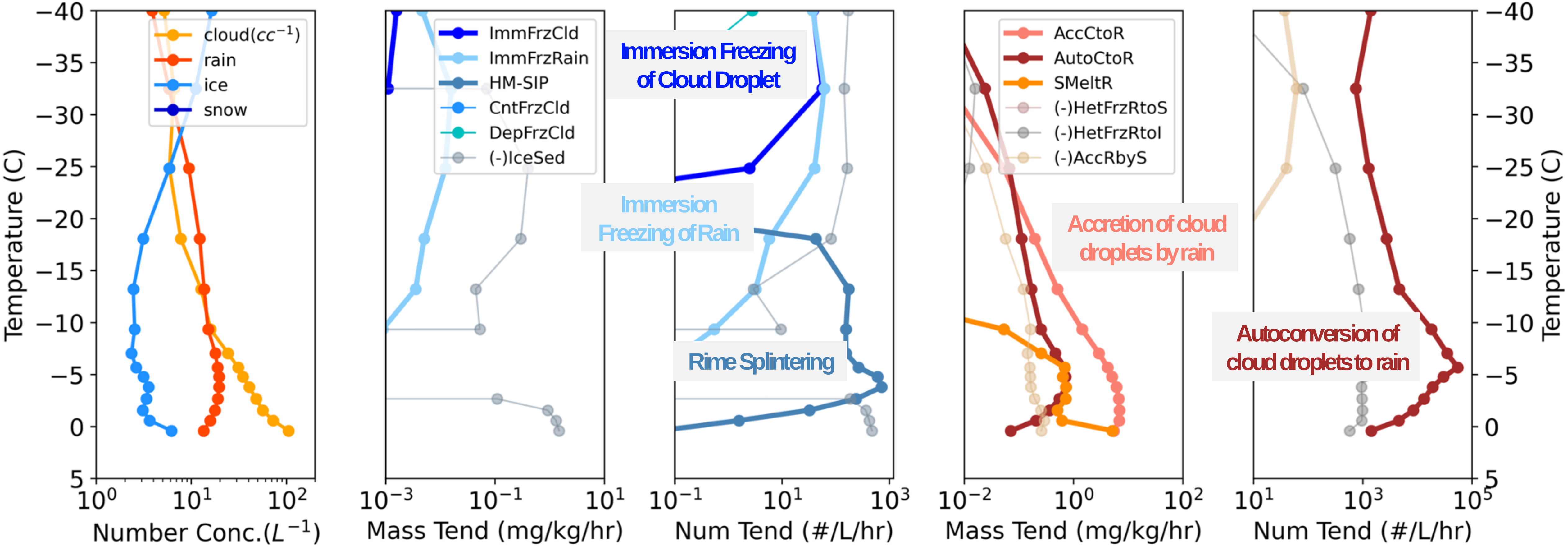
Immersion freezing of rain depends on the cloud's INP population



Thank you to Paul DeMott and Gabor Vali !

