NCAR

Updates to Microphysics in a Global Model

Eidhammer, T., A. Gettelman and H. Morrison

NCAR

National Center for Atmospheric Research

Consistent Representation of Ice Particle Properties

Ice microphysics in global climate models is important for radiative forcing.

Eidhammer, T., H. Morrison, E. Erfani, D. Mitchell and A. Gettelman

Mixed Phased Hydrometeor in a Global Model

Gettelman, A. and H. Morrison

Consistent Representation of Ice Particle Properties

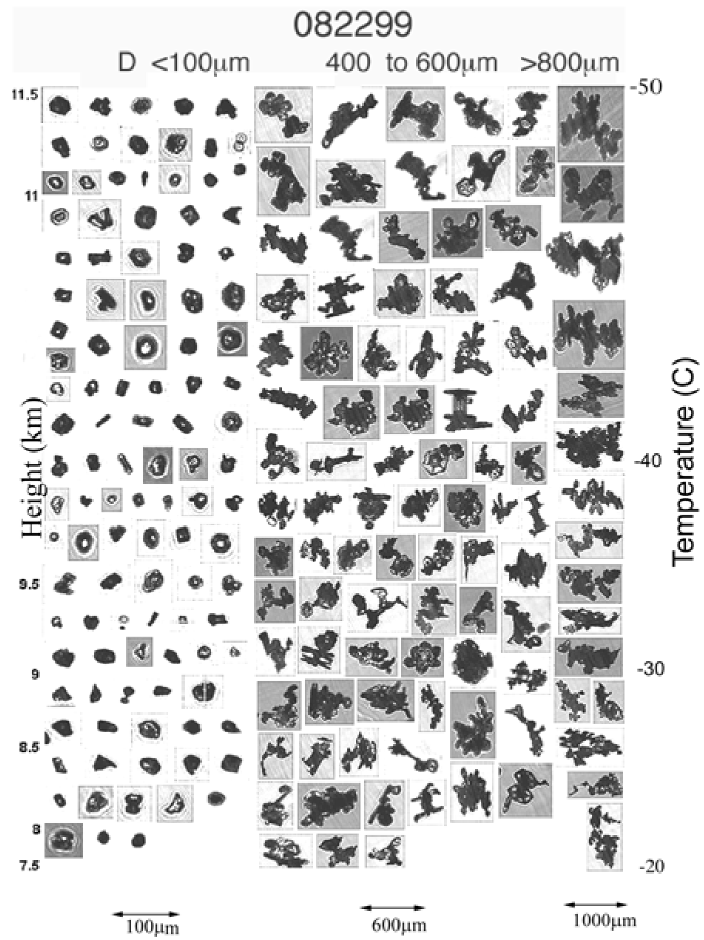
Issues in many current microphysical schemes

Representation of snow and ice is partitioned into different species with specific characteristics (particle density, fallspeed).

Autoconversion from ice to snow, assuming an arbitrary particle size.

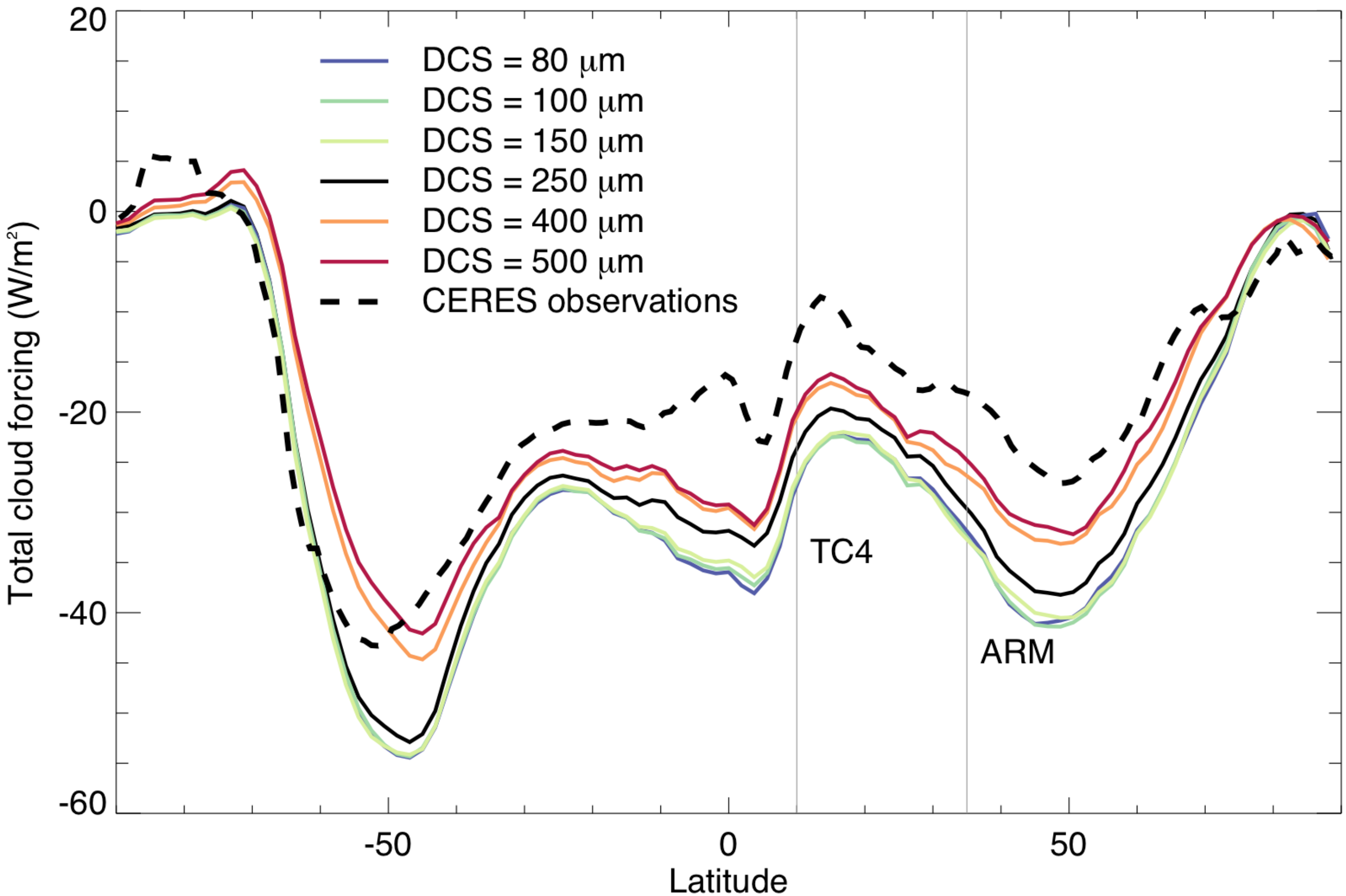
Empirical relationships, such as fallspeed parameters are used beyond appropriate size range

Empirical relationships that are based on some of the same physical properties are not self consistent



