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Evolution of CESM Cloud Microphysics: Parameterization of Unified Microphysics Across Scales (PUMAS)

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Cloud Microphysics Kills!

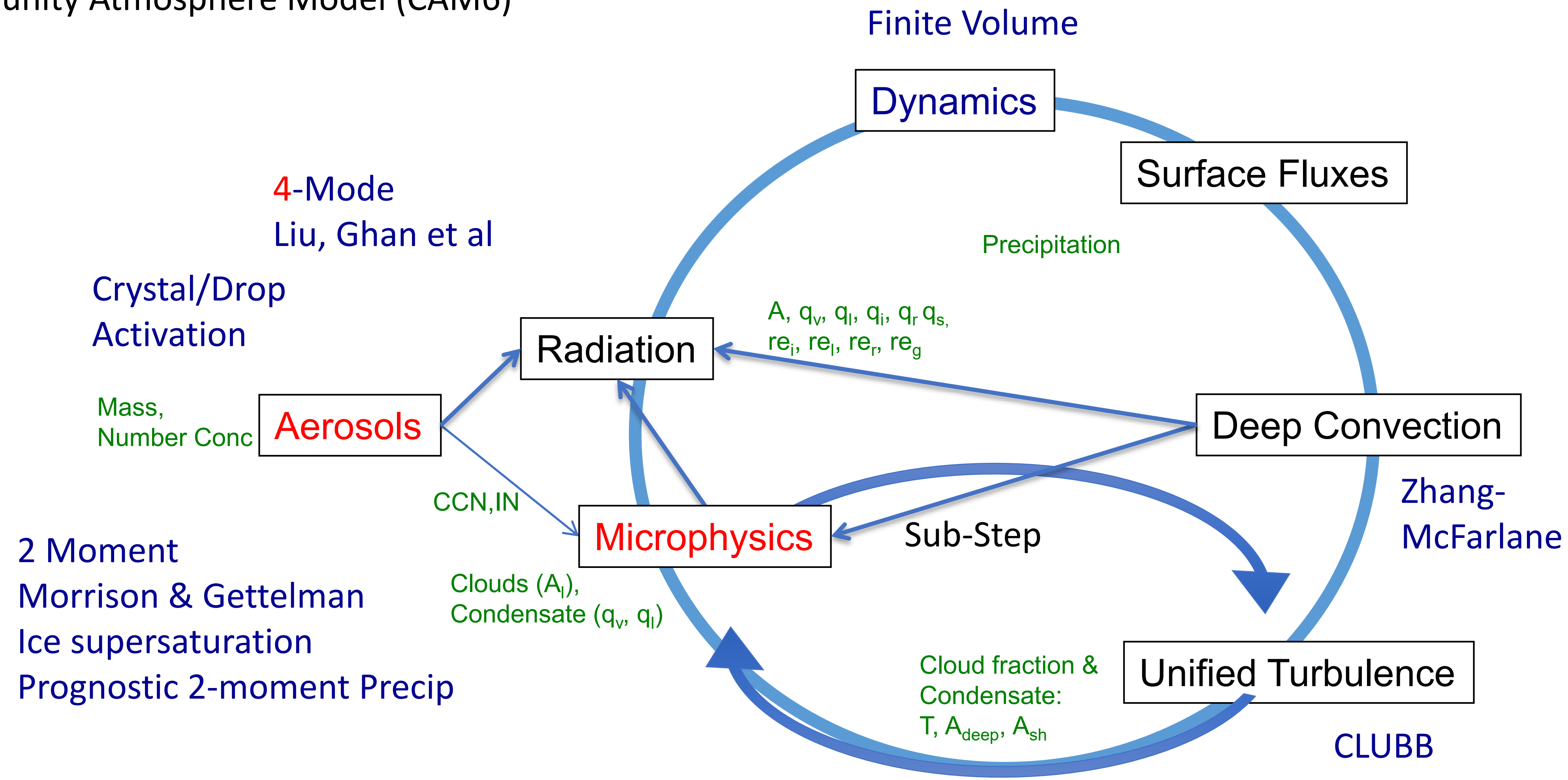
- Clouds are responsible for most severe weather
  - Tornadoes, Thunderstorms, Hail, Tropical Cyclones
- Critical processes depend on cloud microphysics (Thunderstorms, Hail, even Tornadoes)

Outline

- What is cloud microphysics
- CAM Microphysics Evolution
- Some current work
- Where do we go from here: introducing a new name (PUMAS)

What is Cloud Microphysics?