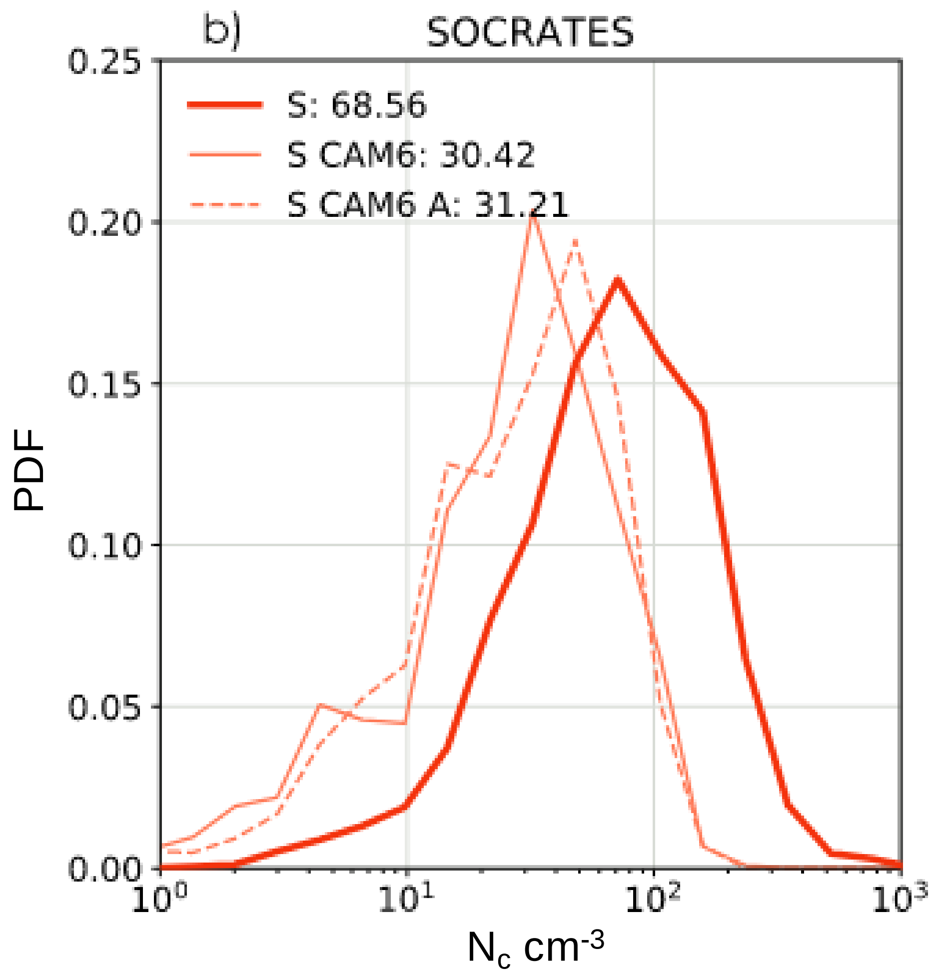
All clouds, DJF, SO region (-65<Lat<-50 and 80<Lon<165)

CAM6 microphysics tendencies reveal processes that dominate simulated ice formation in Southern Ocean clouds



All clouds, DJF, SO region (-65<Lat<-50 and 80<Lon<165)

Low cloud droplet number and high cloud water amount will drive an over-active autoconversion process in CAM6



I. McCoy et al. (2021)

Autoconversion of cloud droplets to rain

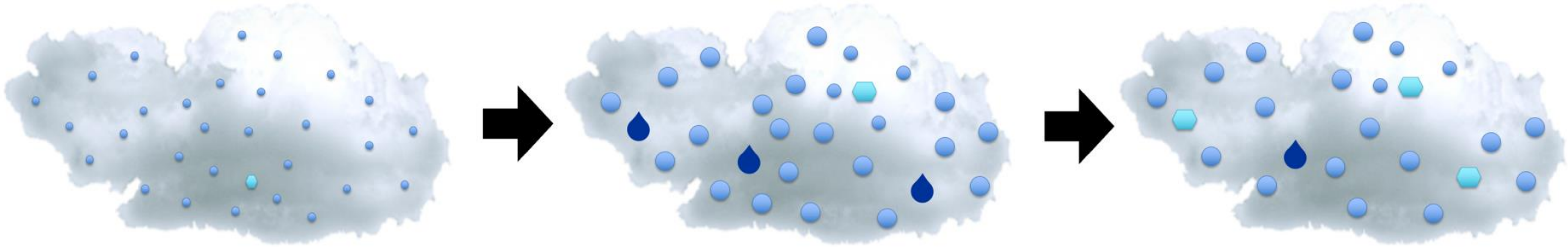
$$\left(\frac{\partial q_r}{\partial t}\right)_{auto} = F_{auto}\ c\ q_c{}^{a}\ N_c{}^{b}$$

$$\left(\frac{\partial q_r}{\partial t}\right)_{auto} = F_{auto}\ 1350\ q_c{}^{2.47}\ N_c{}^{-1.79}$$

q_c = cloud water content
N_c = cloud droplet number concentration
F_{auto} = autoconversion factor
a = micro_mg_autocon_lwp_exp = 2.47
b = micro_mg_autocon_nd_exp = -1.1
c = coefficient

