# Aerosol-cloud interactions and uncertainties in CAM: the role of microphysics

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Thanks to: Climate Process Team (Bogenschutz, Larson, et al), P. Caldwell (LLNL)

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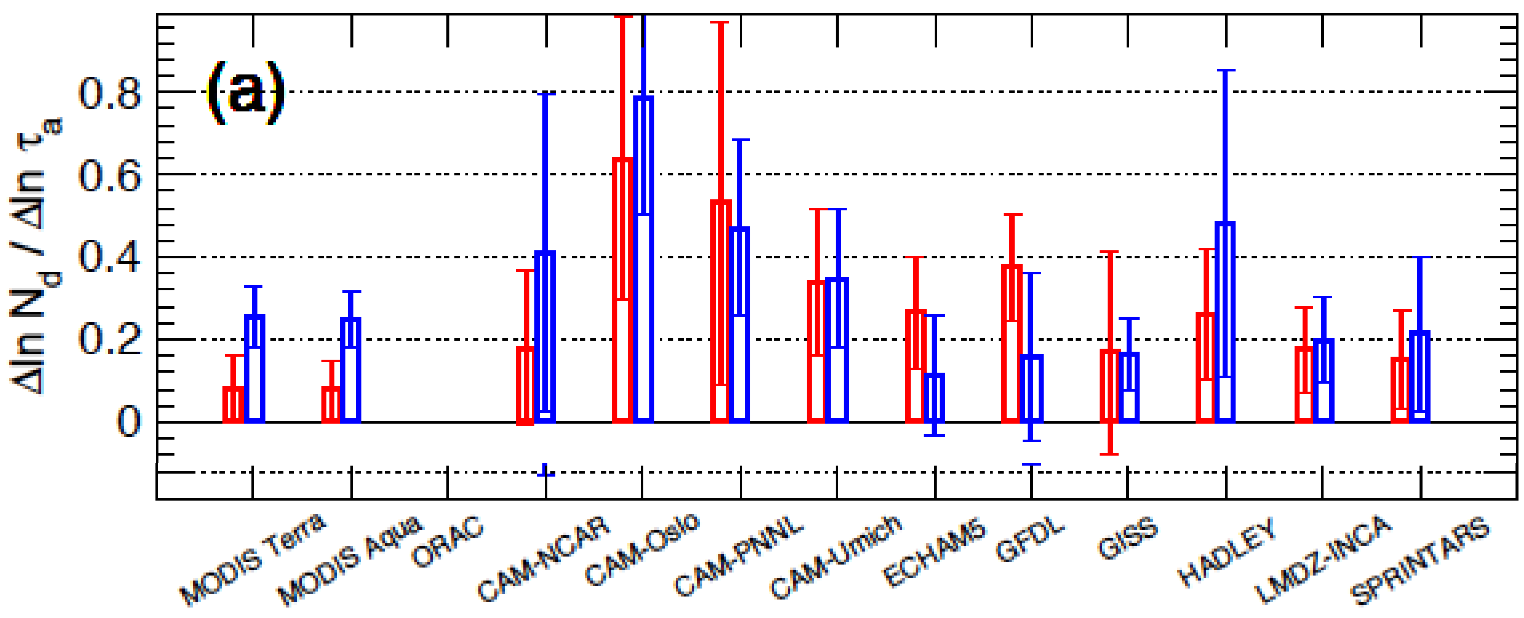
# Motivation

- Aerosol cloud interactions (ACI) are an important contributor to (adjusted) radiative forcing
- ACI may also impact timing and intensity of precipitation.
- ACI as observed with correlations from satellites (dLWP/dAOD) seem to be smaller than simulated in global models: simulations respond more than ‘observed’
- What is going on? How to deal with it? (besides blaming observations)
- Goal: higher confidence in GCM results, better representation of microphysics across scales

# ‘Observed’ v. Simulated ACI

## Change in Number v. AOD




Land Ocean

Quaas et al 2009, ACP

# Hypotheses

- There is something wrong with the way aerosols affect clouds in our global models
- This may come from microphysics: bulk formulations of process rates

Methods:

