Prognostic Precipitation, Multi-Scale cloud physics, and Aerosol Cloud Interactions

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Motivation

- Aerosol-Cloud Interactions are a significant forcing agent on climate
- Altering CCN/IN affects
  - Cloud brightness (cloud radiative effect)
  - Precipitation formation

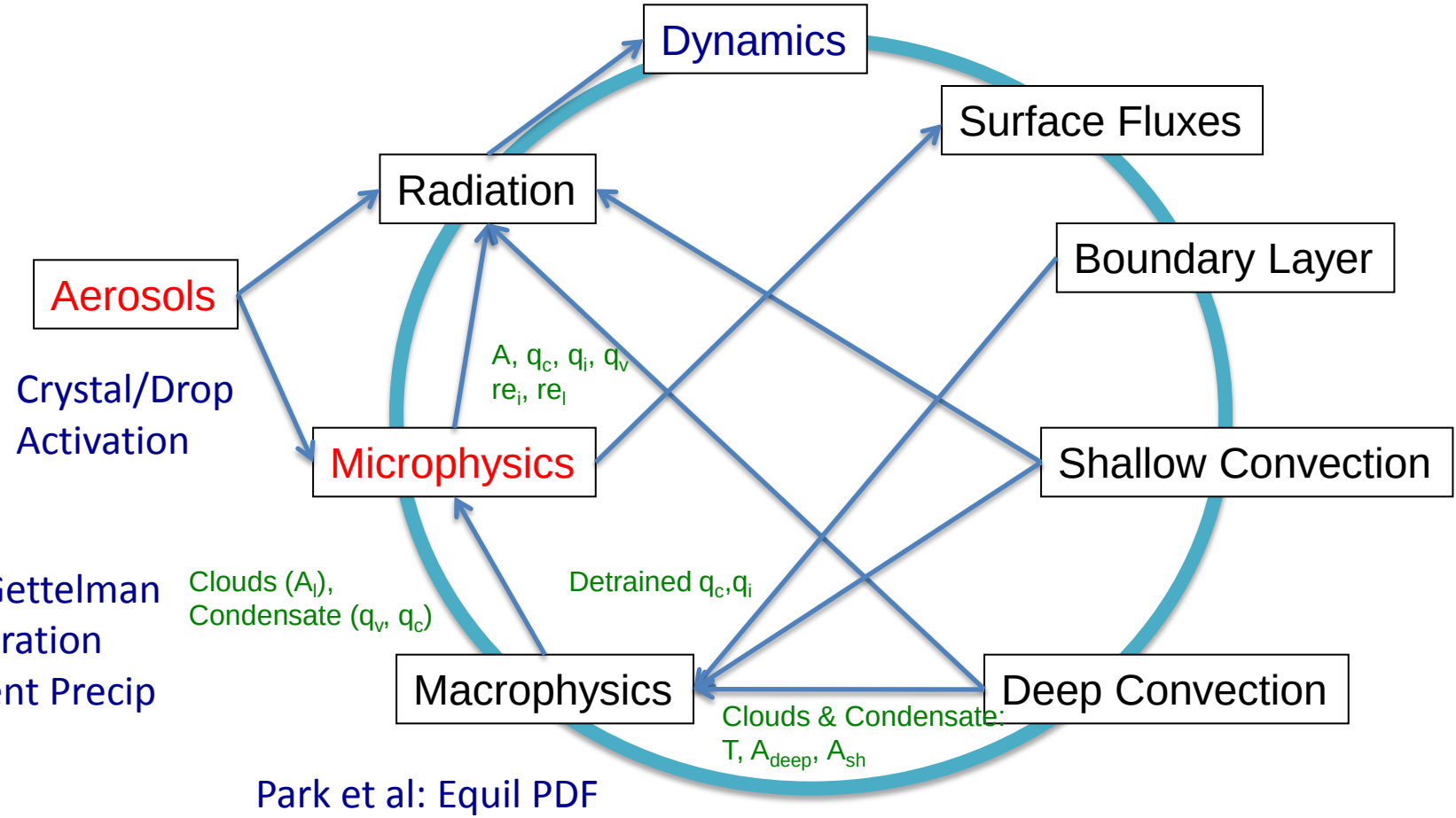
Outline

- Key Microphysics Processes
- Updated Cloud Microphysics for CESM
- Idealized & Single column model experiments
- Sensitivities in a global model

- Models:
  - Kinematic Driver (Met Office, Shipway & Hill 2012)
  - GCM: CESM (CAM5: Gettelman et al 2010; Neale et al 2012)

Community Atmosphere Model (CAM5)

CAM5.1: IPCC AR5 version (Neale et al 2010)



