Evaluation of cloud microphysics and precipitation at multiple scales and its relationship to aerosol-cloud-radiation interactions

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Introduction

An advanced cloud microphysical scheme for global models is described and evaluated at different scales and used to illustrate the sensitivity of aerosol-cloud-radiation interactions to the specification of cloud physics. We focus on the addition of a more complete prognostic treatment of precipitation, and on the interactions between cloud microphysics and large scale condensation. Microphysics and precipitation treatments affect how aerosols interact with clouds, with significant implications for global climate.

Conclusions

- New microphysics scheme (MG2) compares well to mesoscale schemes
- Prognostic precipitation increases the accretion to autoconversion ratio
- MG2 reduces Aerosol Cloud Interactions (Indirect effect) by 30%
- MG2 reduces S. Ocean shortwave radiation biases
- Better formulation of process rates at any resolution

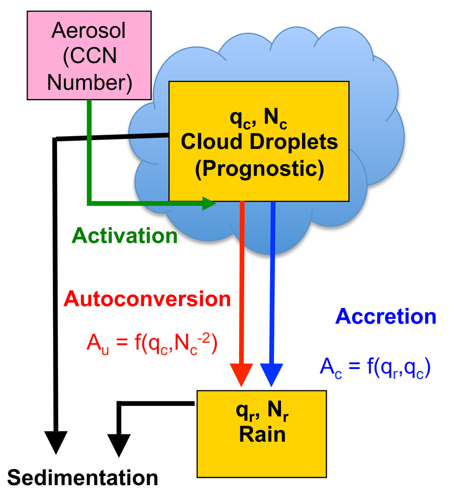
Papers in review in J. Climate: http://www.cgd.ucar.edu/staff/andrew/papers

Methodology

- Community Earth System Model (CESM), Atmosphere model (CAM 5.3).
- 2 moment microphysics (Gettelman & Morrison 2014) including prognostic precipitation ("MG2")
- Add flexible sub-stepping of (Mi)crophysics and (Ma)crophysics
- Tests using Met Office Kinematic Driver (KiD: Shipway & Hill 2012) against other mesoscale model schemes
- Single column Model Tests using warm and mixed phase cases
- Global Model Tests. Fixed SST global simulations. Present (2000) and Preindustrial (1850) aerosols to get indirect effects

Concept

Autoconversion and Accretion control loss of cloud condensate. Balance helps regulate cloud state and also affects Aerosol-Cloud-Interactions (ACI).



1. Activation (CCN) = f(RH,w) W at cloud scale is critical
2. Autoconversion (loss process) is a function of N_c^{-2} (=ACI)
3. Accretion depends on q_r

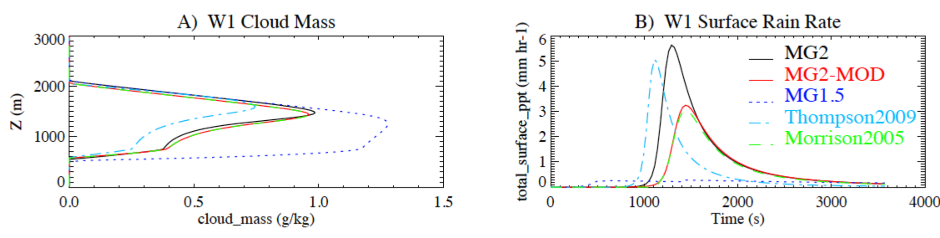
With Prognostic rain:
A. Better representation of q_r
B. Increase in A_c / A_u
C. Reduced ACI (reduced N_c effect)

Offline Tests (KiD)

Off-Line Kinematic Driver, (KiD): Warm rain cases (W1=constant updraft, W2 & W3 = oscillating). Variable N_c yields different LWP.