- Explore Microphysical Process Rates
- Compare to a simple model

Summary / Future work

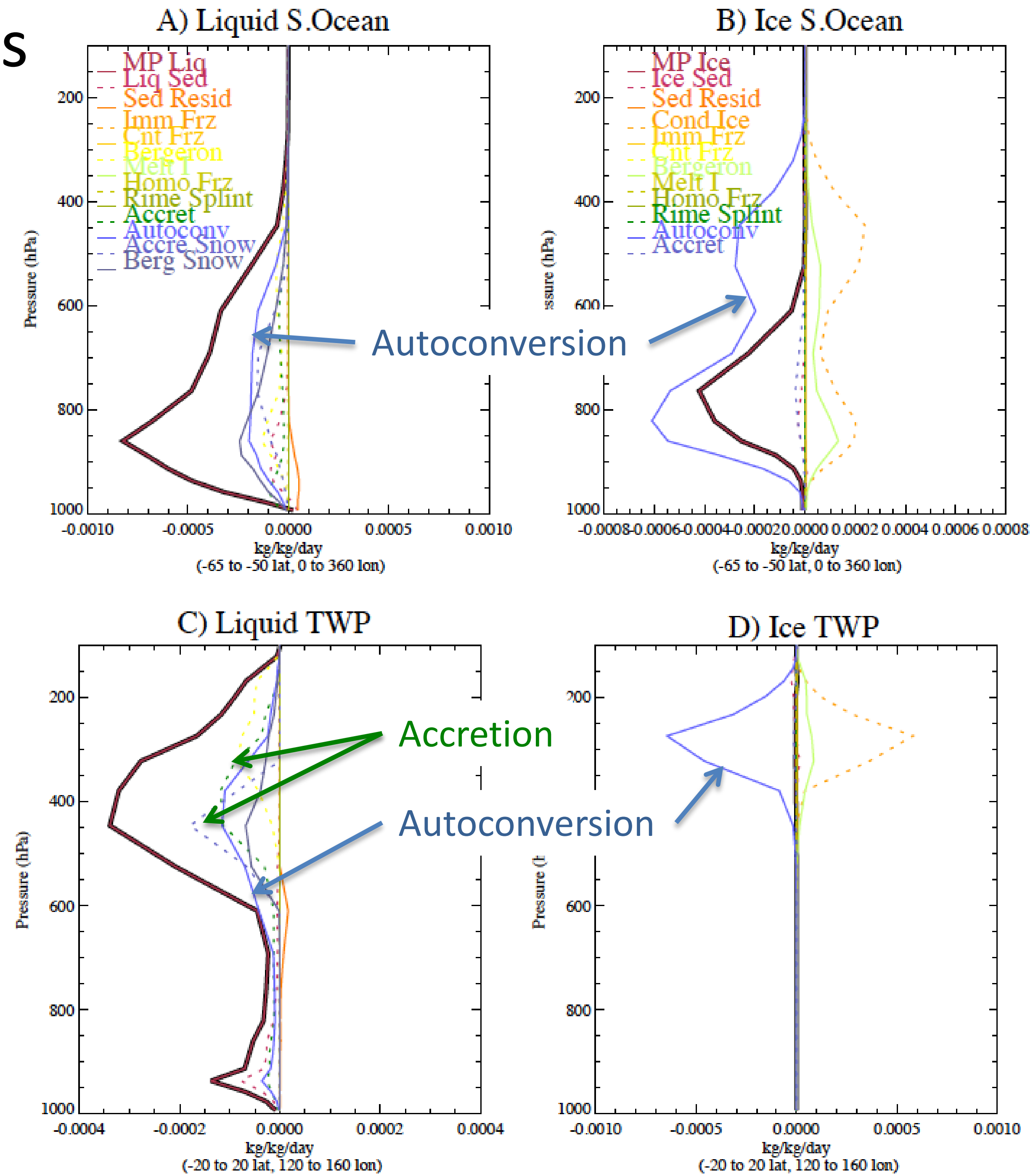
# GCM Microphysics Process Rates

S. Ocean

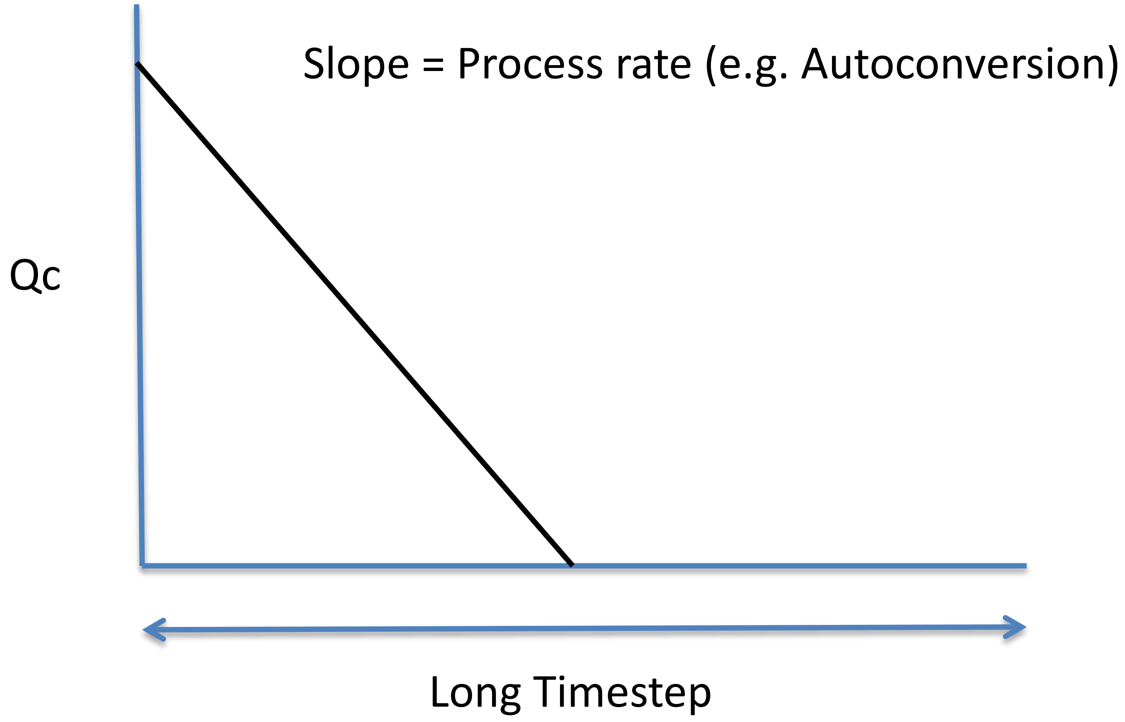
Autoconversion and Accretion are critical

