Improving the treatment of microphysics in cloud models and the MMF

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The problem of representing clouds in models….

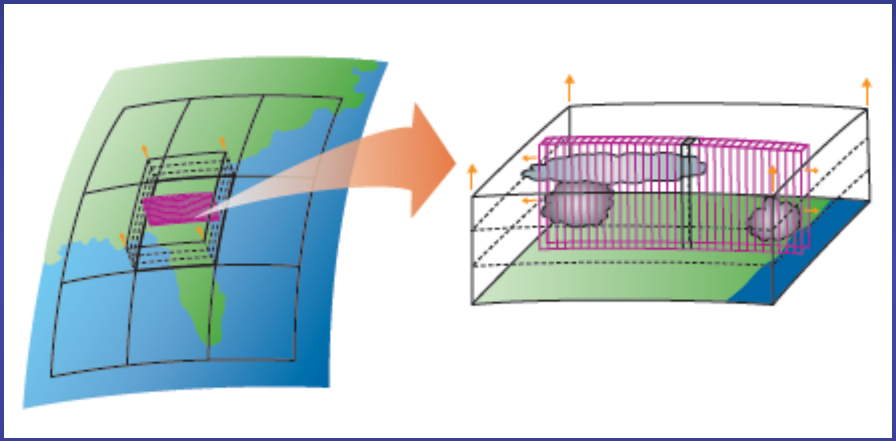
-range of relevant spatial scales of individual clouds, cloud systems, and atmospheric dynamics

(10’s m -1,000’s km)

-range of relevant spatial scales for the cloud and precipitation particles:

cloud microphysics (~ 0.001 - 1 mm)

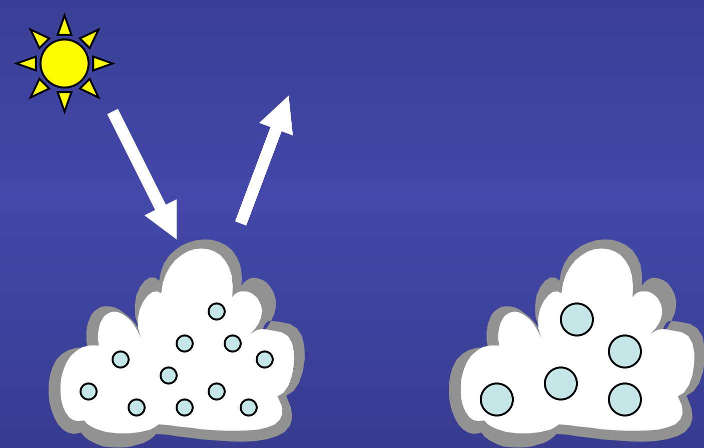
Fine-scale models like MMF and GCRM can resolve larger-scale convective and mesoscale dynamics



- Microphysics must still be parameterized, arguably it is even more important in fine-scale models than conventional large-scale models because it directly drives the moist convection

Microphysics-Radiation Interaction

Impact of aerosol on cloud optical properties (indirect aerosol effect)



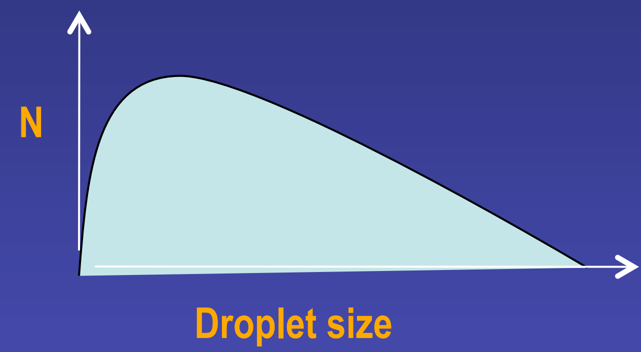
Impact of droplet size

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

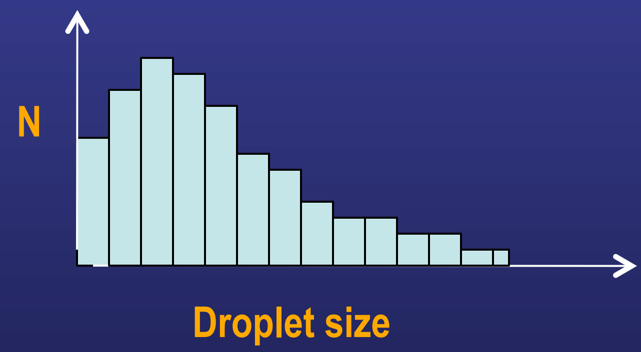
A key point is that to capture cloud-aerosol interactions and important microphysics-dynamics interactions, the microphysics parameterization needs to be detailed enough to allow cloud water content and mean droplet size to vary independently.