Khairoutdinov and Kogan, 2000

Deficiencies in simulating the ice nucleation *process system* highlight a need for process-oriented diagnostics



Low bias in N_d:

- low bias in CCN concentrations (emissions, transport, chemistry, scavenging)
- sub-grid vertical velocity
- Overactive sink from autoconversion and accretion

Supercooled Rain

- A low bias in N_d in SO clouds drives an over-active autoconversion process
- Rain number concentrations in CAM6 far exceed INP number concentrations

Rain Freezing:

- Dominates simulated initial ice formation
- Triggers secondary ice production (only HM rime splintering)

Despite progress in predicting Southern Ocean ice nucleating particles, **the impacts of aerosol on Southern Ocean clouds and ECS are still unknown.**

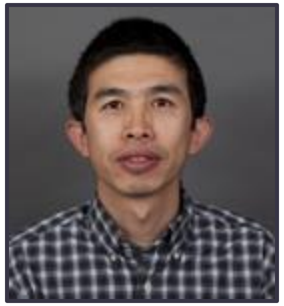
INFORM: Integrating Field Observations and Research Models

An NSF NCAR Director's Office Initiative aims to accelerate scientific discovery by strengthening observation-model integration through building community-ready tools

Gretchen Mullendore
Mesoscale & Microscale Meteorology

Allison McComiskey
Earth Observing Laboratory

Jon Petch
Climate and Global Dynamics Laboratory



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Project Scientist, MMM

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Scientist, MMM

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Wen-Chau Lee
Senior Scientist, EOL

COMPASS

COmmunity Model Process-oriented Assessments for Earth System Science

Targeted Process Systems

1. warm phase aerosol-cloud interactions in stratocumulus to cumulus transition regime
2. convective dynamics and precipitation *(tentative)*
3. atmosphere-land interactions *(tentative)*

1. Observation Process System Database
2. Observation Contextualization
3. CESM Co-located Assessments
4. CESM Process System Assessments

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Justin Richling
Associate Scientist