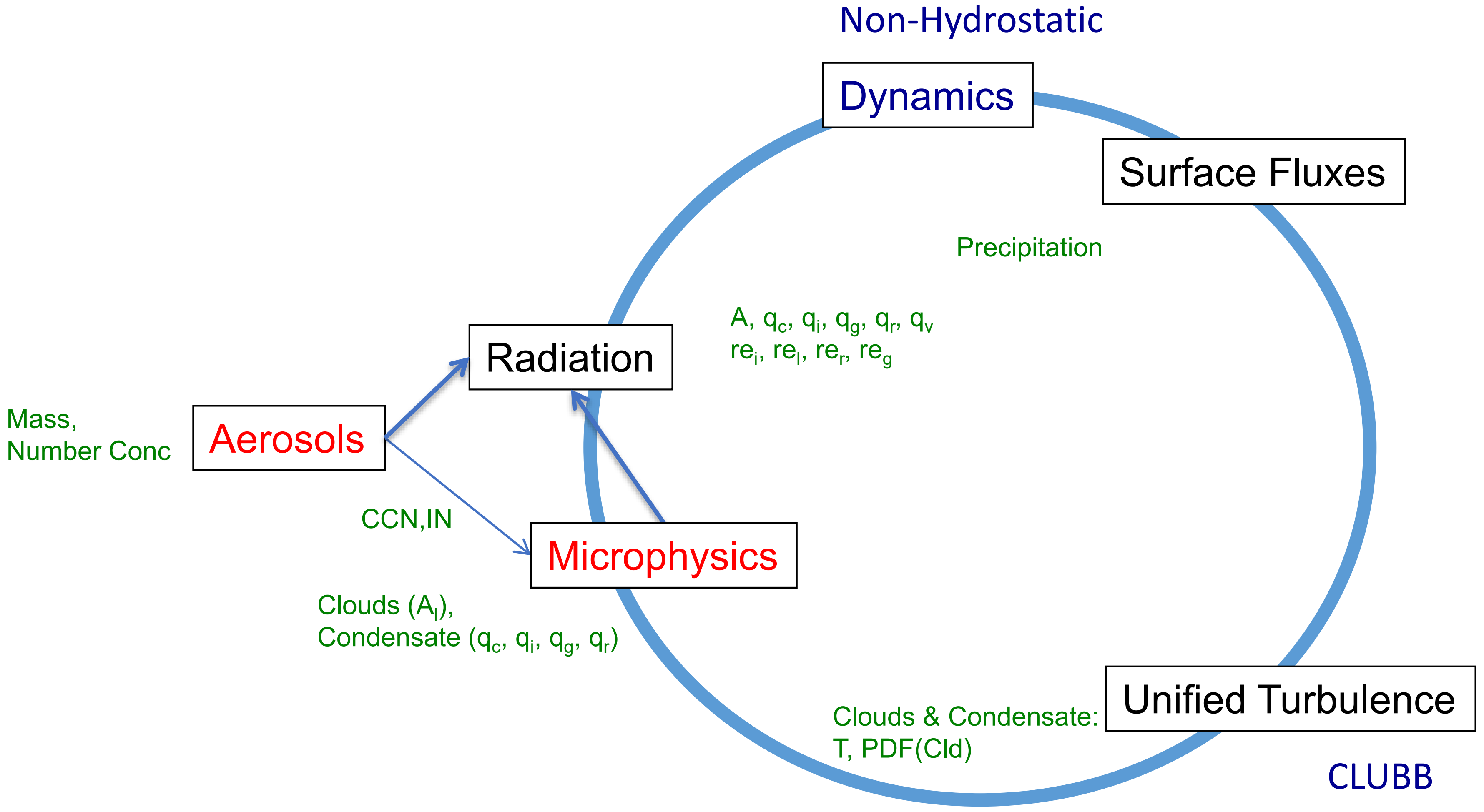
Community Atmosphere Model (CAM6)



A = cloud fraction, q=H_2O, re=effective radius (size), T=temperature
(i)ce, (l)iquid, (v)apor, (r)ain, (s)now

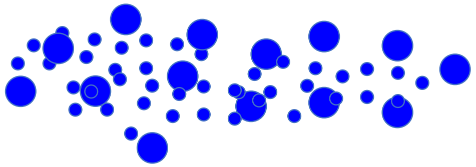
Still need Microphysics Regardless of scale…

What if you ran CAM at 7km? 2km? 1km?



