Parameterization of microphysics and its impact on organized deep convection

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Convective-scale cloud, NWP, and climate models (e.g., "superparameterization") resolve deep convective scale and mesoscale dynamics…

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

Parameterization of microphysics is arguably a key in these models since it is directly coupled to the convective dynamics.

-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

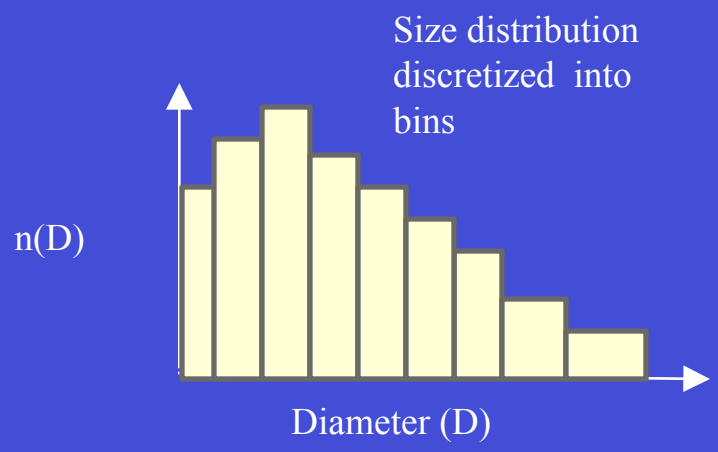
(mostly mass for absorption/emission of LW, particle size important for SW scattering, size and composition important for SW absorption)

-Cloud-aerosol-chemistry interactions

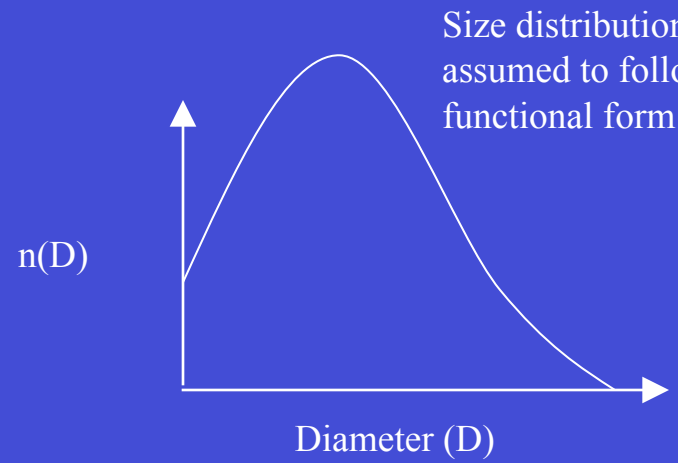
(aerosol affect clouds: indirect aerosol effects, but clouds process aerosols as well)

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., mixing ratio) and assume functional form for the particle size distribution, e.g., gamma distribution:

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

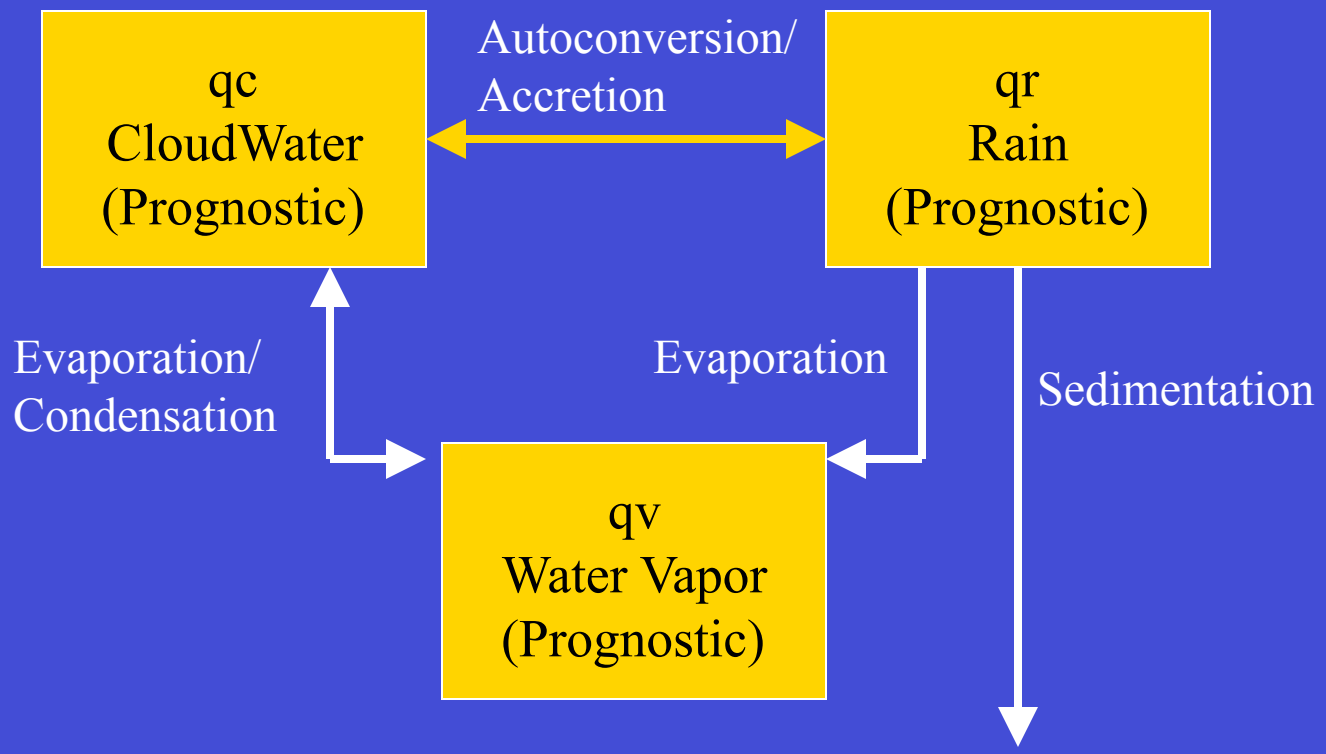
If N_0 and μ are specified, then λ can be obtained from the predicted mixing ratio q:

$$q = int(\pi/6 \rho_w D^3 n(D) dD)$$

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

Liquid microphysics – Kessler (1969)

- **Separate liquid into cloud water and rain**
- **Marshall-Palmer distribution for rain**



Extension to ice phase

…subsequent studies extended the Kessler approach to include ice (e.g., Koenig and Murray 1976; Lin et al. 1983; Rutledge and Hobbs 1984; Lord et al. 1984; Dudhia 1989)

Ice microphysical processes

- Diffusional growth/sublimation
- Aggregation (autoconversion, accretion)
- Collection of rain and cloud water (riming)
- Melting
- Freezing
- Ice particle inititation (nucleation)
- Sedimentation