Isla Simpson
Scientist

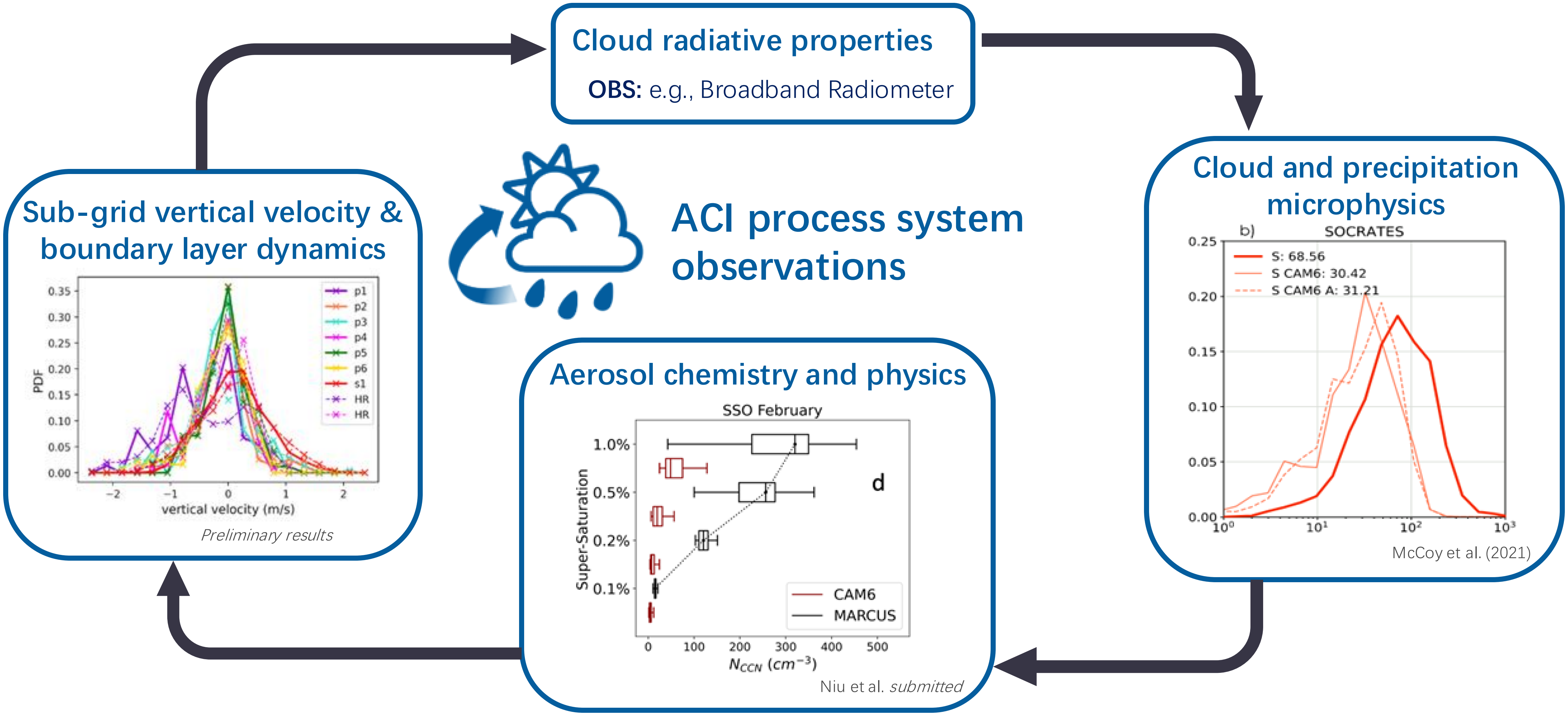
John Truesdale
Software Engineer

Chris Kruse
