



Parameterizing Unified Microphysics Across Scales (PUMAS):

Advancing Simulation for Weather and Climate

Gettelman, Morrison, Eidhammer, Thayer-Calder (NCAR)



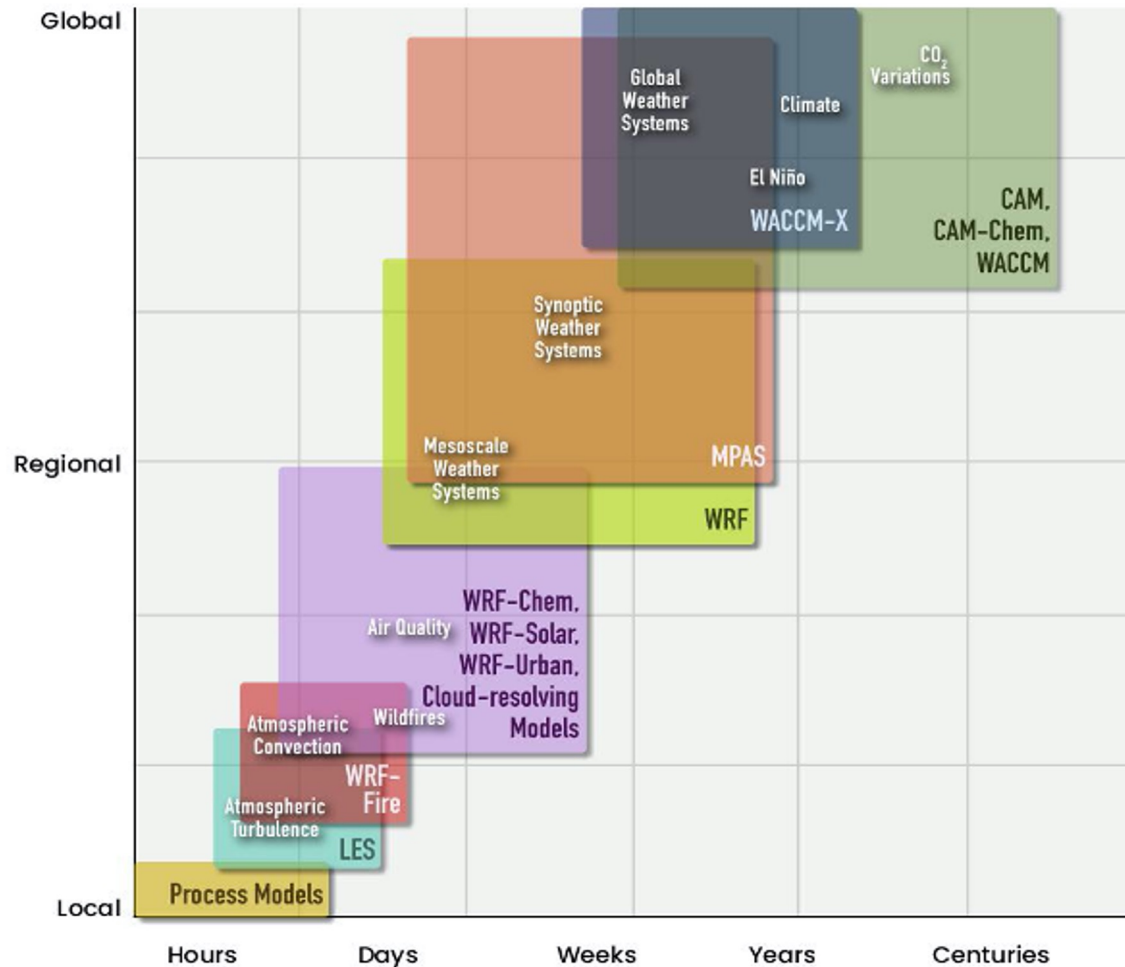
Cloud Microphysics Critical for Weather & Climate

Major Issues for Clouds, Precipitation and Aerosols

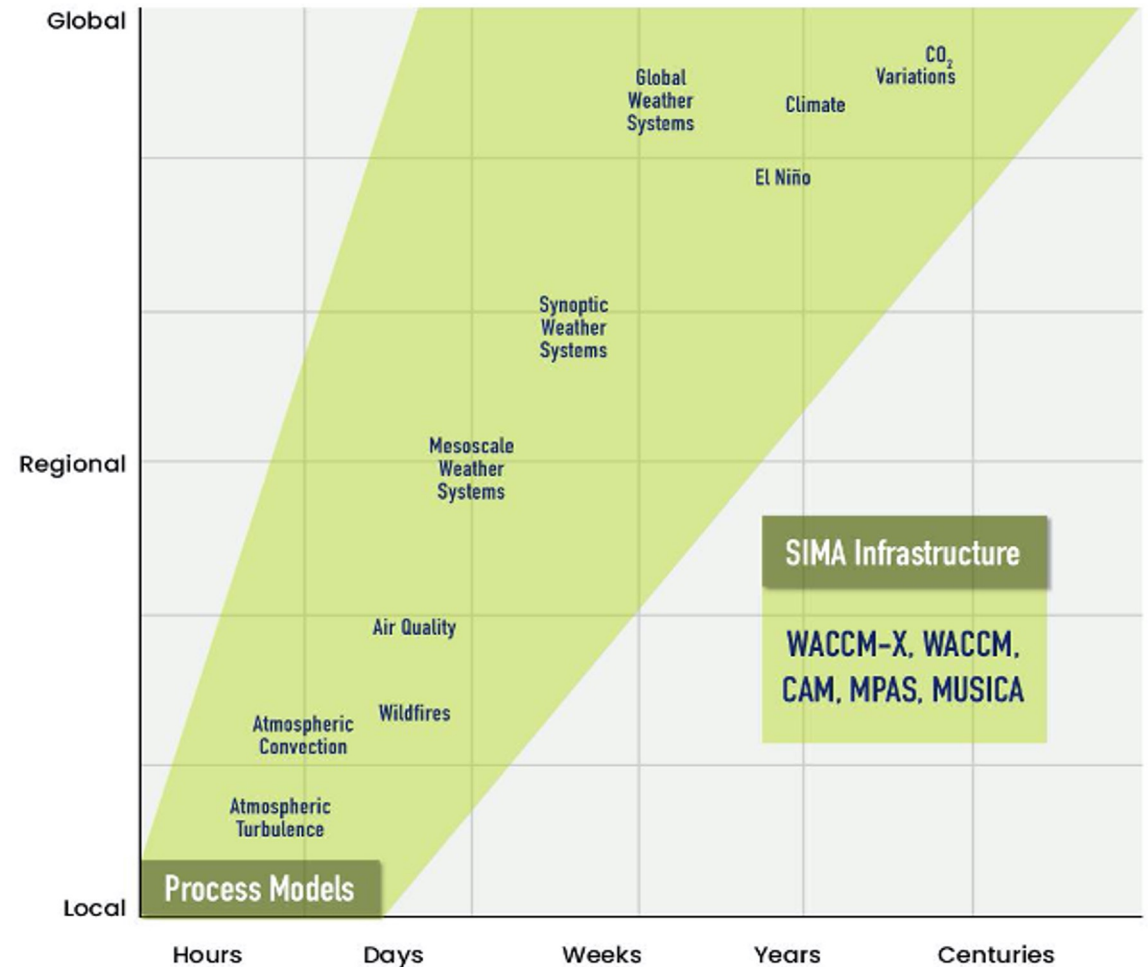
- Cloud Phase
 - Critical for radiative effects at high latitudes AND for cloud feedbacks. Also weather impacts
- Cloud Microphysics: size distributions govern process rates
- Dynamics-Microphysics coupling
 - Vertical structure of clouds: cloud base, freezing, entrainment at top
- Aerosol activation (cloud-aerosol interactions)
 - Vertical velocity critical
- Precipitation Formation: Frequency & Intensity