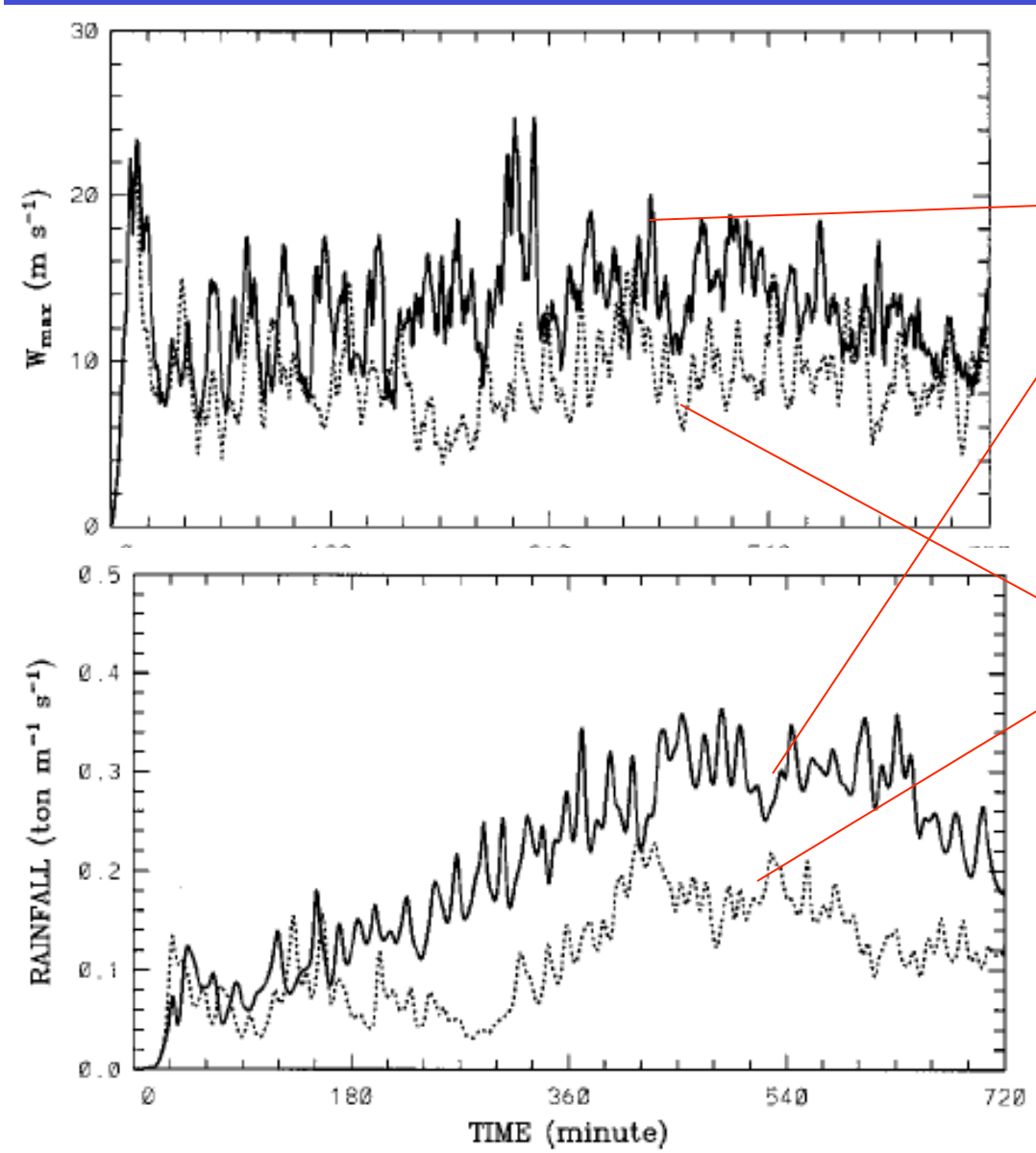
Ice microphysics has important impacts on dynamics and surface precipitation associated with organized deep convection due to:

- **slower fallspeed of snow compared to rain**

- **extra latent heating (cooling) due to freezing (melting)**

(e.g., Leary and Houze 1979; Lord et al. 1984; Fovell and Ogura 1988; Zhang and Gao 1989; McCumber et al. 1991; Liu et al. 1997; McFarquhar et al. 2006)

Example: Impact of ice microphysics on 2D tropical squall line



Ice + Liquid (Koenig and Murray)

Liquid only (Kessler)

Liu et al. 1997

However, there is strong case dependence of effects!

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)**

Key impacts of single vs. double-moment:

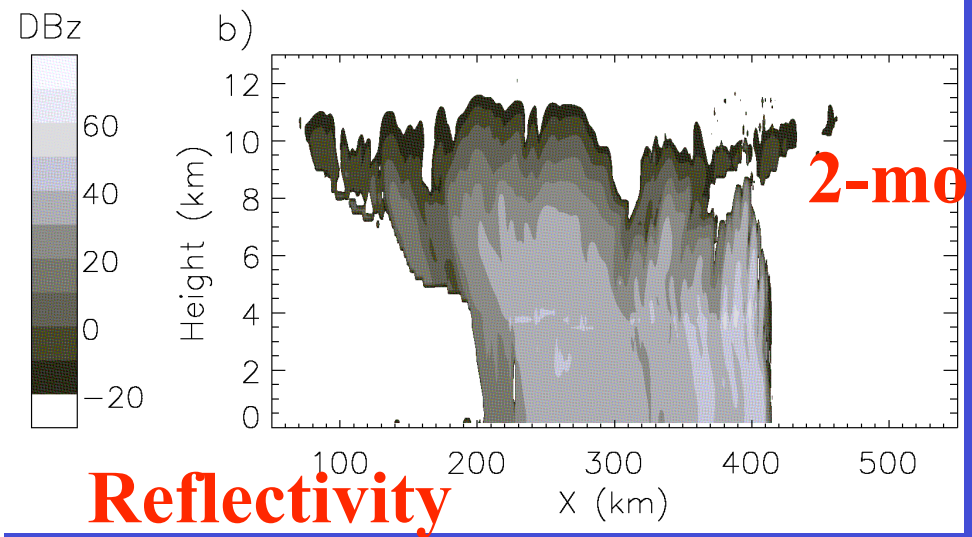
- Sedimentation (treatment of size sorting)

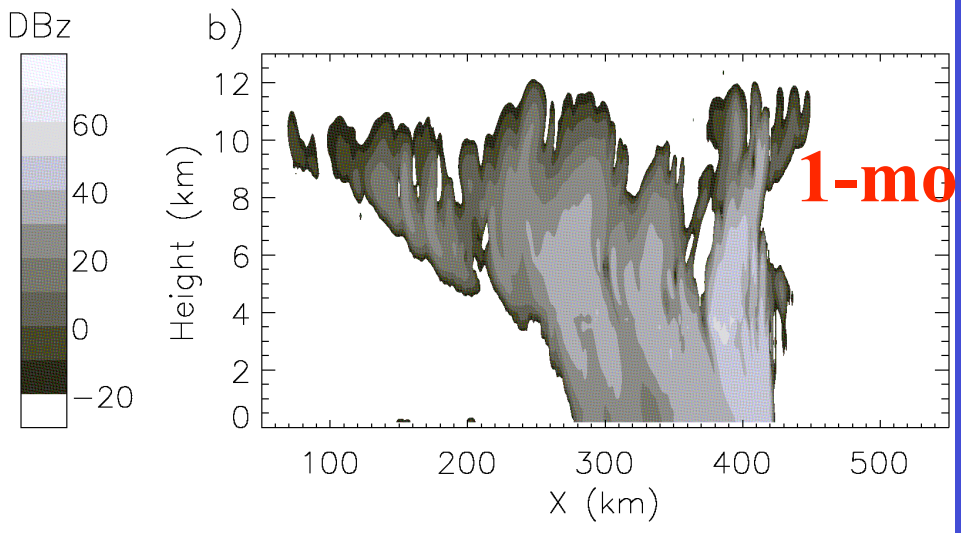
- Evaporation of rain - 2-moment schemes have a more flexible treatment of rain drop mean size

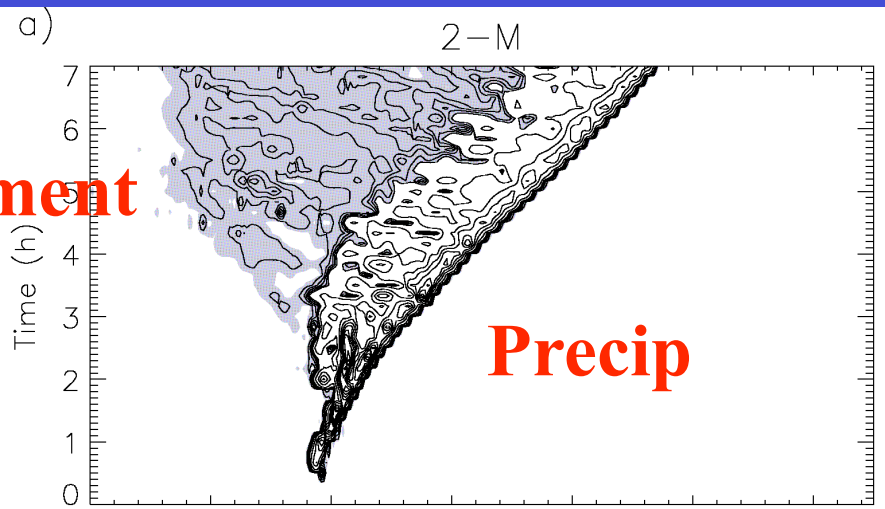
Example: Impact of single vs. double-moment on idealized 2D squall line