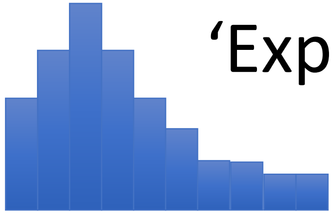
A = cloud fraction, q=H_2O, re=effective radius (size), T=temperature
(i)ce, (l)iquid, (v)apor , (g)raupel (rimed ice)

Types of Microphysical Schemes



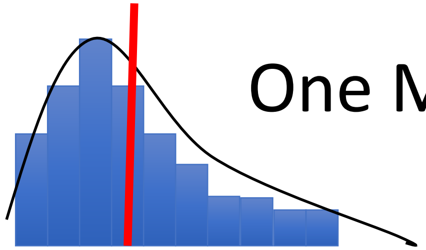
Lagrangian or “Superdroplet’

Follow Lagrangian trajectories of “super-droplets”
Represent individual drop interactions with each other



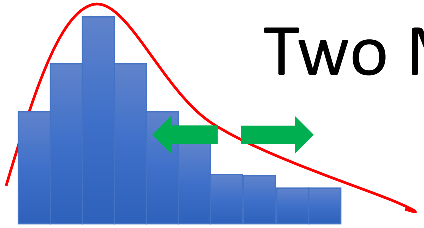
‘Explicit’ or Bin

Represent the number of particles in each size ‘bin’
Number and/or mass by bin for each ’class’ of hydrometeor. Computationally expensive, but ‘direct’



One Moment (Bulk)

Predict the total mass
(Usually) represent the size distribution with a function (fixed shape, size)
Mass for different ‘Classes’ (Liquid, Ice, Precip)
Computationally efficient



Two Moment (Bulk)

Predict mass and number giving more flexibility
Represent the size distribution with a function (fixed or variable shape)
Distribution function for different ‘Classes’ (Liquid, Ice, Precip)

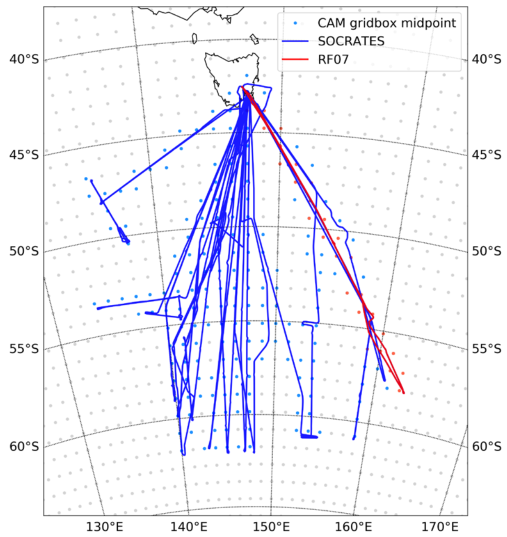
CAM Microphysics Evolution

- CAM4: 1 moment (Rasch & Krisjansson 1998)
- CAM5: 2 moment (MG: Morrison & Gettelman 2008)
- CAM6: 2 moment+ Prognostic Precip (MG2: Gettelman & Morrison 2015)
  - Convective microphysics available (Song and Zhang 2011)
- CAM6.2: 2 moment + Rimed Ice (MG3: Gettelman et al 2019) [On CAM Trunk]
- Other efforts
  - MG2 + Unified Ice (Eidhammer et al 2016)
  - Optimization and GPU directives added (CISL)
- MG2 or MG3 currently being used/available in versions of:
  - CAM5/6 derivative modes (e.g. E3SM & NorESM, others), GISS (Ackerman), GEOS (Barahona)
  - Ported to CCPP as part of NOAA testing
  - Also ported to ECMWF-IFS for comparisons (current work)
  - Made available to Climate Modeling Alliance (CliMA: Caltech effort)