A (not so unique) vision: Seamless Prediction System for Integrated Modeling of the Atmosphere (SIMA)

Atmospheric Modeling Ecosystem in Mid-2010s

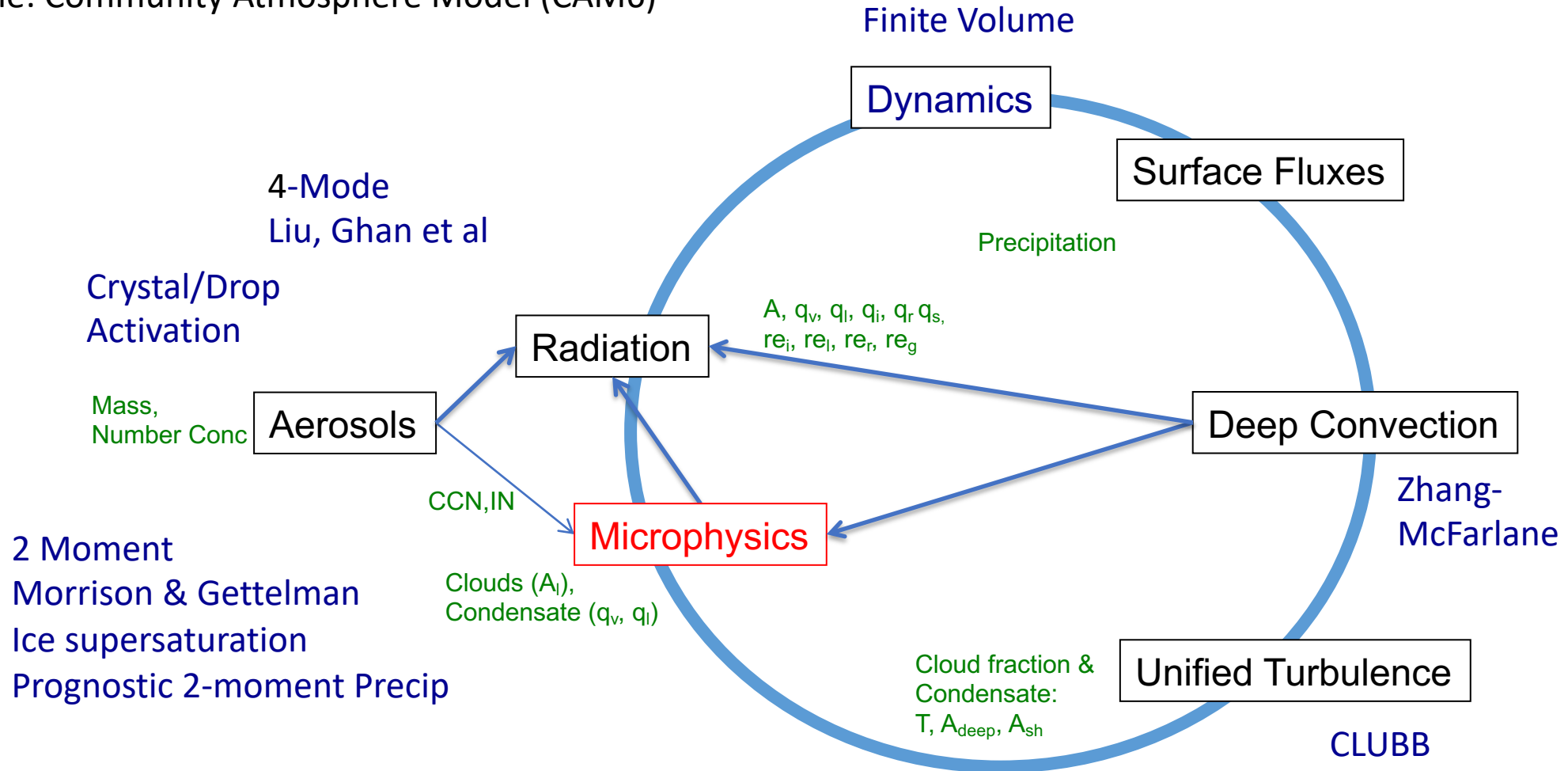


SIMA-based Atmospheric Modeling System in Mid-2020s



What is Cloud Microphysics?

Example: Community Atmosphere Model (CAM6)



A = cloud fraction, q =H₂O, re =effective radius (size), T =temperature
 (i)ce, (l)iquid, (v)apor, (r)ain, (s)now

Types of Microphysical Schemes

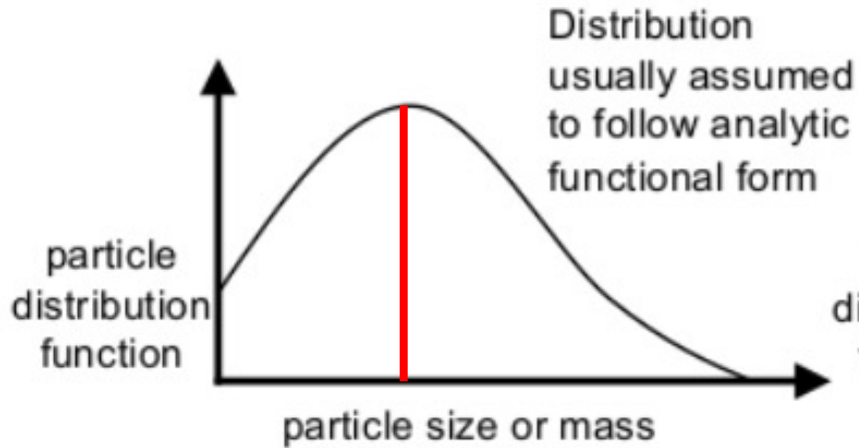
Used in models at scales:

Global & Mesoscale models

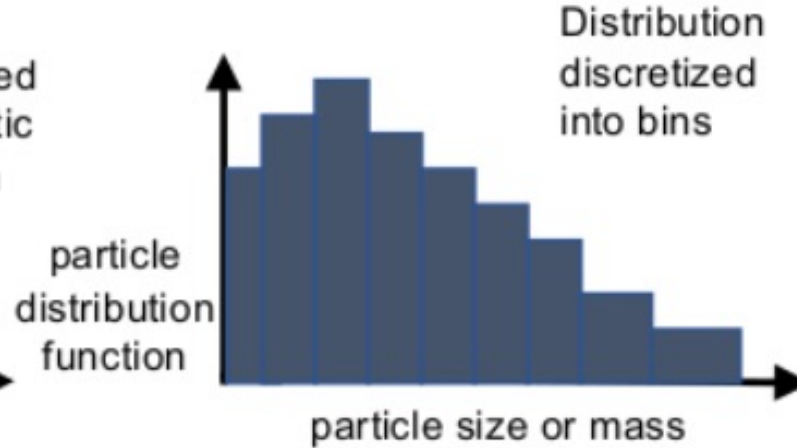
Mesoscale /Large Eddy Simulations/Parcel