Project Scientist

Janine Anquino
Software Engineer

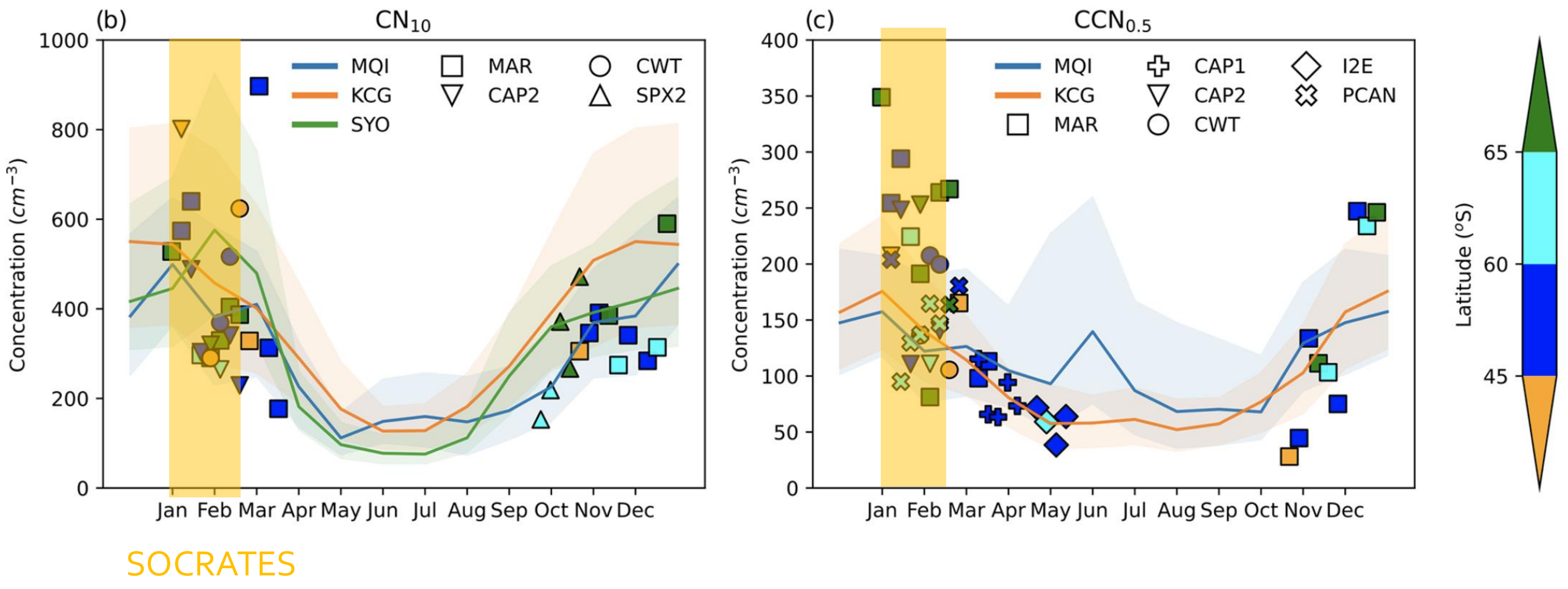
+ 2 postdocs!