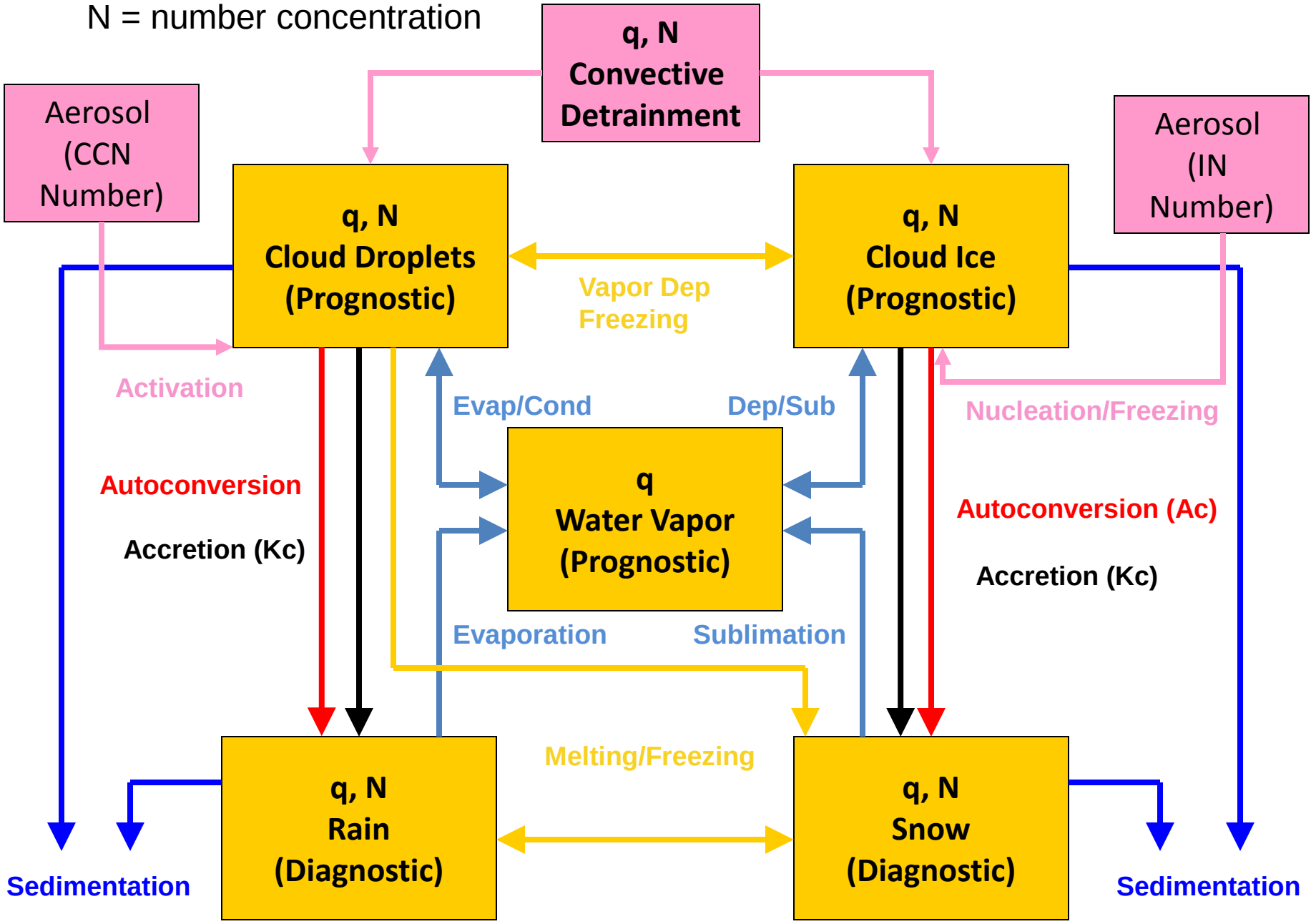
2 Moment
Morrison & Gettelman
Ice supersaturation
Diag 2-moment Precip

Park et al: Equil PDF

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

q = mixing ratio
N = number concentration

Morrison & Gettelman 2008



Auto-conversion (Au) & Accretion (Ac)

Khairoutdinov & Kogan 2000: regressions from LES experiments with explicit bin model

Au = $$\left(\frac{\partial q_r}{\partial t}\right)_{\text{auto}} = 1350 q_c^{2.47} N_c^{-1.79}, \qquad (29)$$

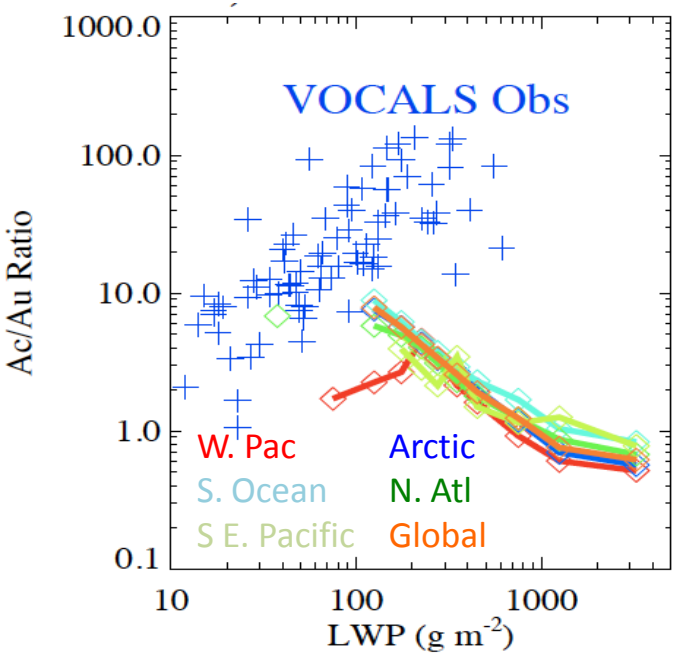
Ac= $$\left(\frac{\partial q_r}{\partial t}\right)_{\text{acer}} = 67 (q_c q_r)^{1.15}. \qquad (33)$$