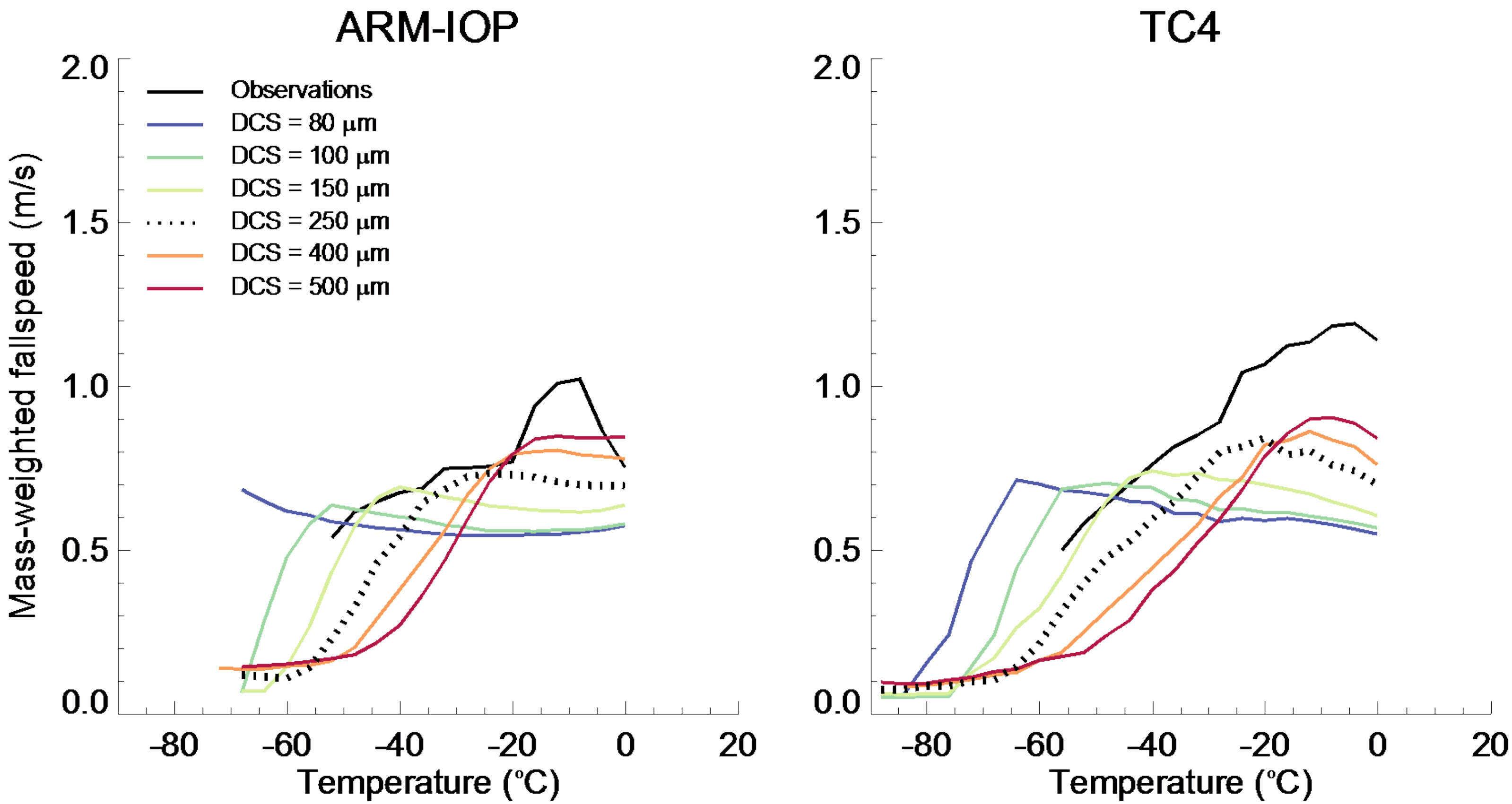
Heymsfield et al. 2002

Total radiative forcing (CAM 5 year simulation)



Eidhammer et al, 2014, ACP

Mass-weighted fall speed (CAM 5 year simulation)



The choice of threshold limit for transition from ice to snow (D_{CS}) has a large impact on fall velocity, size distribution moments and radiative forcing.

Combined snow and cloud ice in CAM

Follow Morrison and Milbrandt (2015) P3 scheme (Predicted Particle Properties).

Eliminate autoconversion from cloud ice to snow

Use lookup-table, based on mass mixing ratio (Q) and number concentration (N) for calculating:

- mass and number weighted fall speeds
- effective radius
- quantities related to the vapor deposition rate, ice self-collection rate, accretion rate of cloud water by ice, and accretion rate of rainwater by ice

New mass-dimension and area-dimension treatment

$m = \alpha D^{\beta}$

$A = \gamma D^{\delta}$

A single power law is not valid for the whole range of particle size distribution (PSD).

α and β are not constants over all ice particle sizes, but they can be approximated as constants over a range of particle sizes

2nd-order polynomial fit in log-log space:

$$\ln m = a_0 + a_1 \ln D + a_2 (\ln D)^2$$

$$\frac{d(\ln m)}{d(\ln D)} = \beta = a_1 + 2a_2 \ln D$$

$$\alpha = \frac{e^{a_0 + a_1 \ln D + a_2 (\ln D)^2}}{D^{\beta}}$$

$$D_m = \frac{\beta + \mu + 0.67}{\lambda}$$

$$\lambda = \left(\frac{\alpha \Gamma(\beta + \mu + 1) N}{\Gamma(\mu + 1) Q} \right)^{1/\beta}$$

The constants a_0, a_1 and a_2 determined from SPARTICUS, and ground based observations

