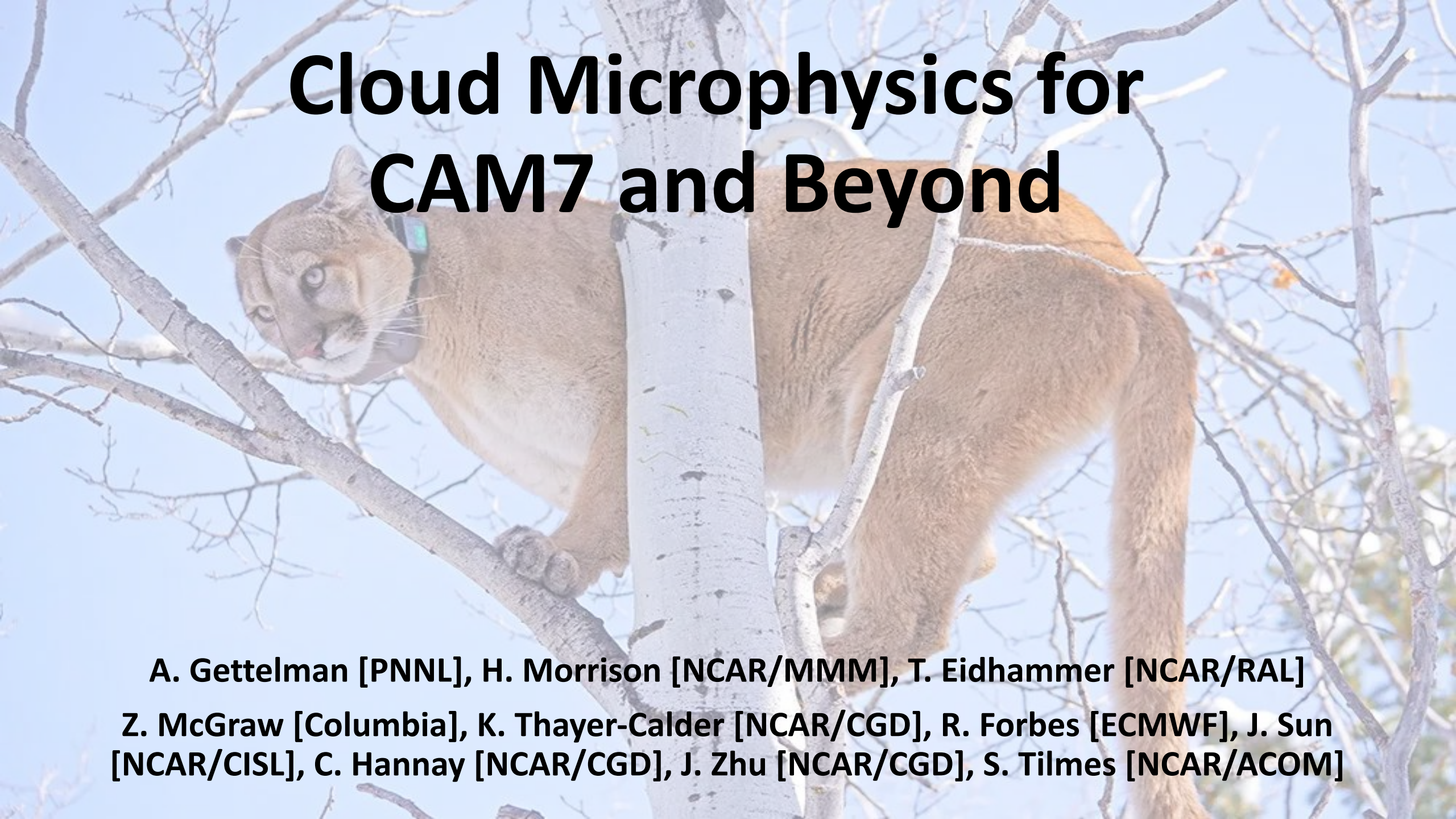
Cloud Microphysics for CAM7 and Beyond



A. Gettelman [PNNL], H. Morrison [NCAR/MMM], T. Eidhammer [NCAR/RAL]

Z. McGraw [Columbia], K. Thayer-Calder [NCAR/CGD], R. Forbes [ECMWF], J. Sun [NCAR/CISL], C. Hannay [NCAR/CGD], J. Zhu [NCAR/CGD], S. Tilmes [NCAR/ACOM]