- Auto-conversion an inverse function of drop number
- Accretion is a mass only function

Balance of these processes (sinks) controls mass and size of cloud drops

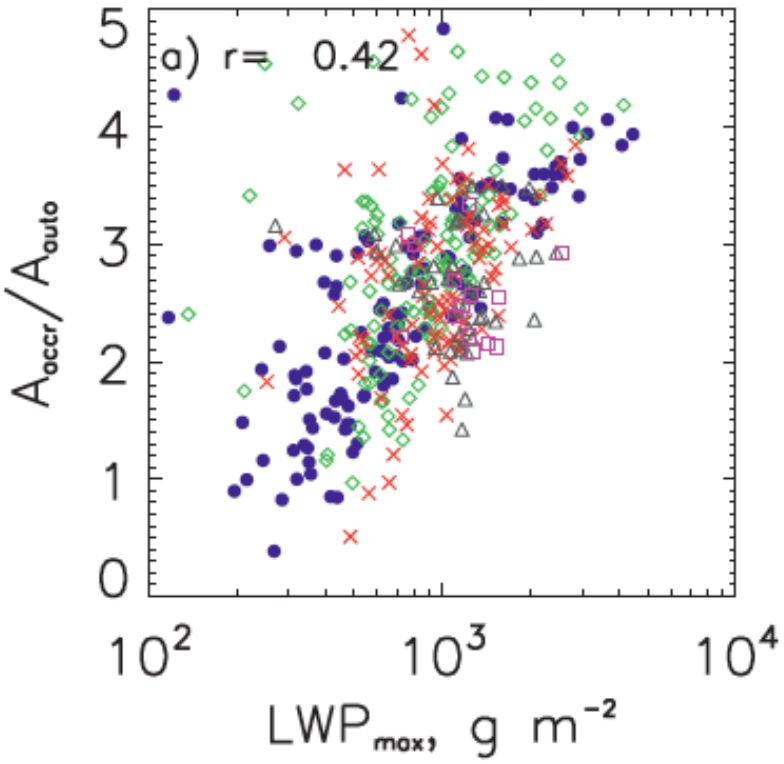
Ac/Au Ratio..

Global Model (CAM)



Gettelman et al 2013, ACP

Large Eddy Simulation

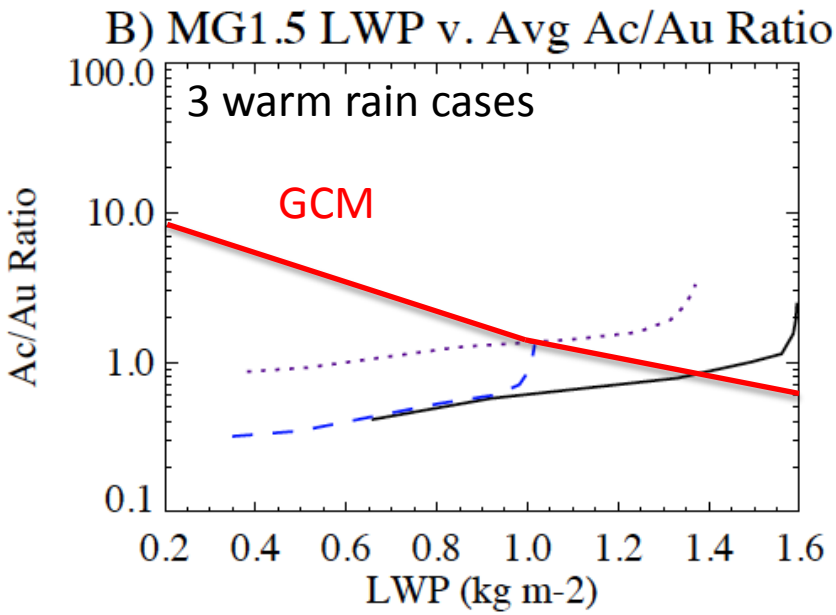


Jiang et al, 2010, JAS

Ratio decreases in the GCM

Very different than LES or Steady State (SS) models

Accretion / Autoconversion: "Off-Line"



Microphysics in off line driver (KiD, Shipway et al 2012).