LES/Parcel

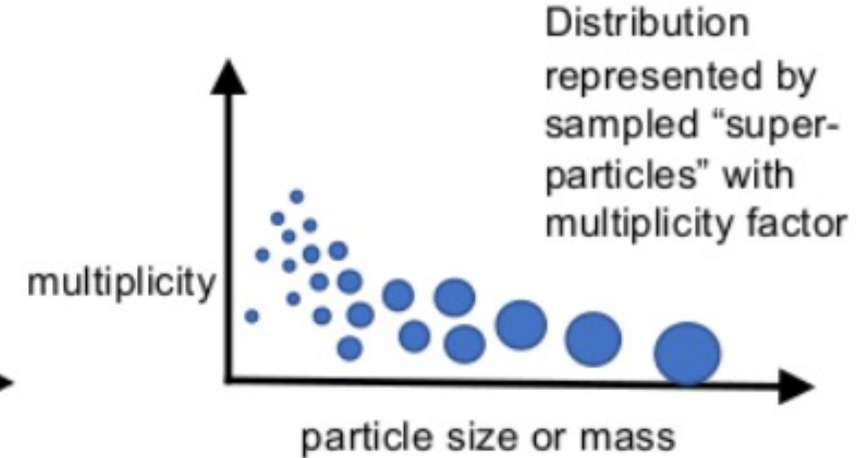
Bulk



Bin



Lagrangian particle-based



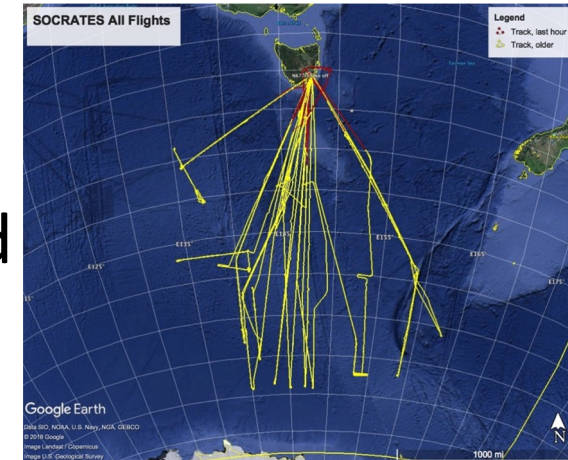
Two Moment = Prognostic Mass and Number

One Moment = Prognostic Mass, Diagnostic Number/Size

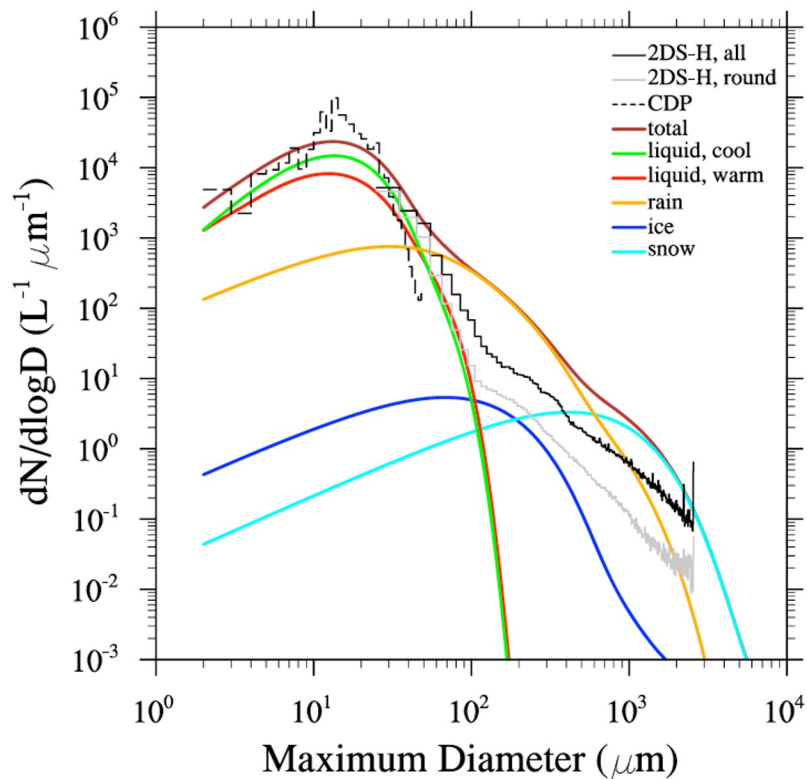
Microphysics, Size distributions

Advanced GCMs/GSRMs can be compared directly to cloud microphysical size distributions (here from SOCRATES).

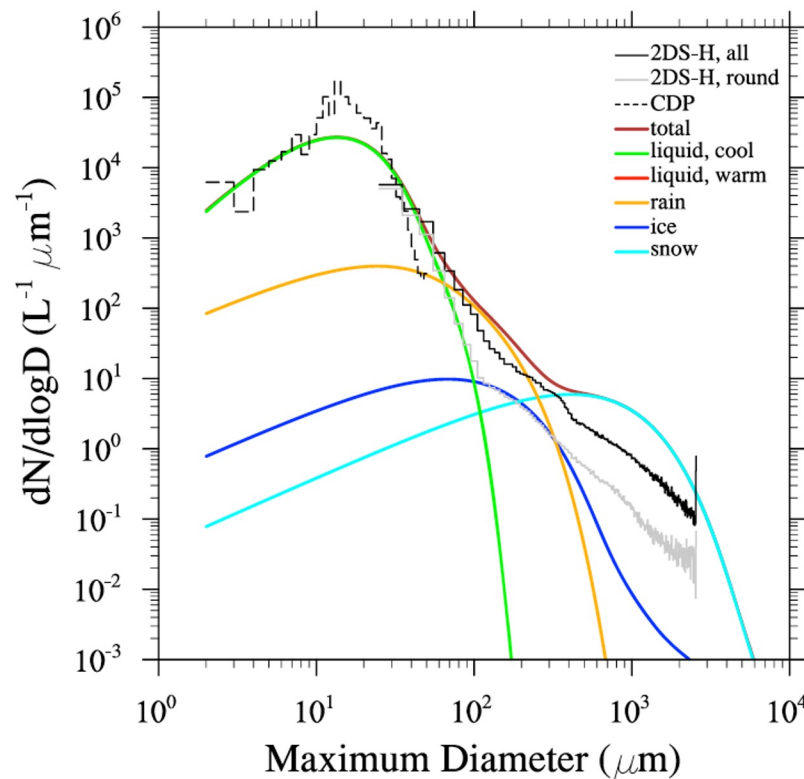
Comparison is GCM cloud microphysics along aircraft flight tracks with in-situ data