Outline

- Evolution of CAM Cloud Microphysics
- Microphysics Updates
- Ice Nucleation Developments
- CAM7 and Beyond

PUMAS = MG3+

- Why? More than Just Hugh and I
- Changes and corrections to the CESM2 microphysical scheme, and introduce a new nomenclature for the scheme
- PUMAS now comes in as an external into CAM
  - https://github.com/ESCOMP/PUMAS
  - Have separate tags for CAM versions
- PUMAS is available with the cam_dev physics (-cam_dev)
  - Otherwise you get MG2/3

PUMASv1 Features (Options in Gray)

- MG3 (graupel/hail) plus….
- Switches to replicate processes in the ECMWF IFS
- OpenACC directives for GPU accelerators
- Fall speed correction for rain/snow/graupel
- Adjust ice number limiter (independent of aerosols, at end of scheme)
- Adds in vapor deposition onto snow as a process
- Implicit fall speed for sedimentation
- Accretion to see newly autoconverted rain (liquid only)

Also nearly ready:

- Refactored Autoconversion and Accretion. Machine Learning for Warm Rain

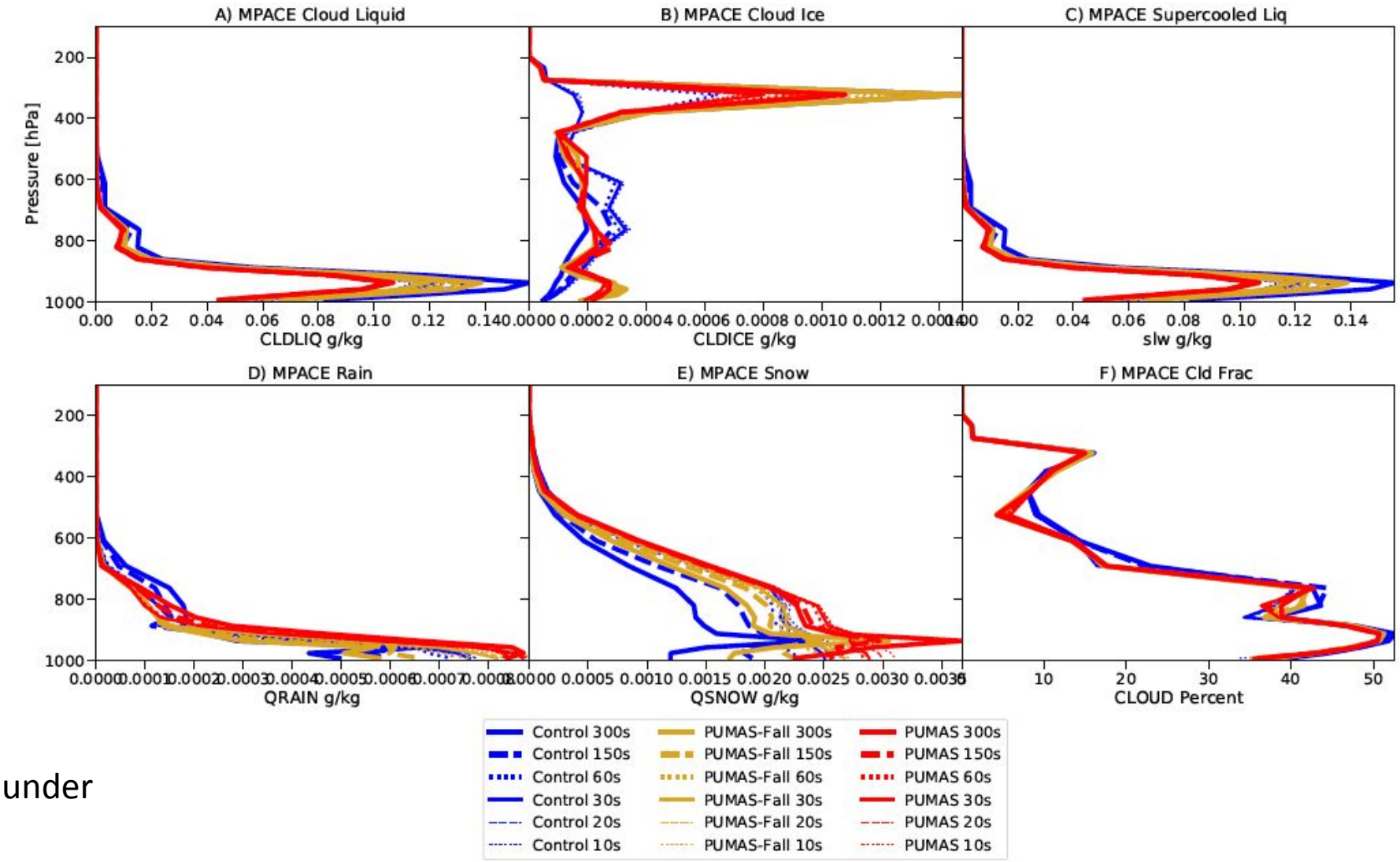
Precipitation Changes

Better Timestep Stability

PUMAS includes:

- Implicit Sedimentation
- Fall speed correction

This results in improved numerical stability across timesteps. **PUMAS minus precip corrections** looks like **control MG3**: not as good

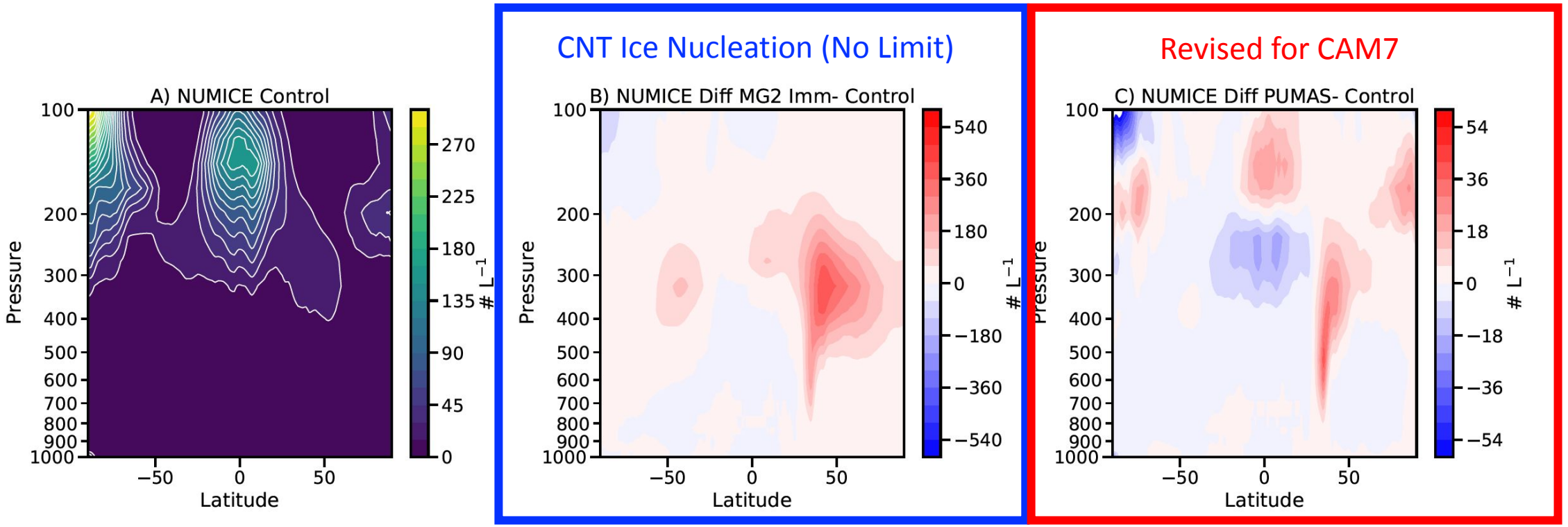


Single column MPACE tests
300s □ 10s timesteps (sub-cycles under 300s CLUBB timestep)

