MMF tests with two-moment microphysics

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Outline of talk

- Overview of microphysics parameterizations in models, examples using idealized case studies of moist deep convection

- Representation of cloud-aerosol-precipitation interactions in microphysics parameterizations

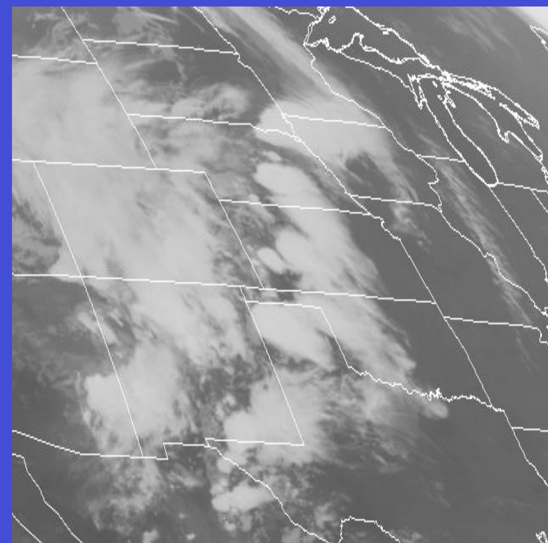
- Description of the new M2005 two-moment scheme implemented in SAM/SpCAM

- Marat….

Earth
in visible light

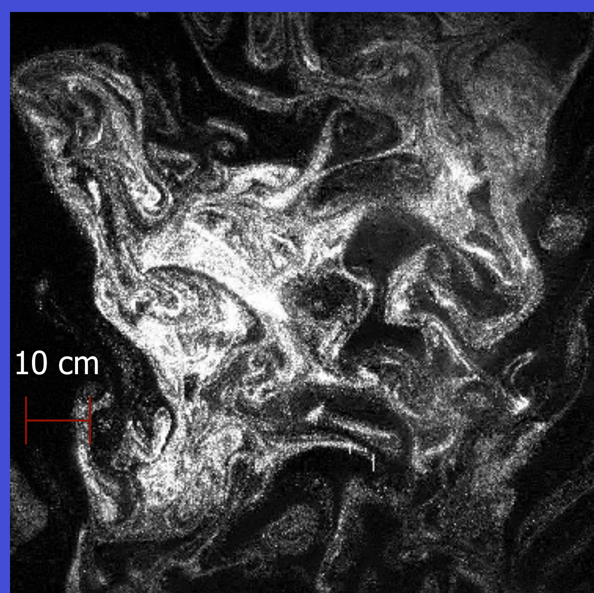
1,000 km

Mesoscale convective
systems over US



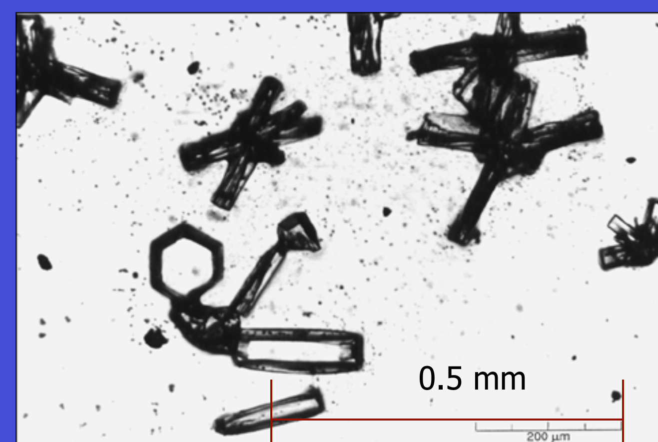
Small cumulus
clouds

Clouds: the range of scales...



Mixing in laboratory
cloud chamber

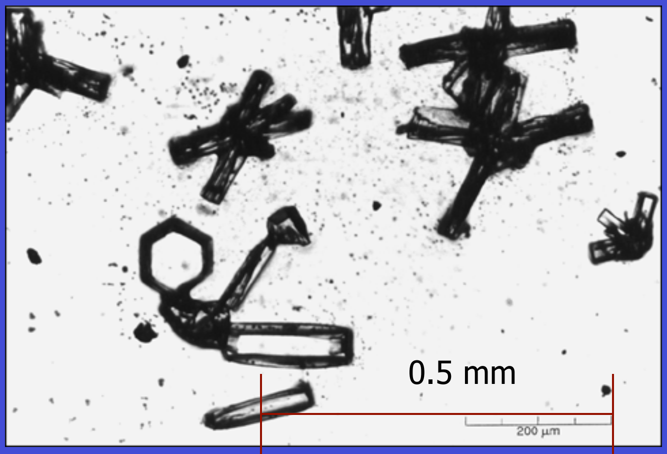
Cloud particles



“microphysics”

microscale processes controlling formation of cloud droplets and ice crystals, their growth and fallout as precipitation

From A. Heymsfield



“High-resolution” models with Dx ~ few km’s or less like MMF and GCRM resolve deep convective scale and mesoscale motion…

…but microphysics and smaller-scale dynamics (turbulence, shallow convection) must still be parameterized.