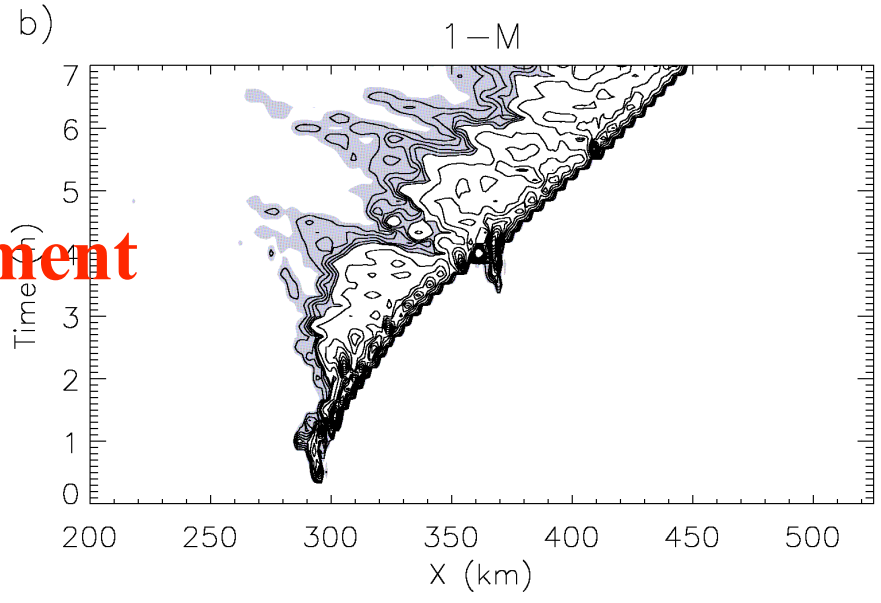
t = 6 hr

Morrison et al. 2009



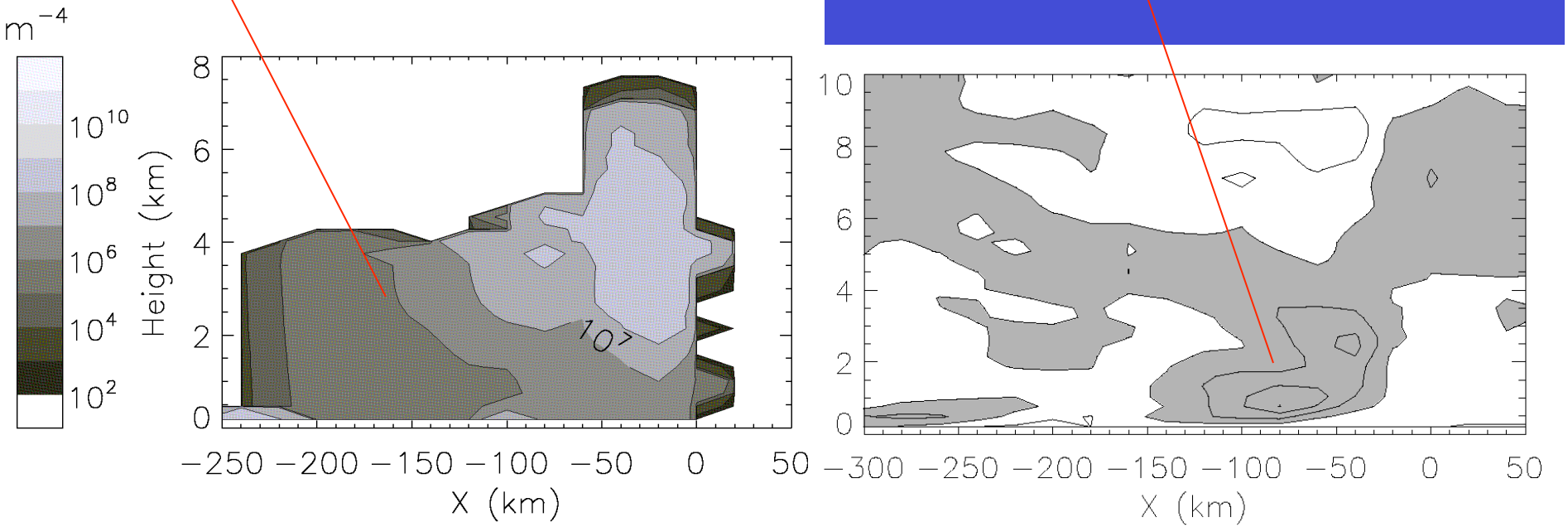






Small N_0, low evaporation rate in 2-moment simulation

Weaker cold pool in 2-moment simulation

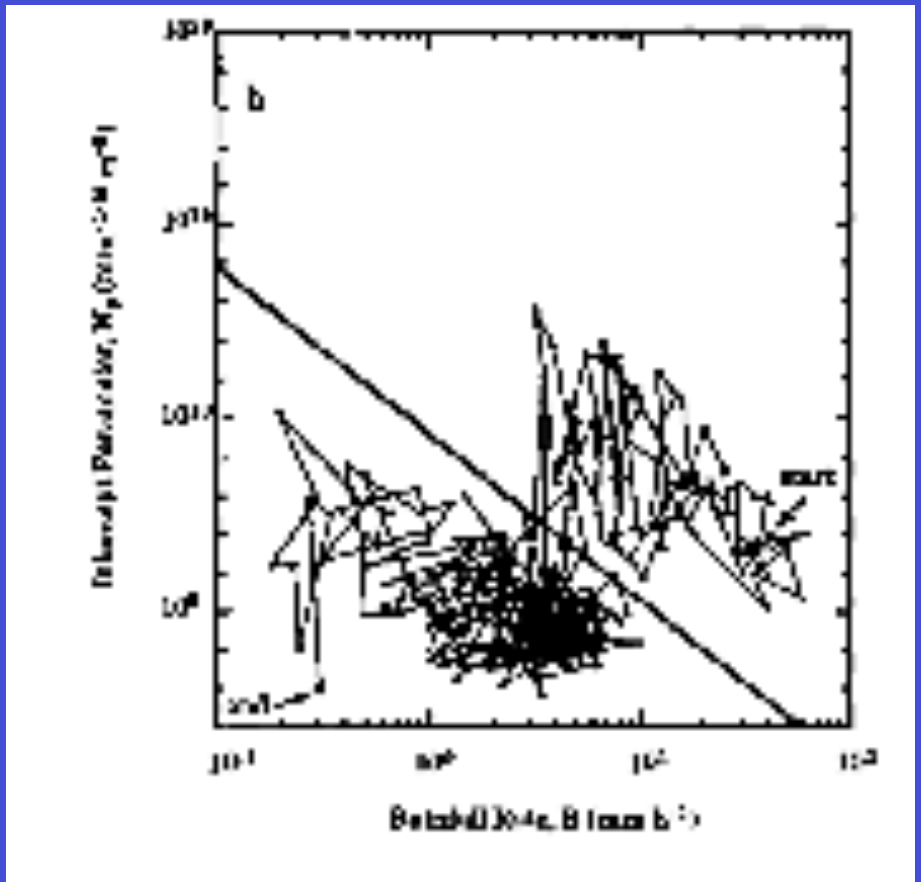


Results are consistent with supercell simulations showing enhanced reflectivity in forward flank region and weaker cold pool with 2-moment vs. 1-moment (Dawson et al. 2009).