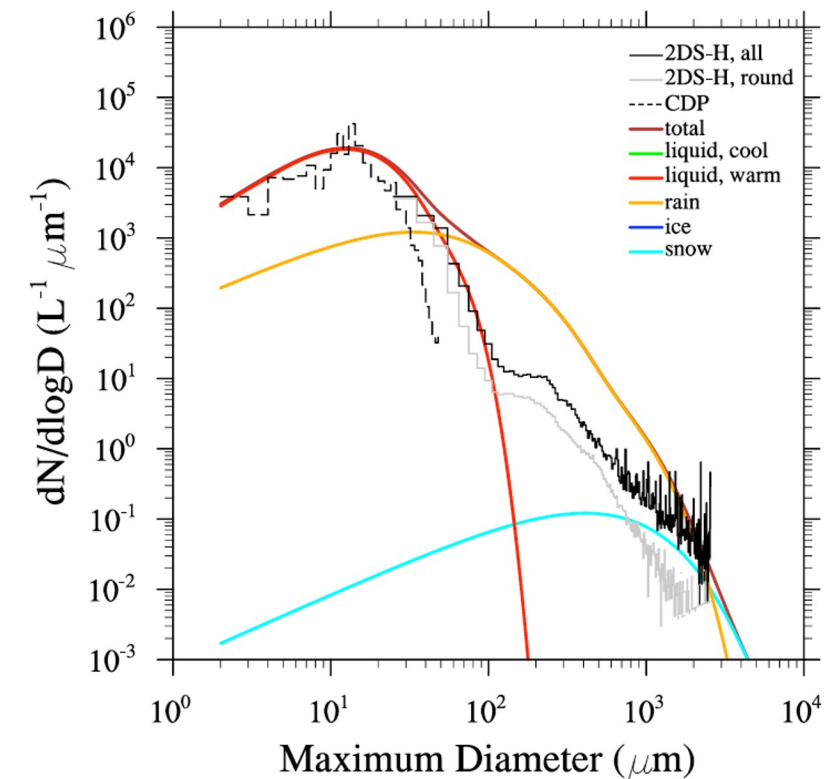
(a) All Clouds



(b) Cold ($T < 0^{\circ}C$) Clouds



(c) Warm ($T > 0^{\circ}C$) Clouds

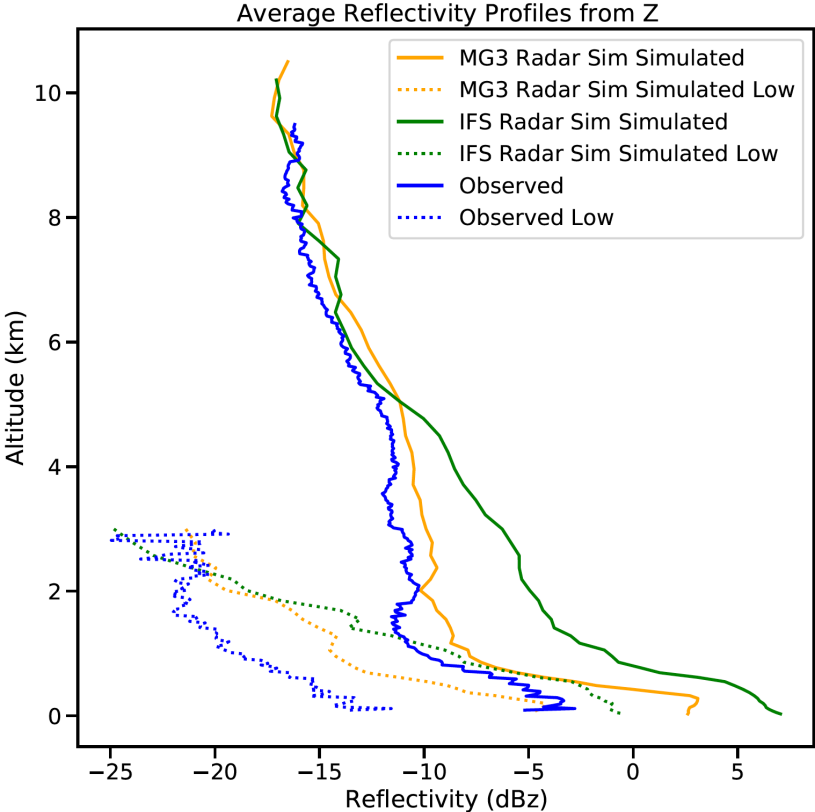


Note potential issue with too large rain sizes

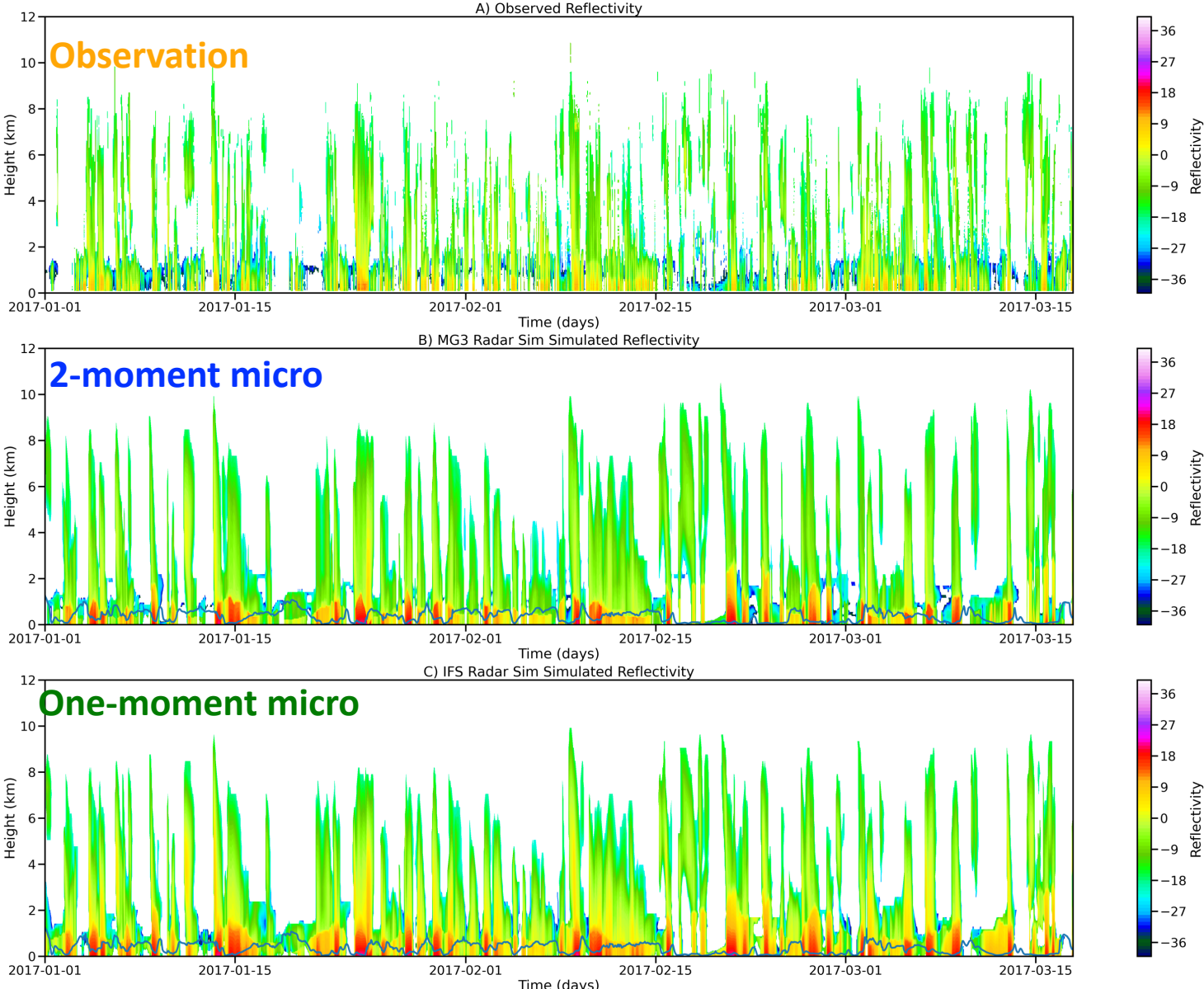
Gettelman et al 2020

Microphysics: Comparing to Reflectivity

Comparisons over Macquarie Island in S. Ocean between a **precipitation radar** and single column simulations with **one-moment** and **2-moment** microphysics in the ECMWF-IFS SCM.