Erfani, E., and D. Mitchell, 2016 ACP

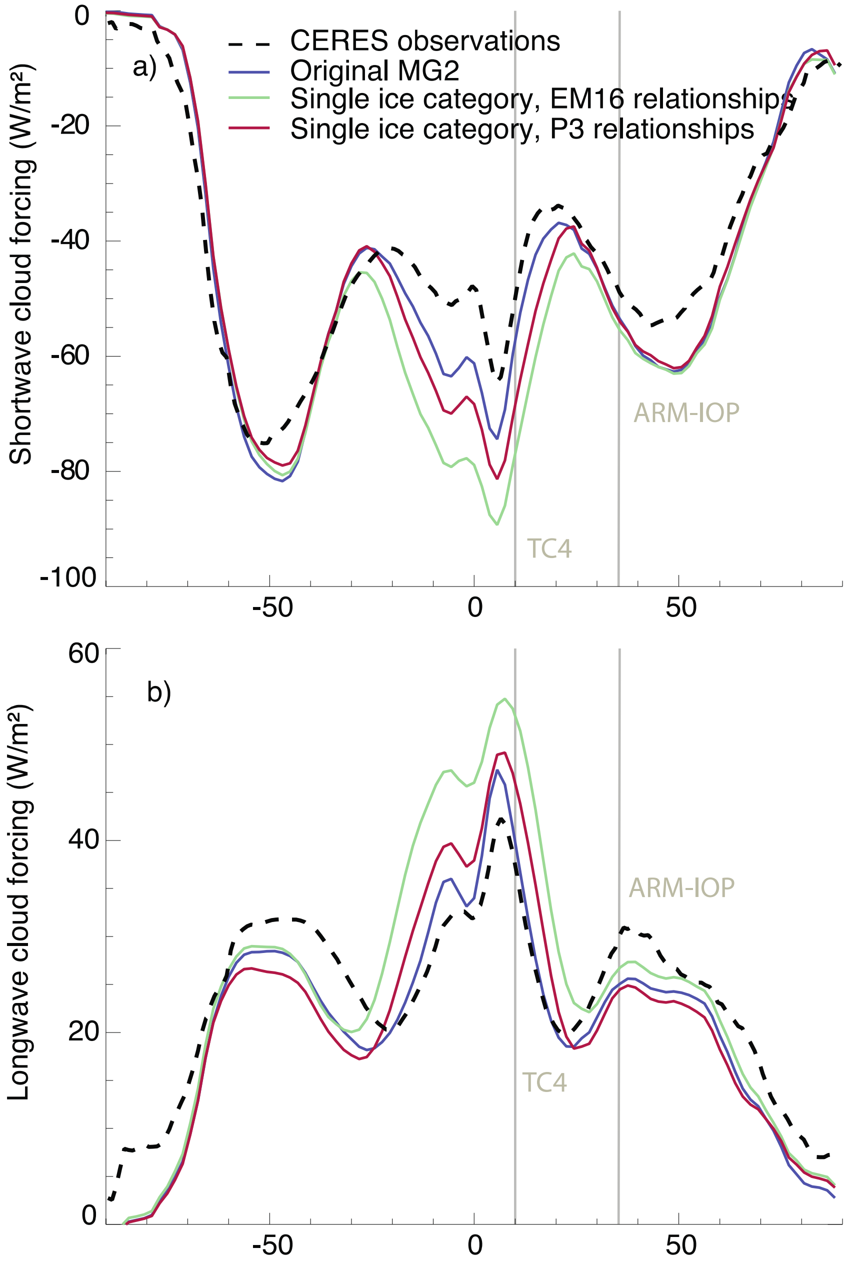
CAM5 sensitivity tests

- 3 sensitivity tests
  - **MG2** Morrison and Gettelman microphysics scheme
  - **P3** (constant α,β,γ,δ), follow Morrison and Milbrandt (2015)
  - **EM16** P3 with Erfani and Mitchell method (variable α,β,γ,δ)

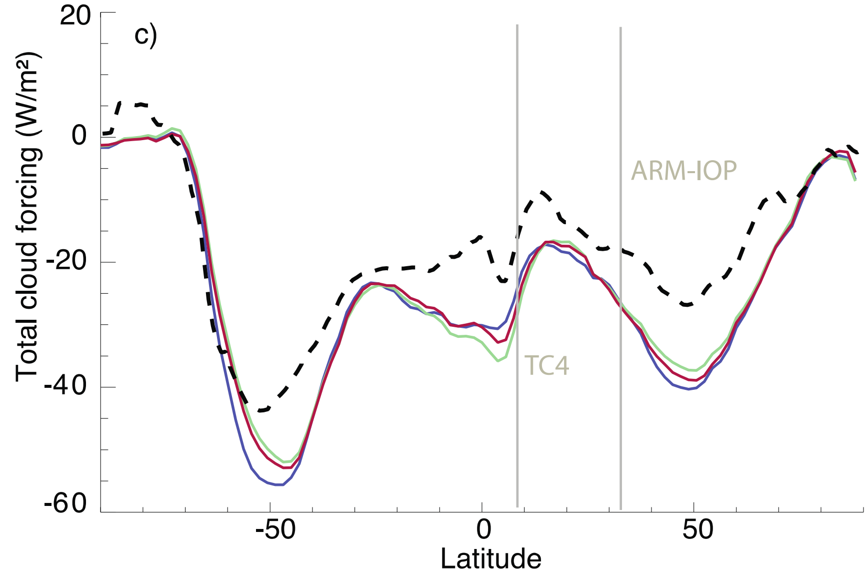
Both P3 and EM15 calculate fallspeed from Mitchell and Heymsfield (2005) by using *m-D* and *A-D* expressions, instead of $V=aD^b$.

Fall speed is self-consistent with other parameters dependent on *m-D* and *A-D* relationships.