Parameterization of microphysics is arguably a key in these models:

-Latent heating/cooling

(condensation, evaporation, deposition, sublimation, freezing, melting)

-Condensate loading

(mass of the condensate carried by the flow)

-Precipitation

(fallout of larger particles)

-Coupling with surface processes

(moist downdrafts leading to surface-wind gustiness, cloud shading)

-Radiative transfer

(mostly mass for absorption/emission of LW, particle size also important for SW)

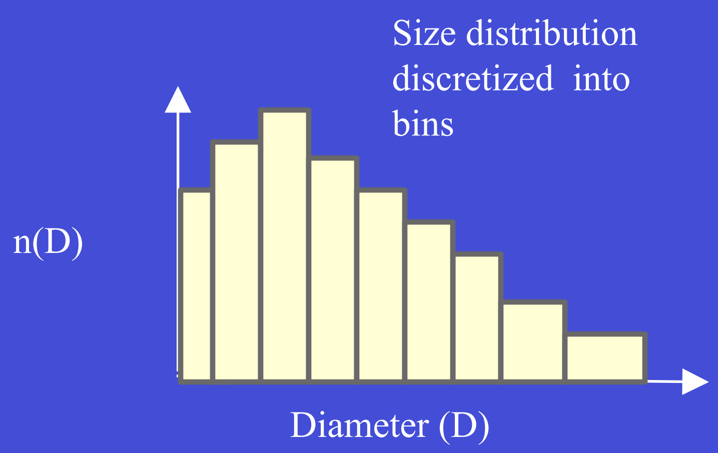
-Cloud-aerosol-precipitation interactions

(aerosol affect clouds: indirect aerosol effects, but clouds process aerosols as well)

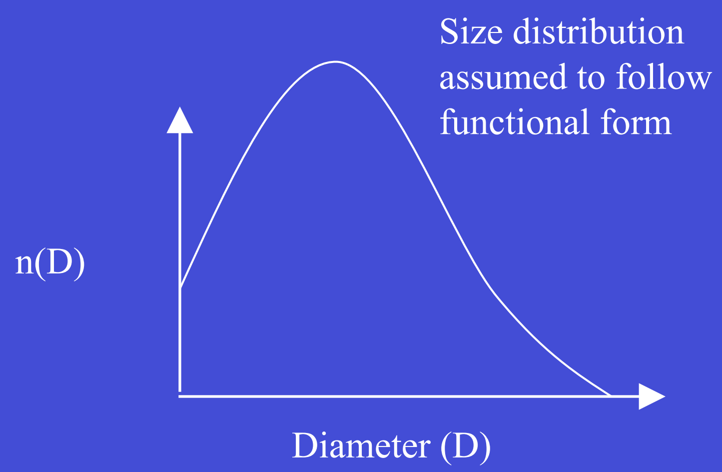
Overview of microphysics parameterizations in models

Microphysics schemes can be broadly categorized into two types:

Detailed (bin)



bulk



Representation of particle size distribution

Bulk schemes predict one or more bulk quantities (e.g., mass mixing ratio) and assume functional form for the particle size distribution, e.g., gamma distribution:

$$n(D) = N_0 D^{\mu} e^{-\lambda D}$$

If N_0 and μ are specified, then λ can be obtained from the predicted mixing ratio q:

$$q = \int_0^{\infty} \frac{\pi}{6} \rho_w N_0 D^{3+\mu} e^{-\lambda D} dD$$

$$\lambda = \left[\frac{\pi \rho_w N_0 \Gamma(\mu + 4)}{6q} \right]^{\frac{1}{\mu+4}}$$

Equations for spherical drops

Multi-moment versus single-moment schemes

- Single-moment – predict mixing ratio only for each species

- Multi-moment – predict additional quantities for each species (number concentration, reflectivity)

Prediction of additional moments allows greater flexibility in representing size distributions and hence microphysical process rates.

$$n(D) = N_0 D^{\mu} e^{-\lambda D}$$

- **Prediction of 2nd moment (number concentration N) allows N_0 to vary with q and N, giving scheme more flexibility** **(e.g., Koenig and Murray 1976; Ferrier 1994; Meyers et al. 1997; Seifert and Beheng 2001; Milbrand and Yau 2005; Morrison et al. 2005)**

- **Prediction of cloud particle number concentrations in two-moment schemes allows for an explicit, physically-based treatment of cloud-aerosol-precipitation interactions (discussed later…)**

Other key impacts of single vs. double-moment:

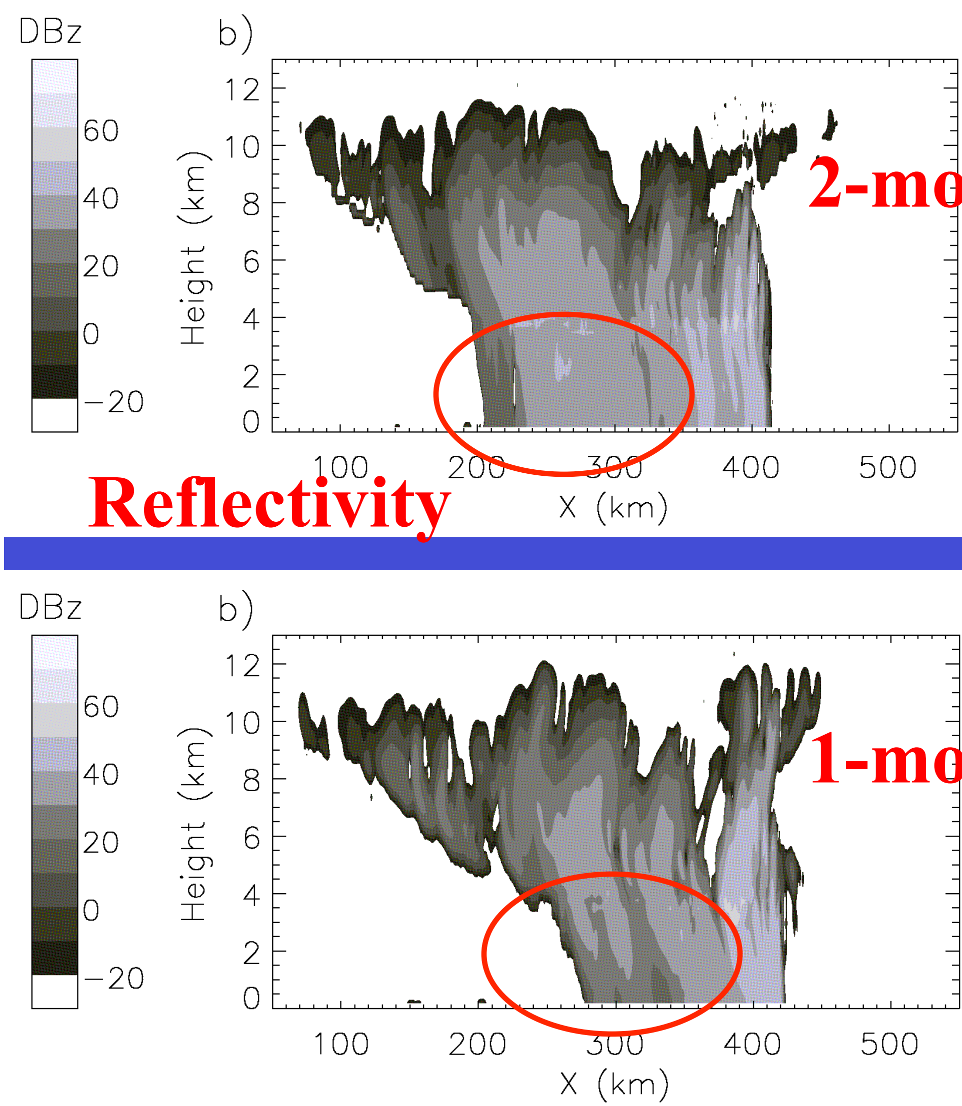
- Sedimentation (treatment of size sorting)

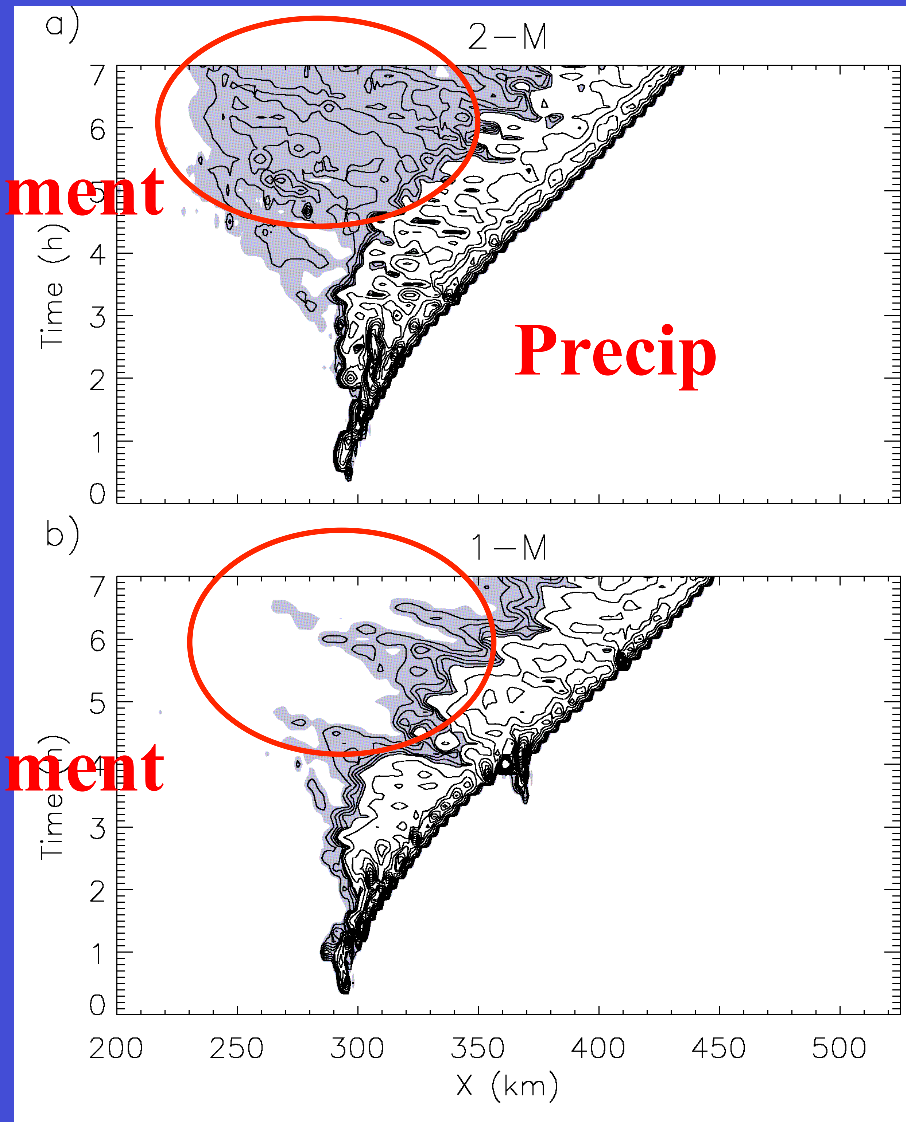
- Evaporation of rain - 2-moment schemes have a more flexible treatment of rain drop mean size