Bergeron process is also important for cold clouds

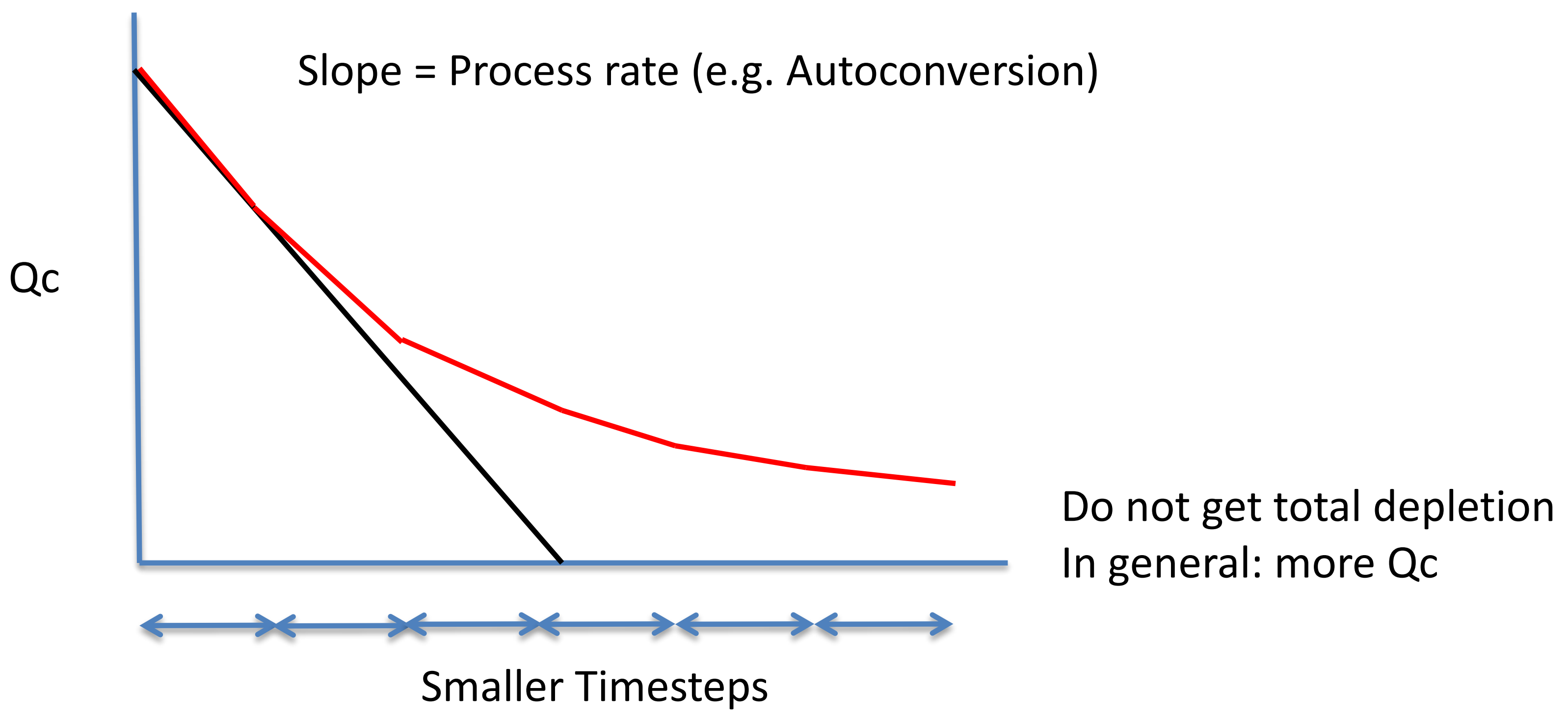
Tropical W. Pacific



# GCM Timestep Issues

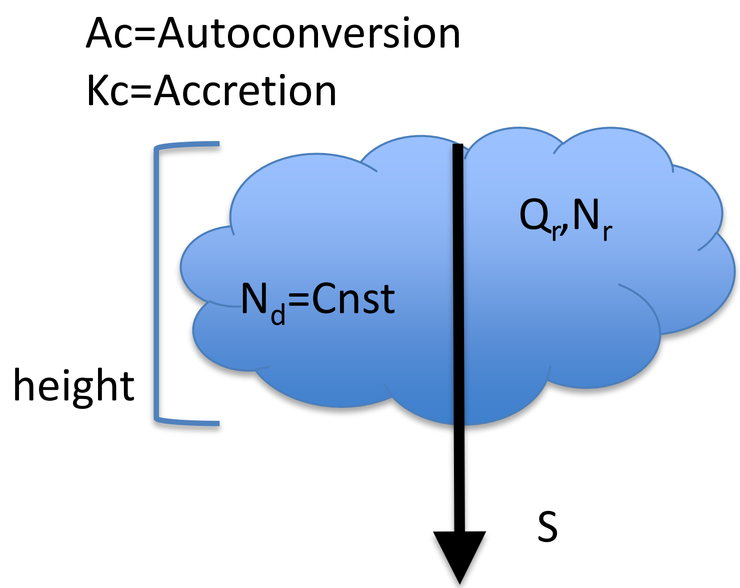


# GCM Timestep Issues



# Simple Steady State Model

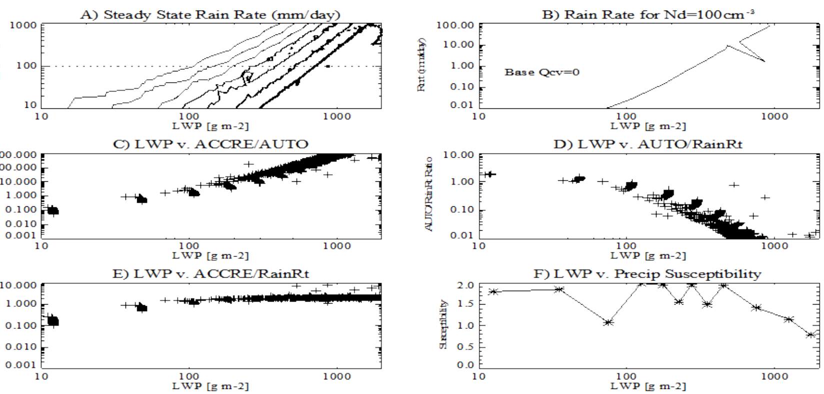
- From Wood, 2009
- Zero-D equilibrium model with liquid ($Q_l$) and rain ($Q_r$)
- Processes: auto-conversion (Ac), accretion (Kc), sedimentation (S)
- Relaxation to adiabatic assumption
- Specify $N_d$, height
- Solve for $N_r$, $Q_r$, $Q_l$
- Use Bulk formulas for Ac,Kc (KK2000). Same as MG1.0 in CAM5