Increases in Ac/Au ratio

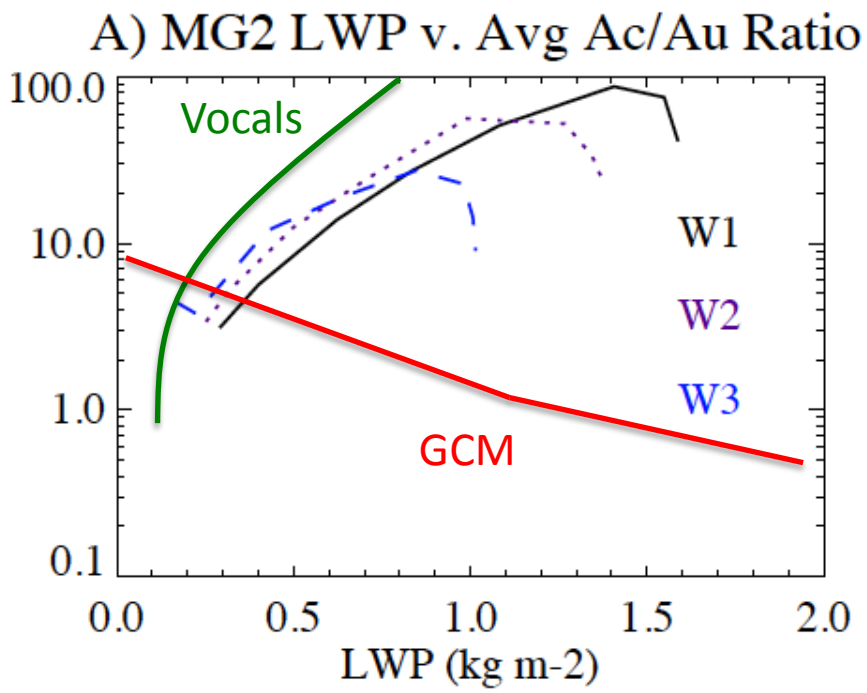
Full model has decreases in this ratio
Coupling of microphysics to condensation is a problem

Steady State Model, Full Microphysics both similar to LES and Observations

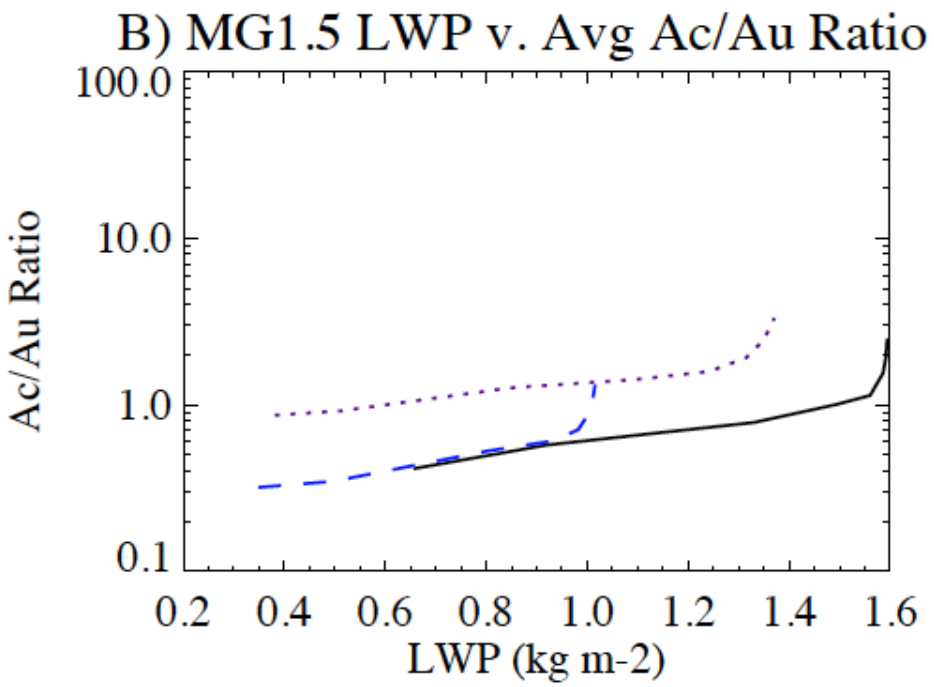
Issues: Timesteps & Diagnostic Precip

Accretion / Autoconversion

MG2: Prognostic



MG1.5: Diagnostic



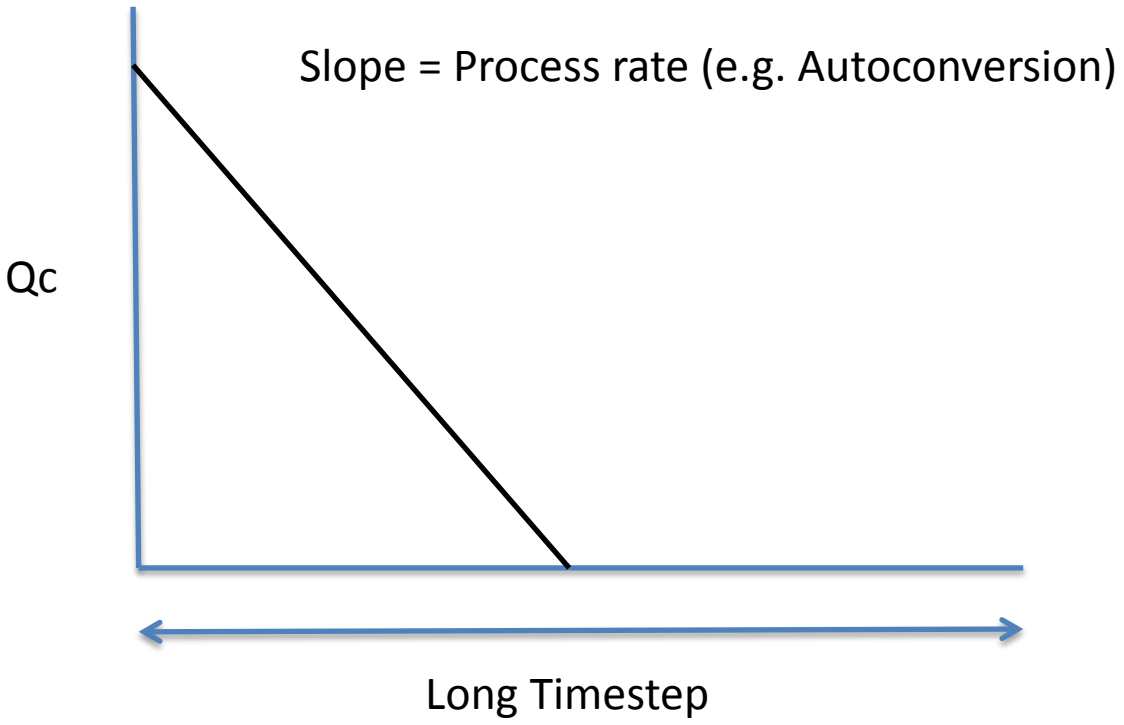
Note: Off line driver shows increases in Ac/Au ratio even in MG1.5
MG2 is 'better' (looks more like steady state model)

