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

A. Gettelman, H. Morrison (NCAR), R. Wood, C. Terai (UW-Seattle)

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

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

Autoconversion and Accretion are critical

Bergeron process is also important for cold clouds

Tropical W. Pacific
GCM Timestep Issues

Slope = Process rate (e.g. Autoconversion)
GCM Timestep Issues

Slope = Process rate (e.g. Autoconversion)

Do not get total depletion
In general: more Qc
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

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
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) Susceptibility (Feingold et al):
\[ \frac{d\ln R}{d\ln A} = \left( \frac{d\ln R}{d\ln LWP} \right) \left( \frac{dLWP}{d\ln A} \right) \]
(or in this case \( \frac{d\ln (RainRt)}{d\ln (Nc)} \))

Steady State Model

Large Eddy Simulation

Susceptibility (So) Increases then decreases with LWP, more accretion with higher LWP
Steady State Model & GCM Precip

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

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

Set $q_r = A_c$

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

Result: much lower $K_c/A_c$ 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)
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.