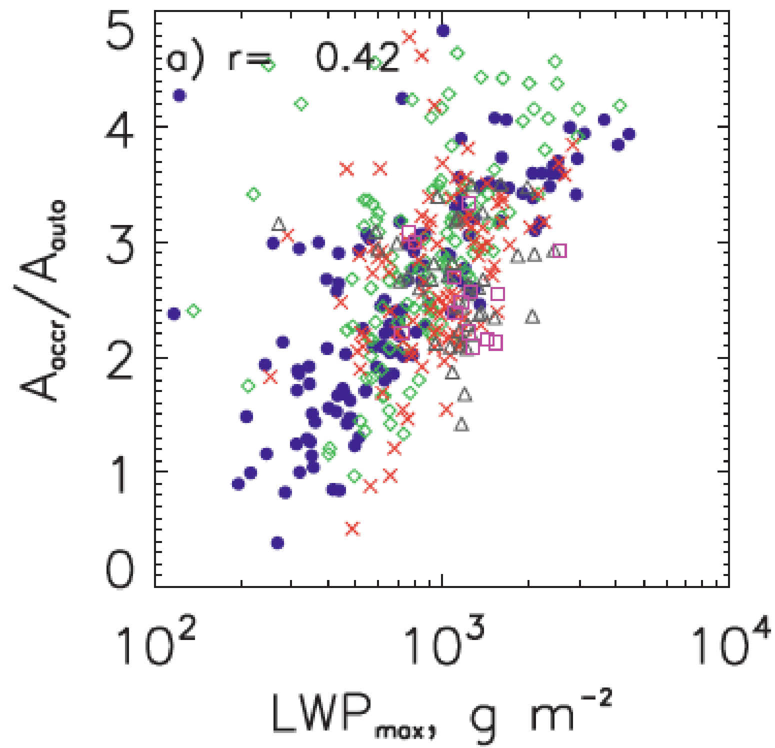

Idealized representation using similar formulations to GCM

# Model Results: Microphysical Processes

Steady State Model




Large Eddy Simulation



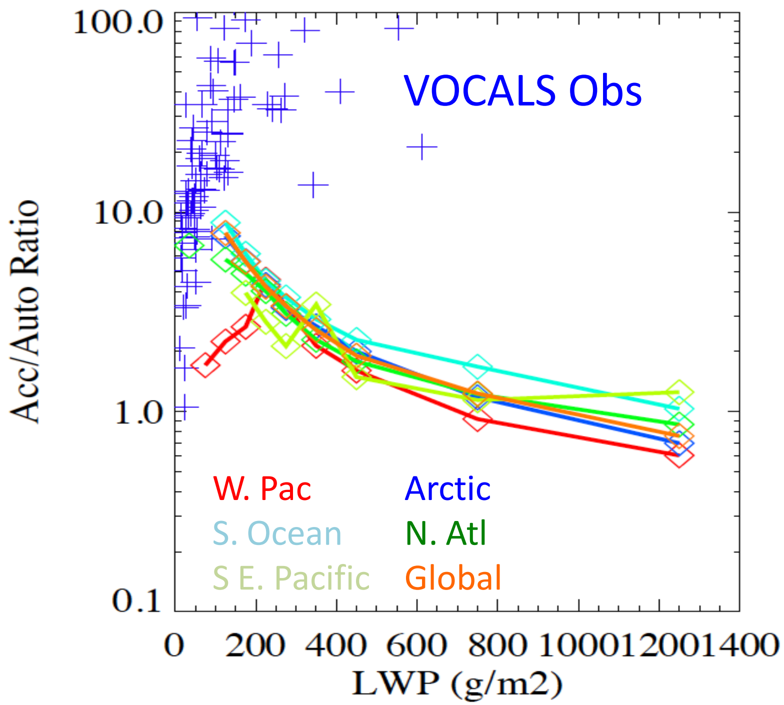

Jiang et al 2010

LES (Jiang et al 2010) and steady state (Wood et al 2009) model results

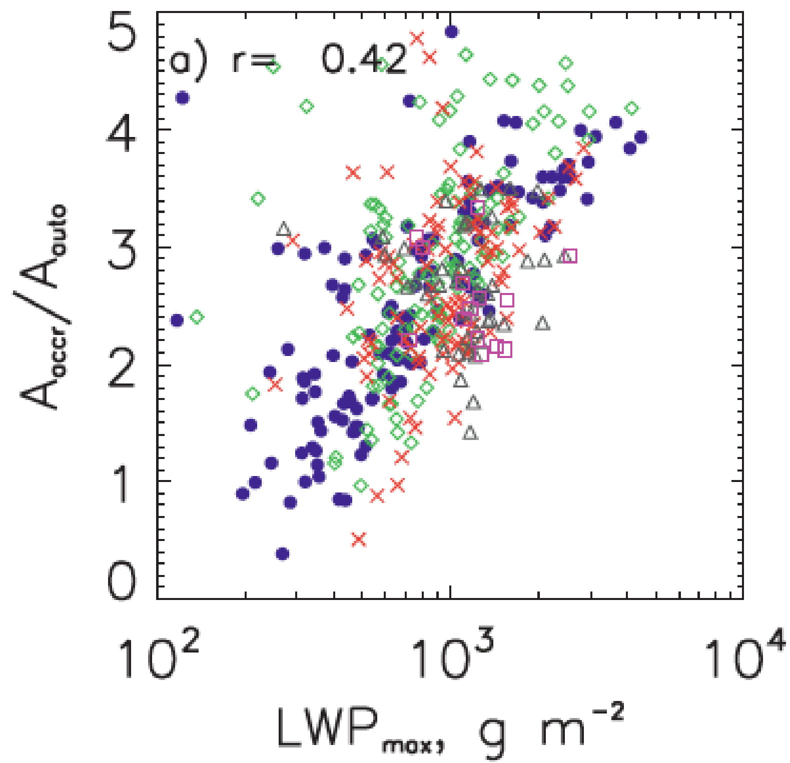
- Similar monotonic increase of Accretion/Auto Ratio with LWP
- LES ='explicit' microphysics, Steady State model = bulk microphysics

