Evaluation of Cloud Microphysical Parameterizations in Cloud-resolving Model Simulations Using the ARM Observations

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Motivation

- Cloud resolving model (CRM) is a convenient platform to test parameterizations used in the multiscale modeling framework (MMF).
- MMF simulations produce too much high-level cloud with high optical depth.
- Investigation of the microphysics parameterizations in the embedded CRM can provide insight for the cause of these issues.

Model Setup

- CRM: System for Atmospheric Modeling (SAM) is the embeded CRM in the Colorado State University MMF.
- Case: ARM SGP 1997 summer IOP and its subcases; large scale forcings from variational analysis by *Zhang et al* (2001).
- Radiation scheme: CAM3 radiation.
- Microphysics: *Morrison et al* (2005) two-moment schemes and the default one-moment schemes in SAM.
- Domain size (2D): 1024 km $\times$ 27 km.
- Resolution: $\Delta x = 1$ km, $\Delta z = 75$ m $\sim$ 500m, $\Delta t = 10$ s.
- Radar simulator: Quickbeam (*Haynes et al*,2007) using size distribution consistent with microphysics.

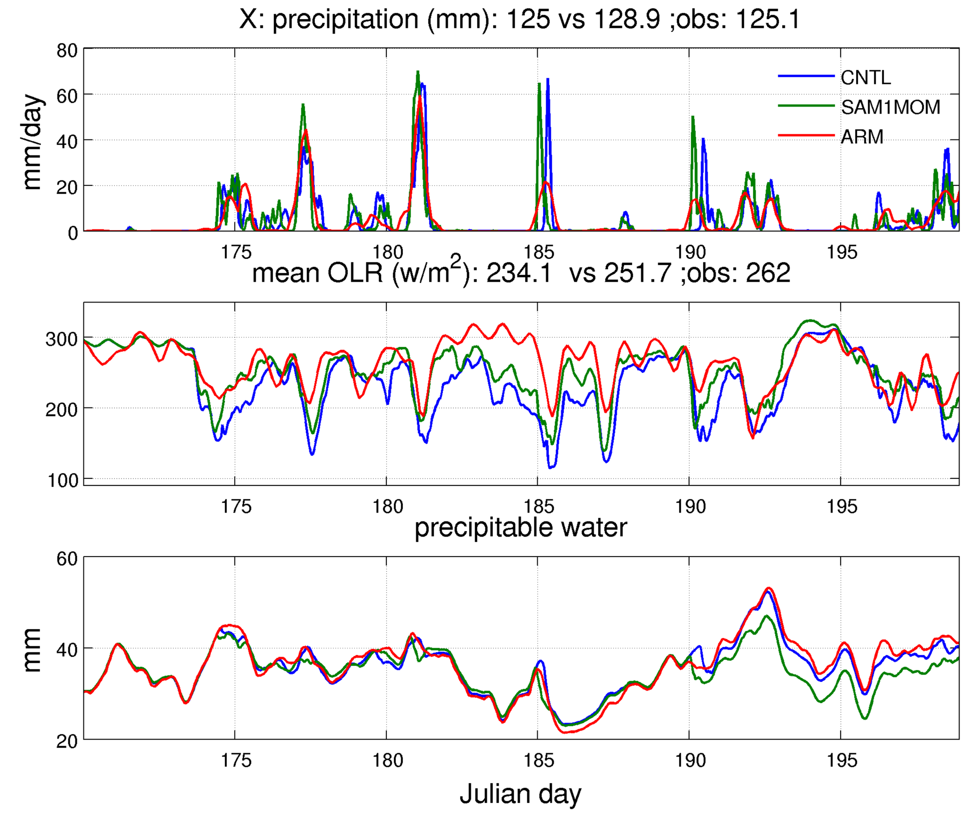
Results

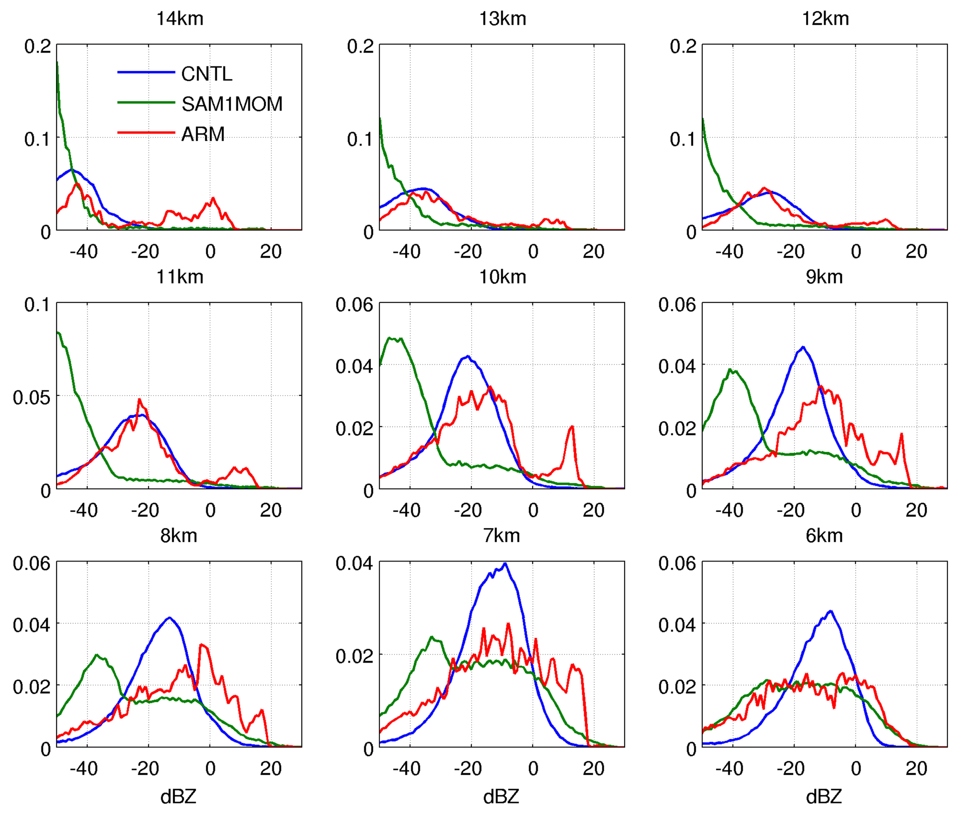
- Two-moment microphysics better reproduce the observed reflectivity histograms compared to one-moment microphysics.
- Two-moment microphysics generates significantly more cloud than the ARM MMCR observations and one-moment microphysics has much less cloud cover.
- The **periodic lateral boundary conditions** play an important role in the positive bias of cloud occurrence by artificially maintaining residual cloud after convection, in both microphysics schemes.
- N_i is too high in two-moment microphysics; improvements in ice nucleation schemes may better represent convective clouds.

Other tests showing little improvement

- Use prescribed radiative forcing
- Apply large scale subsidence to vertical velocity and hydrometeors.
- Increase teminal fall speed for ice, $V_{T,i}$ by 50%
- Use thermodynamic nudging with $\tau = 2$ hr. $\sim$ 50 hr.
- Switch to 3D, higher resolution, different domain size.

