From Mixing Ratios to Particle Sizes in CSRM Microphysics

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Radiative Transfer in Convective Systems

• CSRMs typically employed for MMF generally use single-moment bulk microphysics, e.g., prognostic treatment for mixing ratios of cloud liquid, cloud ice, graupel, rain, snow.

• Radiative properties of cloud particles depend not only on mixing ratio, but also on size and shape.
Radiative Transfer with Single-Moment Microphysics

• Single-moment methods provide no basis for specifying particle sizes for radiation, since no information is provided on particle number concentrations.

• Observations (e.g., McFarquhar, 1999, *JGR*; Heymsfield and Platt, 1984, *JAS*) provide limited guidance in specifying particle sizes.
Limited Double Moments for CSRMs

• Double moments treat as prognostic variables both mixing ratio and particle number. With assumptions on the shape of the size distribution, effective sizes characterizing the cloud particle distribution for radiation can be inferred.

• For computational simplicity, apply double moments to cloud liquid and cloud ice only. Larger rain, graupel, and snow particles are less important for radiation.
Activation of Cloud Particles

Cloud liquid and ice have exponential size distributions:

\[ n(D) = n_0 \exp(-\lambda D) \]

where \( D \) is equivalent sphere diameter.

For liquid, the number of activated CCN depends on supersaturation \( s \).

\[ N = C s^k \]

To determine the number of activated IN, functions of ice supersaturation, which vary with temperature range, are used (Meyers, DeMott).
Supersaturation

• Non-equilibrium overshoot at cloud base, with supersaturation a function of vertical velocity and thermodynamic state (variant of Twomey formula).

• In cloud-interior, supersaturation resolved on cloud grid, taking account of condensation and vapor deposition on cloud and ice.

• Activity spectrum reduced by advected, previously activated particles.
Ice Nucleation

- Primary nucleation by condensation freezing and deposition, using ice activity spectrum
- Contact nucleation
- Hallet-Mossop rime splintering
- Homogeneous aerosol freezing, using CCN activity spectrum
Growth of Droplets and Crystals; Precipitation

- Supersaturation evolution equation allows for deposition of vapor on liquid and ice
- Liquid drops (CCN-activated) freeze about -36 C
- Autoconversion of cloud liquid to precipitation
- Accretion of cloud droplets by precipitation
- Terminal speed depends on particle size; integrated over size distribution
Double Moments in WRF CSRM

- Number Concentrations and Particle Sizes
- Roles of homogeneous freezing of cloud droplets and aerosols
- Impact of uncertainty in homogeneous freezing of ammonium sulfate aerosol
- Roles of heterogeneous nucleation processes
- TOGA-COARE 2D integration
KWAJEX observations from Heymsfield et al. (2002, J. Atmos. Sci.)
CEPEX observations from McFarquhar (1999, J. Geophys. Res.)
\[ <D> : \text{number-weighted mean size}; \]
\[ D_{ge} : \text{radiatively weighted mean size (Fu and Liou, 1993, JAS)} \]
SW SURFACE FLUX

downward flux component (W/m²)

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LW SURFACE FLUX

downward flux component (W/m²)

WRF  TOGA-COARE OBS (Minnis/IMET)

Princeton, New Jersey
What are the key processes determining particle numbers and sizes?
Homogeneous freezing of droplets is the key process determining ice particle concentration.
Homogeneous freezing of droplets is the key process determining ice particle size.
Impact of Uncertainty in Homogeneous Freezing of Ammonium Sulfate Aerosol

EXPERIMENTAL UNCERTAINTY: HOMOGENEOUS AEROSOL FREEZING

- CONTROL
- AIDA CORRECTION

Ice number concentration (L⁻¹) vs. altitude (km)
Impact of Uncertainty in Homogeneous Freezing of Ammonium Sulfate Aerosol

EXPERIMENTAL UNCERTAINTY: HOMOGENEOUS AEROSOL FREEZING

- $D_{ge}$: CONTROL
- $D_{ge}$: AIDA CORRECTION
- $<D>$: CONTROL
- $<D>$: AIDA CORRECTION

altitude (km)

ice particle size (microns)
What are the dominant heterogeneous freezing processes?
Condensation freezing and deposition dominate heterogeneous ice nucleation. Contact freezing is of minor importance.
Impact of Rime Splintering

![Graph showing impact of rime splintering on ice particle concentration vs altitude in a visible cloud. The graph compares 'CONTROL' and 'NO HM' scenarios.](image-url)
Impact of Rime Splintering on Particle Size

![Graph showing the impact of rime splintering on particle size. The graph plots altitude (km) against ice particle size (microns). There are two lines labeled D_\text{ge}: CONTROL and D_\text{ge}: NO HM, and two dashed lines labeled \langle D \rangle: CONTROL and \langle D \rangle: NO HM. The graph illustrates the decrease in particle size with altitude for different conditions.](image-url)
Summary, I

• Limited double moments can capture key observed features of size and number of cloud liquid and ice particles for tropical convection
• Homogeneous droplet freezing is key control on number and sizes of cloud particles
• Contact nucleation of limited importance
Summary, II

• Rime splintering produces local maximum in particle number above cloud base but has little impact on particle sizes
• Uncertainty in homogeneous freezing of ammonium sulfate aerosol implies uncertainty in ice numbers and particle size near anvil tops
• Complete aerosol/chemistry/cloud coupling possible using this framework