Some current work

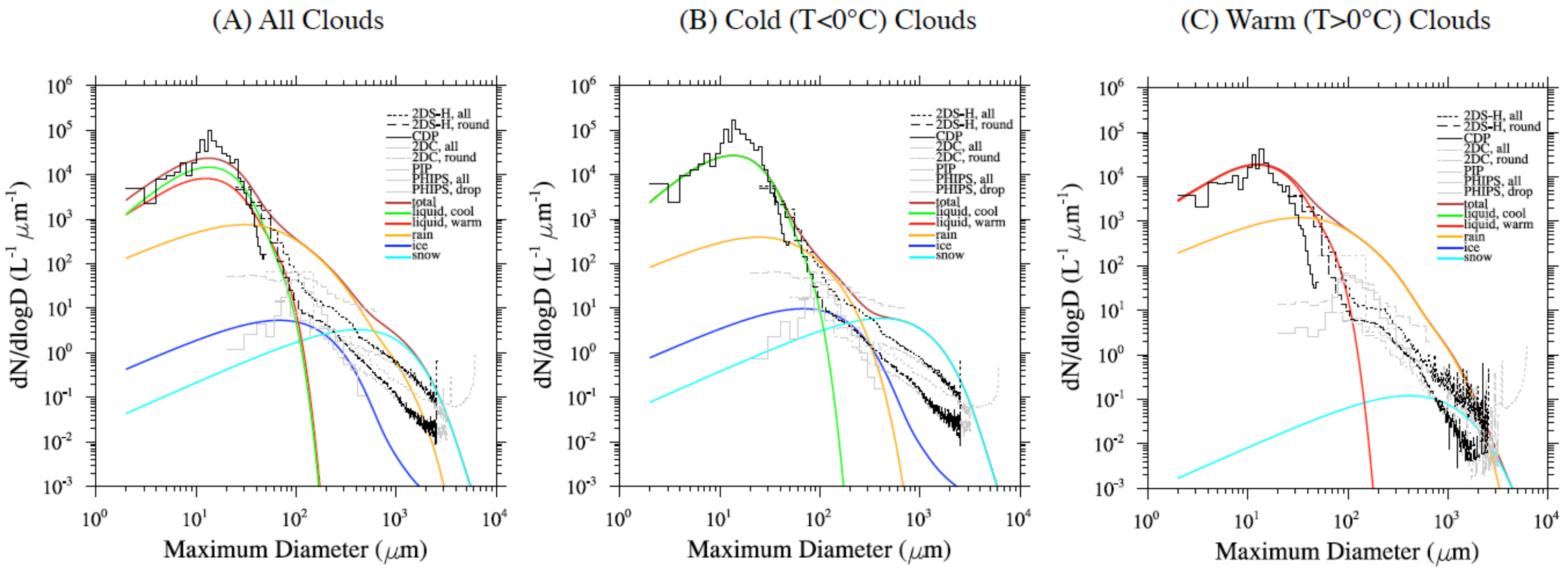
- S. Ocean Cloud Studies
- Unified Ice porting into MG3
- Machine learning the warm rain process
- Not discussed (maybe elsewhere)
  - Optimization and GPU Port of MG2 microphysics (CISL, Dennis Group)
  - CCPP version of MG3 from NOAA
  - Ice nucleation, especially in mixed phase (McCluskey)
  - CARMA sectional aerosols/cloud modeling with CAM

Southern Ocean Cloud Studies (SOCRATES)



CAM6 simulations along flight tracks in the S. Ocean (Jan-Feb 2018)

- Model size distributions compared to observations.
- CAM6 does very well (this is a 100km global GCM v. in-situ aircraft)
- Not enough supercooled liquid water (distribution not peaked enough)
- Too much warm rain
- Using this to play with the functional form of size distributions