Gettelman, Forbes, Fielding, in Prep

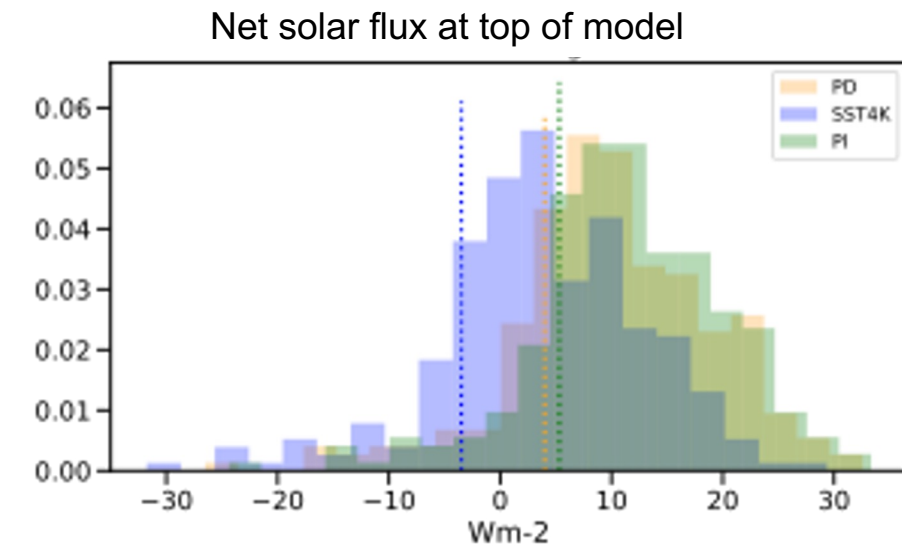
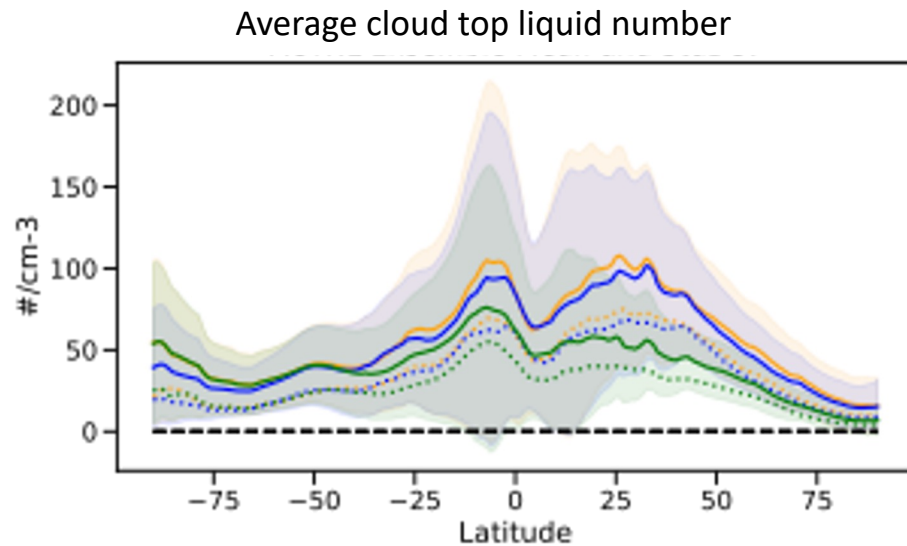
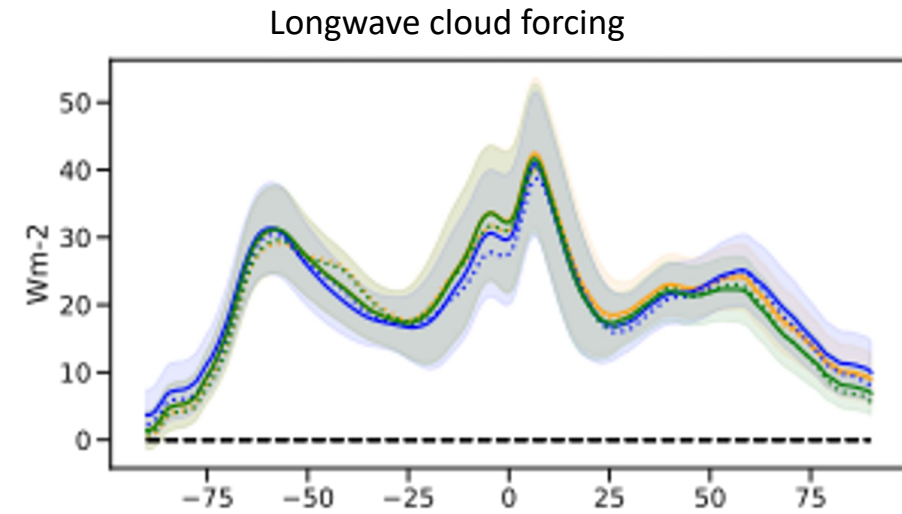
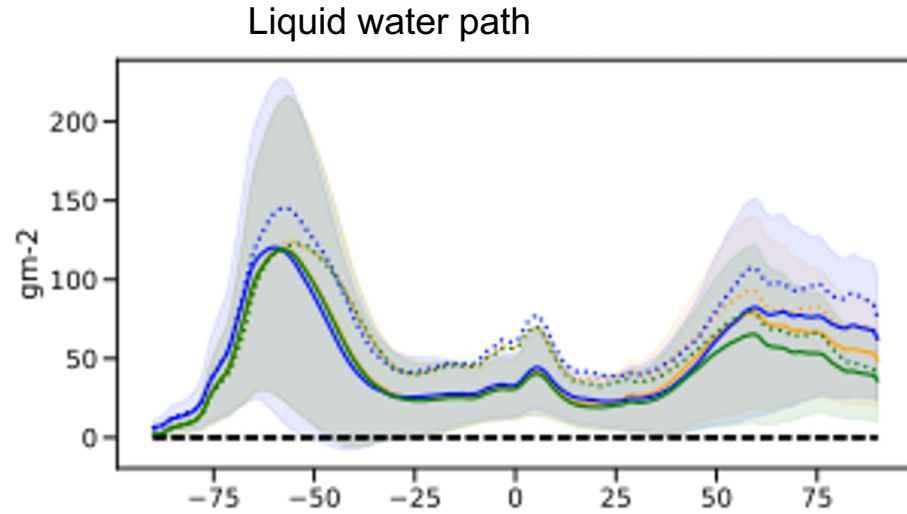


Robustness: Parameter Uncertainty

Perturbed Parameter Ensemble (PPE)

Eidhammer, Gettelman, Thayer-Calder, Duffy

- Control run (Baseline CAM6 parameters)
- Mean over all 250 simulations

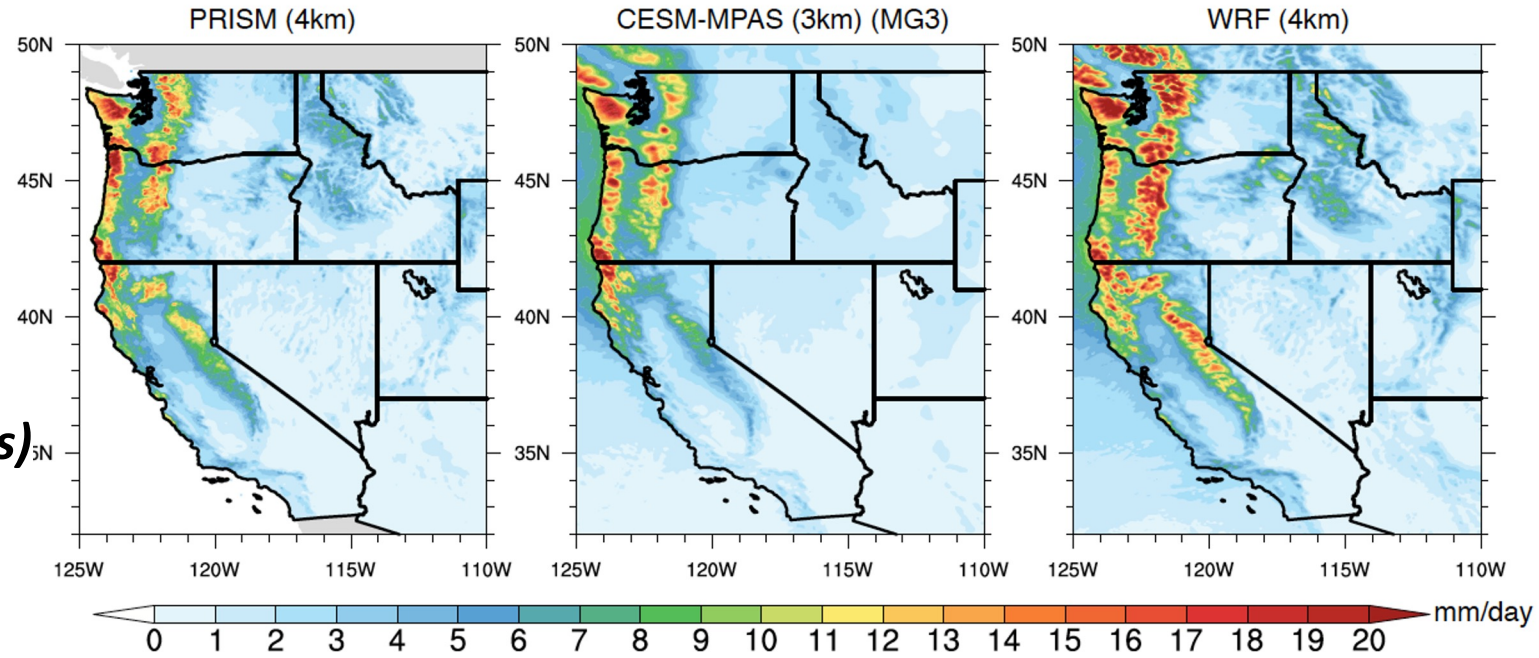


Climate Extremes: Variable-Resolution (60→3 km)