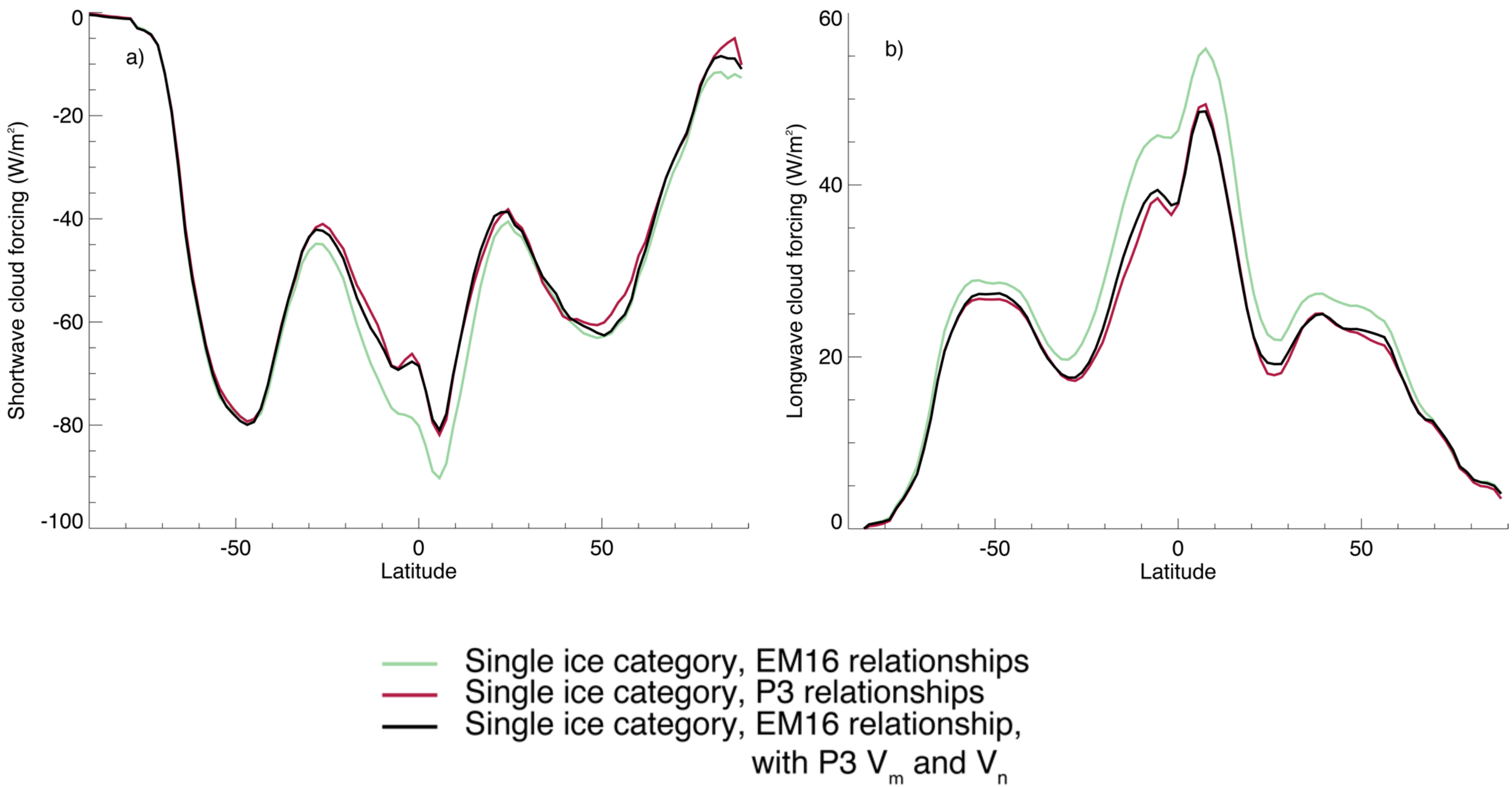
Radiative Forcing



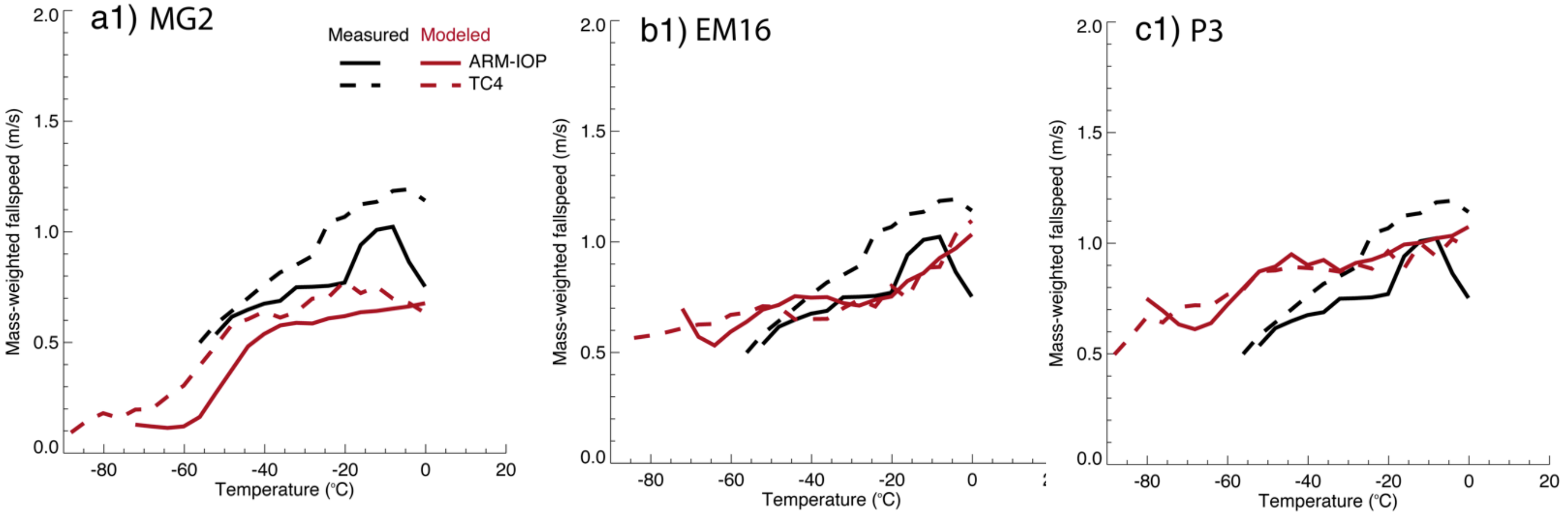
Total radiative forcing



Sensitivity to mass-weighted fallspeed



Mass weighed fallspeed



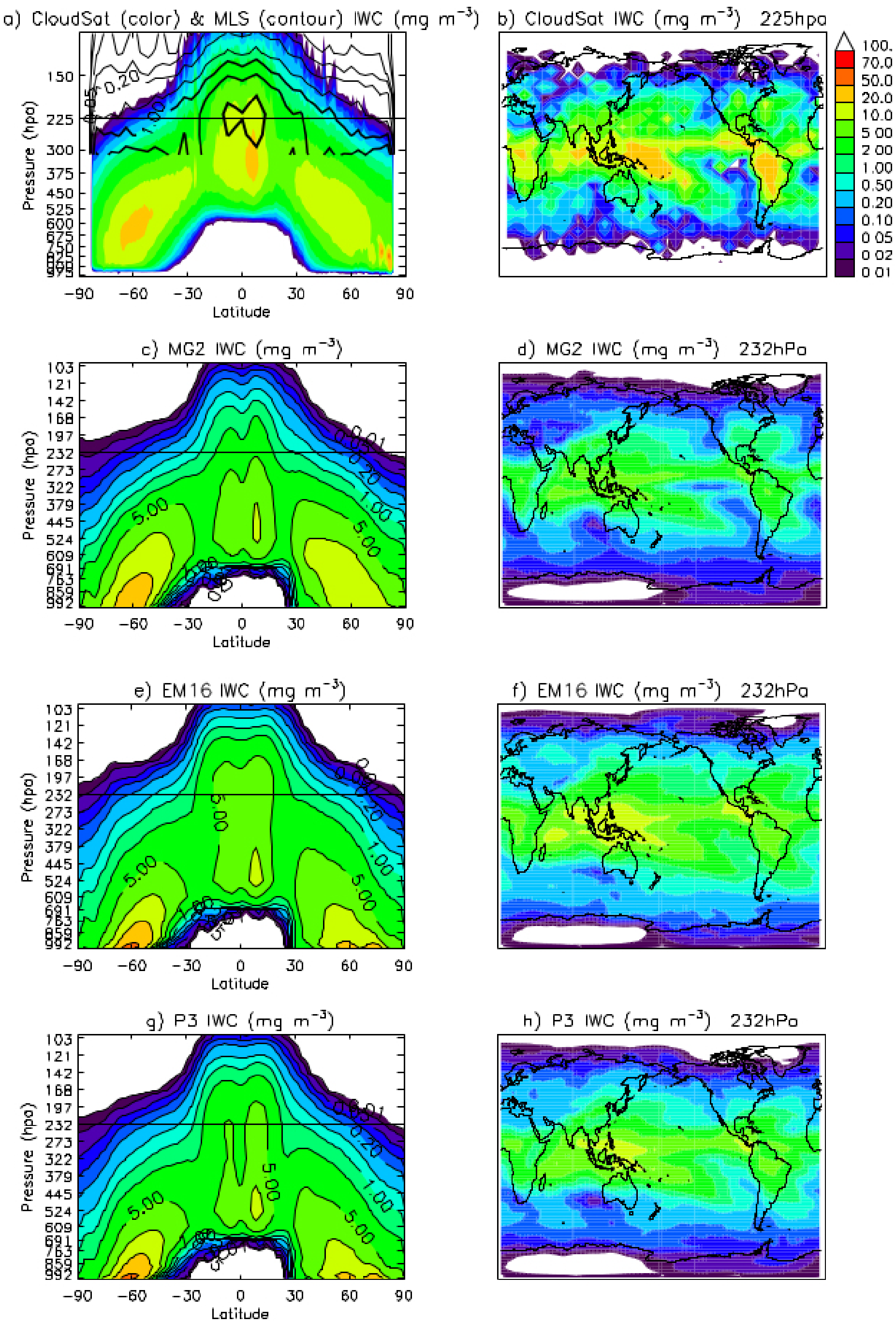
Ice Water Content

Observations (CloudSat & MLS)

MG2

EM16

P3



Summary of part 1

- Conceptual improvement to ice microphysics in CAM5
- Proof of concept

  One single category for ice (cloud ice + snow)

  Self-consistency between description of physical properties of ice (fall velocity, effective radius, density)

Eidhammer et al, 2017 J. Climate

Mixed Phase Hydrometeors in a Global Model

Gettelman, Morrison, NCAR

Motivation

- Aiming at a single microphysics package for global models that can work from the mesoscale to the climate scale.
- Global models typically do not have a mixed phase hydrometeor (hail/graupel). Resolved vertical velocities are too low to have them matter, but they do matter for higher resolution.
- Now: global simulations are pushing into mesoscale resolutions, and even convection permitting resolutions.
- To develop a scale-insensitive cloud physics package, the cloud microphysics should permit formation of hail/graupel.
- This is for post-CESM2