# GCM Kc/Ac Ratio..

Global Model (CAM)




Large Eddy Simulation




Ratio decreases in the GCM

Very different than LES or Steady State (SS) models

Note: GCM uses similar bulk microphysics as SS model

Can also see in Precipitation Susceptibility

# LES Model: LWP v. Susceptibility

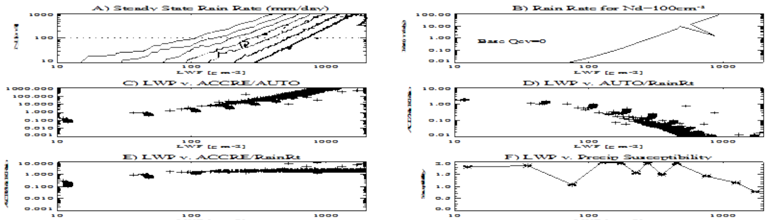
Jiang et al 2010, JAS

Precipitation (R) Susecptibility (Feingold et al):

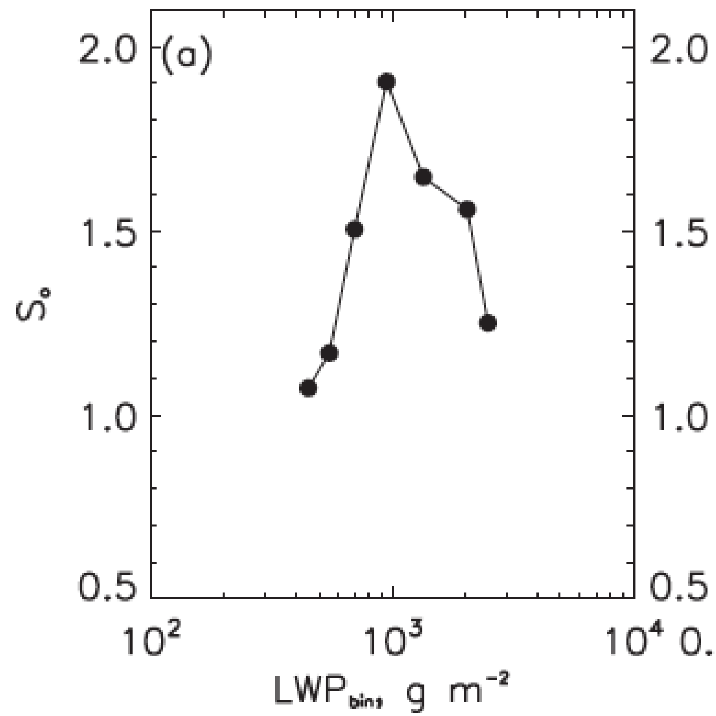
dlnR/dlnA = (dlnR/dLWP) (dLWP/dlnA)