- Global Model: CESM-MPAS: 3km regional, no hydrostatic dynamics.
- Regional climate model: WRF (CONUS) 4km (Rasmussen et al., 2021)

W. USA Wet-season (Nov-Mar) precip (5yrs)

- CESM-MPAS results compare well to obs
- Smaller biases than WRF mesoscale model



Wet-season (Nov-March) mean precipitation over western US (1999-2000)

Daily precipitation Intensity PDF

4km Mesoscale Model (WRF)

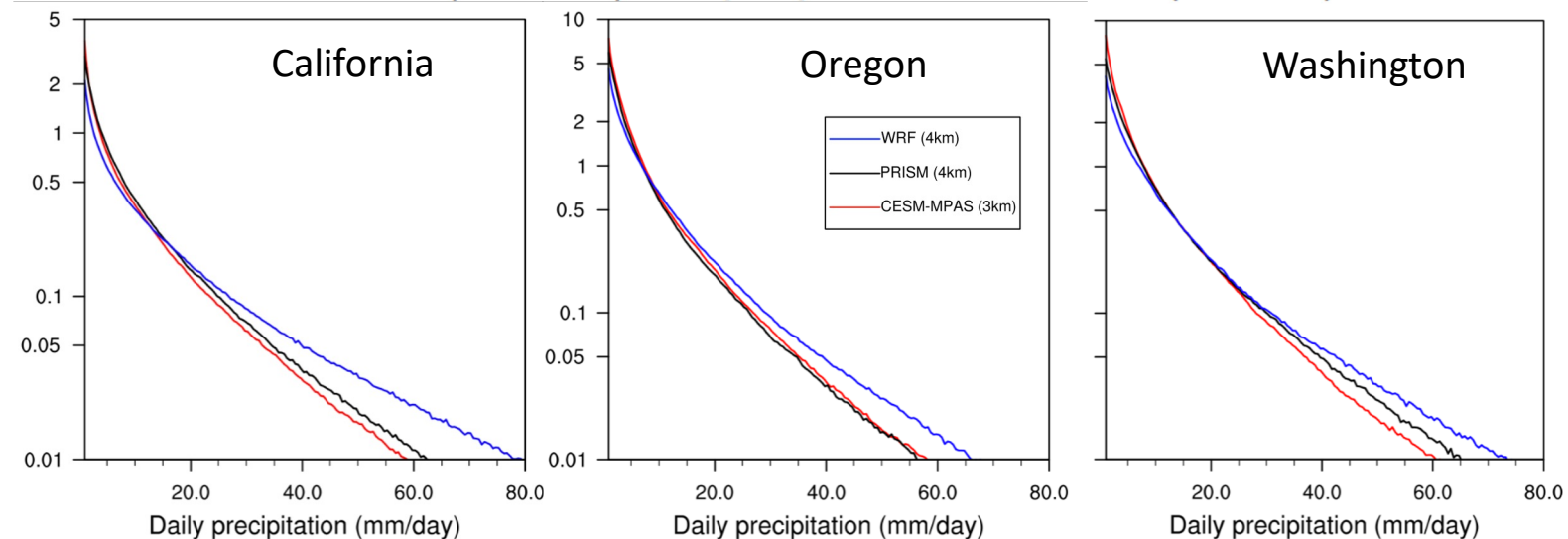
3km Global Model (CESM)

4km Observations

CESM captures **observed PDF** better than

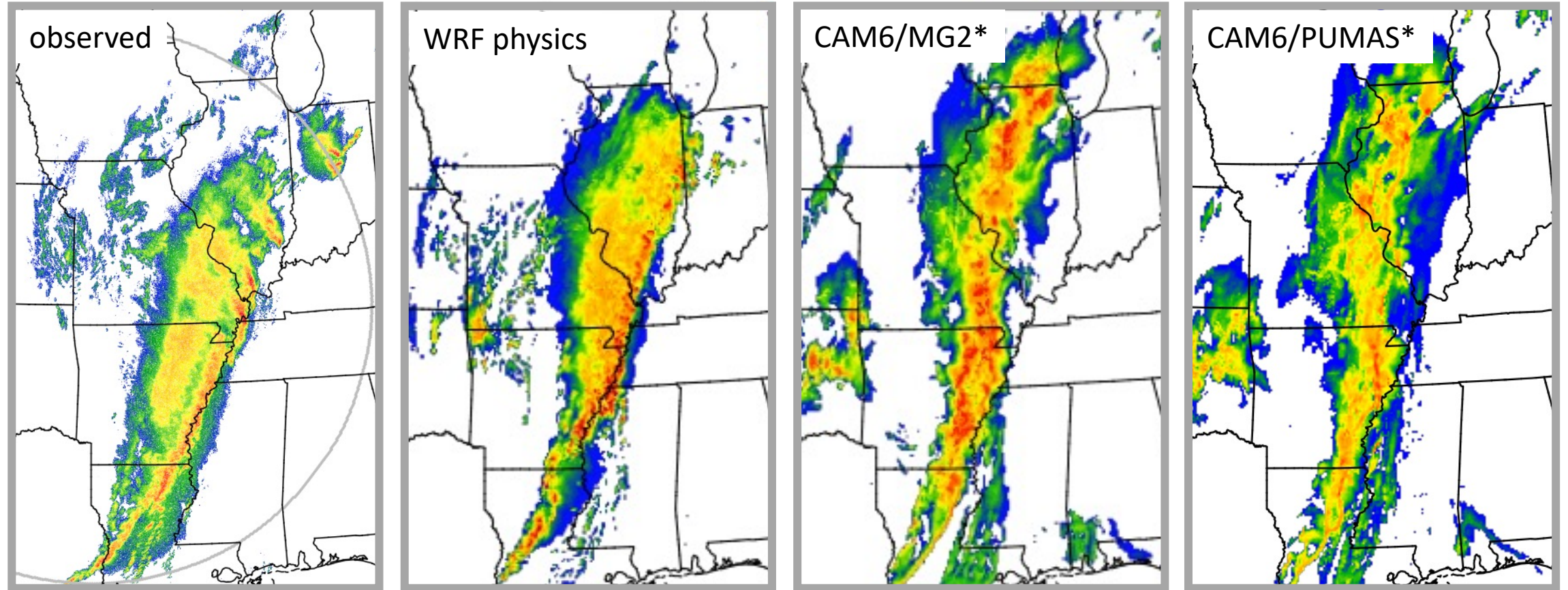
WRF, especially for extreme precipitation

X. Huang, NCAR

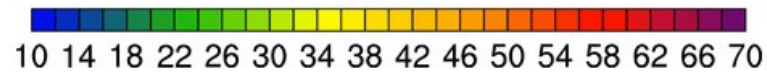


Climate Extremes: Variable-Resolution (60→3 km)

- Central US Summertime squall line. 24 hour forecast valid 0 UTC 27 April 2017
- Mesoscale model v. Climate Model