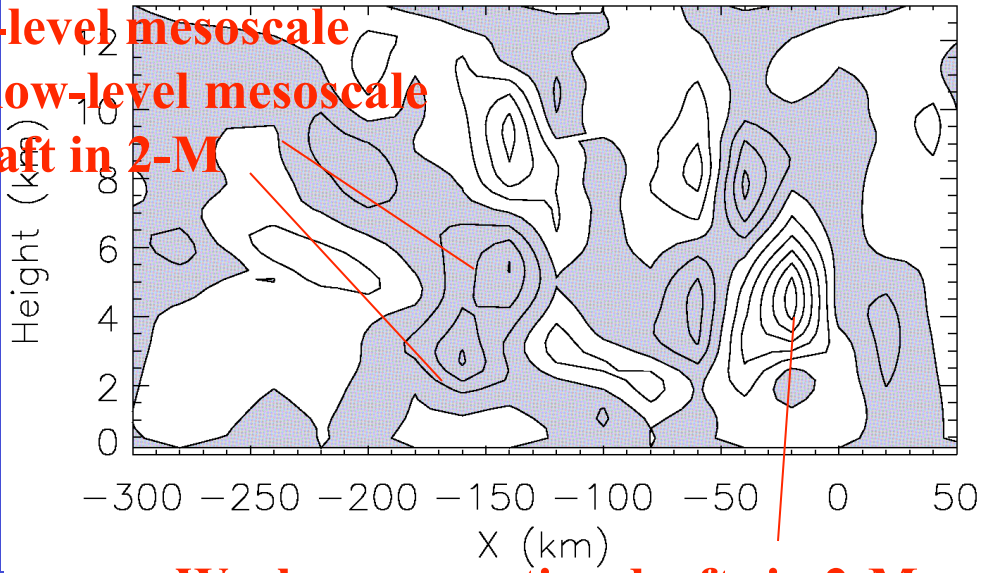
Spatial structure of N_0 in 2-moment scheme is consistent with observations (e.g., Waldvogel 1974; Tokay and Short 1996).

"Whenever the situation changed from uniform (widespread rain) to convective (shower or thunderstorm), there was a sudden increase in the parameter N_0….the contrary was true when the situation changed from widespread to convective." – Waldvogel (1974)

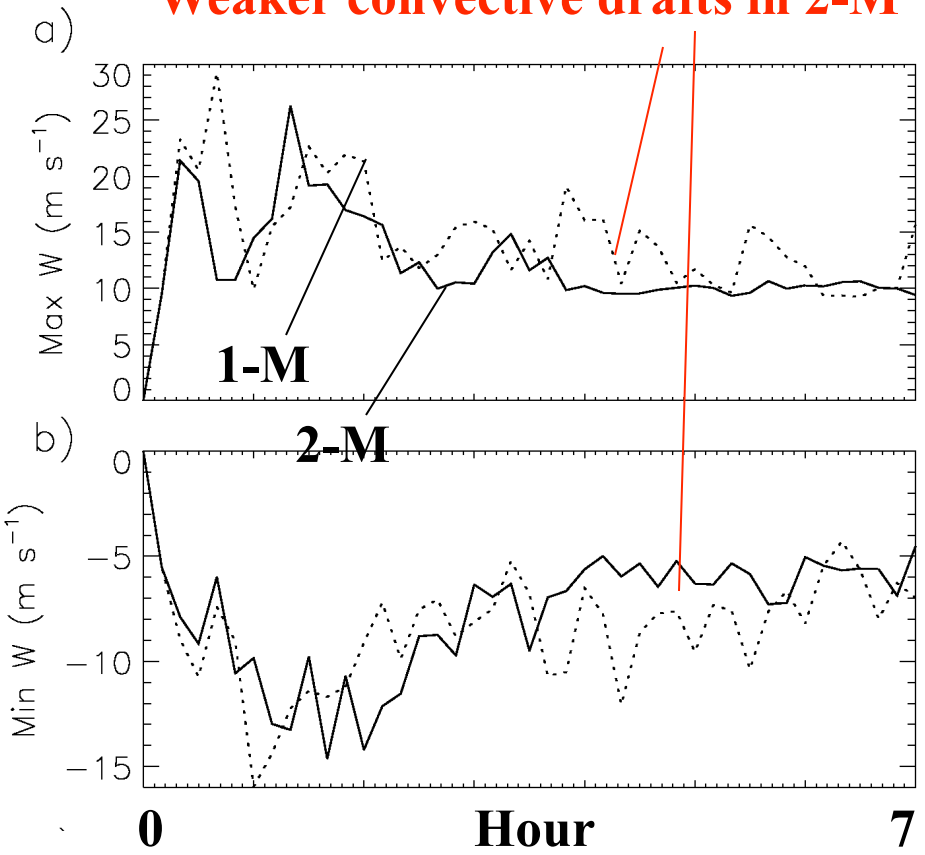
Disdrometer-measured N_0 in a tropical squall line (Tokay and Short 1996)



Stronger mid-level mesoscale updraft, weaker low-level mesoscale downdraft in 2-M

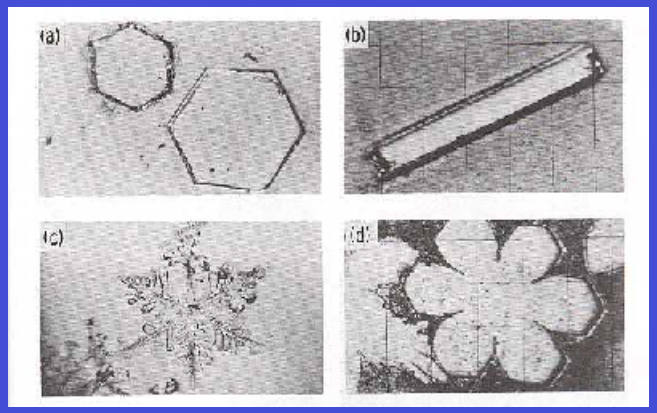


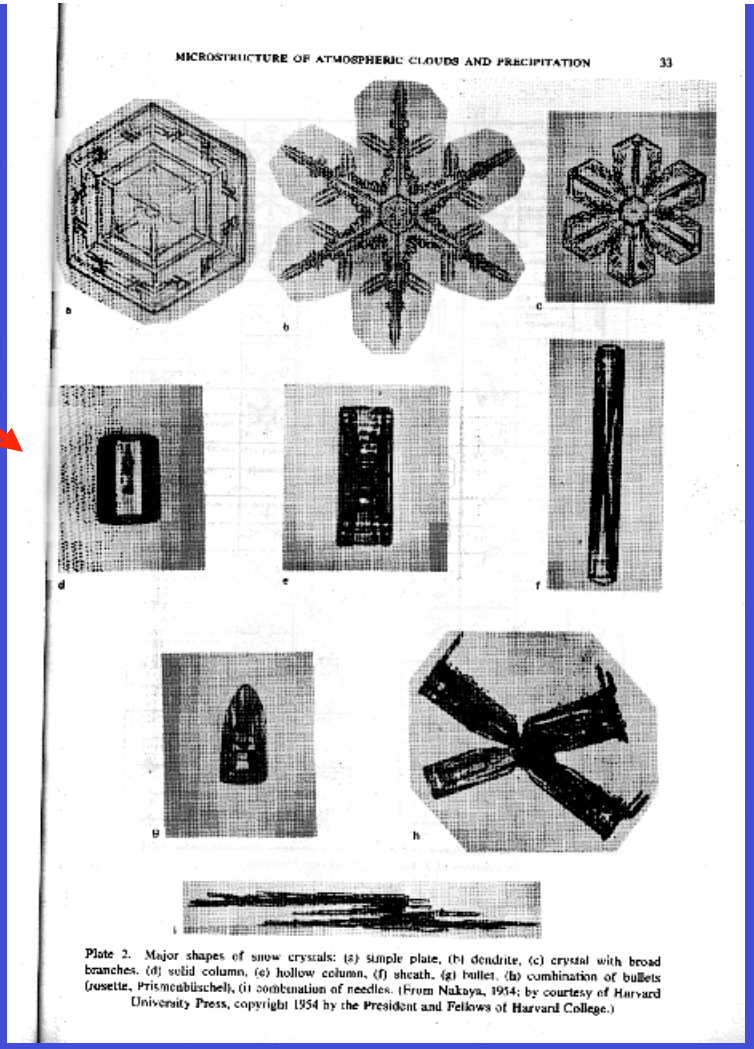
Weaker convective drafts in 2-M



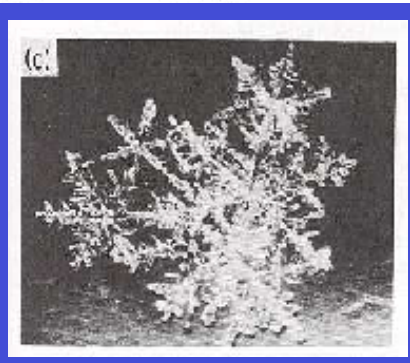
Ice microphysics is significantly more complicated than liquid because of the wide variety of ice particle characteristics…