(or in this case dln(RainRt)/dln(Nc)

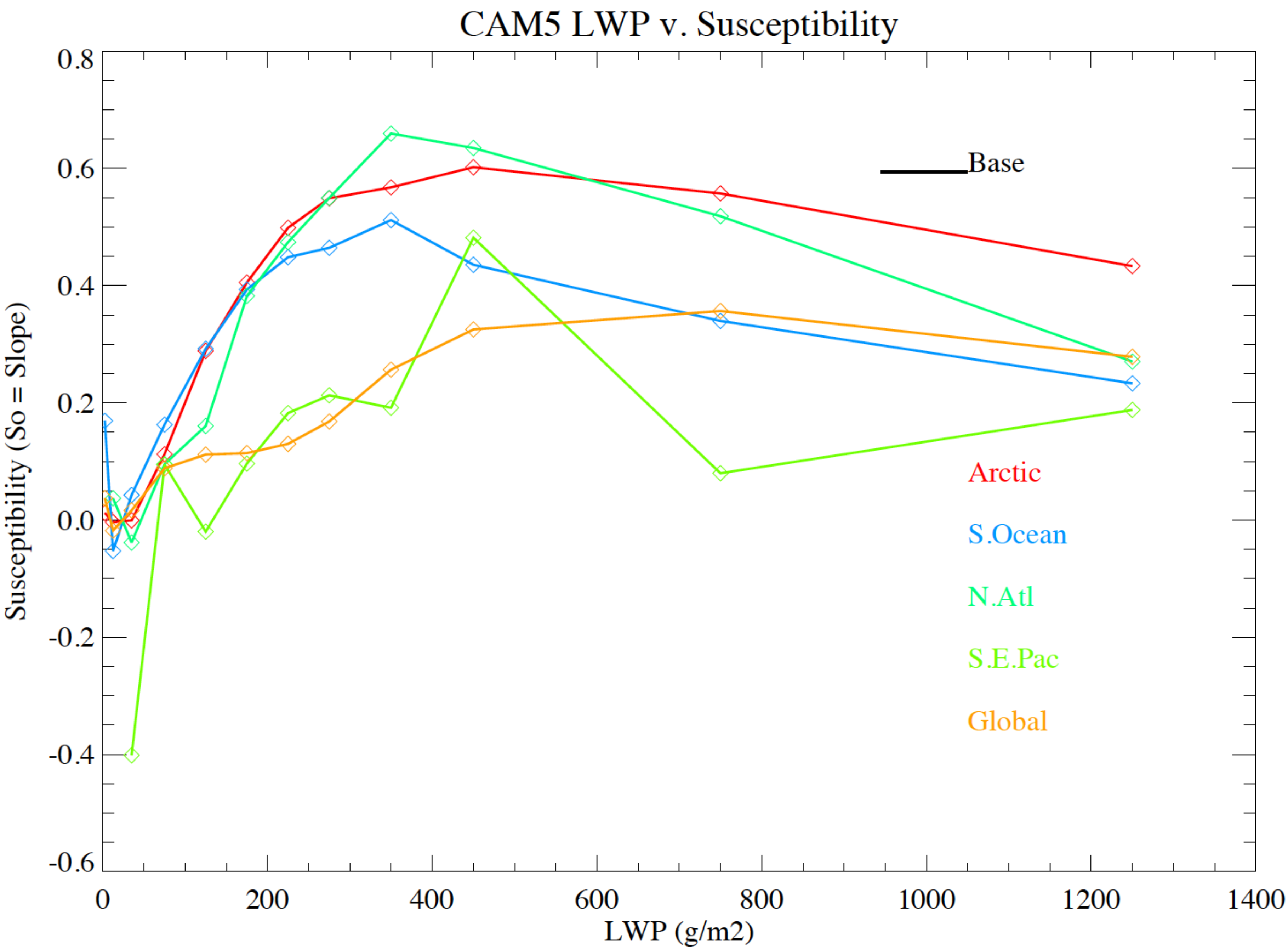
Steady State Model




Large Eddy Simulation

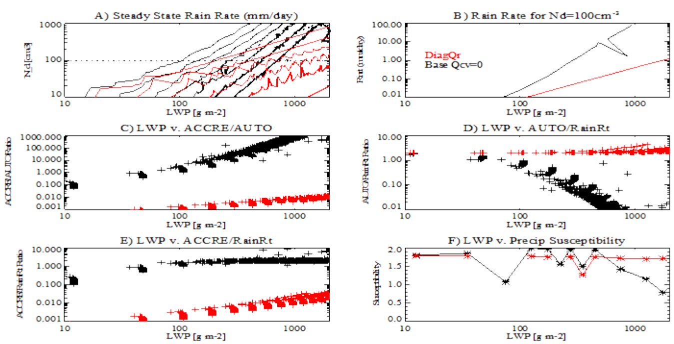



Susceptibility (So) Increases then decreases with LWP, more accretion with higher LWP



CAM5 LWP v. Susceptibility
Susceptibility (So = Slope)
LWP (g/m2)
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
0
200
400
600
800
1000
1200
1400
Base
Arctic
S.Ocean
N.Atl
S.E.Pac
Global