‘Ni Max’ Changes

- Artificial limiter on ice number
  - Suppresses CAM6 ice nucleation when Meyers (1992) ice nucleation removed)
  - In CESM1 and CESM2 (only an issue in CESM2, Meyers 1992 used in CESM1)
  - Results in less ice, more supercooled liquid water in cold climates
  - Was not intended (happened when microp_aero was refactored for CAM6)
- Noted by McGraw (U. Oslo); Thanks Zachary and Trude S. !
- Picked up by Jiang Zhu (Paleo) to reduce paleo-climate sensitivity

Revised Aerosol Number for Ice Nucleation



Note 10x change in scale!

Without Ni max limit = excessive Ice number

Revisions (for PUMAS):

1. Better calculation of aerosol number for ice nucleation (‘num_to_mass_in = .false.) [Tilmes]
2. Limit dust fraction in ice nucleation (5%). Similar to BC (already 1%) [McGraw]

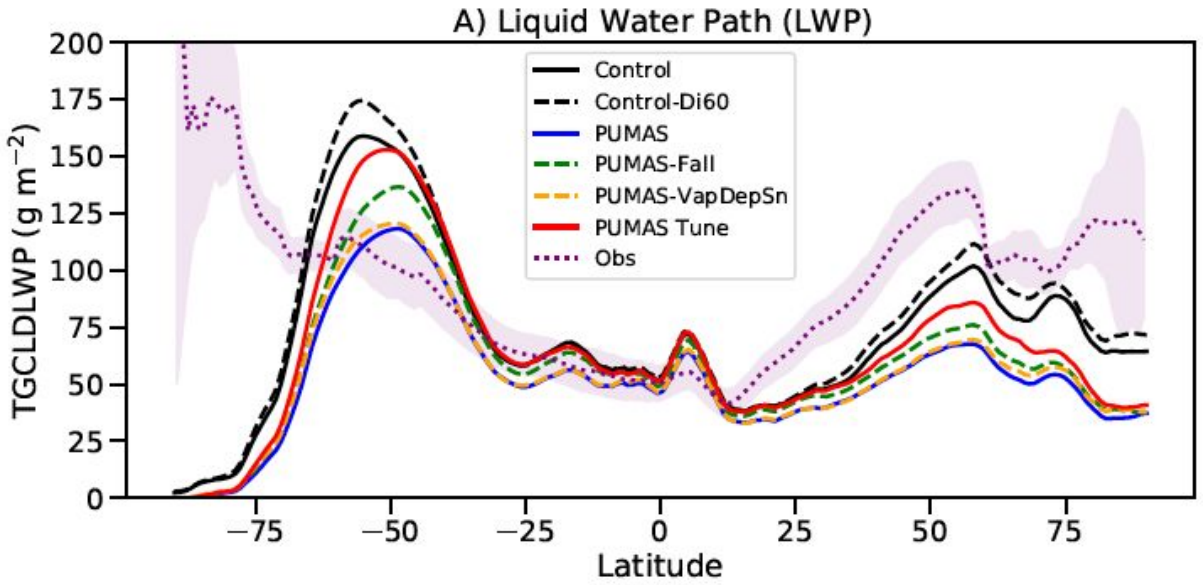
Global Tests

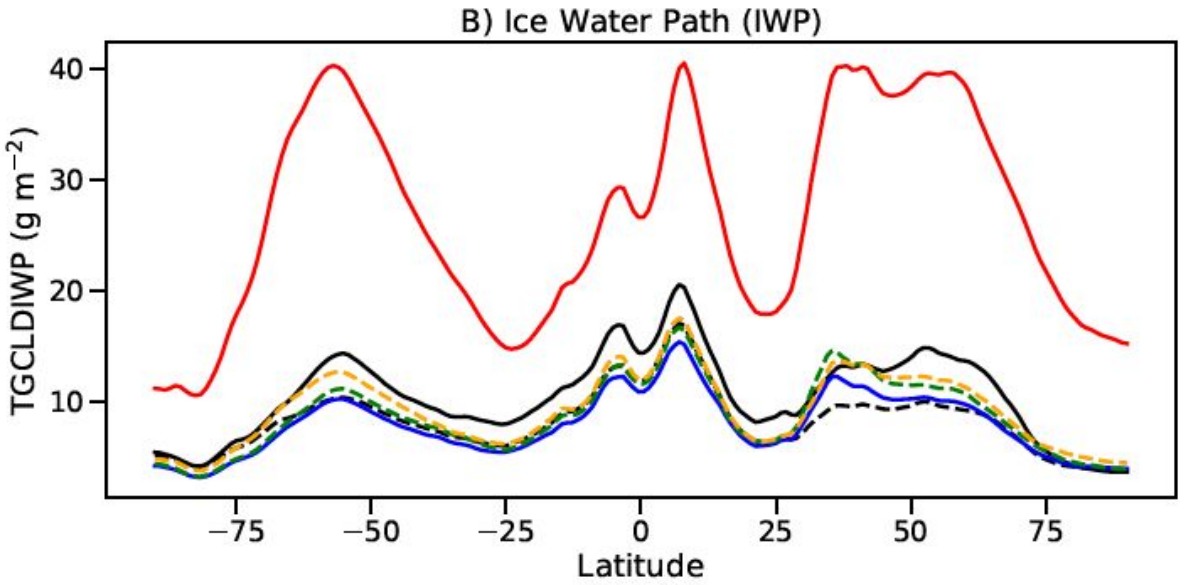
6 years, F2000climo: Present day (control), PI Aerosols, SST+4K

- Not much change in cloud feedback

PUMAS code reduces LWP and IWP from **Control**

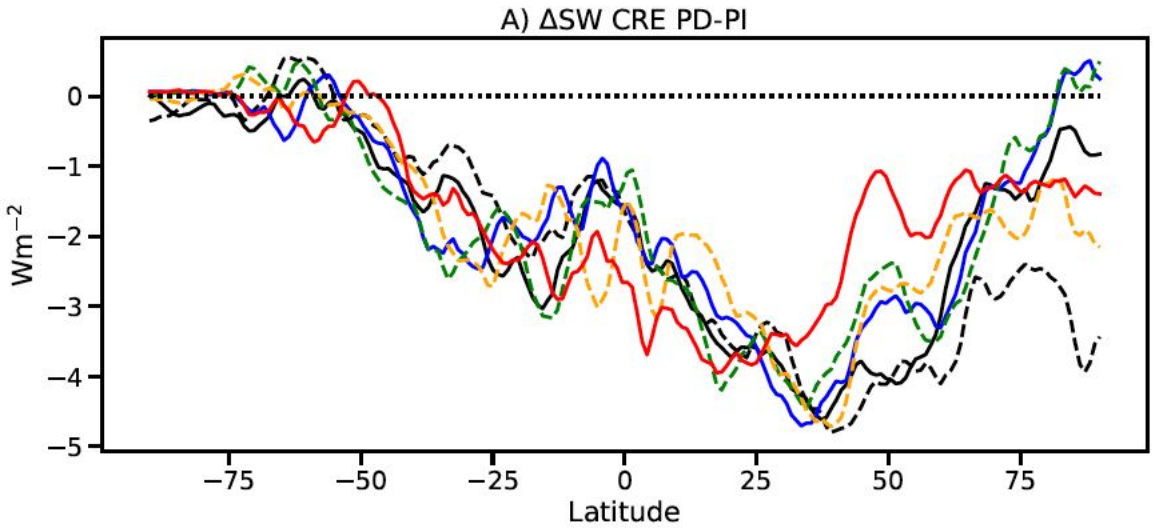
Can **Tune** this back to increase IWP and balance TOA Fluxes