Full model has decreases in this ratio
likely coupling of microphysics to condensation is a problem

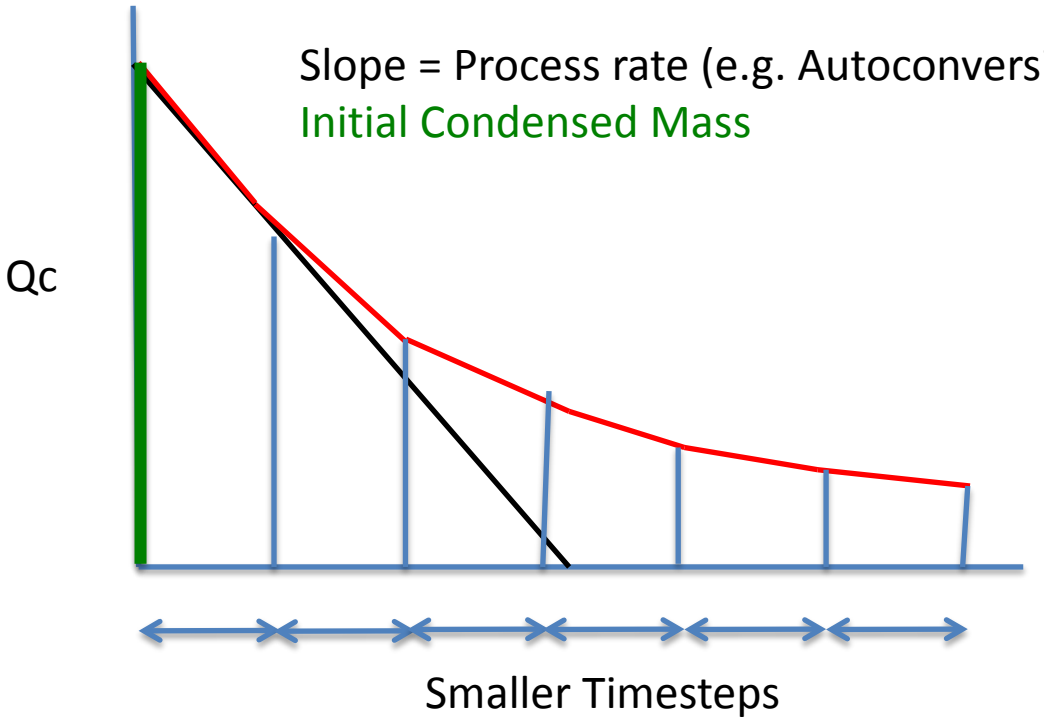
Key Results

- ACI dependent on process rates
- Too much auto-conversion in the GCM: or too little accretion
- Accretion depends on Rain, and diagnostic rain may be the problem
- How to correct it
  - Prognostic rain helps
  - Also: better coupling to condensation