# Steady State Model & GCM Precip

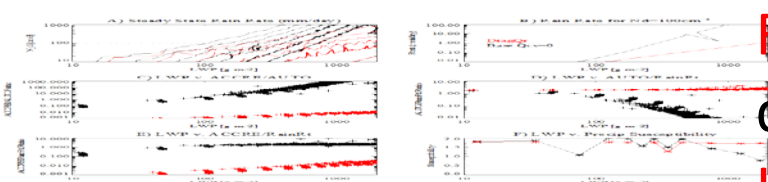



- Now: simulate what a GCM does. All precip removed each timestep
- Precipitation for accretion formed by autoconversion

$$\frac{\partial q_r}{\partial t}_{accr} = K_c = 67(q_c q_r)^{1.15}$$

Set $q_r$=$A_c$

$$\frac{\partial q_r}{\partial t}_{auto} = A_c = 1350 q_c^{2.47} N_c^{-1.79}$$



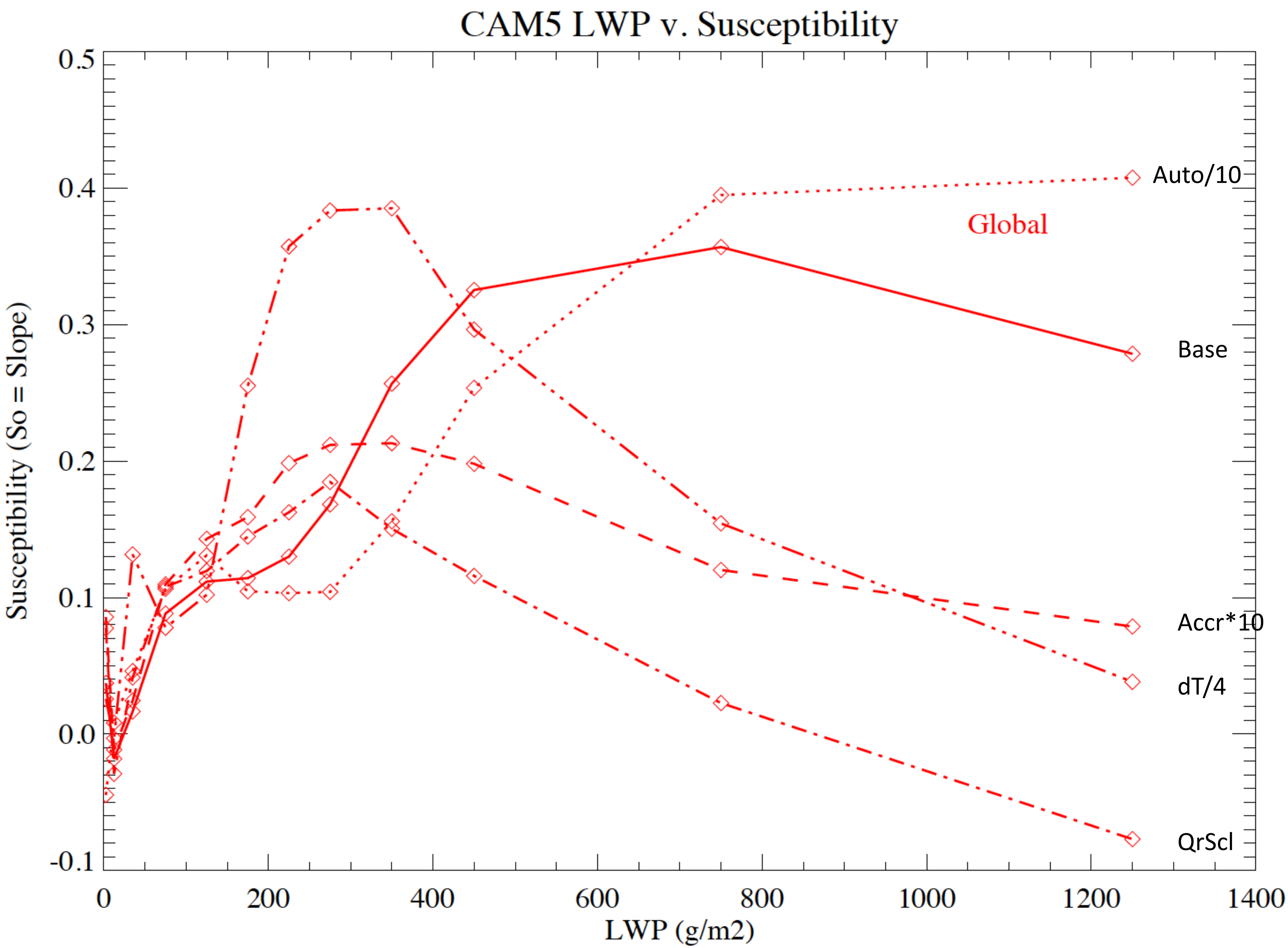
Result: much lower Kc/Ac ratio, no decrease in susceptibility!