Pristine ice crystals, grown by diffusion of water vapor



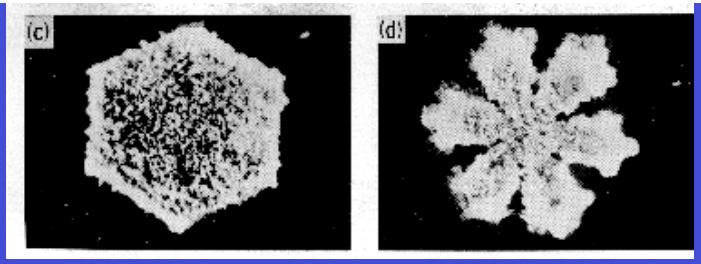


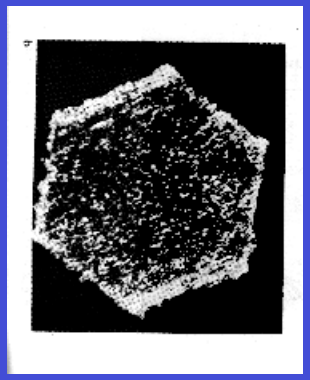
Snowflakes, grown by aggregation

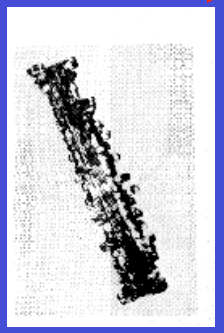


Pruppacher and Klett

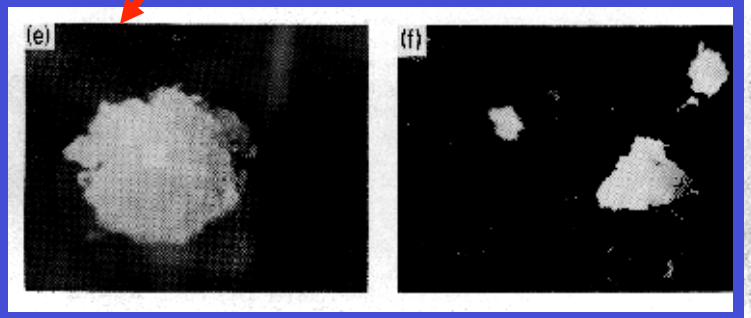
Rimed ice crystals (accretion of supercooled cloud drops)

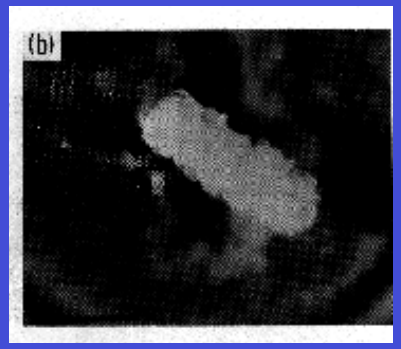






Graupel (heavily rimed ice crystals)





Hail

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 determined a priori.

Rutledge and Hobbs, JAS 1984

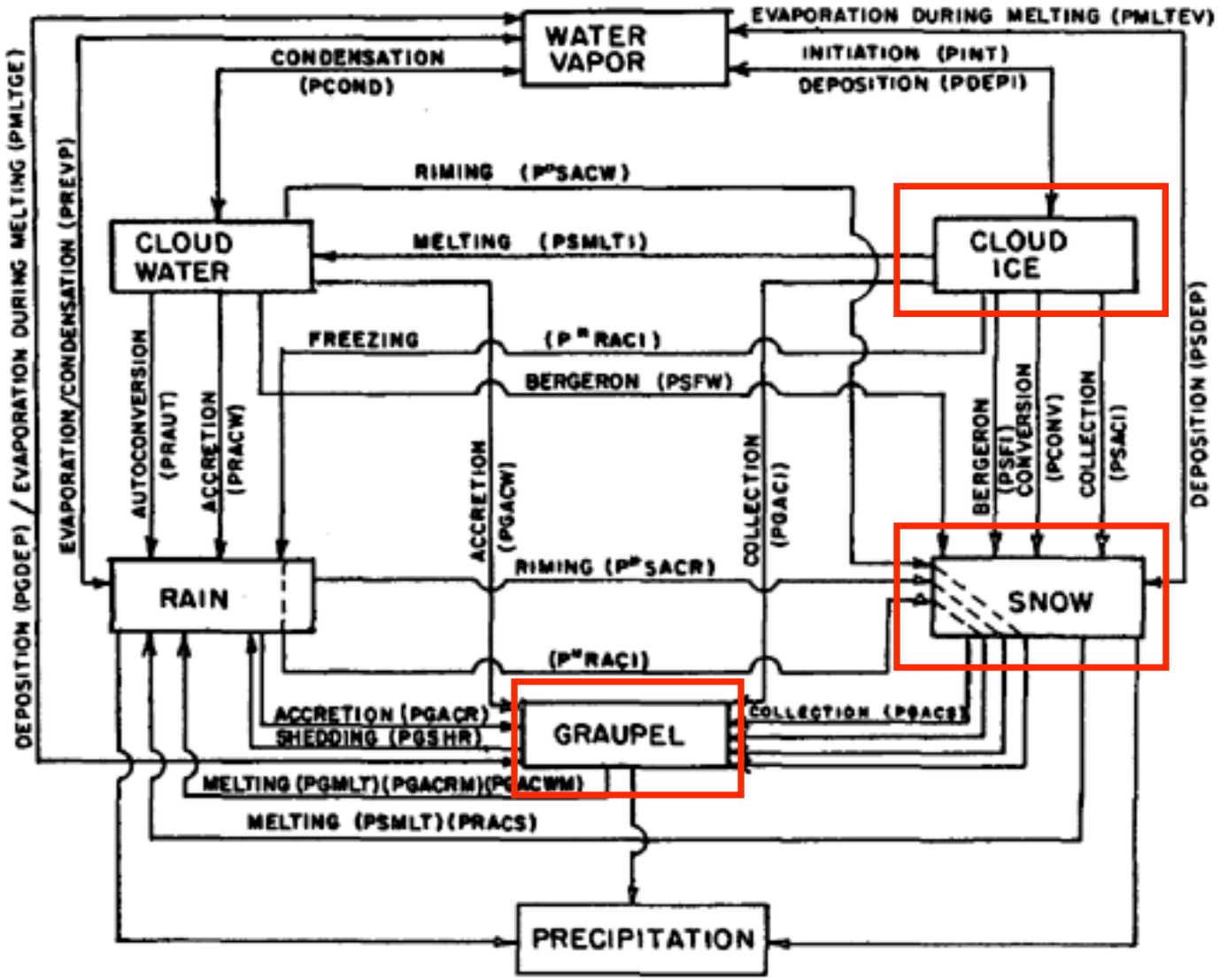
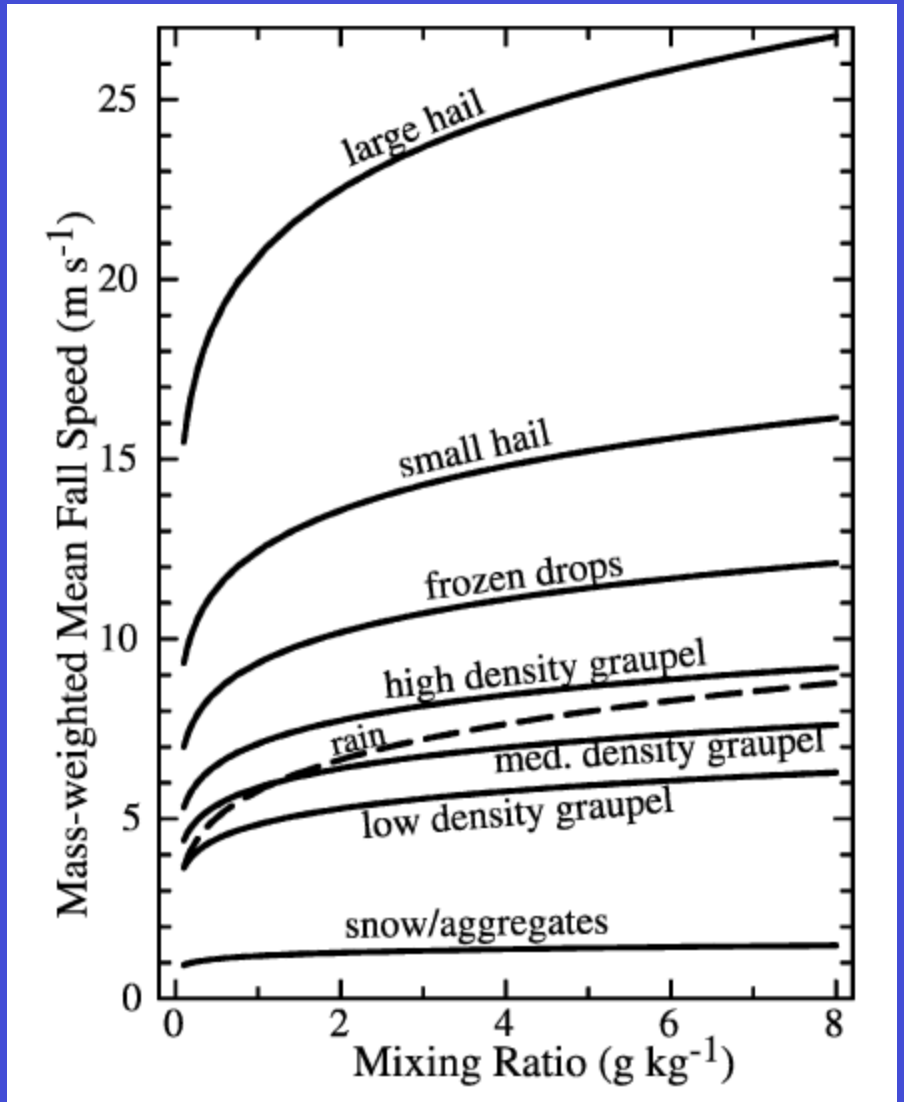