Example: Impact of single vs. double-moment on idealized 2D mid-latitude squall line

t = 6 hr

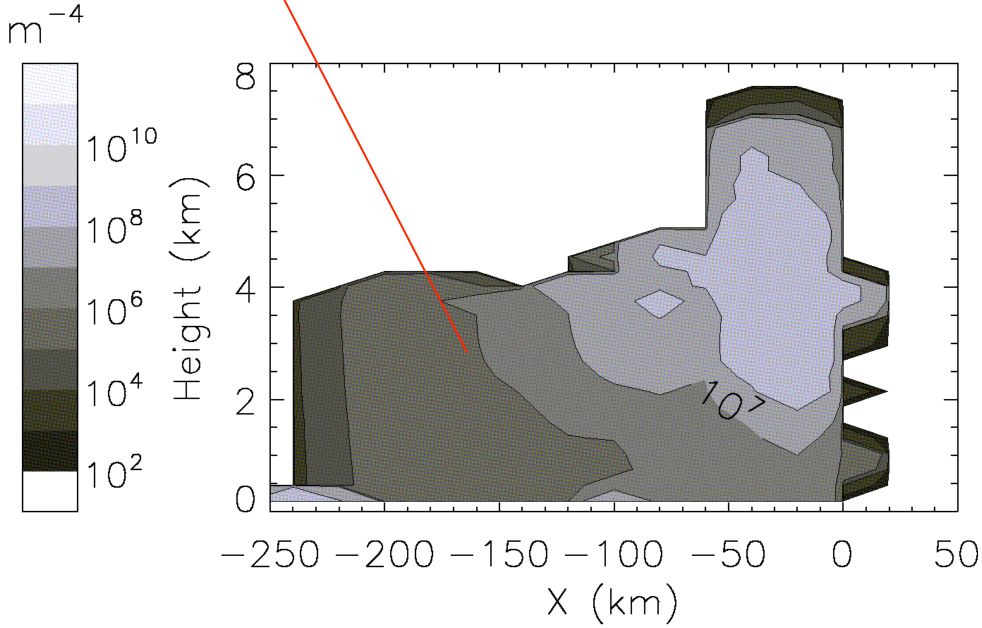
Morrison et al. 2009

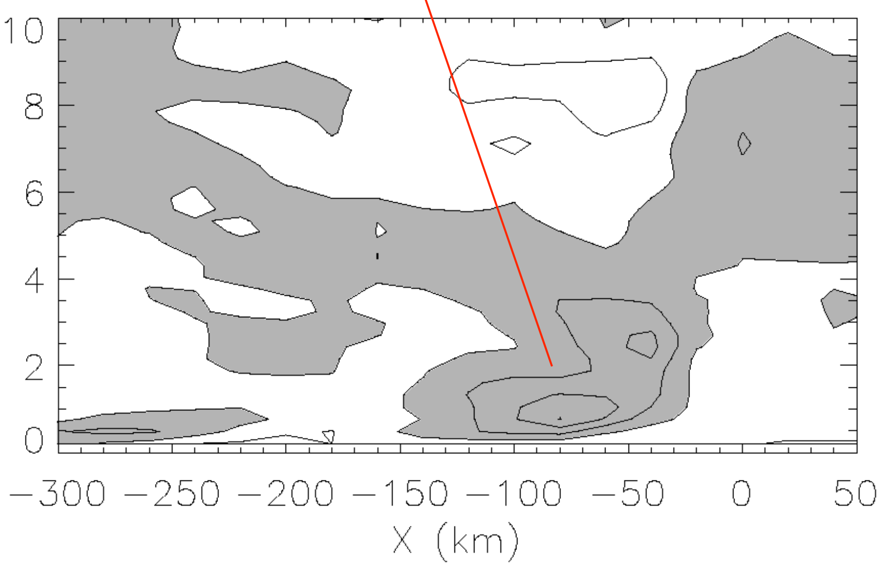




Small N_0, low evaporation rate in 2-moment simulation

Weaker cold pool in 2-moment simulation

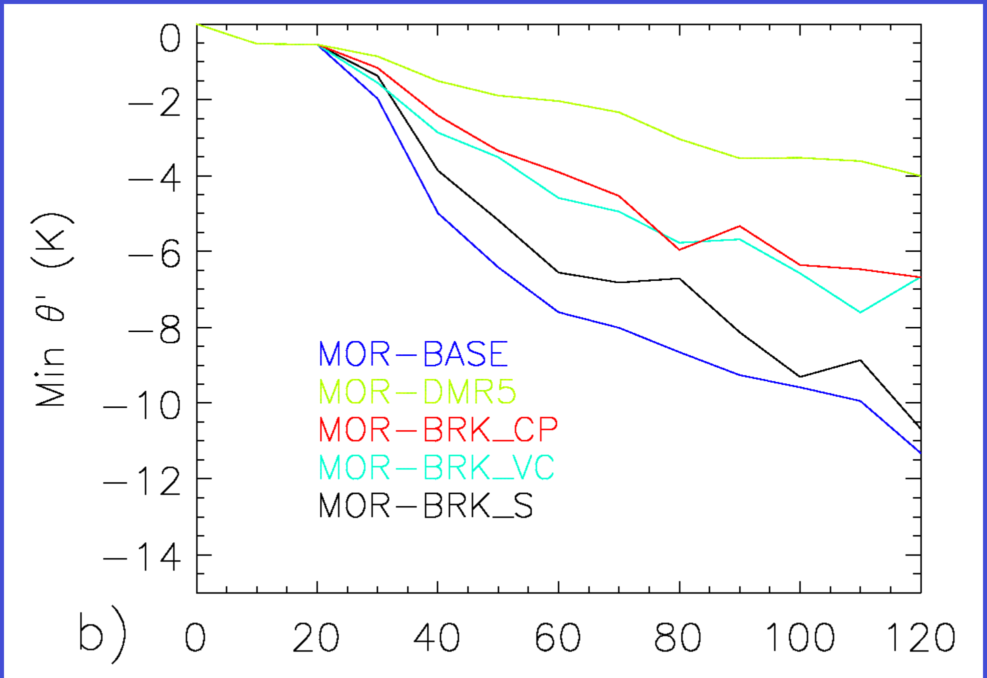


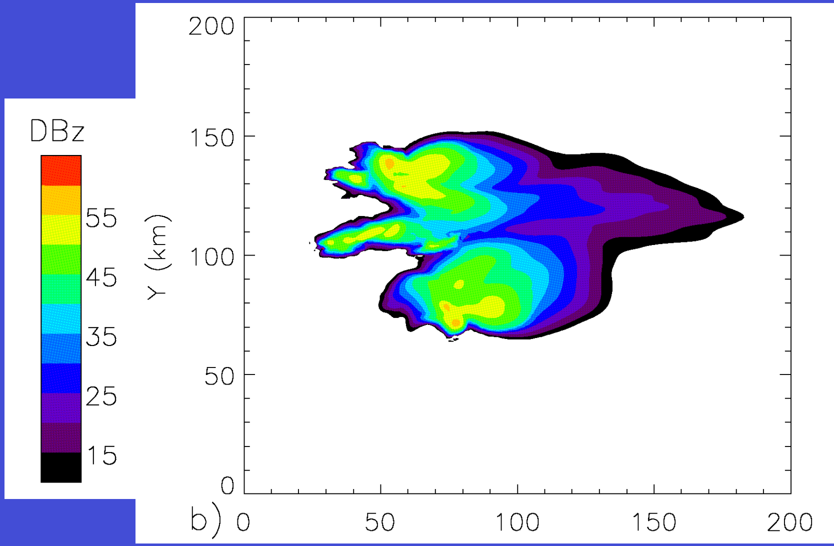


Morrison et al. 2009

• **Other parameters also impact rain drop size distribution and hence evaporation rate (rain drop breakup, rain size distribution width or shape, size of melted or shed drops, etc.).**

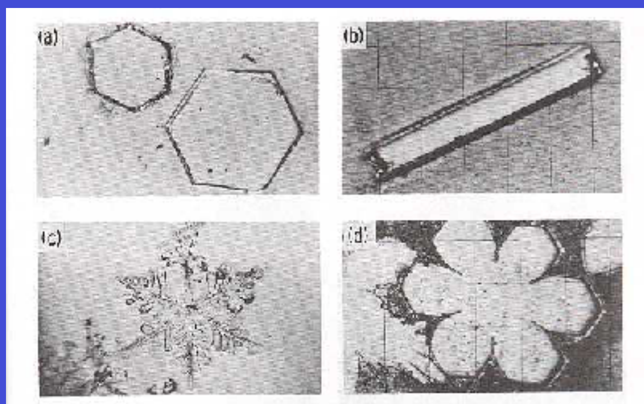
Example: parameterization of rain drop breakup in simulations of supercell thunderstorms, Δx = 1 km