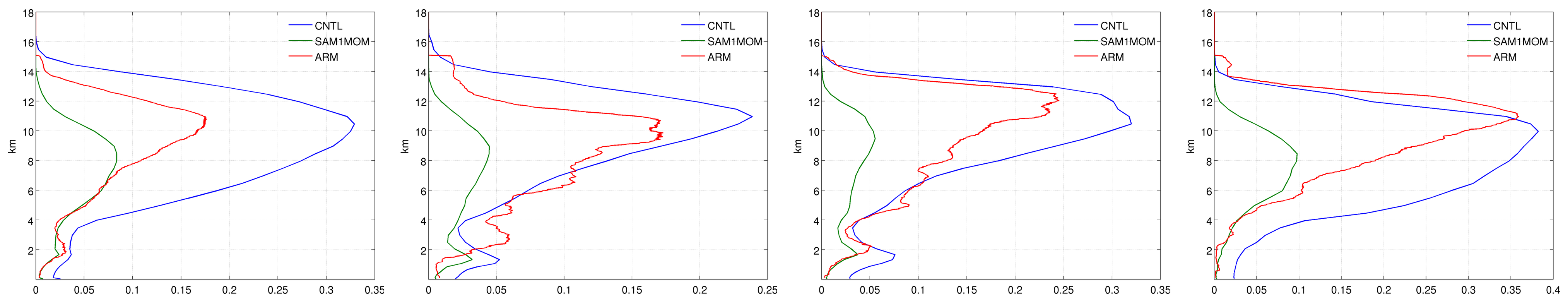
ARM9707: month-long simulaitons





- **CNTL:** 2-moment
- **SAM1MOM:** 1-moment
- **ARM:** observations
- precipitation events are well reproduced.
- OLR from both schemes are too low.
- dBZ$_e$ histograms are normalized w.r.t. total cloud occurrence
- SAM1MOM: reflectivity too low (peak 20 dB off)
- CNTL: good agreement with OBS above 11km, with peak at about the same reflectivity values. More deviation below 10 km.

Cloud occurrence



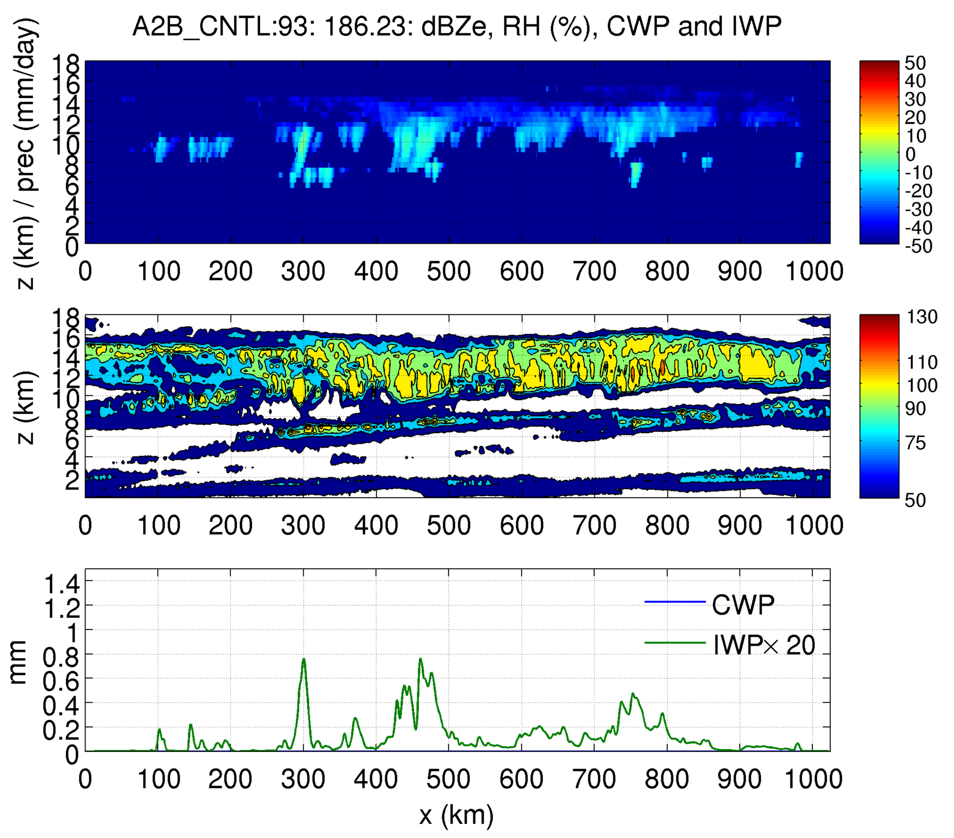
(month-long) (A:178-182) (B:189-194) (C:194-199)