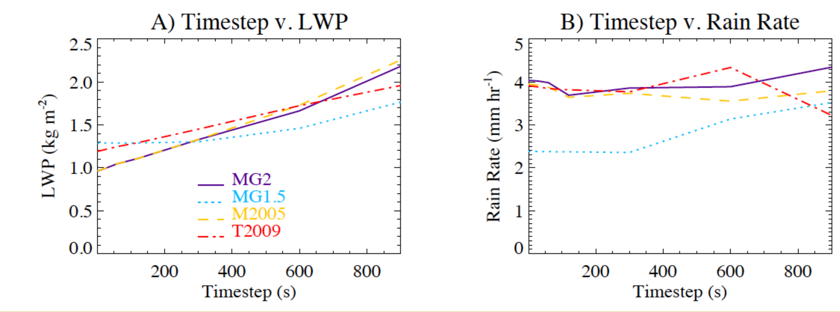
Comparison To Other Schemes

Simulations compare well to Morrison et al (2005) and other mesoscale schemes (MG2 difference is just saturation as shown by MG2-MOD with M2005 saturation).



Time step Sensitivity

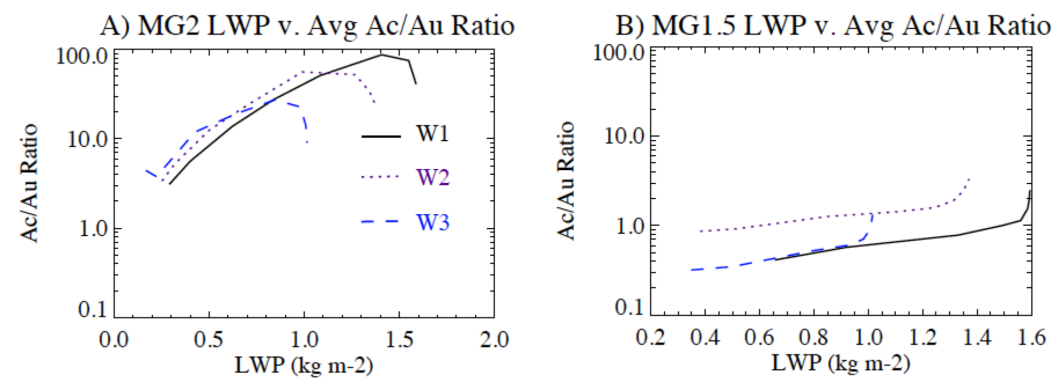
New scheme (MG2) moderate sensitivity of LWP to time step. Rain process not very time step sensitive. Similar to other schemes.



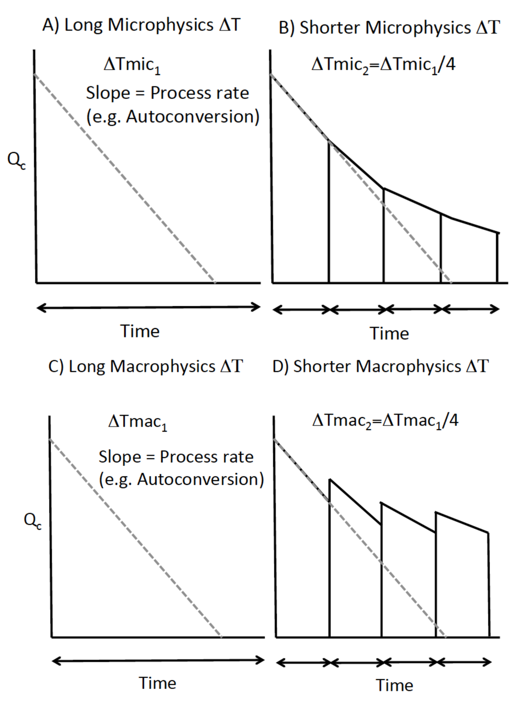
Ratio of Process Rates

Prognostic Precipitation (MG2: Left) has larger increase of Ac/Au with LWP than diagnostic precipitation.

MG2 looks more like LES simulations with bin microphysics.



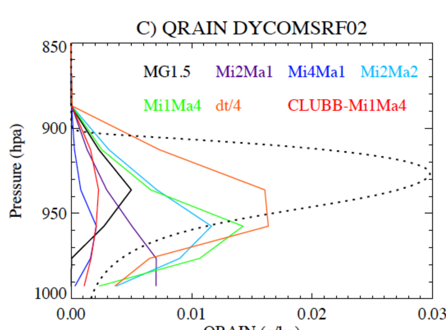
Sub-stepping: Single Column Model Tests



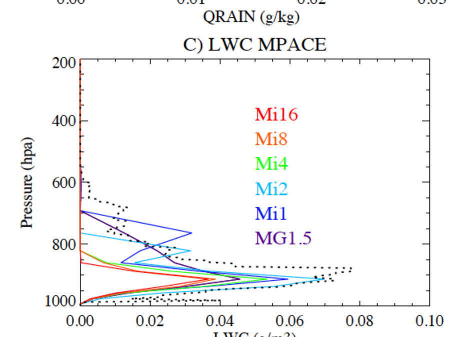
(Mi)crophysics sub-steps: Long microphysics steps =high process rates. Nonlinear process rates result in different evolution of condensate (not total depletion in a timestep).