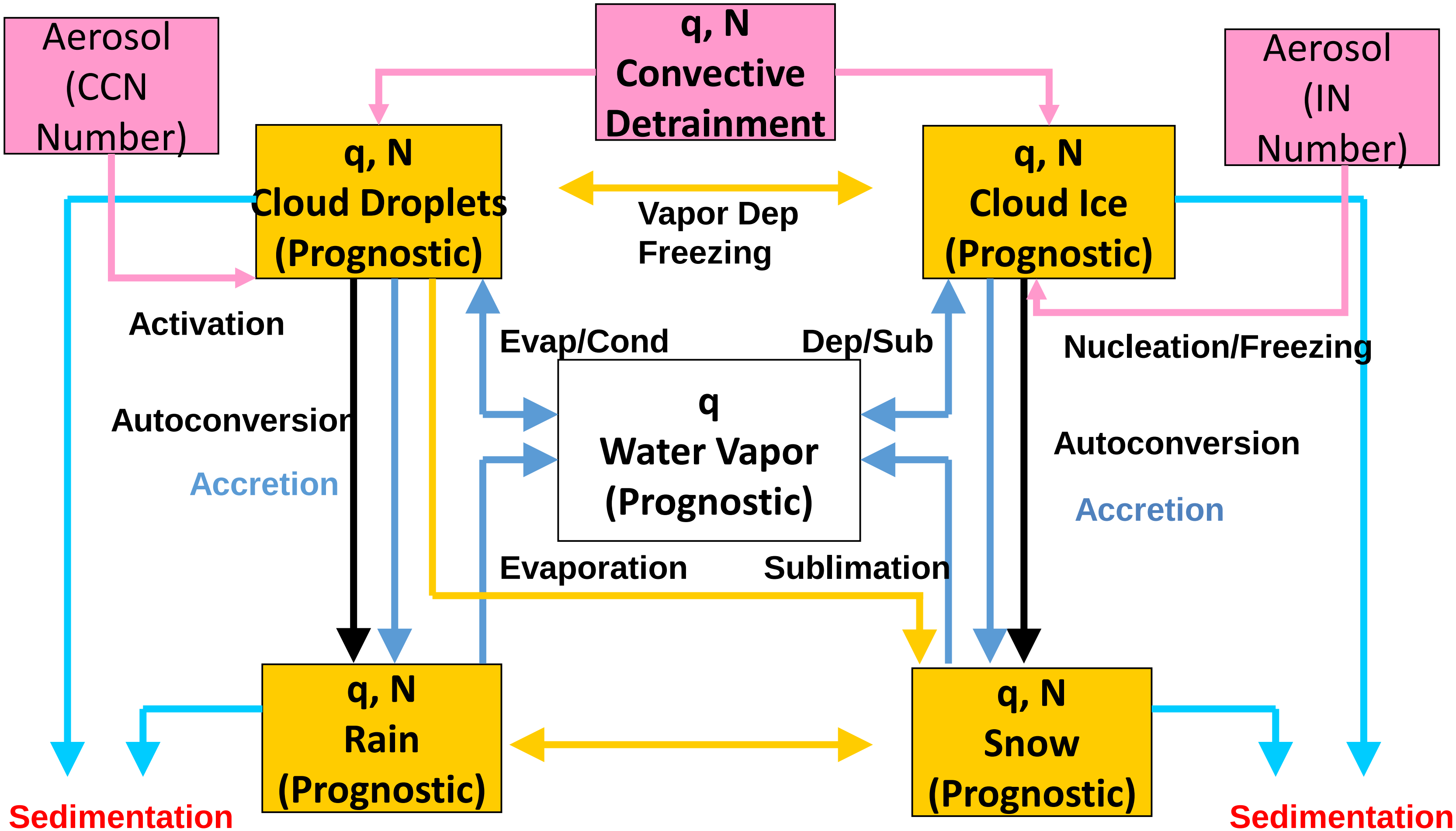
MG2→ MG3

- MG3 = MG2 + hail/graupel phase.
- MG3 = bulk, 2-moment, 5 class scheme
    - Liquid, Ice, Rain, Snow, Hail/Graupel
- Similar treatment to Morrison et al 2005 (WRF scheme).
- Use a switch to select hail or graupel (different fixed density), or turn it off. When off, bit for bit with MG2.
- Update: now we have a version that appears to work

Morrison & Gettelman 2008, 2015

MG2

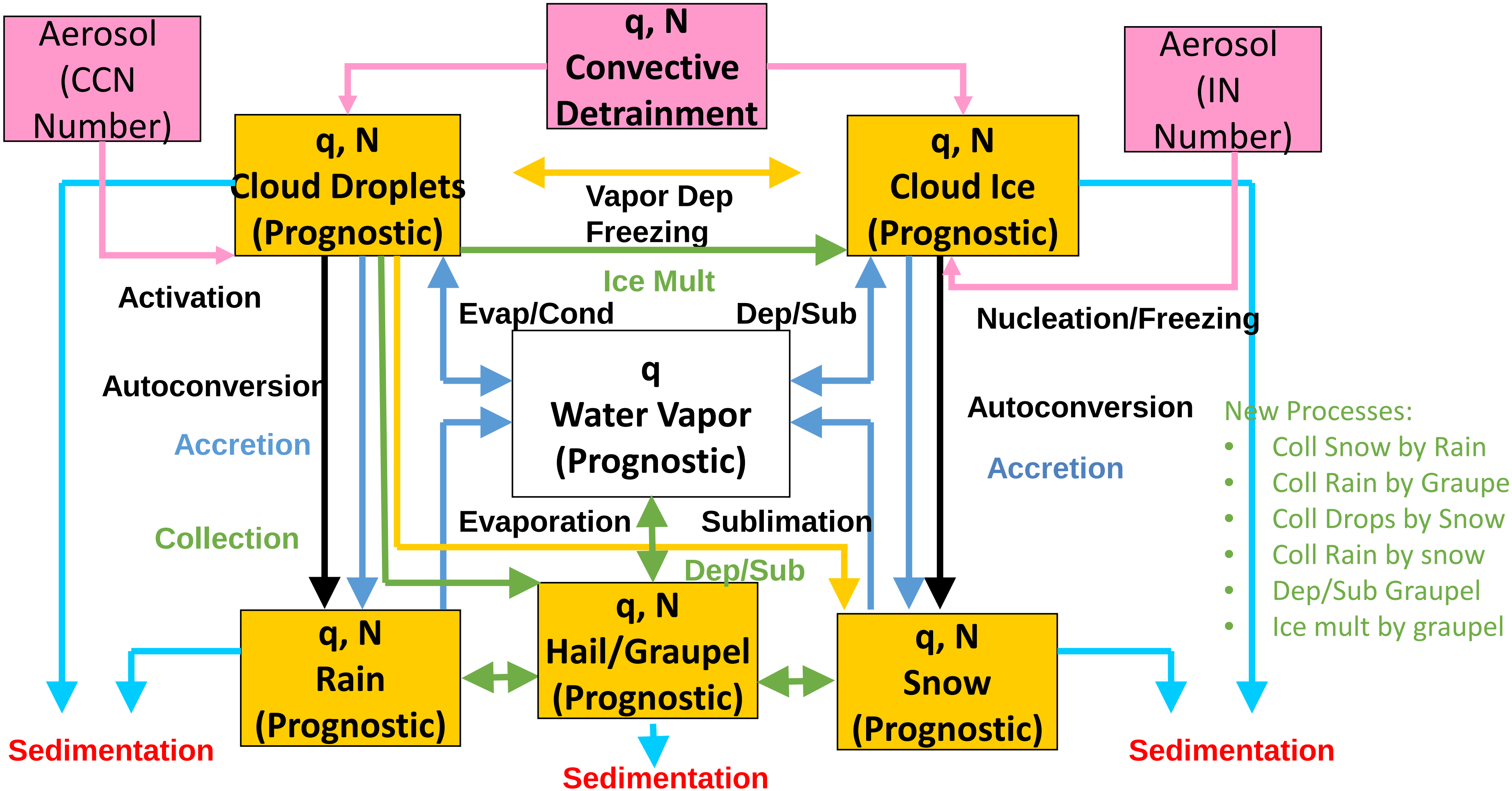
q = mixing ratio
N = number concentration