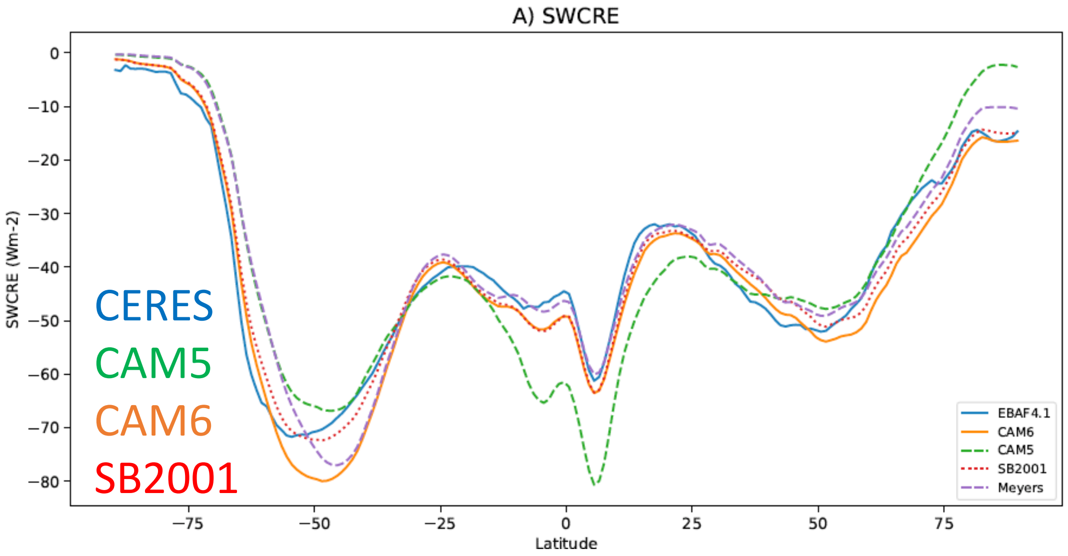
Gettelman et al 2020 (Submitted to JGR)