Observation process system database for streamlined model assessment

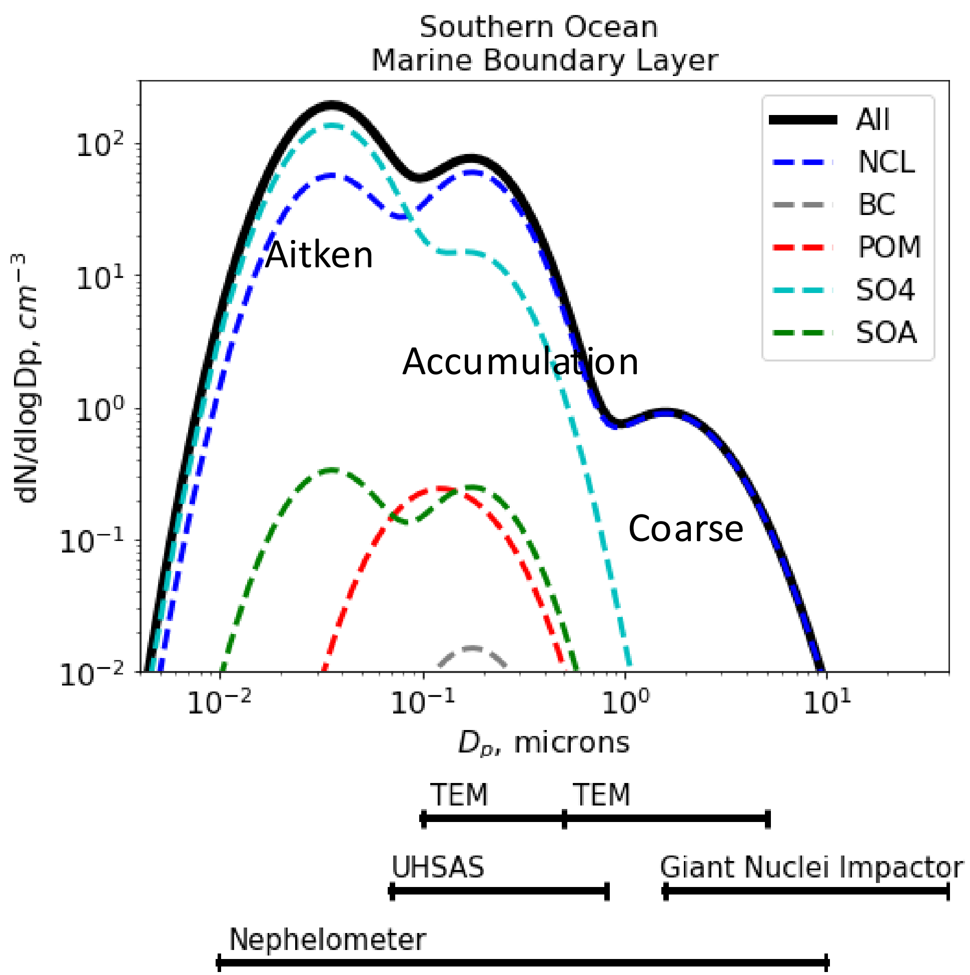


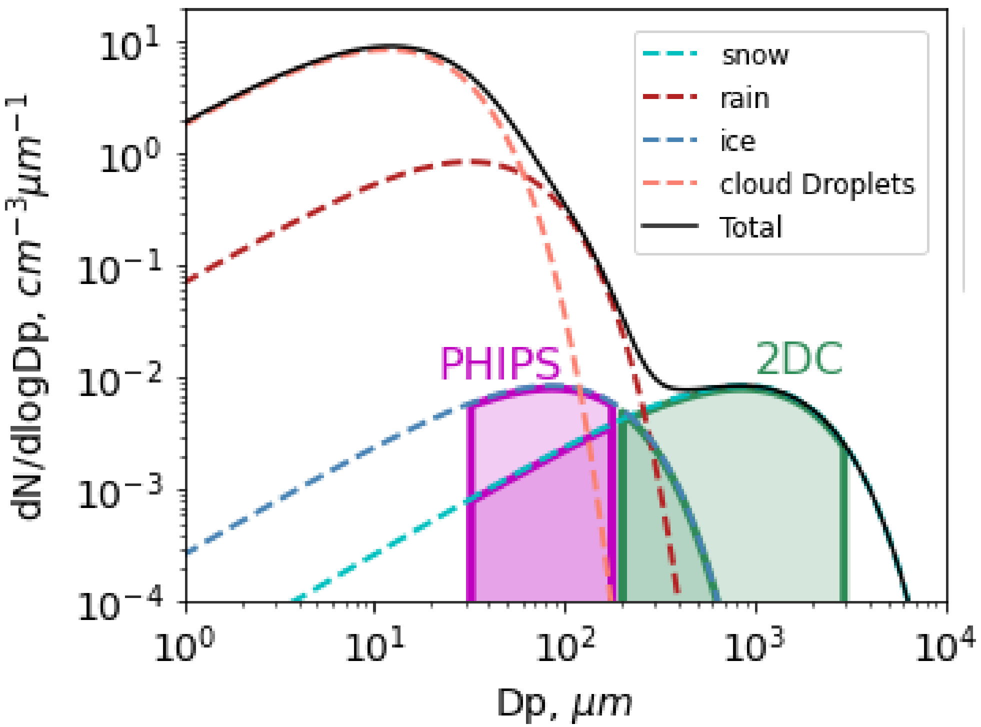
Best practices are needed for addressing representation and scale mismatches

- Contextualize and composite observation period (cloud type, aerosol conditions)
- Establish best practices for model (nudging methods, resolution)