MG3

q = mixing ratio
N = number concentration

Sources & Sinks



Status

- Update (Feb 2017)
  - Fixed conservation and number concentration issues
- Implemented and running (SCAM tests passing)
  - Conserves energy and mass
  - Output diagnostic budgets
- Completed global simulation (1˚, CAM6 physics)
  - Conserves energy and mass (RESTOM-RESSURF = 0.029 Wm^{-2} for 5 yrs)
  - Climate effect: minimal, small increase in ice mass (SH subtropics)
  - Numbers, sizes, concentrations and fall speed seem reasonable

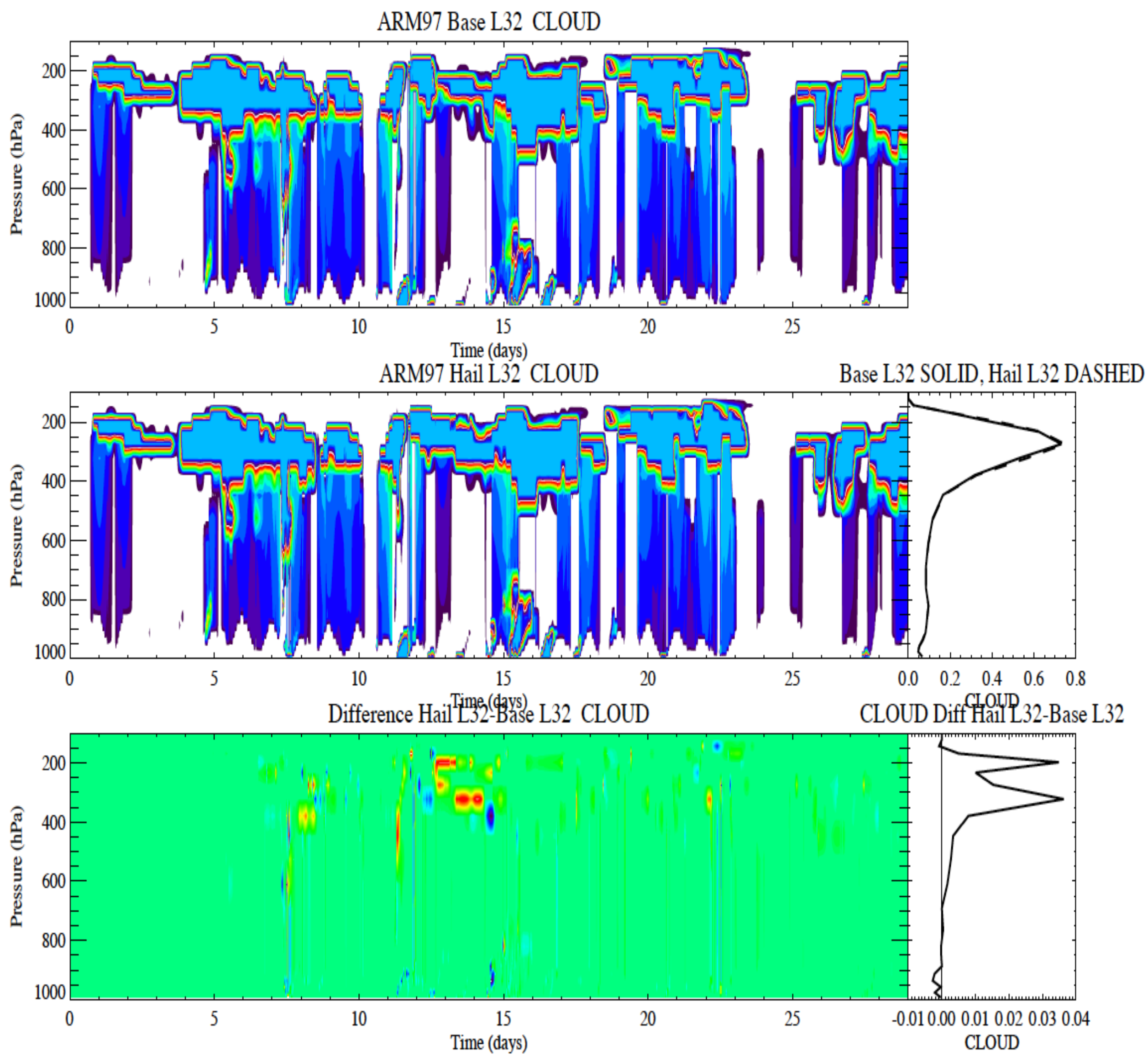
Single Column (SCAM) Tests: Cloud Fraction

ARM Case (ARM SGP Site, June 1997)