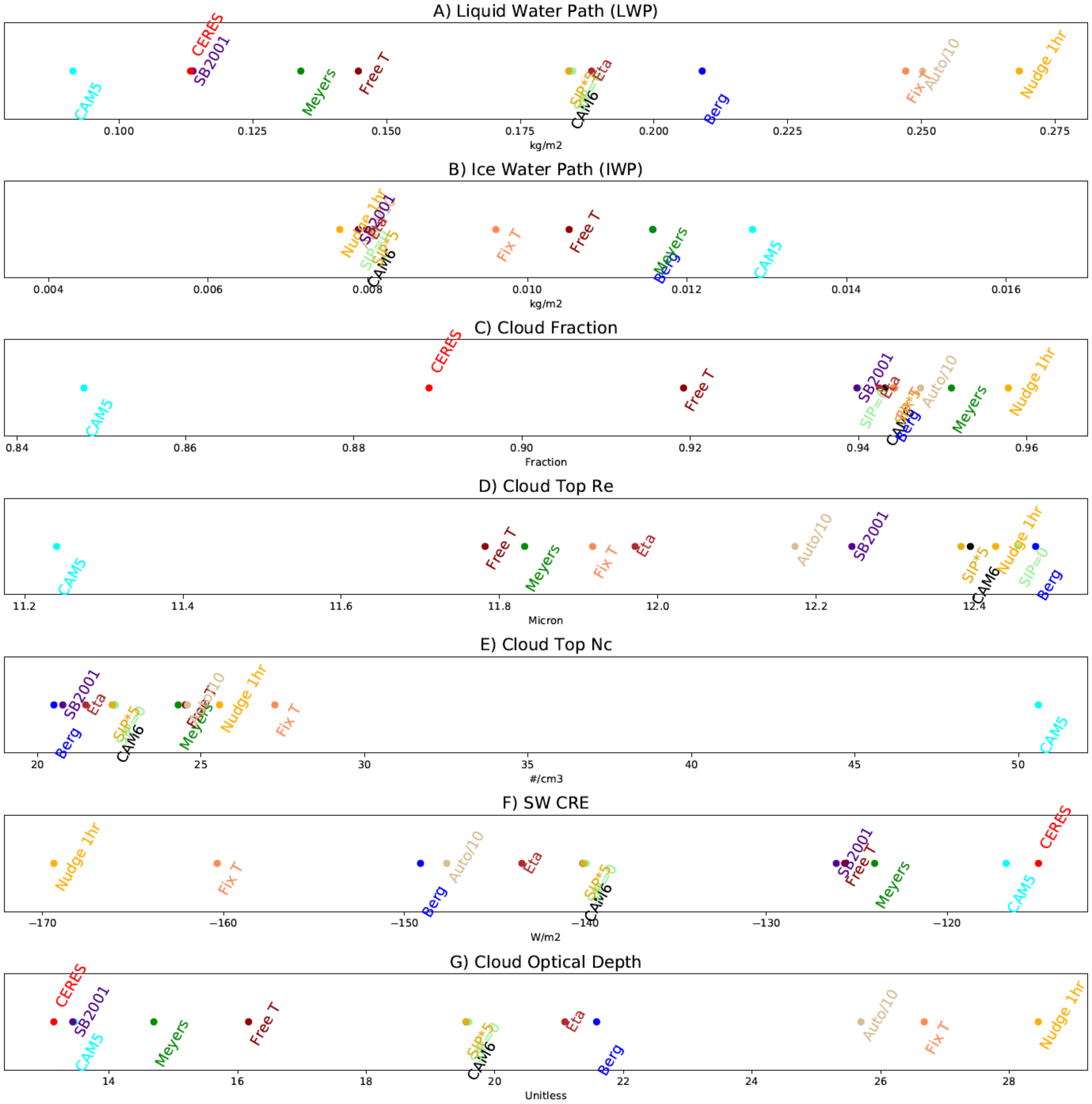
SOCRATES

Sensitivity Tests

CAM5/6 simulations averaged over the S. Ocean (45-65S, 130-170E) v. **CERES**

- **CAM6** still has big regional radiative biases
- **CAM5** right for the wrong reasons
- CAM6 with **SB2001** autoconversion better
- CAM6 **SB2001** better global Cld Rad Effects



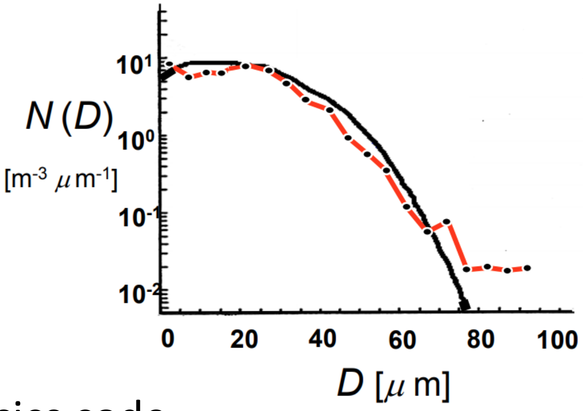


Unified Ice

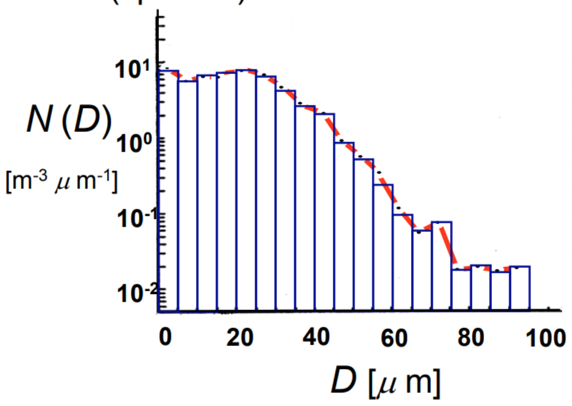
- Similar to Predicted Particle Properties (P3: Morrison and Milbrant) for combining ice and snow. Single category of ice. Not rimed yet.
- Based in Eidhammer et al (2016)
- Putting it together with a separate rimed ice variable (in MG3)
- Have it running globally. Trying to understand how to balance the climate with a new ice/snow class combined. (Non-trivial)

Machine Learning

Bulk: $N(D) = N_0 D^{\alpha} e^{-\lambda D}$



Bin-resolving: (spectral) $N(D) = \sum_{i=1}^{I} N_i$



Can we do the warm rain process better?