Reflectivity (dBZ)



(* Computed using single-moment reflectivity diagnostic)

Machine Learning the Warm Rain Process

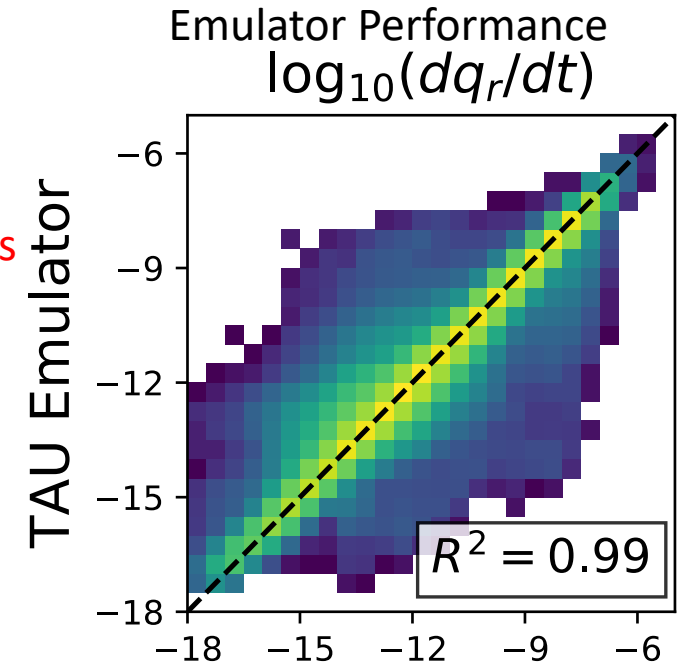
NN Emulator reproduces detailed code

Can we do the warm rain process better with Machine Learning?

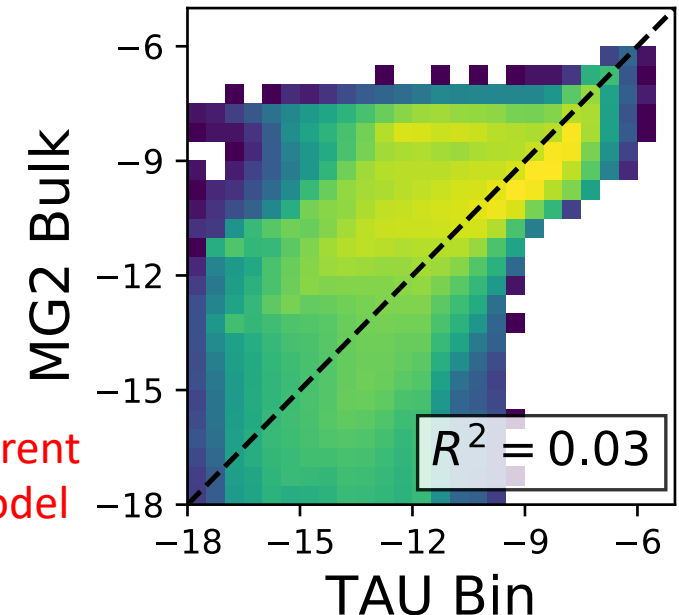
Replace traditional GCM bulk rain formation with a bin model formulation for stochastic collection. This is too expensive for climate use. So emulate it with a neural network.

Results:

- We can change the answer in the model with the bin code.
- Very slow when using full treatment
- Recover speed and recover results with a neural network emulator (it works)
- Embedded NN in the microphysics: maintains conservation with series of checks



Bin code is Different than original model

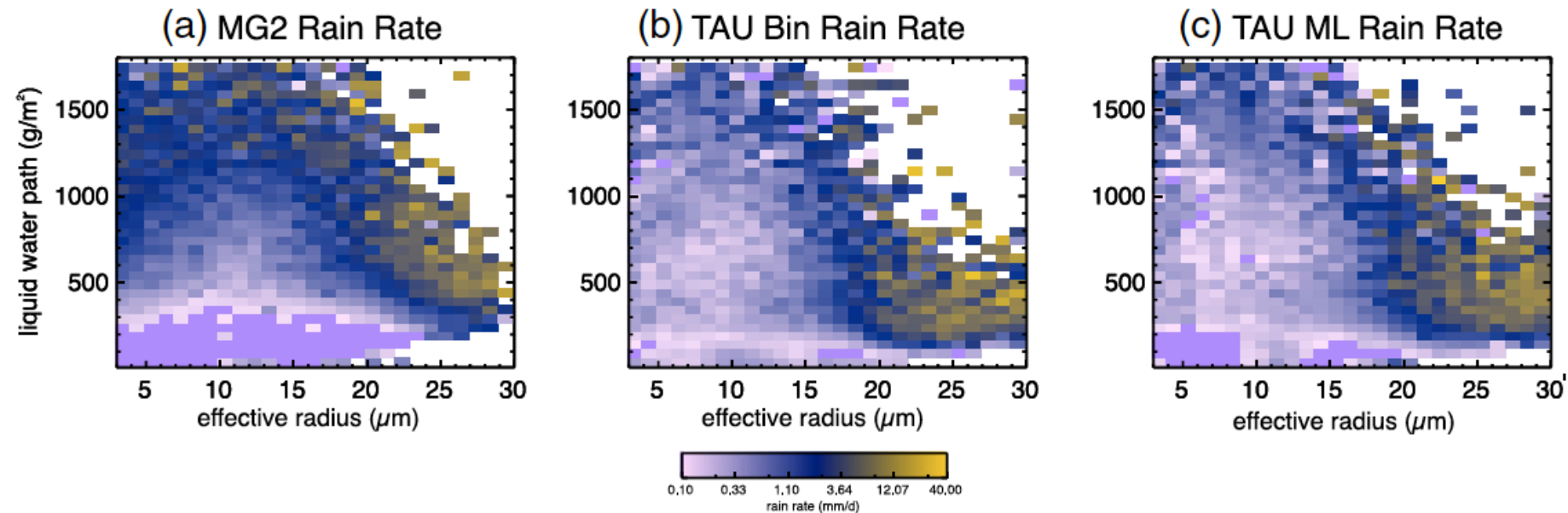


Improving results with Machine Learning

Stochastic collection equation for warm rain in a bulk scheme

Reduces rain rate for small drop sizes but large LWP

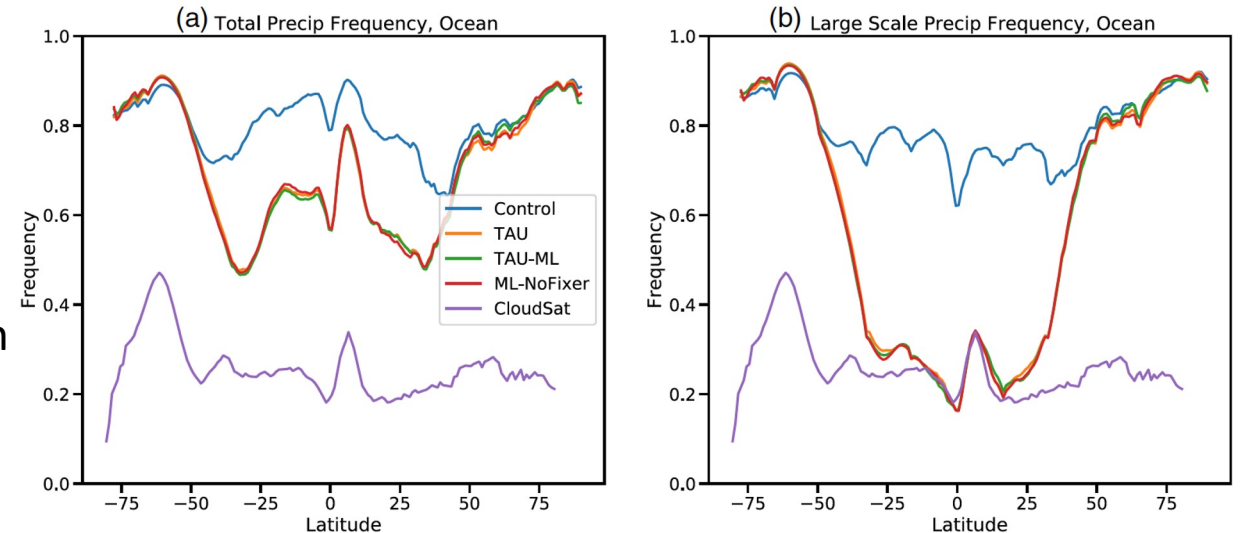
Emulator reproduces this



Precipitation Frequency

Control v. Observations and Bin precipitation and ML Emulator.