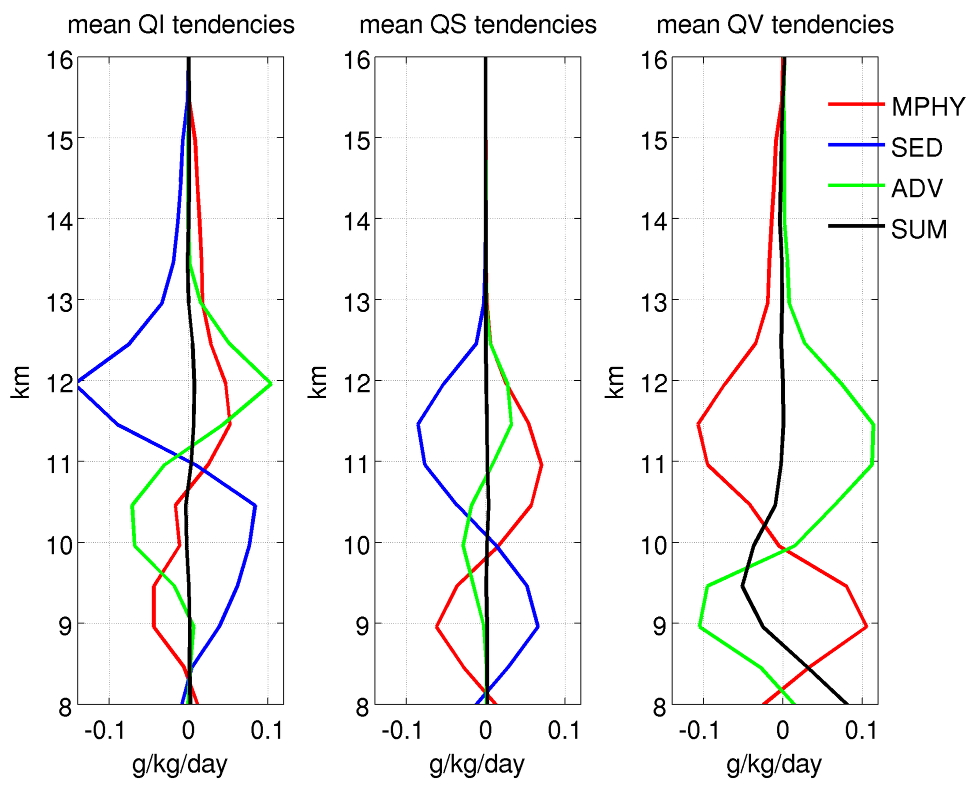
OLR (W/m^2) and precip. (mm)

CASE	A	B	C	X	A	B	C	X
CNTL	251	239	243	234	33	23	19	125
SAM1MOM	270	263	260	252	34	25	19	129
OBS	260	249	253	262	33	21	20	125

- CNTL: too much cloud
- SAM1MOM: not enough cloud
- Less cloud in subcases
- Issues with dry periods