(Ma)crophysics sub-steps: Long macrophysics steps may also mean high process rates, and different evolution of condensate.

Notation: MiXMaY is X microphysics steps for each of Y macrophysics steps (Mi2Ma2 = 2 micro for each of 2 macro, or 4 micro total per time step)



Liquid Clouds
DYCOMS case: better rain structure with sub-steps, and with more Macro and Micro substeps Dotted line is LES estimate.

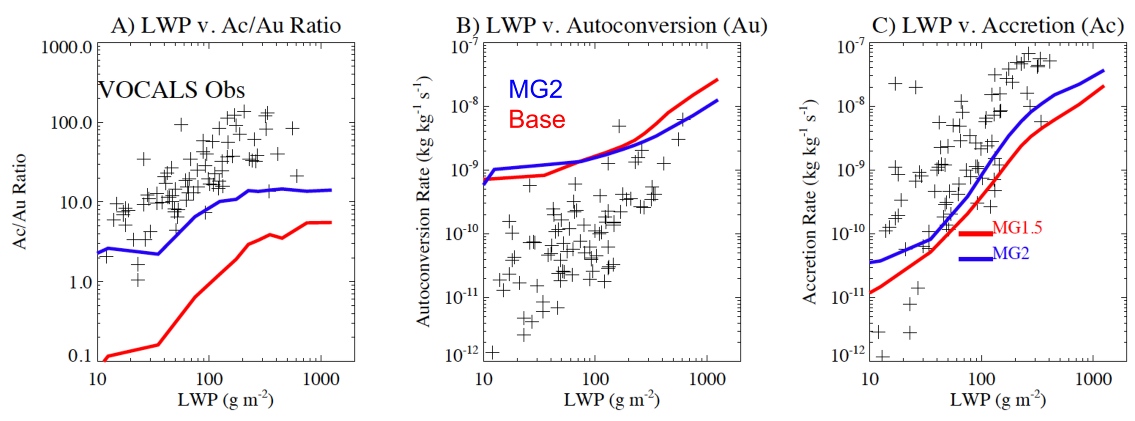


Mixed Phase Clouds
MPACE case: LWC increases (Mi1→Mi2) then decreases with more microphysics substeps (Mi2→Mi16). Retrieved LWP is the dashed line.

Global Results

Better Process Rates

- Prognostic precipitation (q_r) increases accretion (Ac)
- Also means a different mean state climate (balance of LWP & r_e)
- Note: still too much autoconversion at low LWP. Problems with bulk process rates?



Global model Ac/Au ration and components for MG2 and MG1
"VOCALS Obs" are actually a detailed model using observations as input

Reduced Aerosol Cloud Interactions

Diagnose Aerosol-Cloud-Interactions (ACI) with difference of simulations containing 2000 or 1850 aerosol emissions. GHGs and SSTs are the same. ACI are the difference in cloud radiative effect (shown in figure below).