Implication: Diagnostic Precipitation may be a problem

# Sensitivity Tests

Take ideas from the steady state model…

- Base
- Auto/10 : Decrease Autoconversion
- Accr*10 : Increase Accretion
- QrScl (scaled qr in accretion rate $qr^{0.75}$)
- dT/4: smaller physics timestep in the GCM…
  - 1800 → 450s (dynamics and advection 450s)



CAM5 LWP v. Susceptibility
Susceptibility (So = Slope)
LWP (g/m2)
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
0
200
400
600
800
1000
1200
1400
Global
Auto/10
Base
Accr*10
dT/4
QrScl

# Summary

- Autoconversion v. Accretion rates critical in CAM
- Steady state model reproduces LES:
  - Accretion v. Autoconversion and Susceptibility
  - Bulk process rates are not the problem
  - Can ‘break’ full prognostic rain link, and recover some of behavior with altered process rates
- CAM seems to have too much auto-conversion
- Why?
  - Diagnostic Precipitation (altering rates lowers ACI ~20%)
  - Numerics: Smaller timestep = +accretion (ACI?)
- Attempts to ‘fix’ these rates have impacts on microphysical balance, can reduce ACI by 20%

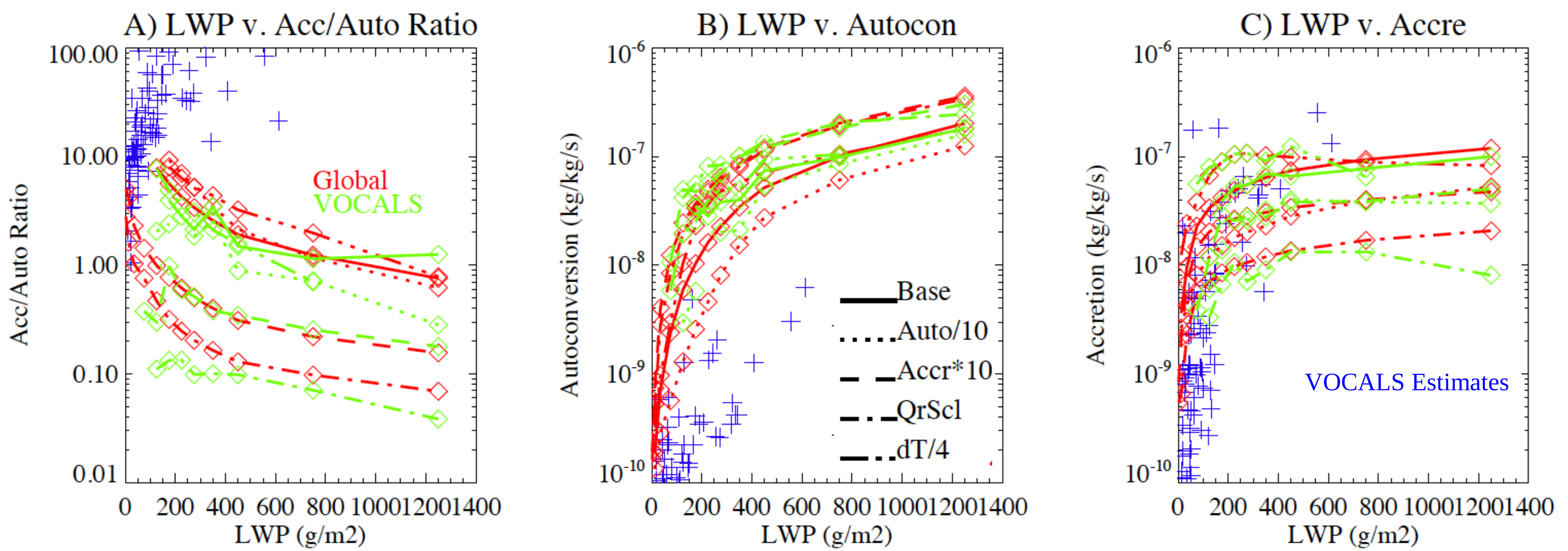
# Future work

- Rebuilding coupling between microphysics and macrophysics in CAM
  - Sub-stepping removed from MG
  - Can sub-step macro & micro together: like dT/4
  - Nearly done with infrastructure
- Implementing prognostic precipitation
  - First global tests last week
- 1D version of steady state model
  - Use to test diagnostic precipitation assumptions

# MG Microphysics Development

- MG1.0: No further development beyond CAM5.2. Has ‘sub-column’ switch
- MG1.5: Option on CAM development trunk.
  - Refactored code (Santos): much cleaner, only one ‘use’ statement.
  - Significant answer changes based on changes to aerosol activation.
- MG2.0: in process (Morrison, Gettelman, Santos, Caldwell, Bogenschutz)
  - New flexible coupling to sub-columns and macrophysics
  - Adding prognostic precipitation
  - May add a mixed phase hydrometeor (graupel)
  - Designed to be model-independent, scale-insensitive
- Convective Microphysics: still in development
  - Modified Song & Zhang 2011 scheme: very interesting simulation with high LWP and reasonable cloud forcing (Lin Su), but different MG implementation.
  - Conceptual idea: unified microphysics for stratiform and convection.
- Goal: integrate with the rest of the moist physics (whatever they may be)
  - Sub-column generators, radiation, convective closure

# Process rates v. Estimates from Obs




Comparisons with estimates based on observed droplet size distributions from the VOCALS campaign (S.E. Pacific Marine strato-cumulus), and stochastic collection equation.

Simulations have lower Kc/Ac Ratios: Ac increases faster, and Kc flattens at higher LWP in the GCM.