GCM Timestep Issues



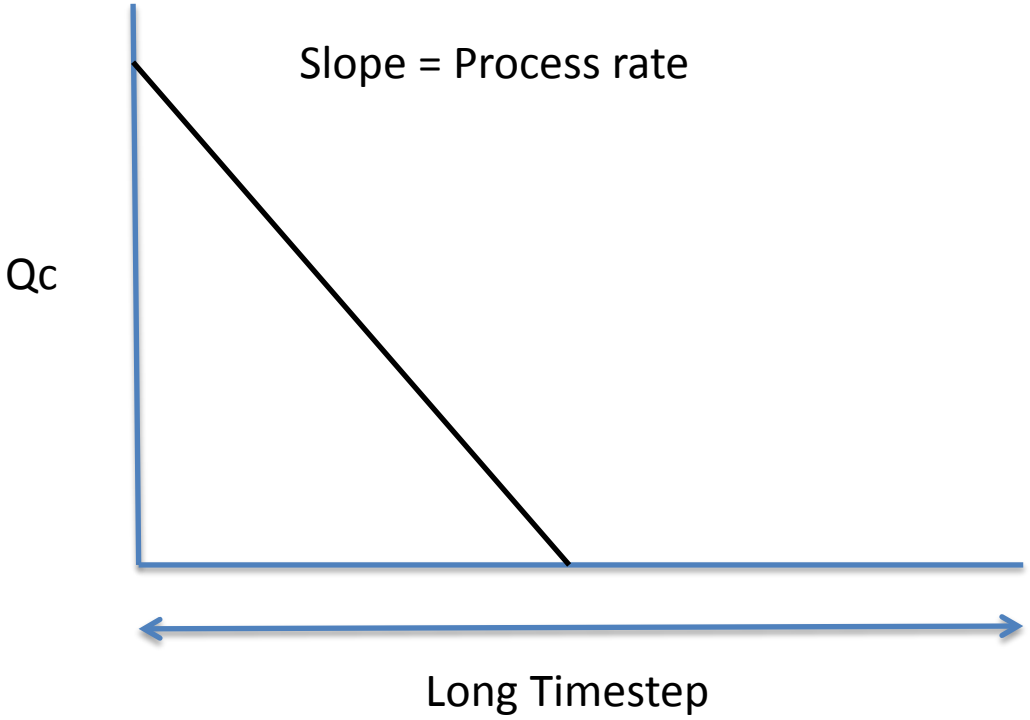
GCM Timestep Issues



Do not get total depletion
In general: more Qc

GCM Timestep Issues

Macrophysics Timestep
(Large scale Condensation)



GCM Timestep Issues

Macrophysics Timestep
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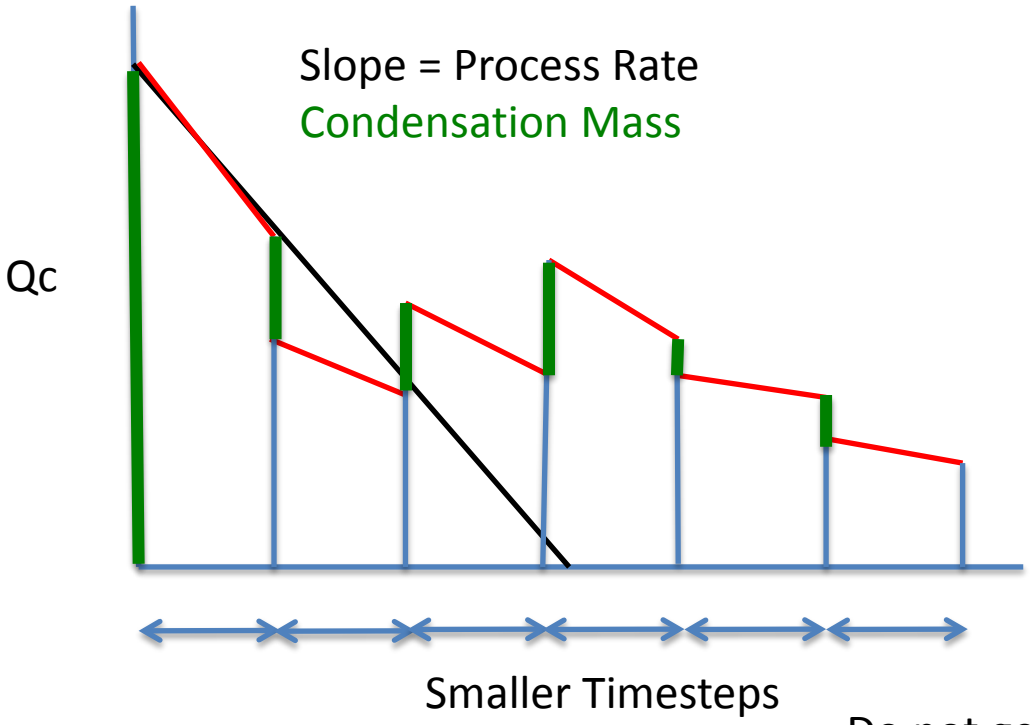