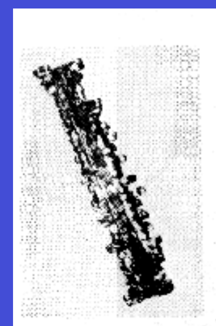


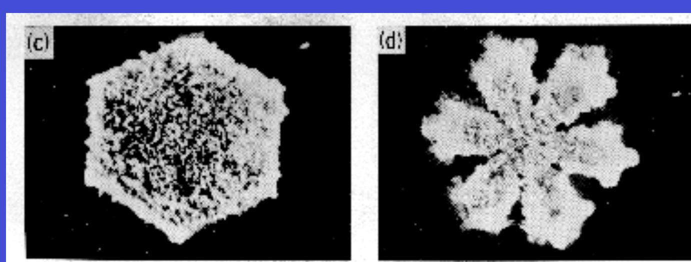


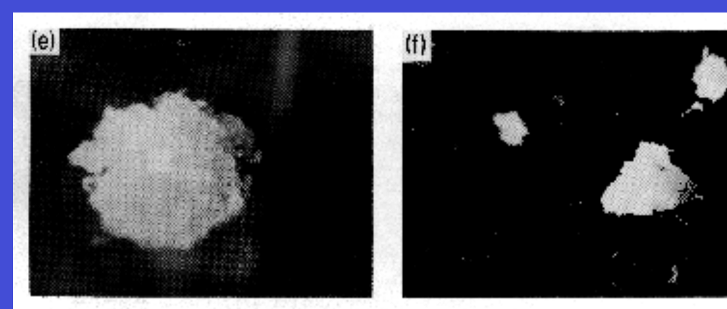
Morrison and Milbrandt (2010)

Ice microphysics is a key uncertainty in microphysics schemes, due to complications arising from different ice particle types









•Different types of ice (small ice, snow, graupel, hail, etc.) are typically parameterized by partitioning ice into different species whose characteristics (e.g., particle density, fallspeed) are specified a priori.

Rutledge and Hobbs, JAS 1984

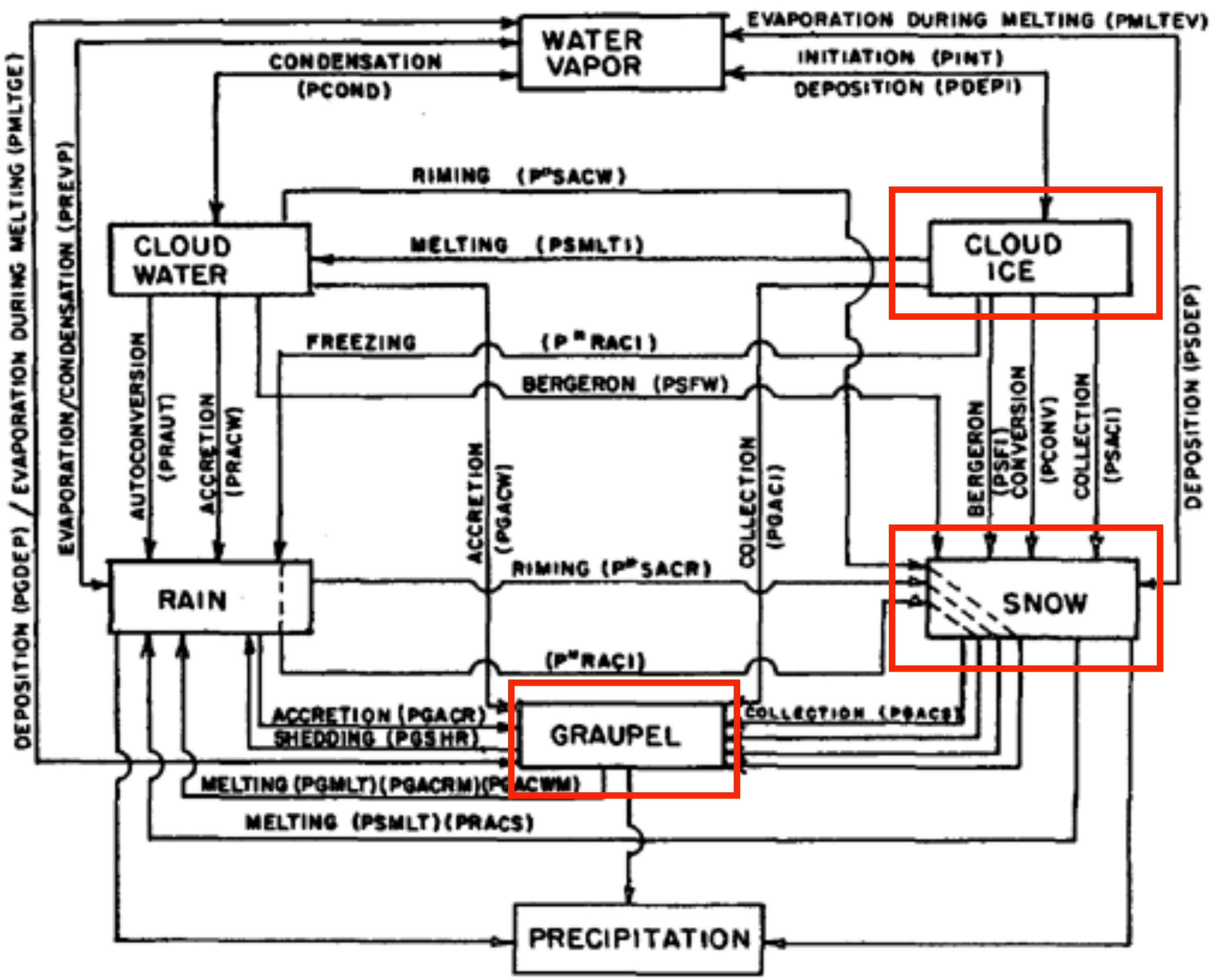
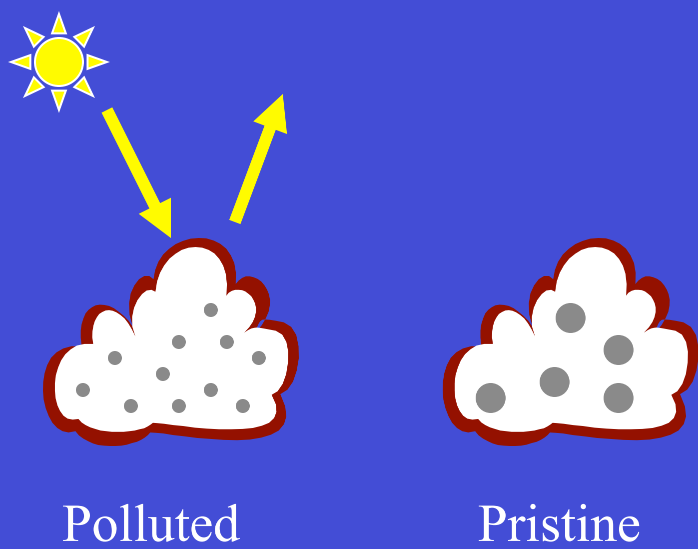