Our goal is to develop a flexible, computationally inexpensive microphysics scheme for MMF and GCRM that has this level of detail.

Bulk parameterization – population of different droplet sizes is assumed to follow some functional form, only bulk quantities (total water content, number concentration, etc.) are predicted.



Bin parameterization – population of different size droplets is explicitly predicted using different size bins



Traditional bulk microphysics parameterizations (i.e., one-variable parameterizations predicting cloud water mixing ratio only) do not allow mean droplet size and water content to vary independently.

Bin microphysics parameterizations are too expensive for application here (but are used as a benchmark to test simpler bulk parameterizations).

Two-variable bulk parameterizations (i.e., predicting both mixing ratio and number concentration of cloud droplets) provide a valuable alternative because they are inexpensive but allow mean droplet size and water content to vary independently.

Warm-cloud microphysics (i.e., no ice) is relatively straightforward as drops are (mostly) spherical. Our two-variable bulk scheme for warm clouds was able to reproduce most features of bin model results (Morrison and Grabowski, 2007, JAS)

However, in warm clouds (as well as ice clouds) there remain uncertainties in treating interactions between microphysics and unresolved cloud variability.

Ice microphysics is significantly more complicated because of the wide range of ice particle characteristics….

Small ice crystals, grown by diffusion of water vapor

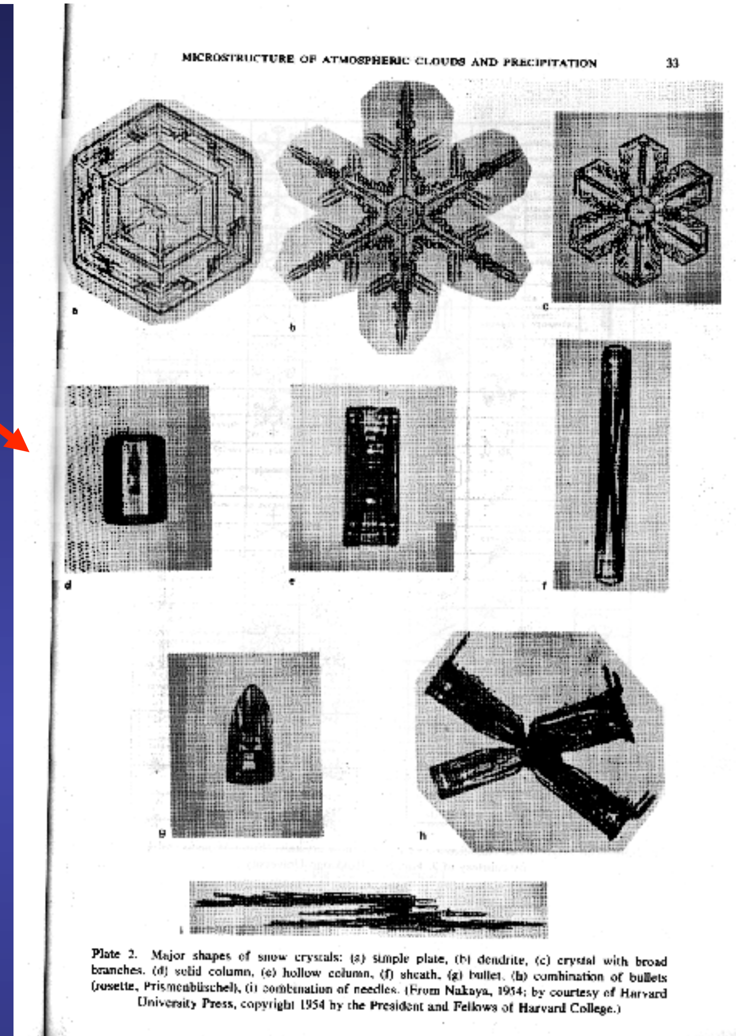
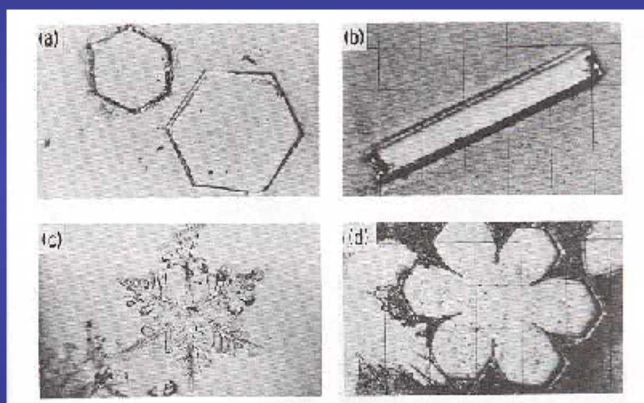