Replace autoconversion, accretion and self collection

Use a stochastic collection kernel:

1. Break distributions of cloud and rain into bins
2. Run stochastic collection kernel from a bin microphysics code
3. Use altered distributions to estimate AUTO+ACCRE tendency

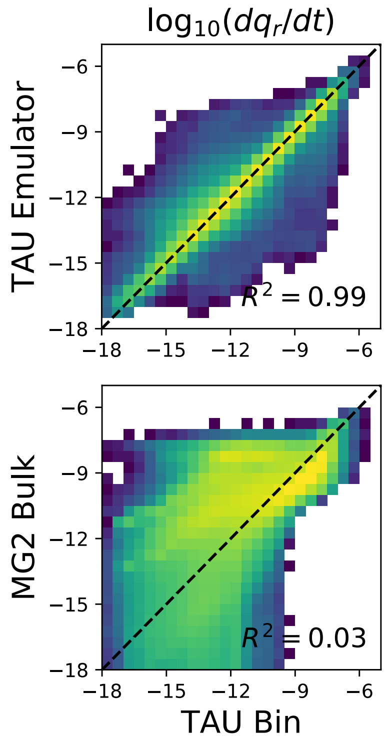
Preliminary Results:

- Similar climate, but different process rate tendencies
- Rain formation process looks more like a bin model…different precip structure
- But 3x slowdown in CAM run time!

So try to emulate it with a neural network. Mostly works.

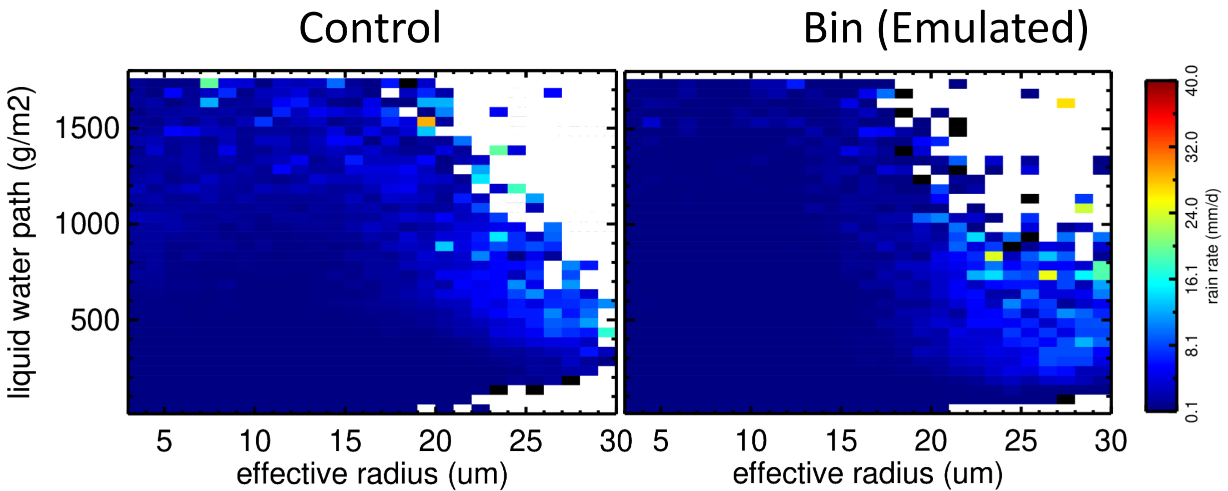
- But still needs some 'guardrails'

Developing first paper now



Control =significant rain for all R_e

Bin = Little rain for R_e<15um (all LWP)



Summary

- MG2 and 3 (graupel) are currently available in CAM6
- Suggest we get rid of KK2000 autoconversion
  - Either use SB2001 (namelist switch)
  - Exploring whether emulating stochastic collection is a good strategy (at least 6 months out from a verdict)
- Goal is developing flexible options in the microphysics…

Where do we go from here? PUMAS

PUMAS = Parameterization of Unified Microphysics Across Scales

- Based on MG3. Not just M & G anymore!
  - There are 5 NCAR labs + outside collaborators on the title slide
- State of the art bulk 2 moment microphysics for all scales of modeling
  - LES to Mesoscale/Regional to GCM for Weather/Climate
- More flexible microphysics across scales
  - Scalable and efficient for different models
  - Served from an external github repository: more modern software
  - Include unit tests
  - Interfaces for different models
  - Enable broader contributions
  - Incorporate performance improvements and GPU directives
- Where should we go? Happy to take ideas

Current PUMAS Status

- GitHub repository established (https://github.com/ESCOMP/PUMAS)
- Working towards begin able to pull over MG3 into CAM from there
- Developing unit tests
- Science efforts:
  - Unified Ice
  - Efficiency (Vectorization & GPU directives)
  - Independent aerosol formulations (separate lightweight aerosols)
  - Ice Nucleation
  - Convert a version to CCPP interface