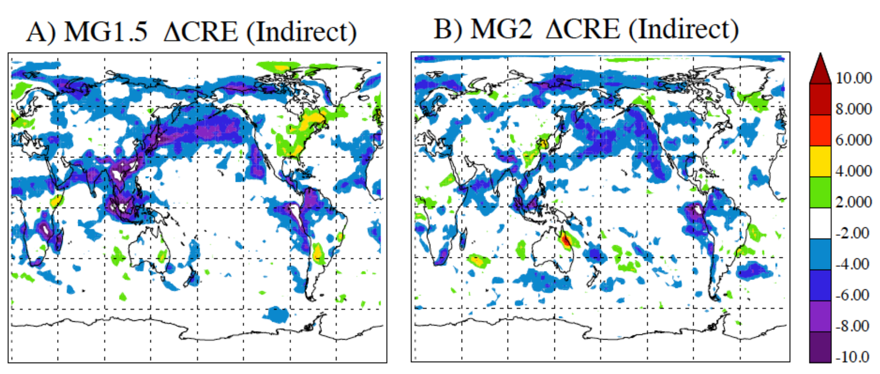
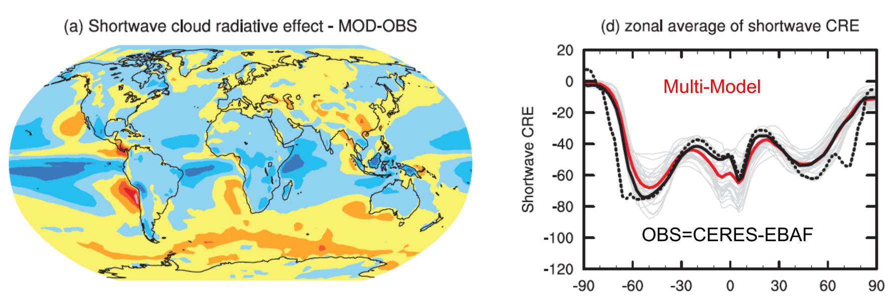


TABLE Radiative Flux Perturbation from MG1.5 and MG2. 2000-1850 aerosol emissions differences in W m^{-2} (except LWP). ΔR is the change in top of atmosphere flux (LW+SW). ΔCRE is the change in cloud radiative effect (also called cloud forcing: LW+SW) and its component changes are ΔSWCRE (shortwave) and ΔLWCRE (long wave). Also shown are the percent changes in Liquid Water Path (ΔLWP) and the change in aerosol Direct Effect (ΔDE).

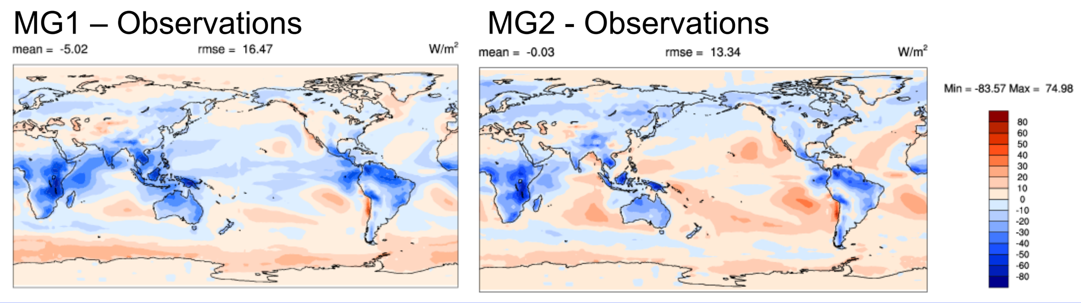
Run	ΔR	ΔCRE (L+S)	ΔSWCRE	ΔLWCRE	ΔLWP (%)	ΔDE
MG1.5	-1.22	-1.25	-2.47	+1.22	+9.9%	-0.09
MG2-Mi2Ma1	-1.08	-0.76	-0.91	+0.15	+5.8%	-0.29
MG2-Mi4Ma1	-1.05	-0.91	-1.15	+0.23	+6.9%	-0.33
MG2-Mi2Ma2	-0.80	-0.57	-0.92	+0.35	+5.6%	-0.35
MG2-Mi1Ma4	-0.87	-0.78	-0.78	0.0	+4.8%	-0.31
CLUBB-Mi1Ma6	-1.43	-1.16	-1.10	-0.06	+4.9%	-0.39

New microphyiscs (MG2) with better process rates reduces ACI significantly Sub-stepping microphysics and macrophysics (in the table) further reduces ACI. Up to 50% reduction in Mi2Ma2 case.

Reduced S. Ocean Cloud Biases



IPCC AR5 (2013) Figure 9.5. Multi-Model shortwave cloud radiative effect compared to observations.



CESM SW Cloud Radiative Effect

S. Ocean biases are improved with MG2. Why? Less ice cloud and high cloud, but similar low cloud. High cloud better.

References

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