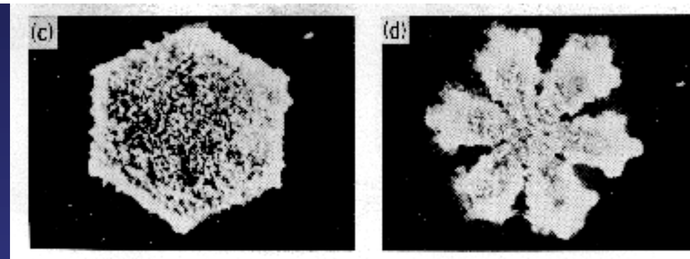
Plate 2. Major shapes of snow crystals: (a) simple plate, (b) dendrite, (c) crystal with broad branches. (d) solid column, (e) hollow column, (f) sheath, (g) bullet, (h) combination of bullets (rosette, Prismenbüschel), (i) combination of needles. (From Nakaya, 1954; by courtesy of Harvard University Press, copyright 1954 by the President and Fellows of Harvard College.)

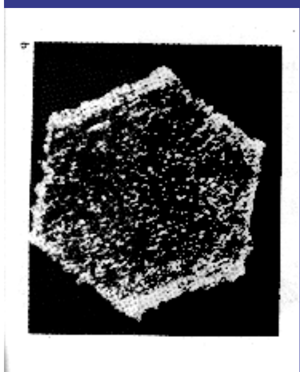


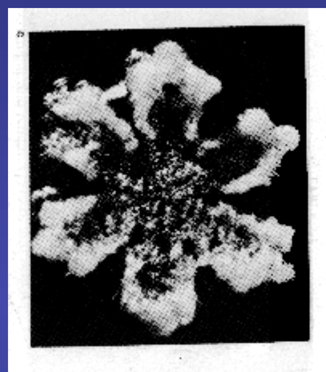
Snowflakes, grown by aggregation

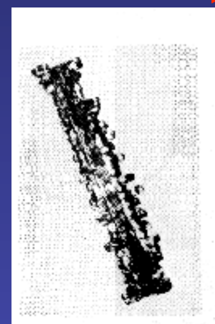
Pruppacher and Klett

Rimed ice crystals (accretion of supercooled cloud water)

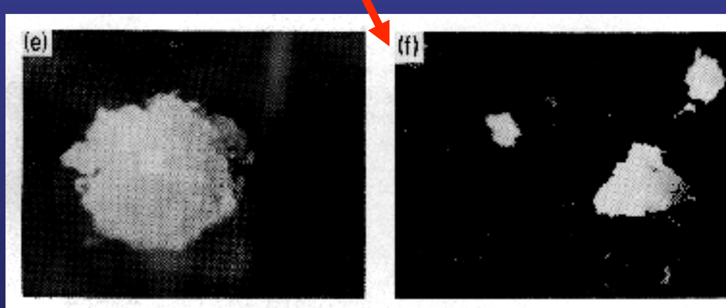








Graupel (heavily rimed ice crystals)