Base MG2

MG3: Hail

Difference

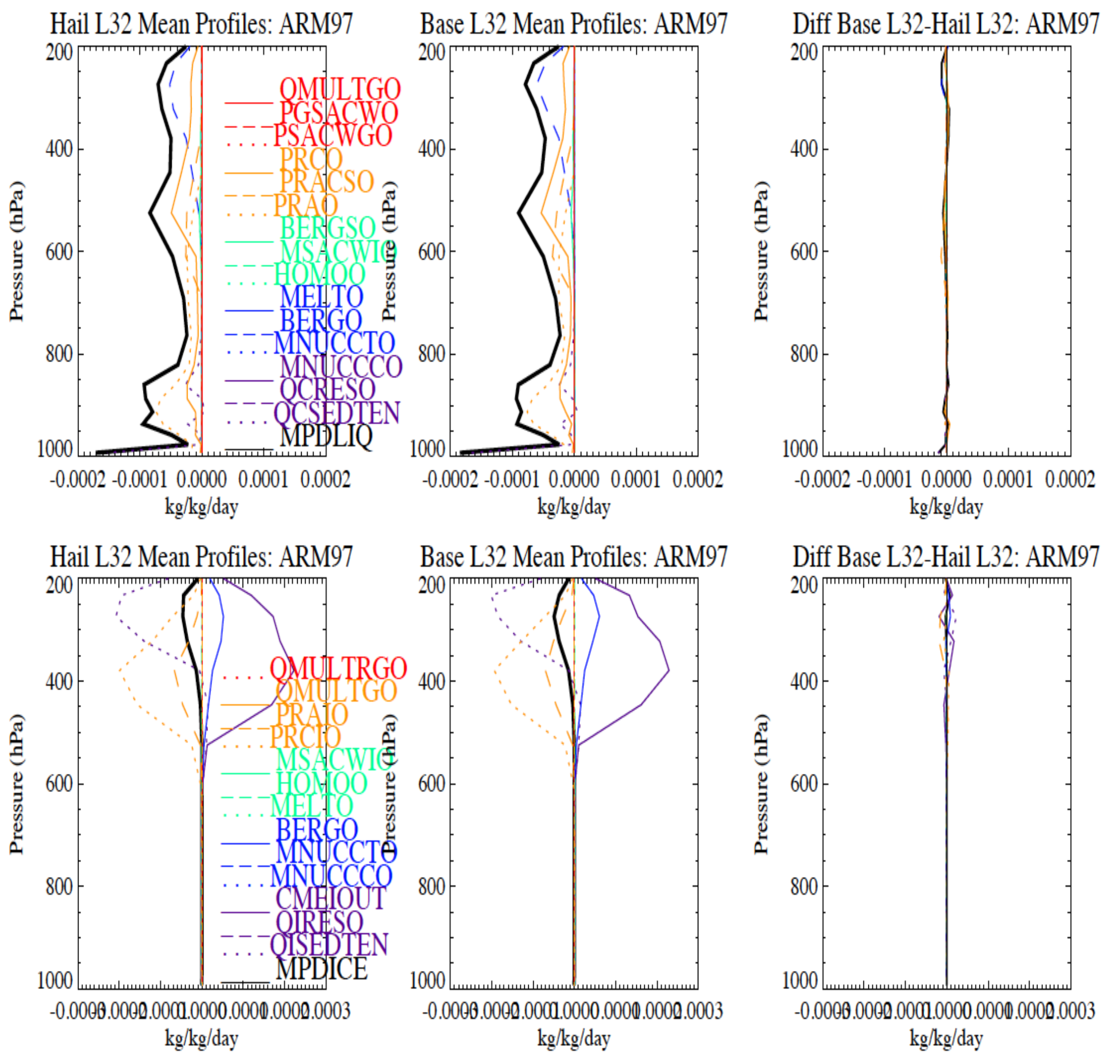


SCAM Tests: Process Rates

ARM Case (ARM SGP Site, June 1997)

Liquid

Ice

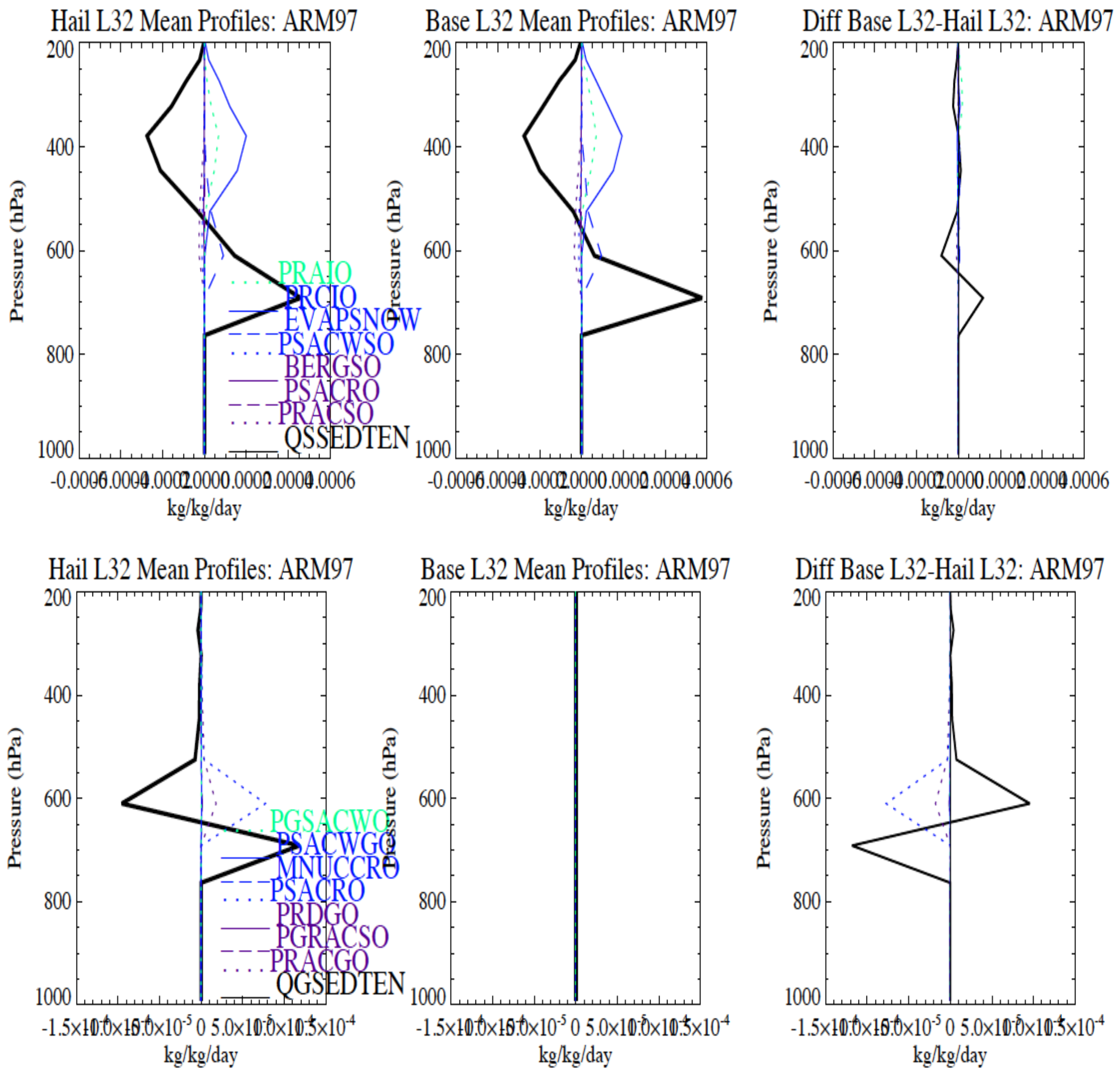


SCAM Tests: Process Rates

ARM Case (ARM SGP Site, June 1997)