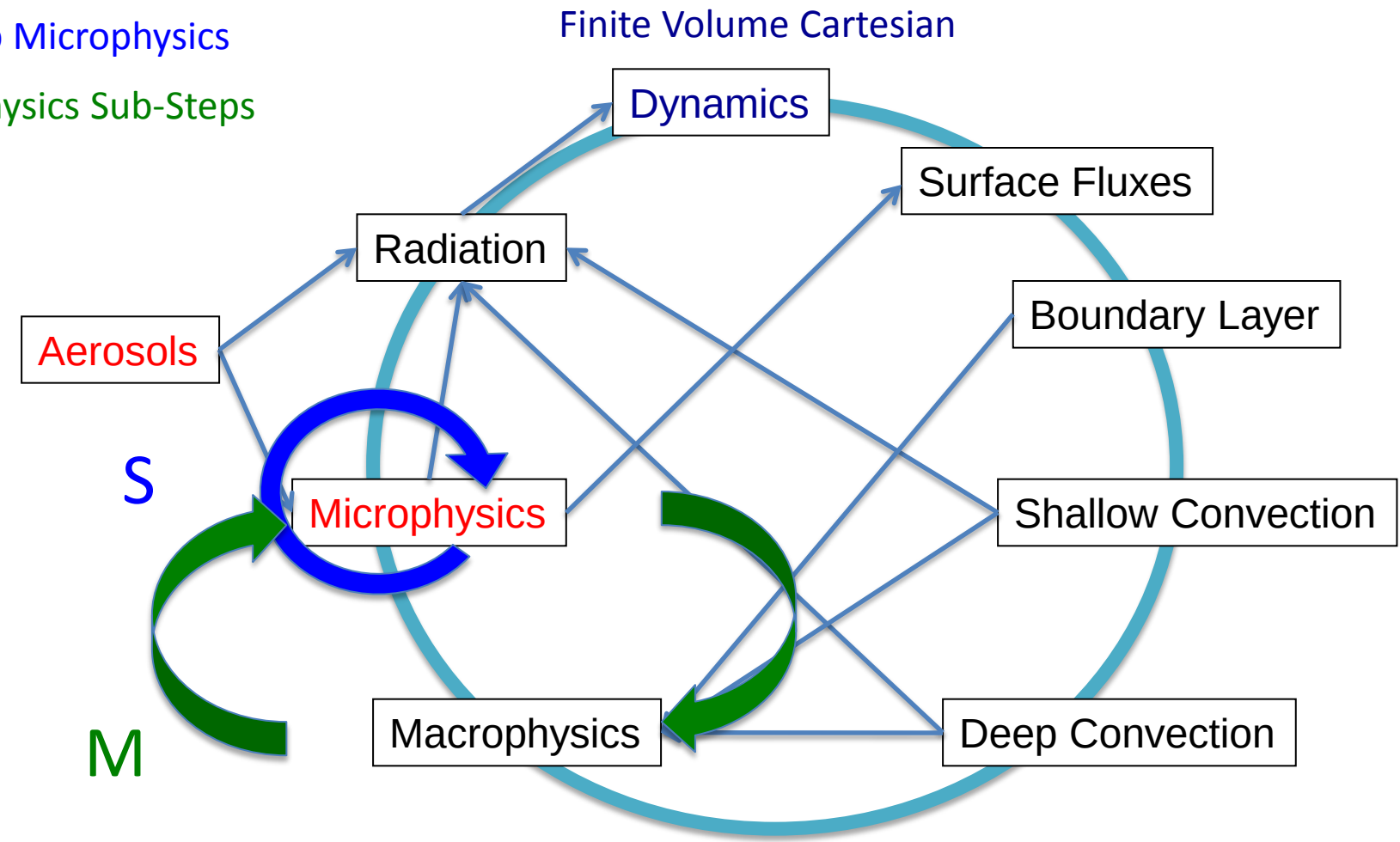
Do not get total depletion
Note: Condensation can switch sign

Community Atmosphere Model (CAM5)

CAM5.1: IPCC AR5 version (Neale et al 2010)