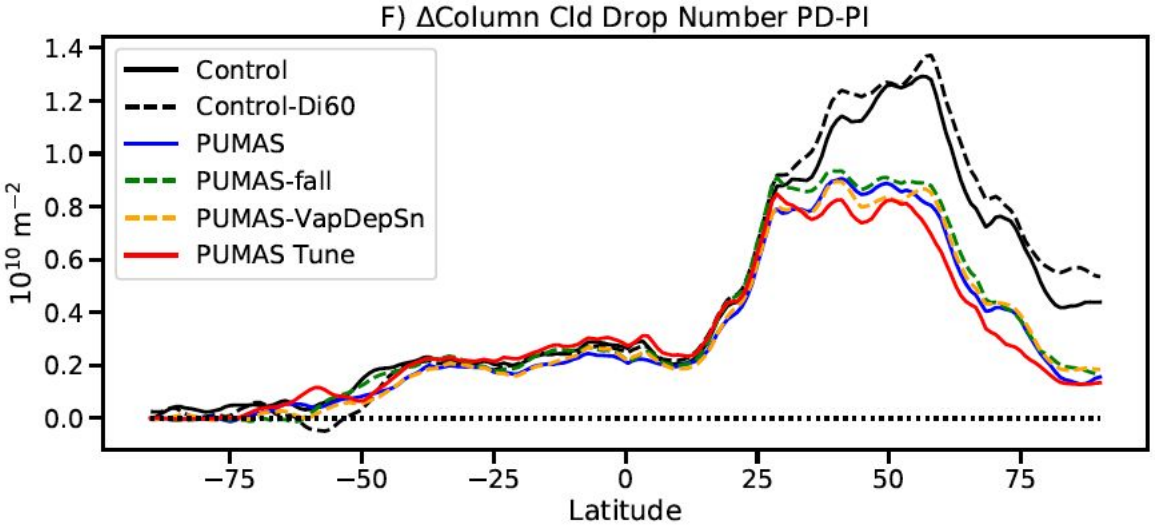




Aerosol Forcing

- Not much change in Net ACI
  - Reductions in SW and LW magnitude
  - Less ΔLWP (%), Drop number
- ACI Reductions with 'Tune' Version (stronger ice clouds)