Snow

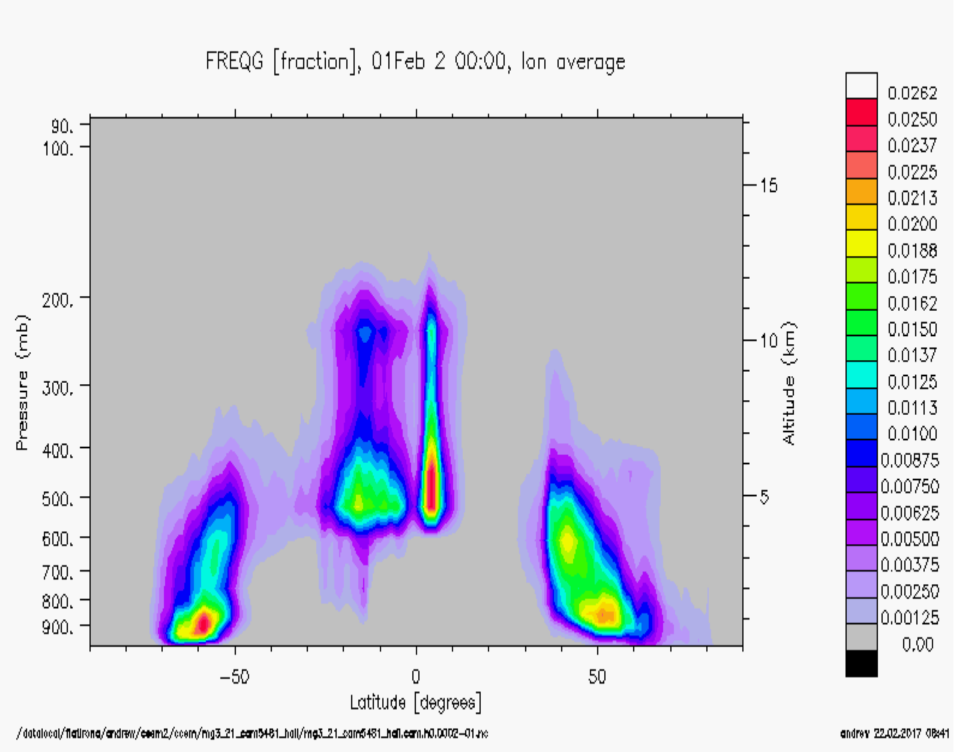
Hail

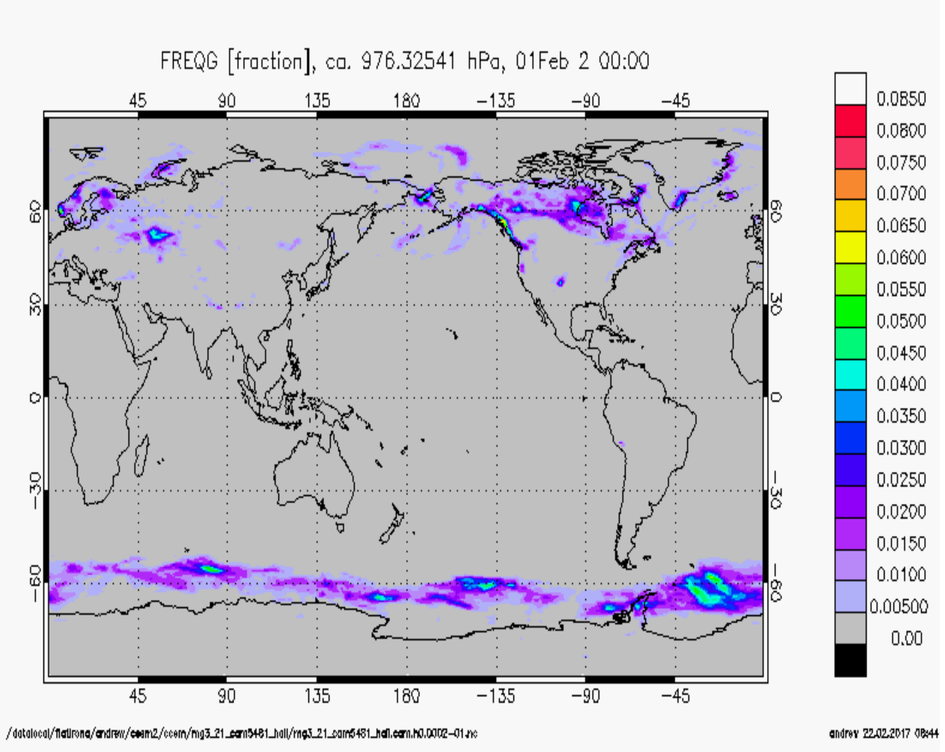


CAM Global Test

- Occurs maximum of 5% of the time locally

Monthly Frequency of Occurrence of Graupel

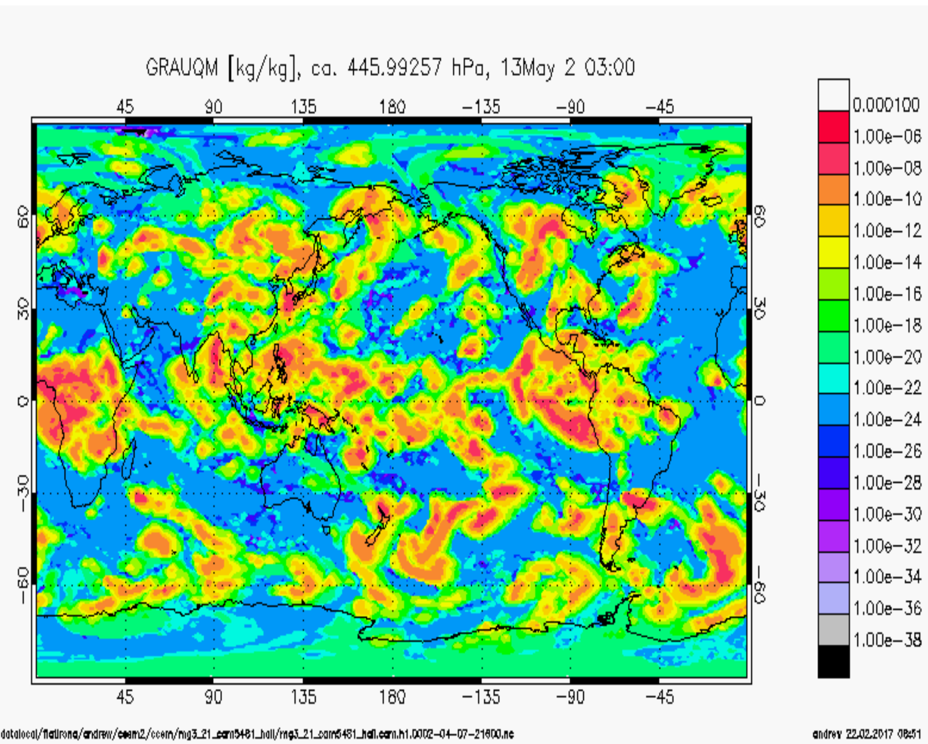




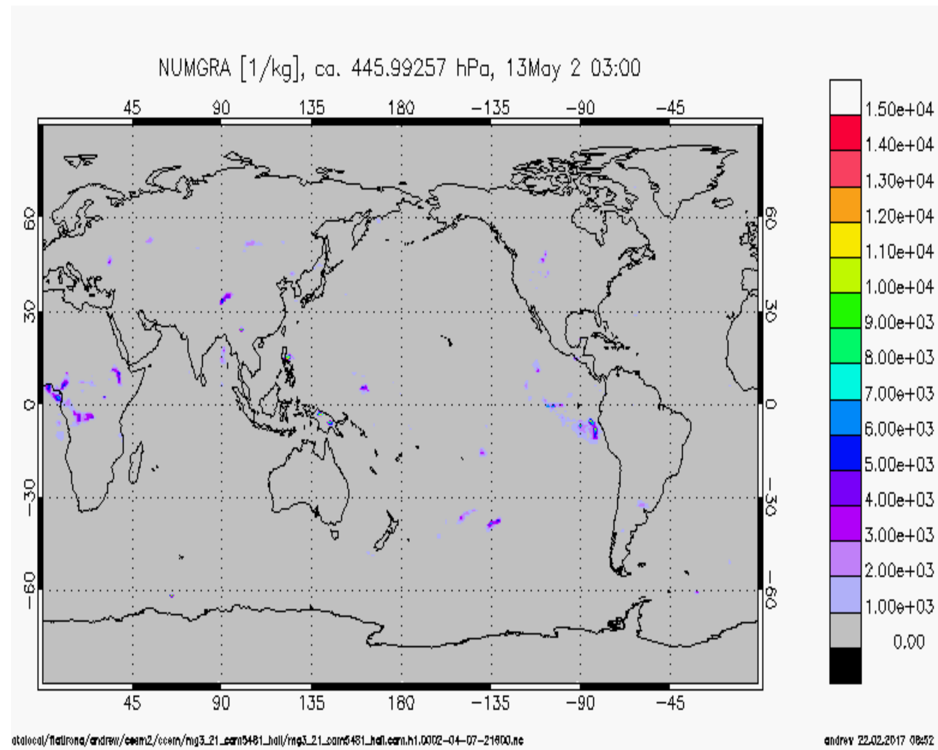
CAM Global Test

- Small mass (10s of ppm)
- Number conc up to 1e.4/kg, 10/L
- Fall speed few m/s

Instantaneous Mass of Graupel



Instantaneous Graupel Number Concentration



Next Steps

Test code ‘where it matters more’

- Code is ‘ready’, but probably needs more testing and a quick paper.
- Port to KiD (kinematic driver, convection case)
- Higher resolution (12km CONUS test?)
- CAM MPAS tests at higher resolution (down to 3km).
- Goal: microphysics ’for all’: same code across NCAR community models