FIG. 1. Schematic depicting the cloud and precipitation processes included in the model for the study of narrow cold-frontal rainbands.

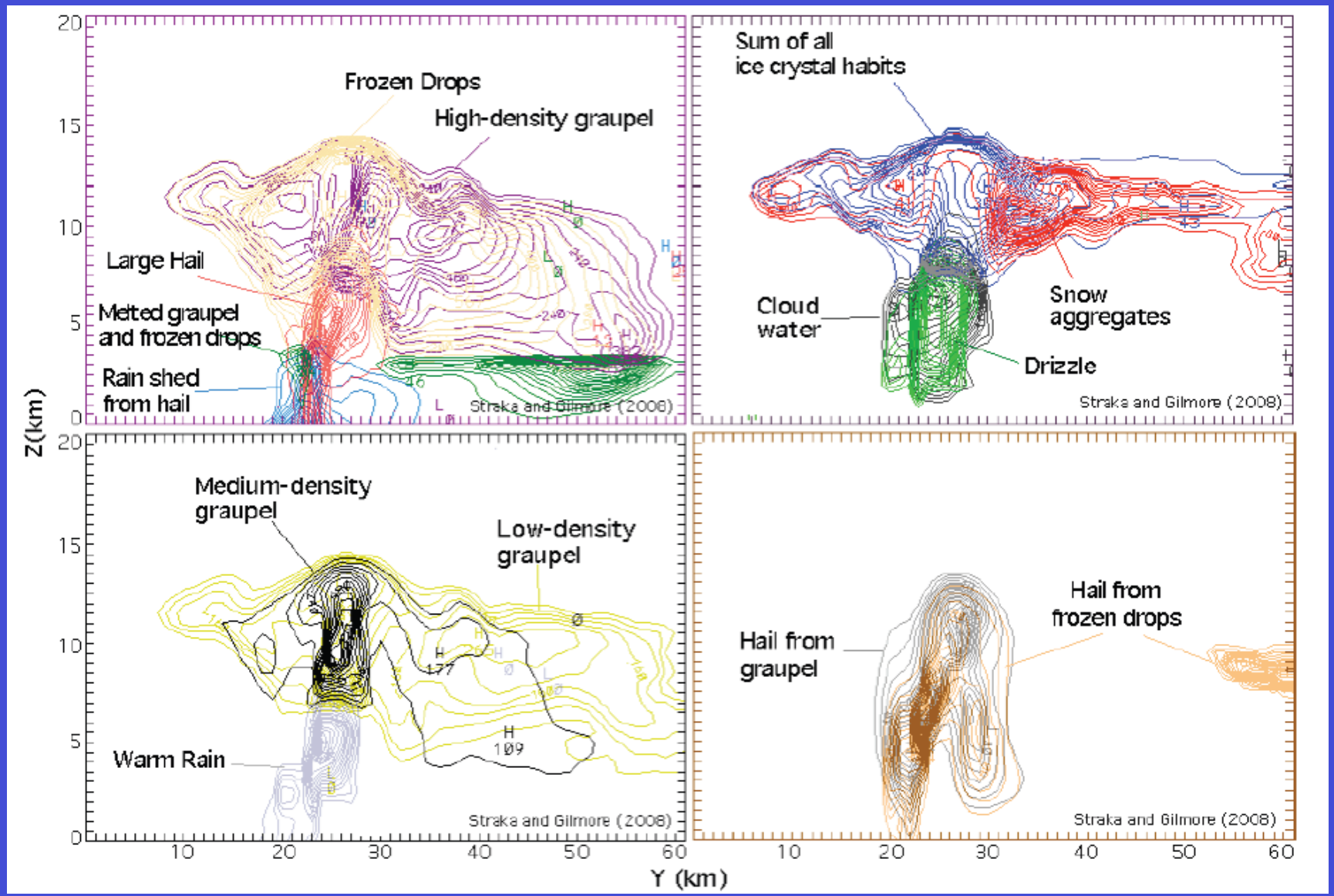
Different ice species have very different characteristics!



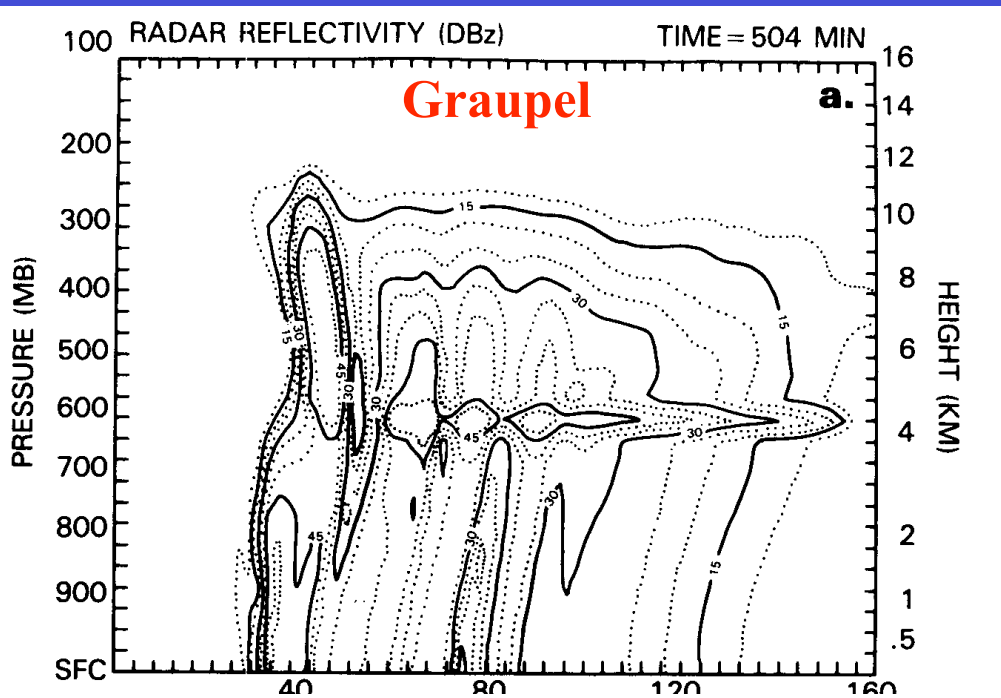
Straka and Mansell (2005)