Issues with periodic lateral boundary condition: An example



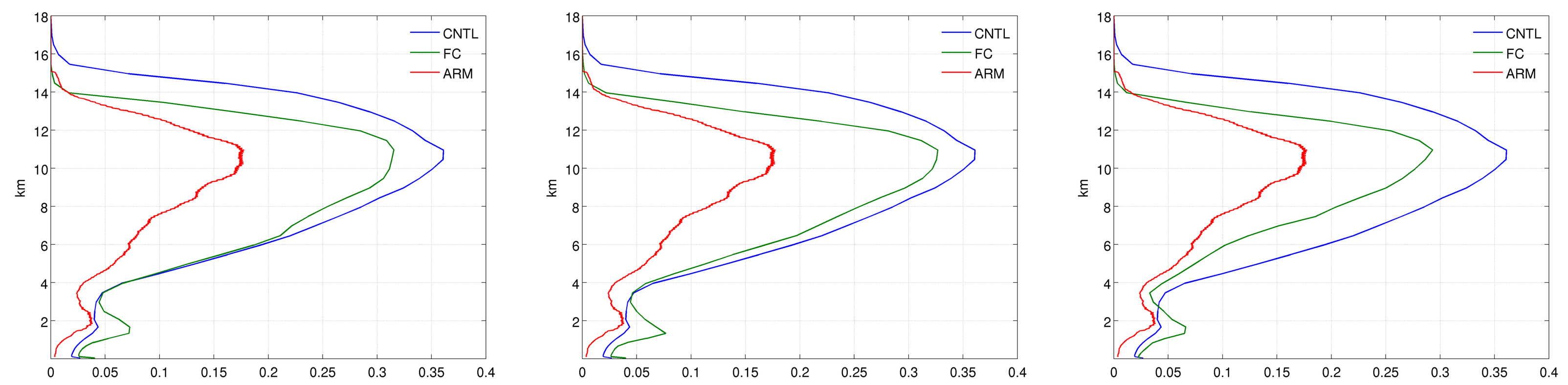


- Cloud free periods according to the ARM MMCR
- Residual cloud can be maintained and cycles within the domain for over 20 hours.
- **MPHY:** microphysics
- **SED:** sedimentation
- **ADV:** vertical transport
- **SUM:** sum of above

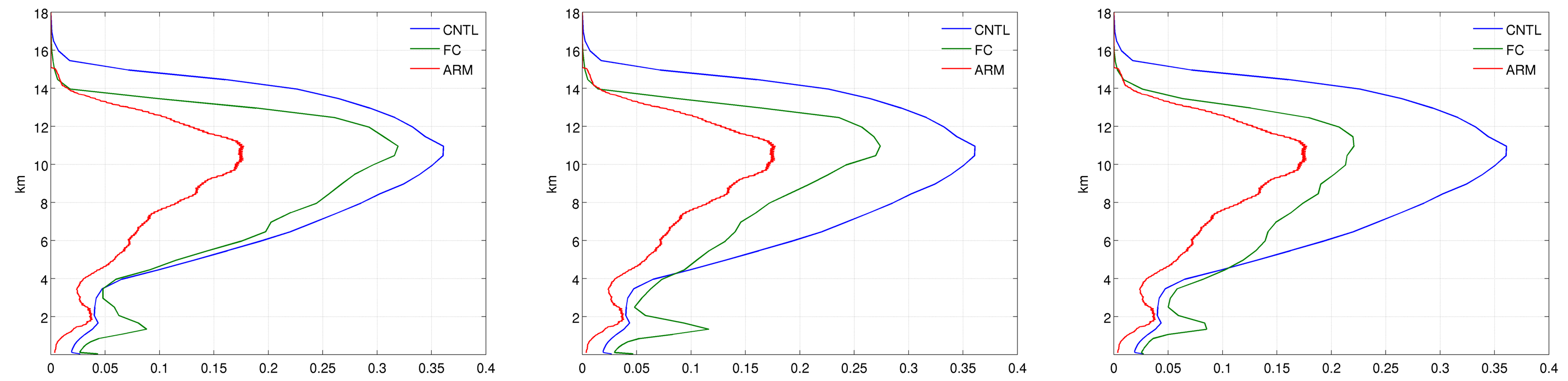
Forecast runs: Influences of periodic B. C.

- Break up the simulation to a series of short pieces.
- Restart with observed sounding for each piece and allow the model to spin-up for each short simulation.
- Stitch together (excluding spin-up) for analysis.