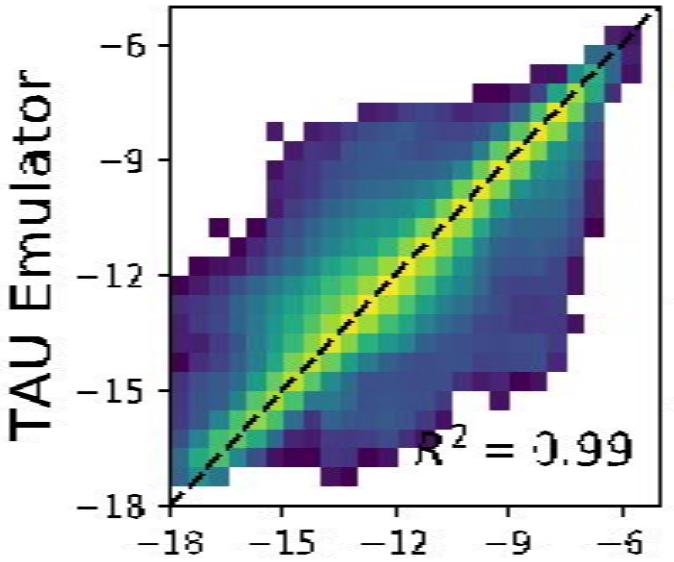




Machine Learning the Warm Rain Process

Emulator Performance

$\log_{10}(dq_r/dt)$



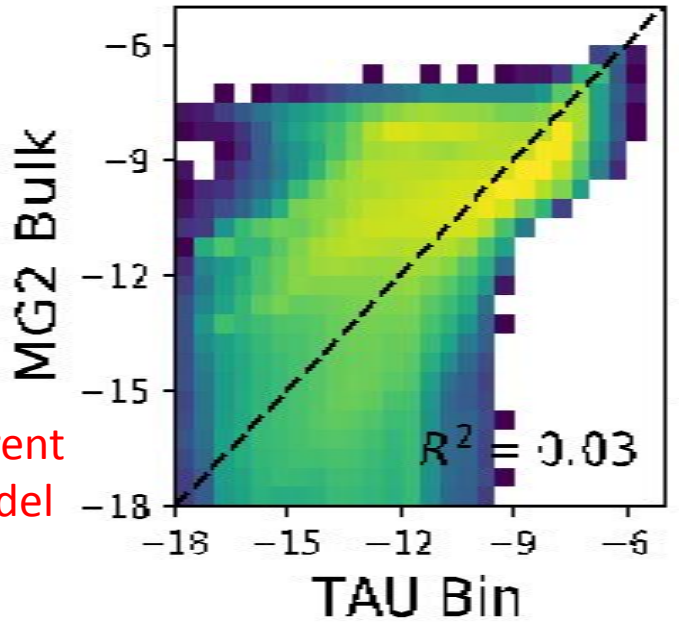
NN Emulator reproduces detailed code

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



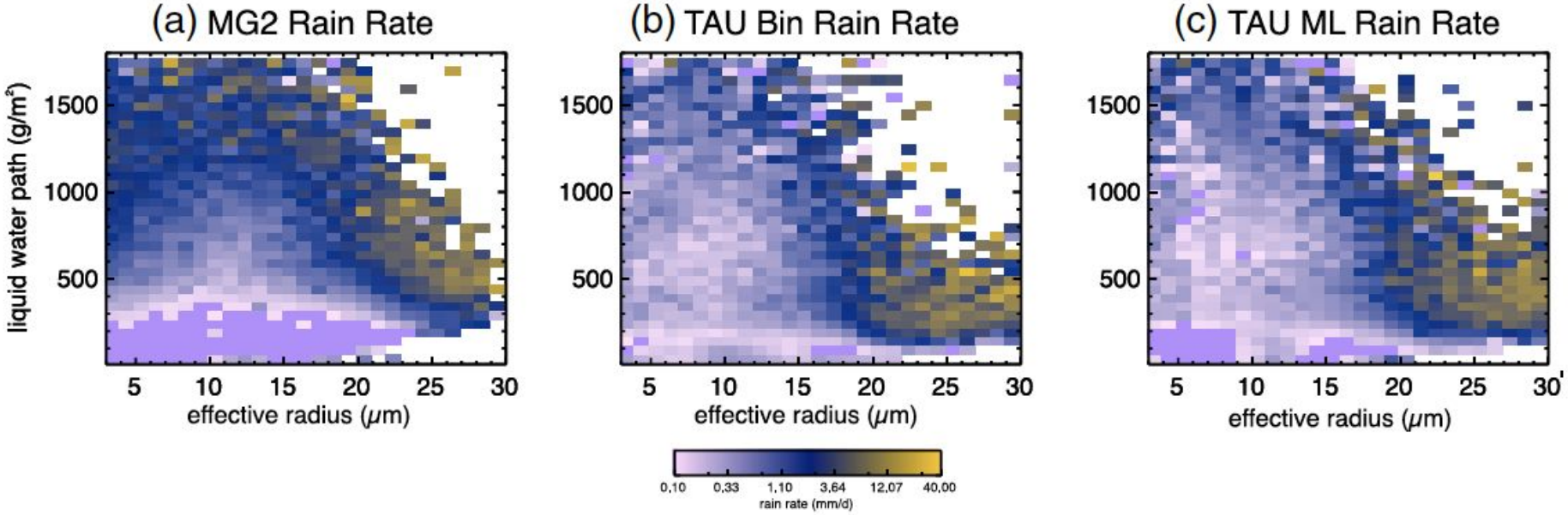
Bin code is Different than original model