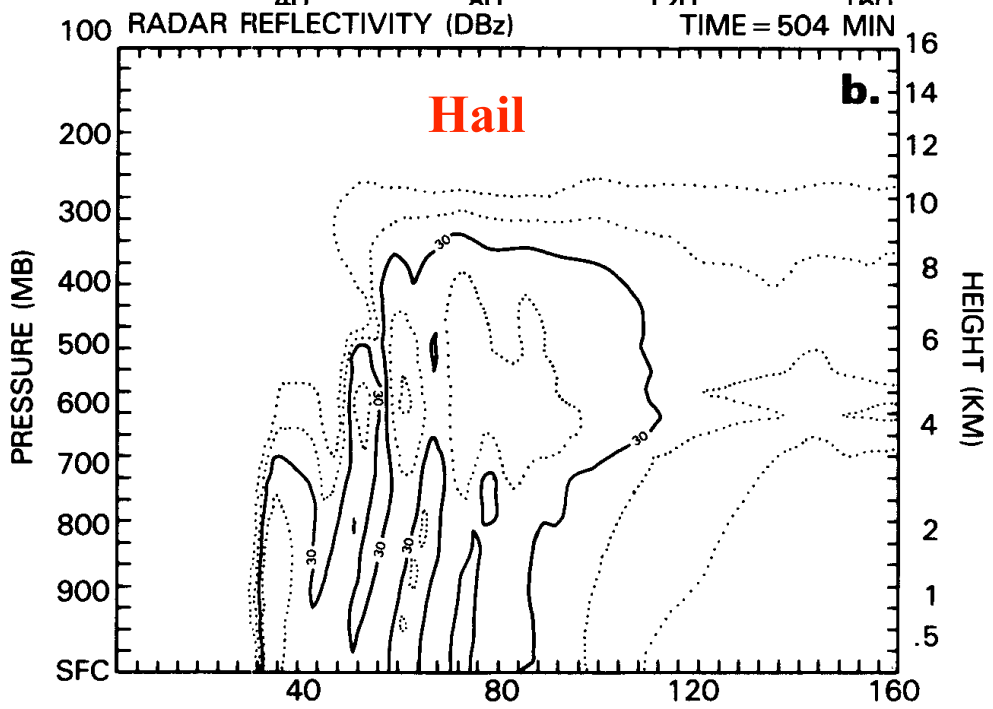
In general, there has been a trend toward more complexity in microphysics parameterizations, i.e., including more species and more moments.

23-class scheme (6 liquid, 17 ice) – Gilmore and Straka (2007)



How ice is separated into different species (cloud ice, snow, graupel, hail, etc.) has a large impact on simulations of organized deep convection.