Rutledge and Hobbs, JAS 1984

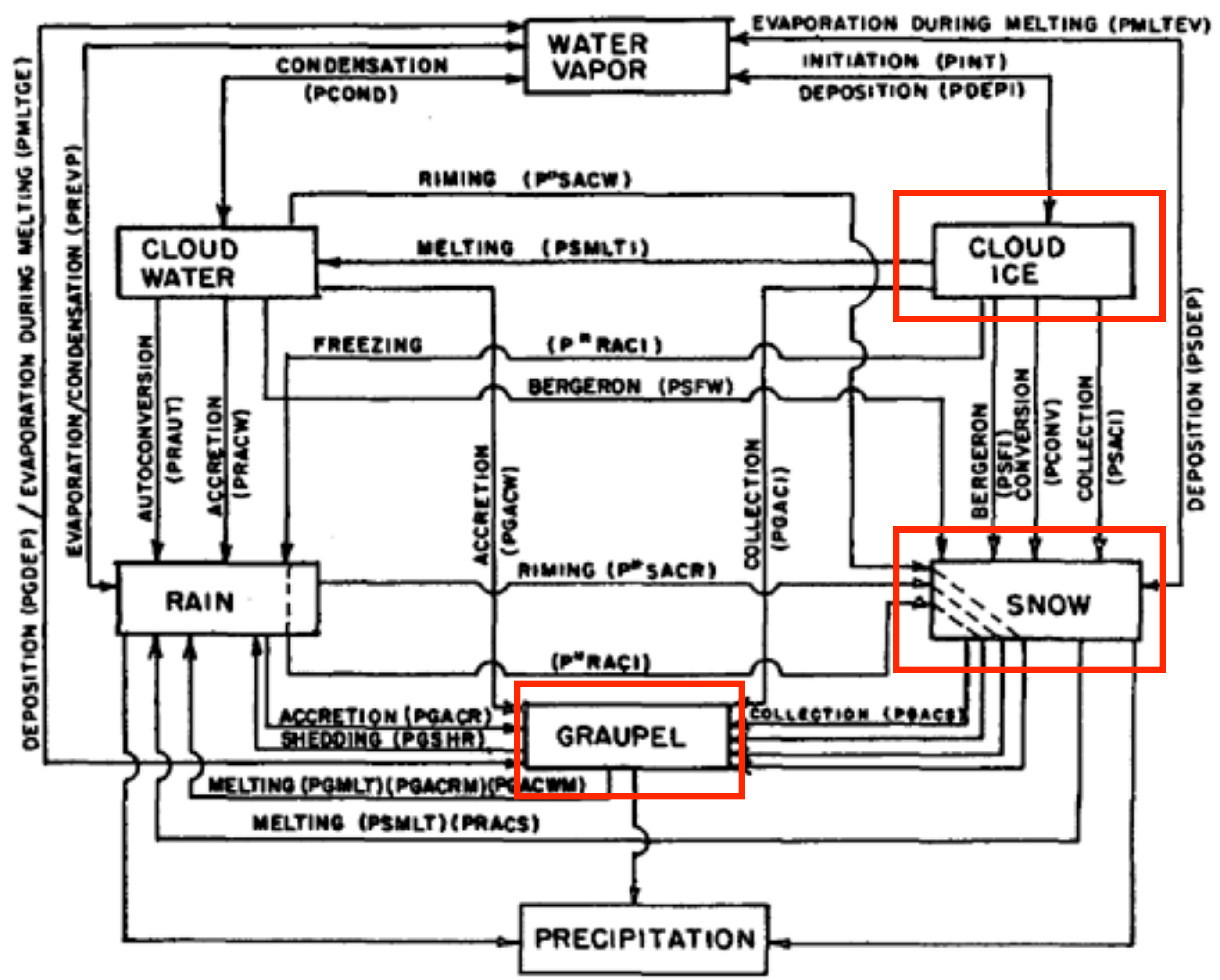


FIG. 1. Schematic depicting the cloud and precipitation processes included in the model for the study of narrow cold-frontal rainbands.