FIG. 1. Schematic depicting the cloud and precipitation processes included in the model for the study of narrow cold-frontal rainbands.

- **In general, there has been a trend towards more complexity in microphysics parameterizations, i.e., including more species and more moments.**

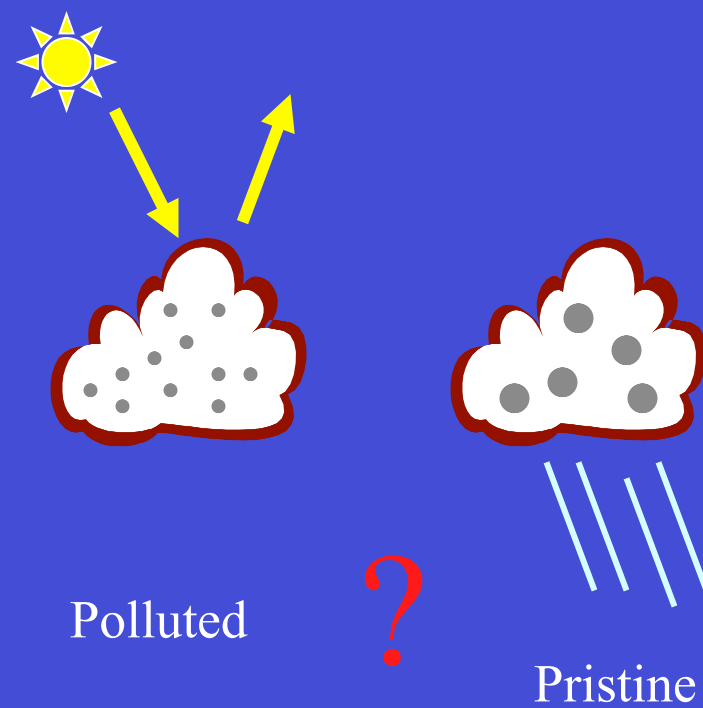
- **Recent work has attempted to move away from this approach by allowing particle type to vary as a function of the rime and vapor deposition ice mixing ratios, which are predicted separately (Stoelinga et al. 2007; Morrison and Grabowski 2008). Cloud ice, snow, and graupel are not separated into different species with fixed characteristics.**

Cloud-aerosol-precipitation interactions



Impact on effective radius

First Indirect Effect
(e.g., Twomey 1977)



Impact on LWC, cloud lifetime

Second Indirect Effect
(e.g., Albrecht 1989)

- For robust treatment, one needs to predict locally the droplet effective radius and mass mixing ratio (or liquid water content).

- Traditional bulk microphysics models (i.e., one-moment schemes predicting cloud droplet mixing ratios only) have insufficient detail.

- Detailed bin microphysics models are too expensive for many applications (including MMF).

- Two moment bulk models provide a valuable alternative.