Gettelman et al 2021, JAMES

Improving results with Machine Learning

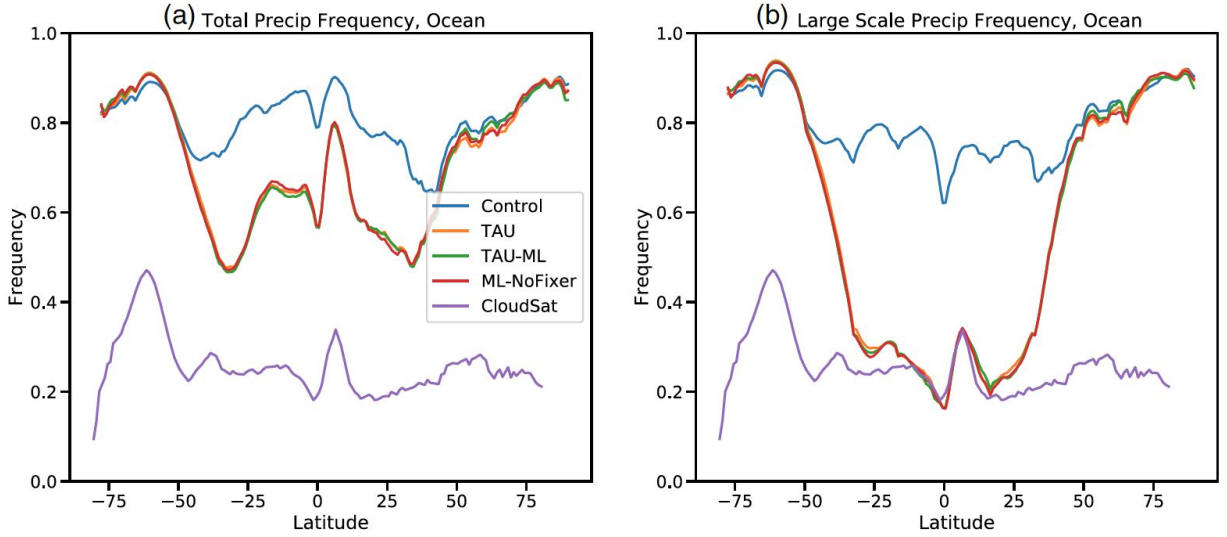
Bin or Emulated code

Reduces rain rate for small drop sizes but large LWP



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



Gettelman et al 2021, JAMES

Next Steps for PUMAS

- More testing at high resolution (3km)!
- Analysis of PUMAS part of CAM6-PPE (Eidhammer Talk)
  - And joint MG2 PPE with NASA-GEOS and NASA-GISS
- Refactored autoconversion and accretion (emulate stochastic collection kernel: Gettelman et al 2021): with Gagne, Chen, LEAP
- Unified ice (remove snow): ‘P3 like’ (increased complexity of ice, but single category for ice/snow, Eidhammer et al 2016)
- Incorporate flexible framework for structure of liquid size distributions from BOSS (Morrison et al 2020), maybe even single category liquid
- Software Engineering Planned
  - Remove Pack/Unpack
  - Add CCPP Metadata and rewrite CAM interface as interstitials

Summary

- Lots of updates in Microphysics
  - NIMAX change, then Immersion freezing adjustments
  - Implicit Fall speed/Sedimentation Correction
- Impacts
  - Reduction aerosol forcing, not much change in cloud feedback
- Moving forward with development
  - Machine Learning Emulators
  - Unified Ice & Snow
  - Flexible structure (BOSS)