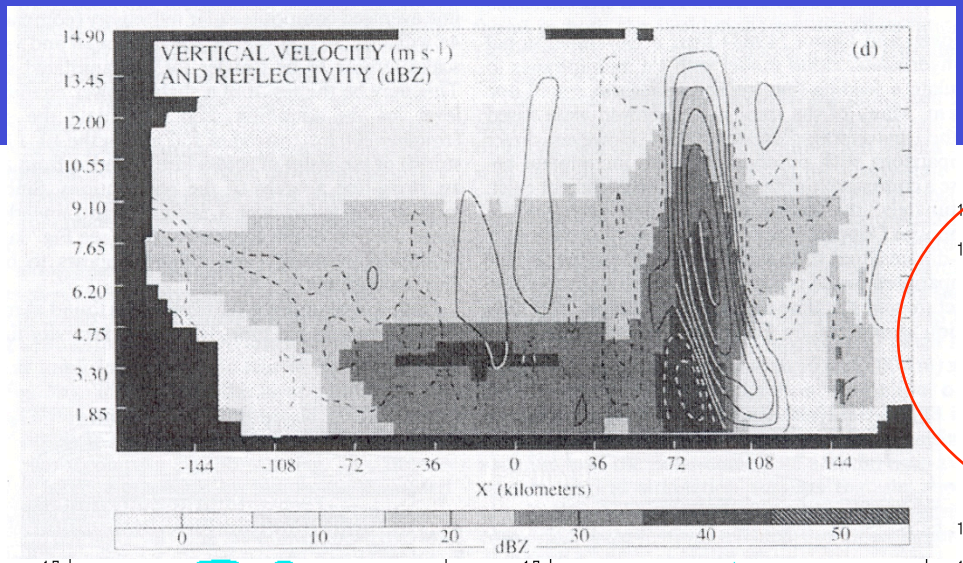


2D tropical squall line simulations

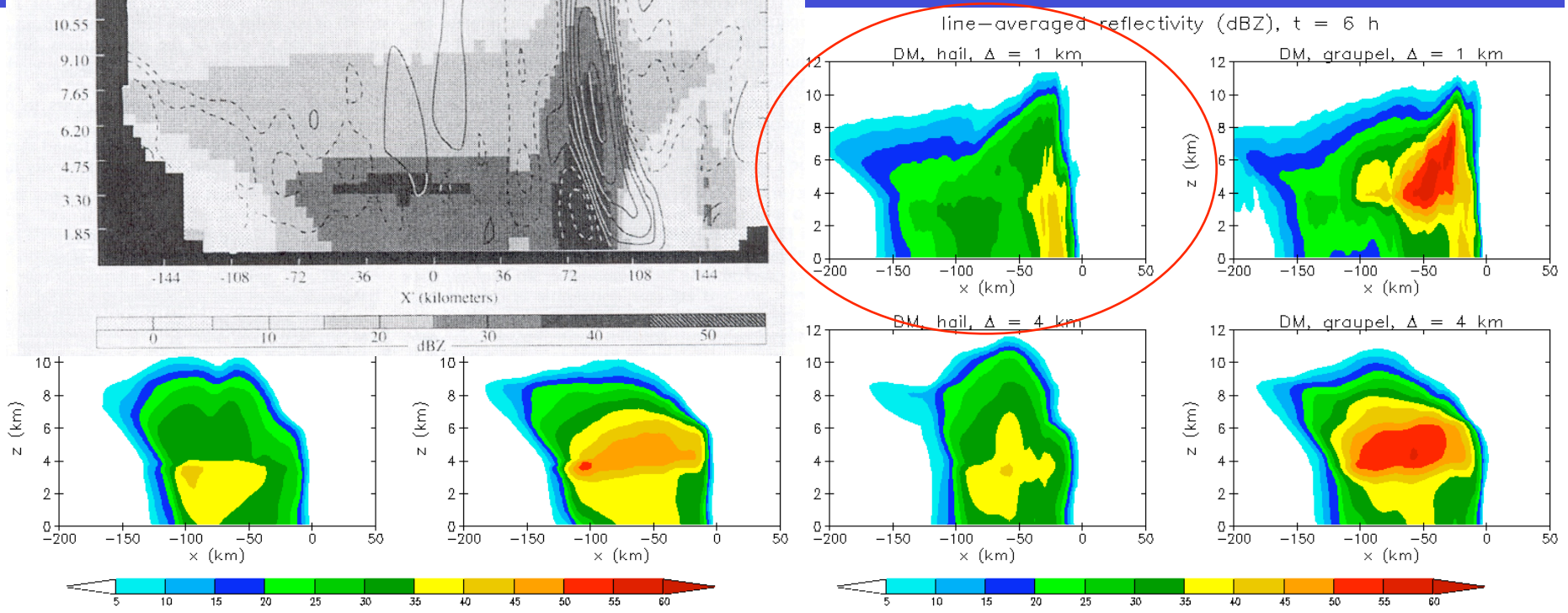
McCumber et al. 1991

3D mid-latitude squall line simulations

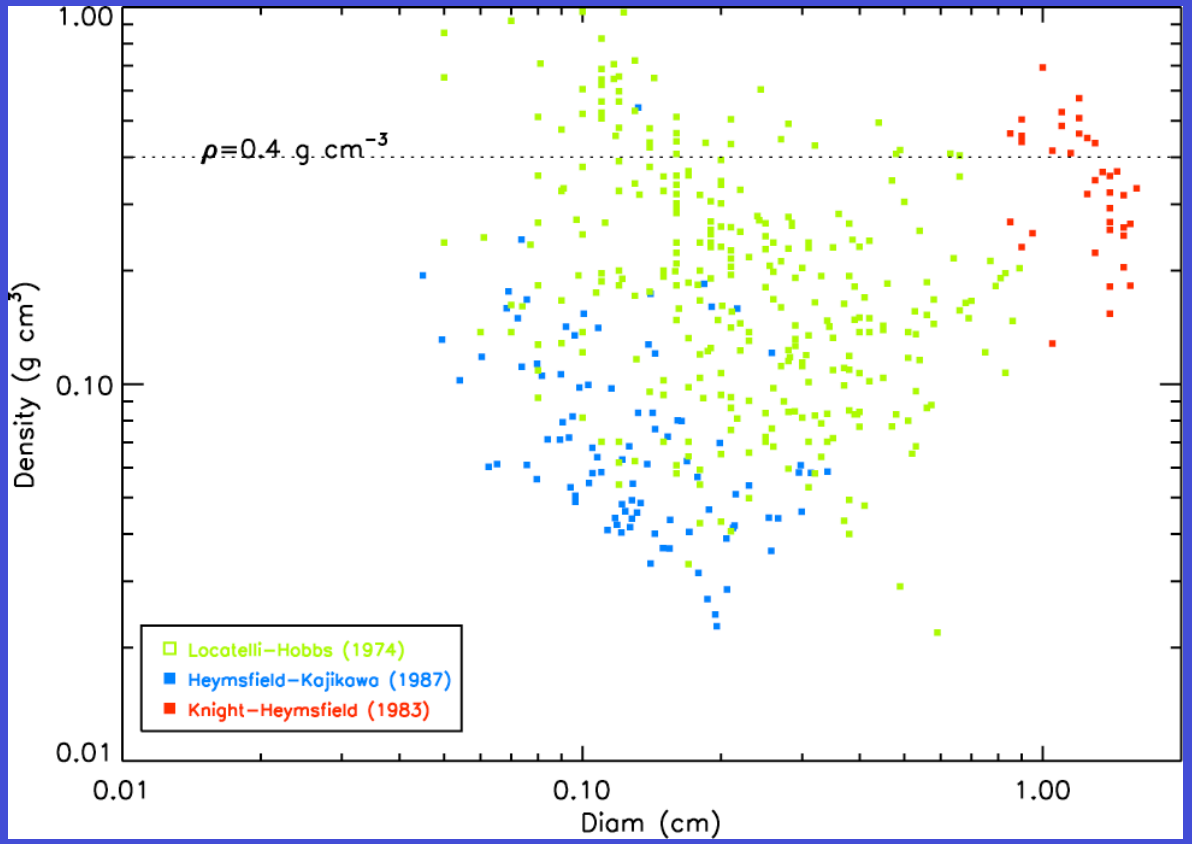
from Biggerstaff and Houze (1993)



Two-moment



Observations suggest large variability of graupel and hail densities. It seems likely that "optimal" parameterization settings in terms of number and type of ice species (e.g., hail vs. high-density graupel vs. low-density graupel) are case dependent.



From A. Heymsfield

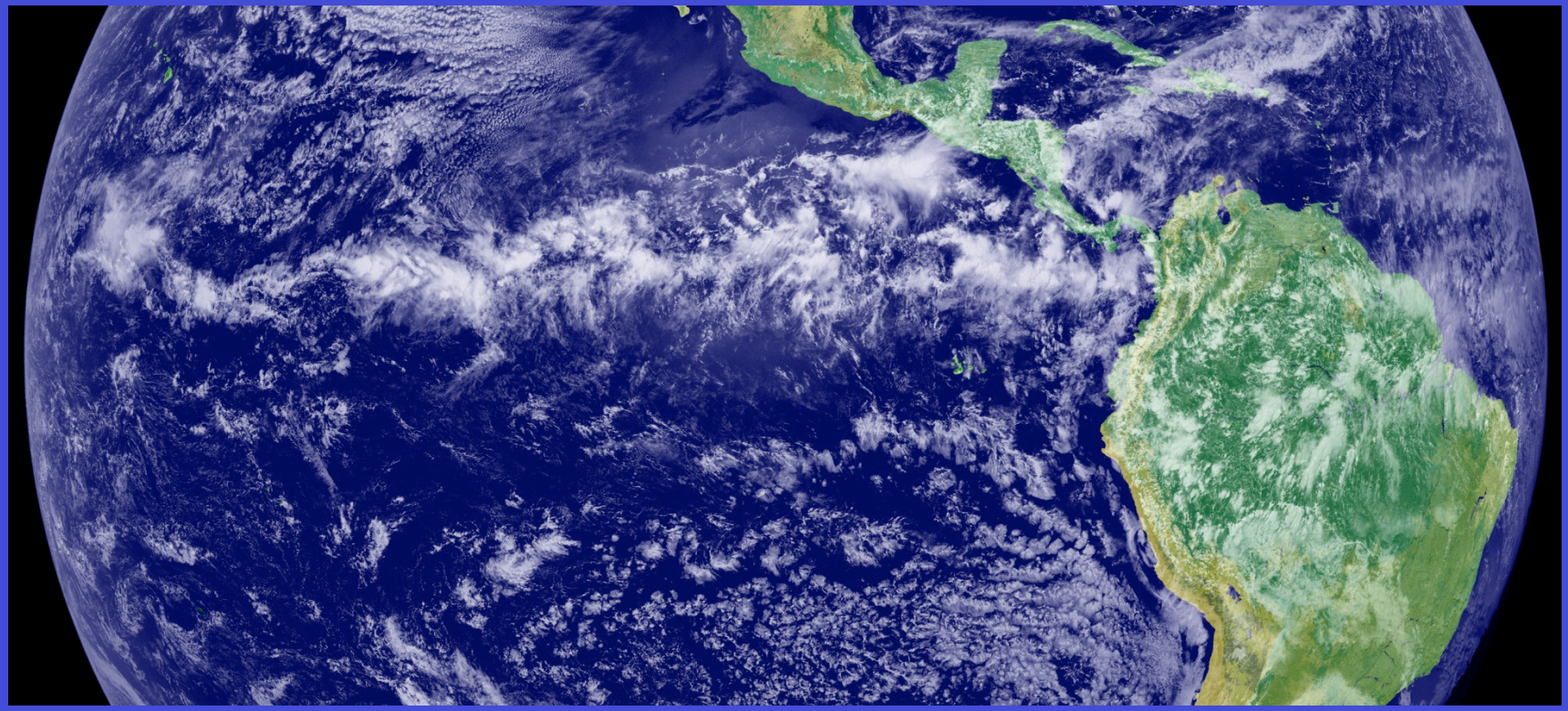
- Can we develop new approaches that move away from a priori categorization of ice into different species, thereby reducing number of variables and necessity of case-by-case tuning? – see my afternoon talk…

Summary

- Microphysics parameterization is key in models, especially high resolution models where deep convection is directly coupled to microphysics.

- Microphysics parameterizations vary widely in complexity, with a general trend toward use of more detailed multi-moment and multi-species schemes.

- The number and type of species and number of moments of the microphysics scheme has important impact on organized deep convection. Flexibility provided by multimoment schemes appears to be important for squall line simulation.

- "Optimal" ice parameter settings for microphysics schemes appear to vary from case-to-case, suggesting need to develop approaches that improve flexibility.

Thank you!
Questions?