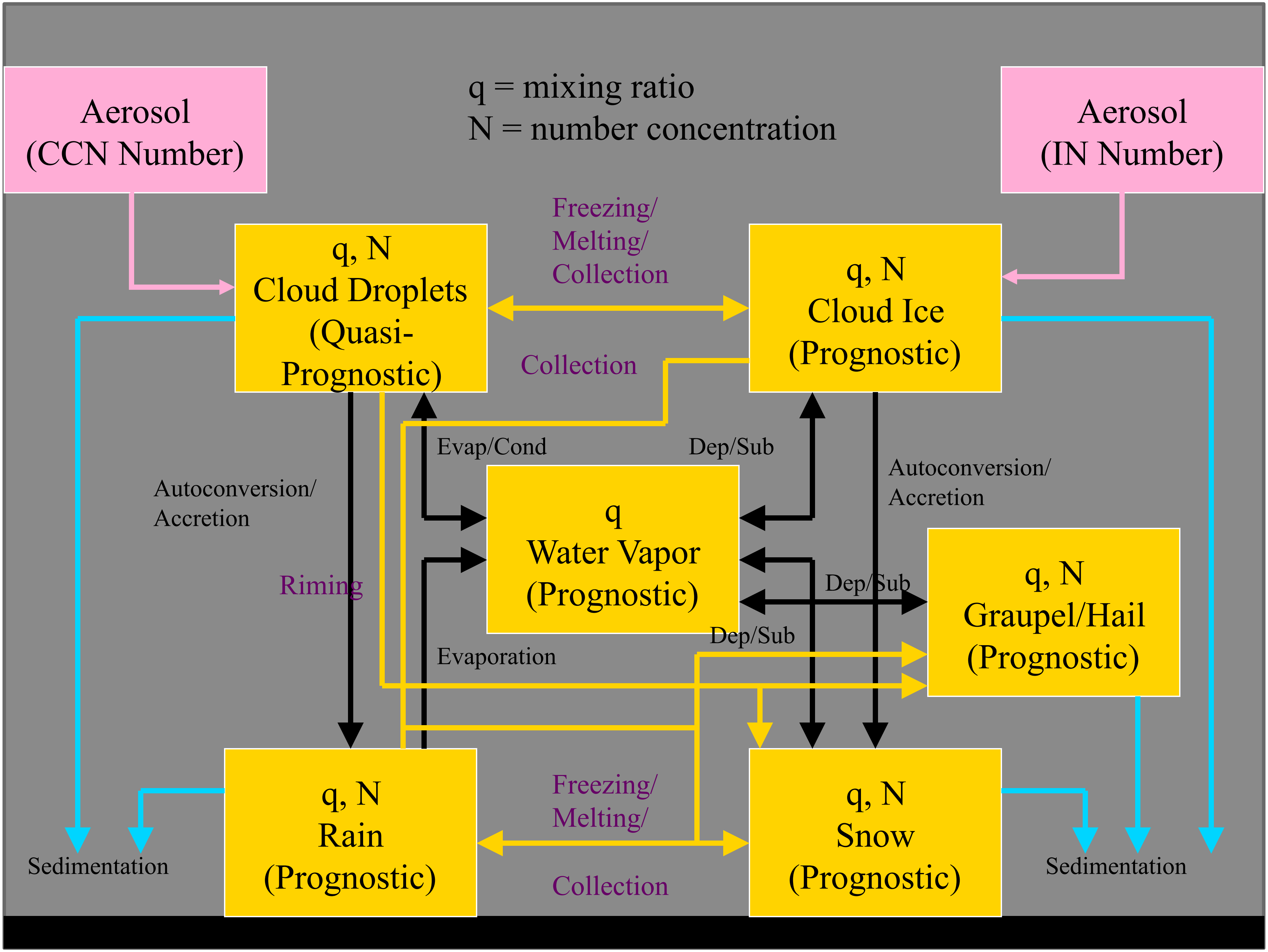
Description of the M2005 microphysics

- Two-moment , five species (droplets, rain, small ice, snow, graupel/hail)

- Coupling with aerosol (CCN and IN)

- Implemented in SAM, WRF, and other models.

- For further details, see Morrison et al. 2005, JAS; 2009, MWR



q = mixing ratio
N = number concentration
Aerosol
(CCN Number)
Aerosol
(IN Number)
q, N
Cloud Droplets
(Quasi-
Prognostic)
Freezing/
Melting/
Collection
q, N
Cloud Ice
(Prognostic)
Collection
Evap/Cond
Dep/Sub
Autoconversion/
Accretion
q
Water Vapor
(Prognostic)
Autoconversion/
Accretion
Riming
Dep/Sub
q, N
Graupel/Hail
(Prognostic)
Dep/Sub
Evaporation
q, N
Rain
(Prognostic)
Freezing/
Melting/
Collection
q, N
Snow
(Prognostic)
Sedimentation
Sedimentation

Future development of M2005 microphysics for MMF

- Testing of Morrison and Grabowski (2008) ice scheme (fewer prognostic variables, more physically-based treatment of riming and conversion to graupel)

- Testing of reduction of prognostic variables to improve cost (diagnose number concentrations for graupel, snow?).

- Further testing/tuning of parameter settings using LES/CRM/MMF – driven by observations.. (ice particle fallspeed-, mass-, and area-size relations from A. Heymsfield, C. Schmitt et al.)