A new three-variable ice scheme: No separate categories for ice, instead growth history determines ice type

$$\frac{\partial N}{\partial t} + \frac{1}{\rho_a}\nabla \cdot [\rho_a(\mathbf{u} - V_N\mathbf{k})N] = \mathcal{F}_N$$

Number concentration of ice crystals, *N*

$$\frac{\partial q_{dep}}{\partial t} + \frac{1}{\rho_a}\nabla \cdot [\rho_a(\mathbf{u} - V_q\mathbf{k})q_{dep}] = \mathcal{F}_{q_{dep}}$$

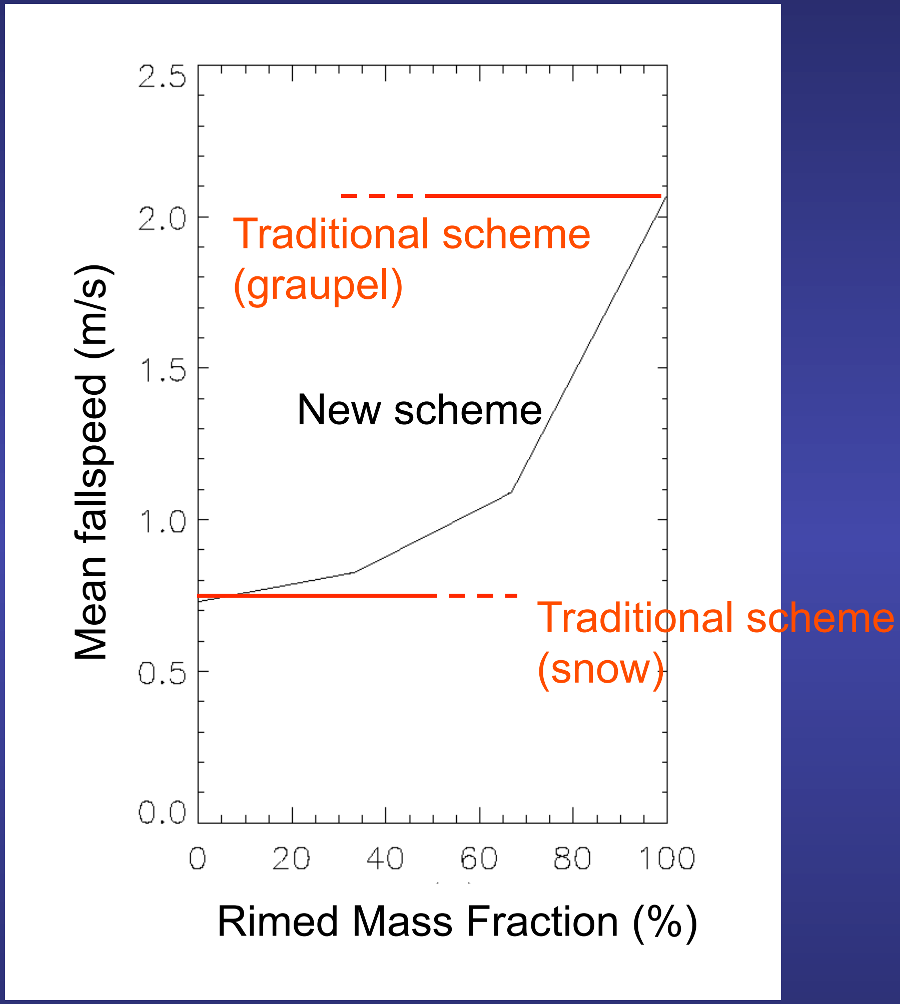
Mixing ratio of ice grown by diffusion of water vapor, q_{dep}

$$\frac{\partial q_{rim}}{\partial t} + \frac{1}{\rho_a}\nabla \cdot [\rho_a(\mathbf{u} - V_q\mathbf{k})q_{rim}] = \mathcal{F}_{q_{rim}}$$

Mixing ratio of ice grown by riming (accretion of liquid water), q_{rim}

Morrison and Grabowski 2008 (JAS)

Example – mean particle fallspeed



Mean mass-weighted fallspeed as function of rimed mass fraction, for q = 0.2 g/kg, N = 1 L^{-1}.

Prospects

- Scheme is being tested in several cloud models for a number of different cases – next step, test in full MMF
- Need close coordination with other parameterization development (radiation, turbulence) in the context of CMMAP