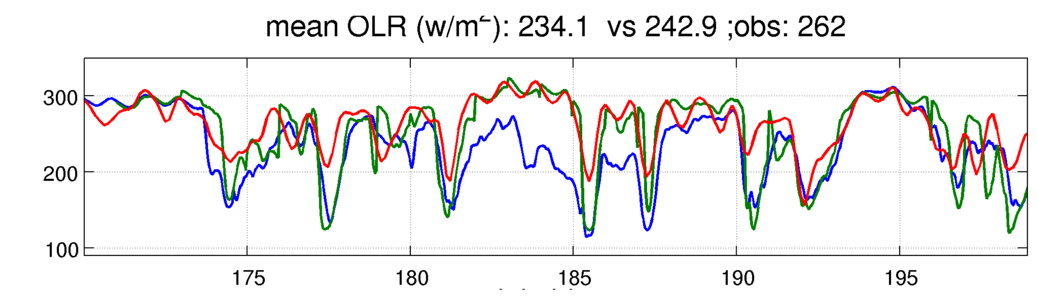
Cloud Occurrence



(2-day f.c., 18 hr. spin-up) (2-day f.c., 12 hr. spin-up) (2-day f.c., 6 hr. spin-up)



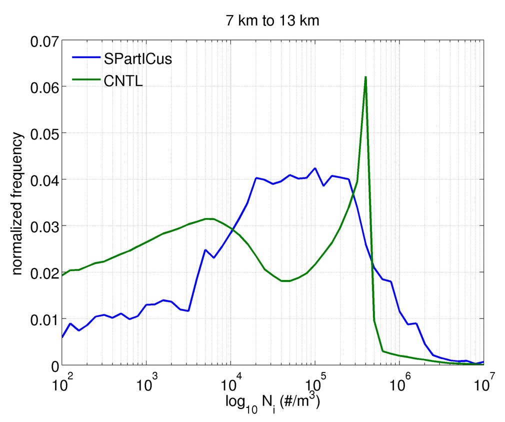
(1-day f.c., 18 hr. spin-up) (1-day f.c., 12 hr. spin-up) (1-day f.c., 6 hr. spin-up)



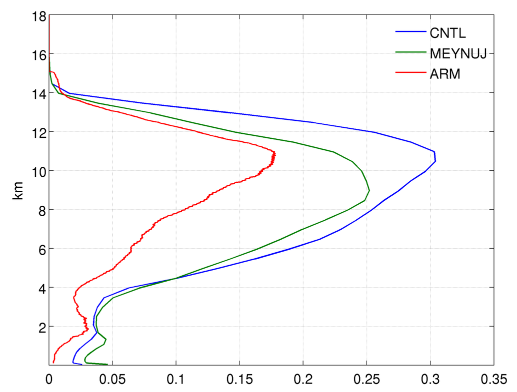
Julianday (1-day f.c., 12 hr. spin-up)

- **CNTL:** Continuous
- **FC:** Forecast run
- **ARM:** observations
- Restarting for each piece cleared the domain of the residual cloud after convection.
- As the length of forecast and spin-up time decrease, the cloud occurrence significantly deceases.
- The OLR time series shows much better agreement with observations for "dry" periods in between convection.

Ice nucleation schemes



- **SPartICus:** obs.
- **CNTL:** 2-moment
- ΔN_i in current ice nucleation schemes is dependent exponentially on T_{abs}.
- Modeled N_i peaks at values about one order of magnitude larger than observations.
- Modeled N_i has a much narrower peak than the observed distribution.



- **CNTL:** Cooper
- **MEYNUJ:** Meyers
- **ARM:** observations
- *Meyers et al* (1992) scheme for condensation/deposition freezing can decrease cloud cover (left), and improve OLR histograms (not shown).
- N_i is also decreased, but too aggressively. Need more subtle treatment on ice nucleation.