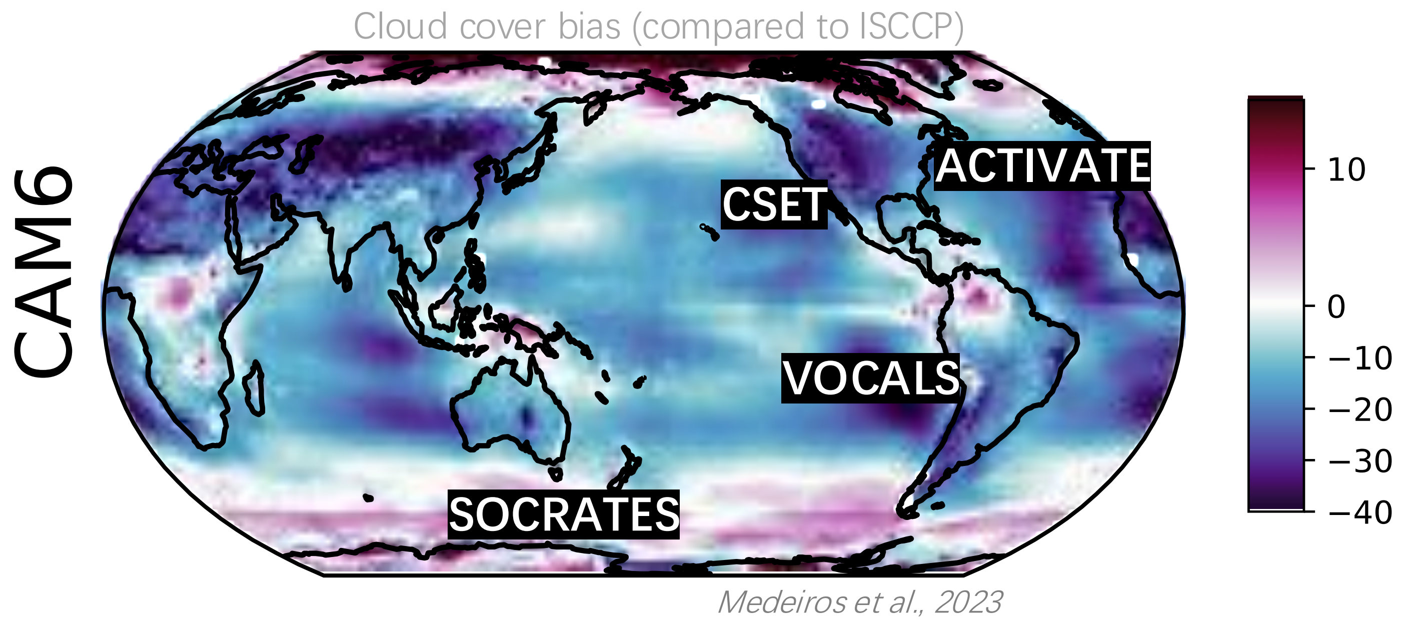


“deploy” instrument simulators in model for co-located comparisons between model and field observation data





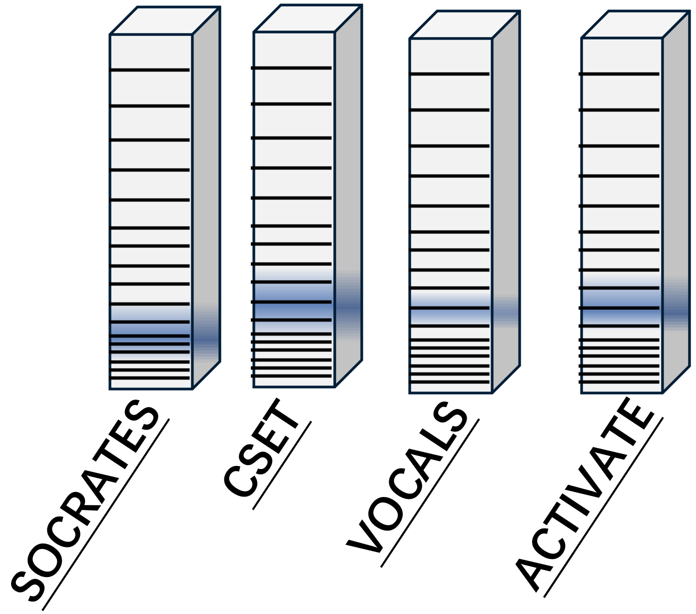
Build a suite of single column atmosphere model (SCAM) IOPs paired with composited process system observations