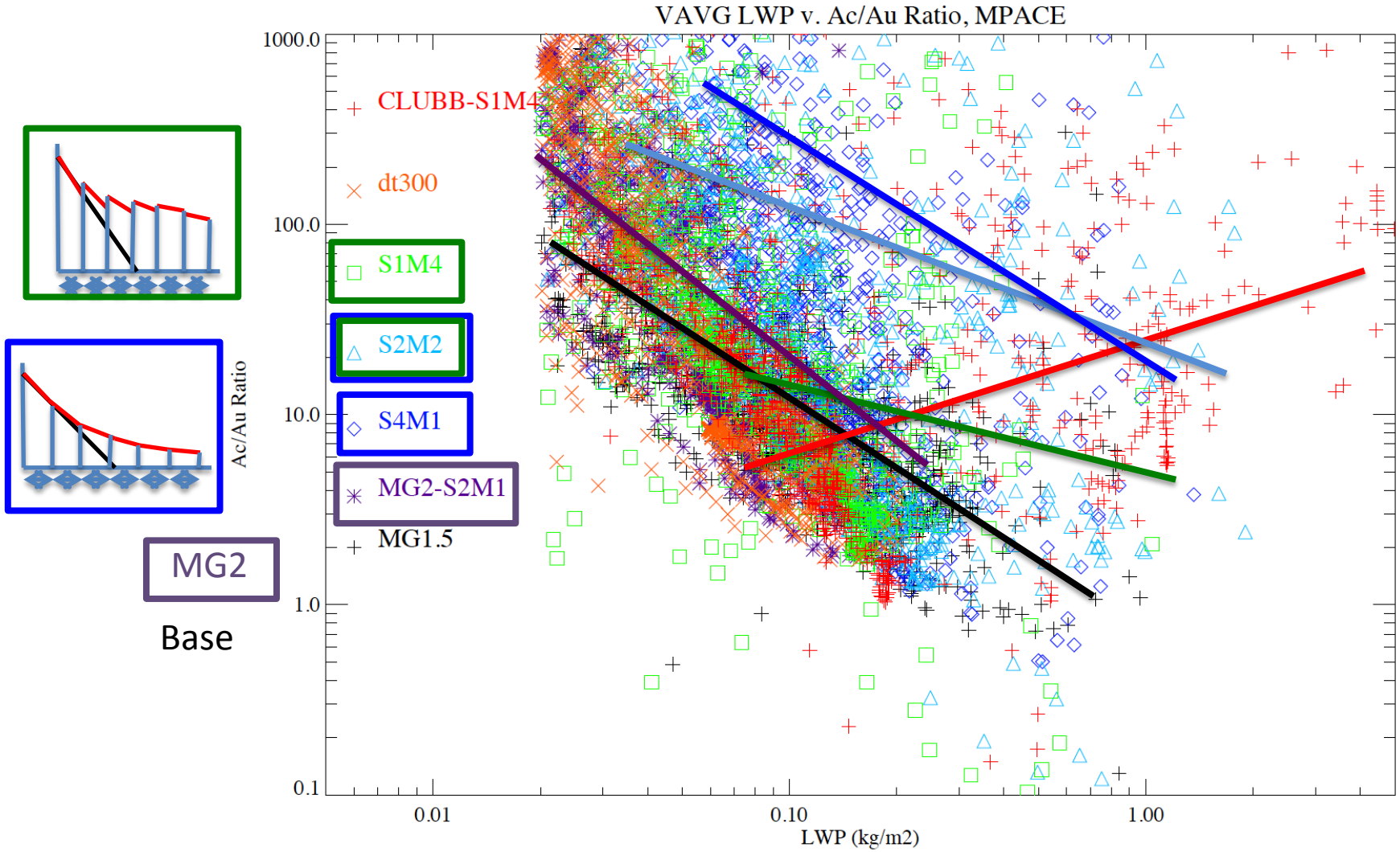
(S)ub Step Microphysics

(M)acrophysics Sub-Steps



Standard is S2M1

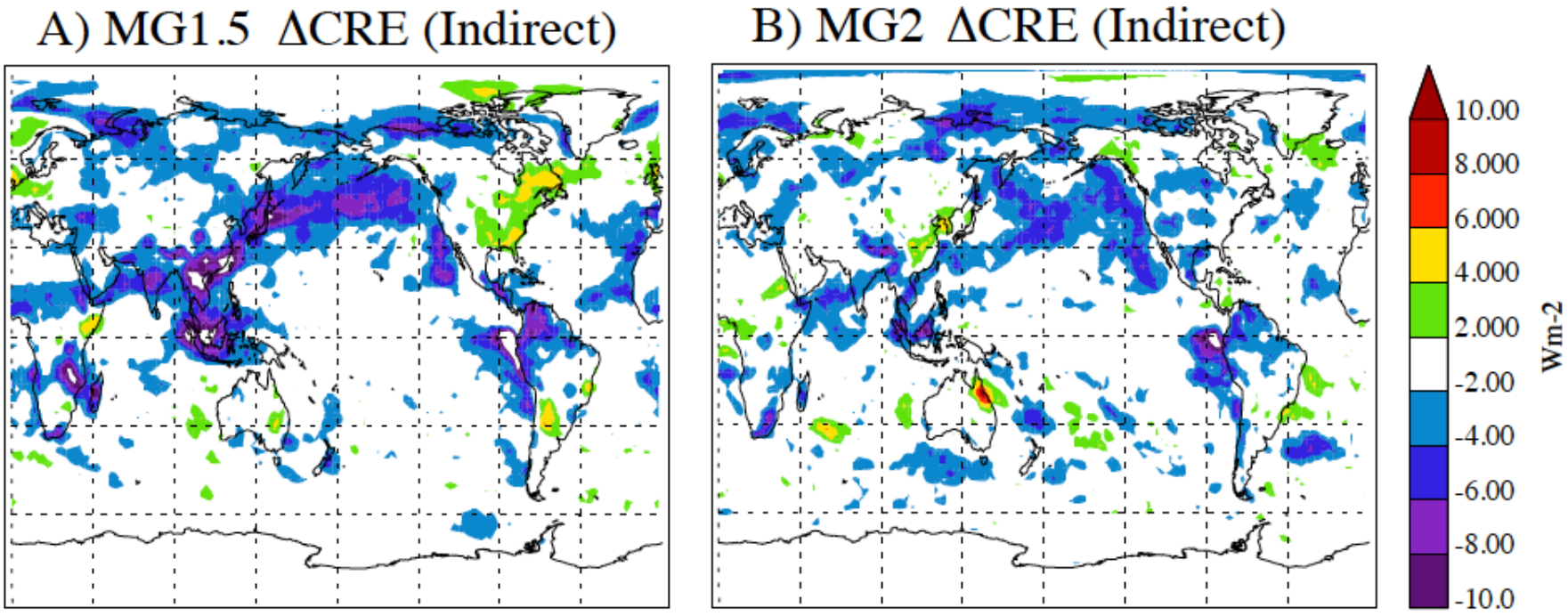
Effects of Coupling on Process Rates



S2M2 & S4M1 & S1M4 = 4 Microphysics sub-steps per 1200 second SCM timestep

ACI: Change in Cloud Forcing

2000 Aerosols – 1850 Aerosols: Cooling in 2000
MG2: ACI (ΔCRE) -40% reduced ACI from SW Cloud Forcing (SWCF=SWCRE)
Coupling Micro-Macro reduces effects further (S2M2, S1M4)



Code	ΔR	ΔCRE (L+S)	ΔSWCF	ΔLWCF	ΔLWP (%)	Est DE
MG1	-1.59	-1.26	-1.69	+0.43	+8.1%	-0.33
MG2	-1.06	-0.79	-1.08	+0.29	+5.7%	-0.27
MG2-S2M2	-0.80	-0.57				
MG2-S1M4	-0.87	-0.78				

Conclusions

- Microphysical process rates important for ACI
  - cloud susceptibility to aerosols depends on Ac/Au
- GCM sensitivity appears to do the wrong thing
  - Not microphysics itself
- Coupling of microphysics to condensation important
  - Correct this with sub-stepping
- Significantly Affects ACI
  - 30% or more reductions