Using stochastic collection from a bin scheme improves large scale precipitation frequency in shallow clouds

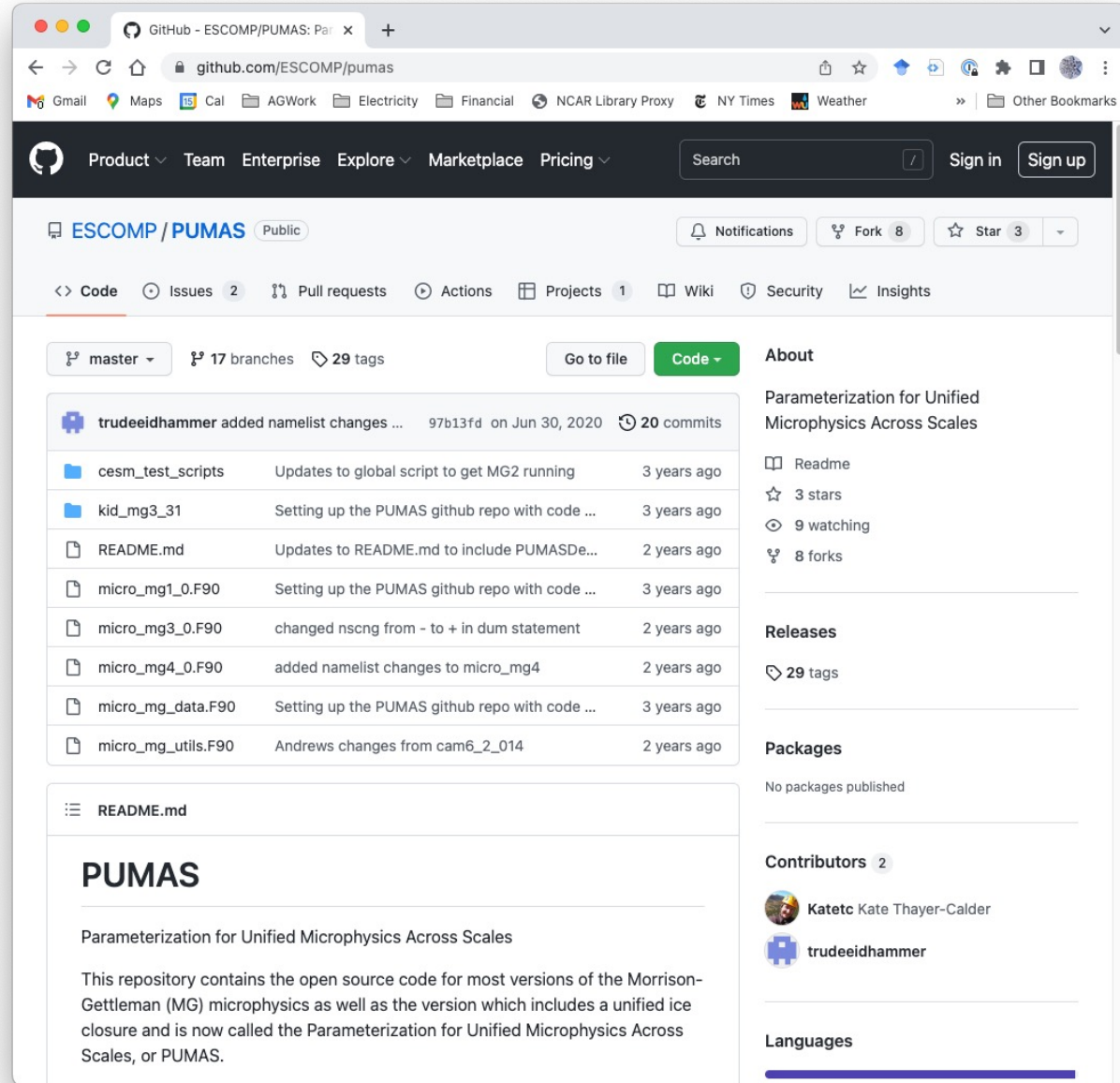


Latest developments

- Ice Nucleation: especially mixed phase
 - Evaluate CNT Treatment (Hoose et al 2010,) v. empirical from data (DeMott et al 2015, McCluskey et al 2018)
- Unified Ice/Snow: eliminate artificial separation
 - Predicted Particle Properties (P3)-like
 - Eidhammer et al 2016 (From Morrison and Milbrandt 2015)
- ‘Open up’ model structure: allow size distribution properties to vary, and learn them from data
 - Morrison et al (2020)

Open Source Code

- <https://github.com/ESCOMP/pumas>
- Used in different GCMs now
 - CESM1/2 (and derivatives)
 - GISS, DOE (E3SMv1), GFDL
 - Single column container version for development/tutorials
- Users contributing to development and evaluation



The screenshot shows the GitHub repository page for ESCOMP/pumas. The repository is public and has 8 forks and 3 stars. The main content area displays a list of files and folders, including cesm_test_scripts, kid_mg3_31, README.md, and various micro_mg files. The README.md file is selected, showing the title "PUMAS" and the description: "Parameterization for Unified Microphysics Across Scales". The repository also has 29 tags, 9 watchers, and 8 forks. The contributors section lists two contributors: Katetc Kate Thayer-Calder and trudeeidhammer.

GitHub - ESCOMP/pumas: Parameterization for Unified Microphysics Across Scales

Public

Notifications Fork 8 Star 3

<> Code Issues 2 Pull requests Actions Projects 1 Wiki Security Insights

master 17 branches 29 tags Go to file Code

trudeeidhammer added namelist changes ... 97b13fd on Jun 30, 2020 20 commits

File	Description	Time
cesm_test_scripts	Updates to global script to get MG2 running	3 years ago
kid_mg3_31	Setting up the PUMAS github repo with code ...	3 years ago
README.md	Updates to README.md to include PUMASDe...	2 years ago
micro_mg1_0.F90	Setting up the PUMAS github repo with code ...	3 years ago
micro_mg3_0.F90	changed nscng from - to + in dum statement	2 years ago
micro_mg4_0.F90	added namelist changes to micro_mg4	2 years ago
micro_mg_data.F90	Setting up the PUMAS github repo with code ...	3 years ago
micro_mg_utils.F90	Andrews changes from cam6_2_014	2 years ago

README.md

PUMAS

Parameterization for Unified Microphysics Across Scales

This repository contains the open source code for most versions of the Morrison-Gettleman (MG) microphysics as well as the version which includes a unified ice closure and is now called the Parameterization for Unified Microphysics Across Scales, or PUMAS.

Releases 29 tags

Packages No packages published

Contributors 2

- Katetc Kate Thayer-Calder
- trudeeidhammer

Languages



Future Work: Where does it all go?

- Better uncertainty quantification (parameters, processes)
- Machine learning/emulators
 - Parameterization replacement
 - Learning model structure (BOSS)
- Model-data fusion, using observations
- Crossing scales (LES--> Global)
- New modeling capabilities for global km scale models
- Scalable complexity
 - Complexity varies by scale (e.g. hail)
- Be careful not to get eaten!