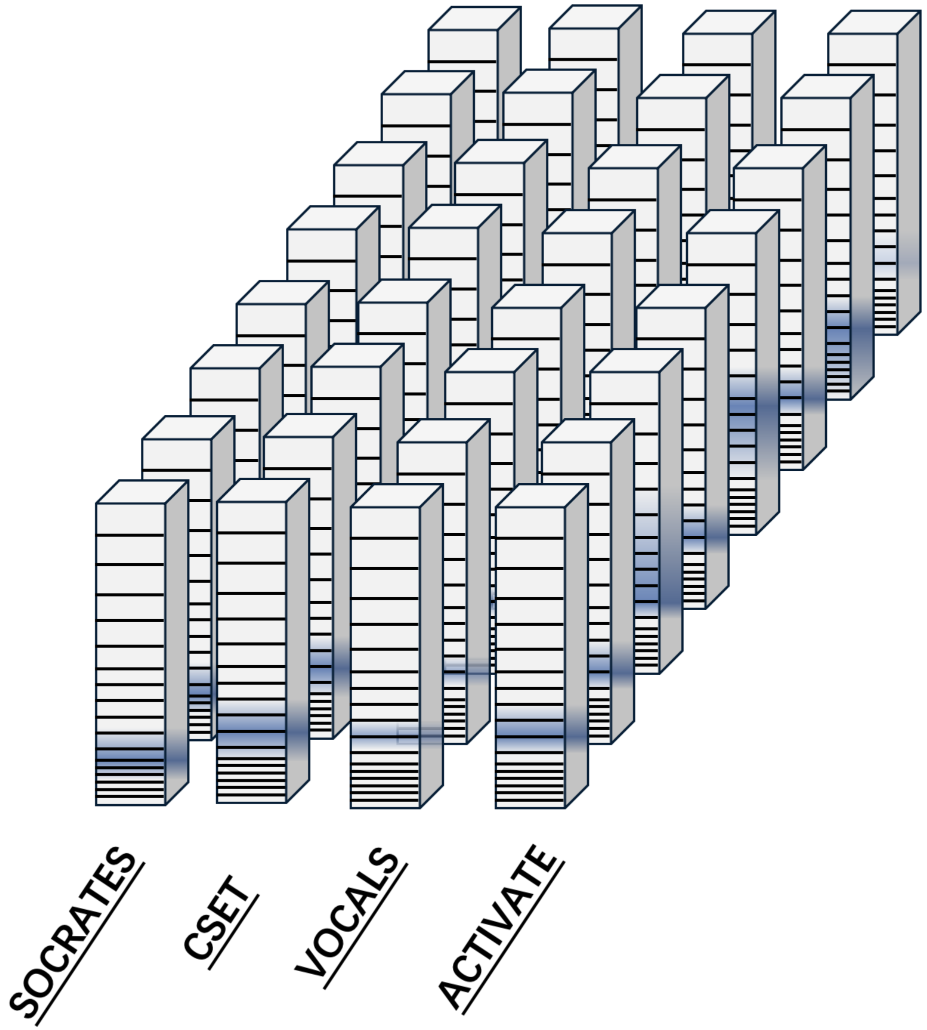
ACI process system observations

+

Suite of SCAM intensive observation period (IOP)



Build a suite of single column atmosphere model (SCAM) IOPs with composited process system observations



Utilities:

- SCAM Perturbed Parameter Ensemble
- Parameterization testing
- Model tuning decision making

Looking forward – how do we do this?

- **Integrate field observations and research models with a focus on process systems**

- **Establish common best practices for field campaign design and execution**
  - "anchor" measurements that trace back to model variables
  - Observation closure studies for parameterizations testing
  - Create guidance for measurement requirements (e.g., ice nucleation, Table 1, *Burrows et al.,* 2022)
  - **Δt !!** –
    - airmass tracers needed,
    - methods for tracking and identifying cloud lifecycle stage,
    - slow-moving platforms –or- multiple platforms

- **Other needs**
  - Laboratory studies (!) that provide a starting point for e.g., SIP
  - Vertical aerosol distributions (e.g., Teathered Balloon/drone measurements)
  - Observations that target natural perturbations (e.g., wildfires) or efforts to conduct (safely and responsibly) cloud seeding experiments

- **Express concerns re: funding**
  - Typically 3 year proposals for field campaigns is extremely challenging for bridging observations and models
  - Where can we automate efforts and leverage large institutions for these services (e.g., NCAR, DOE ARM)