A novel approach for representing ice microphysics in bin and bulk schemes: Application to TWP-ICE deep convection

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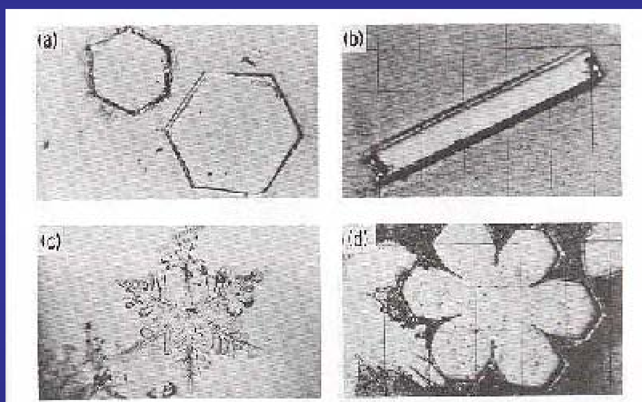
The treatment of ice microphysics has a large impact on model simulations, e.g., precipitation, interactions with dynamics, radiation, etc. However, it is complicated by:

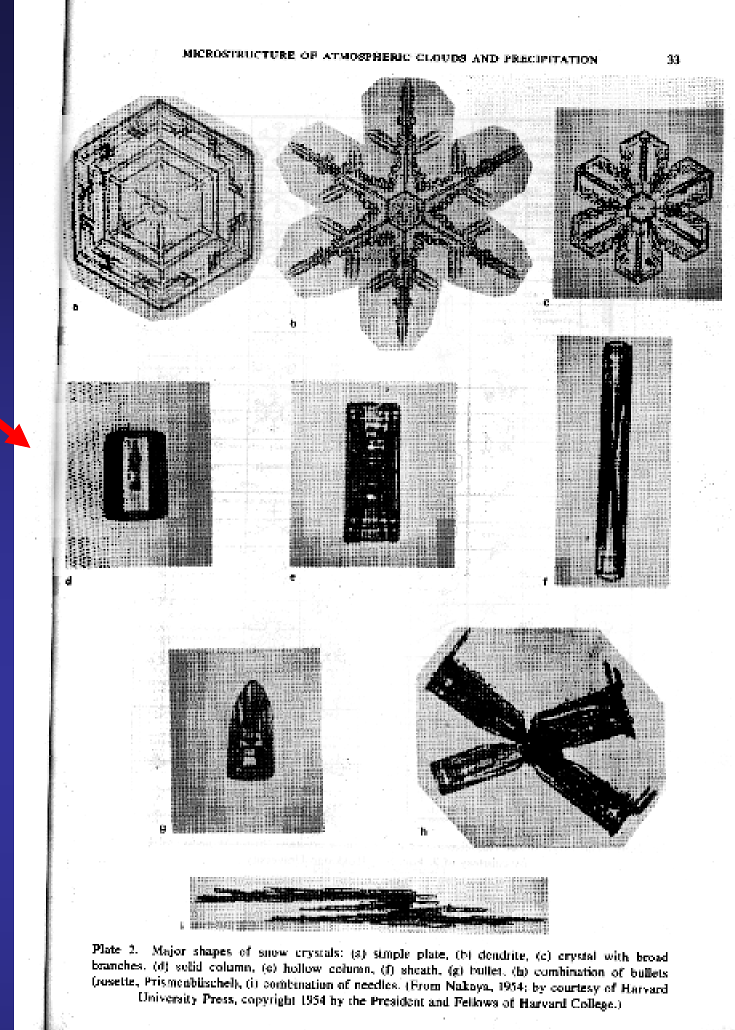
-1) Uncertainty of ice initiation processes

-2) Wide range of ice particle characteristics (e.g., shape, effective density)

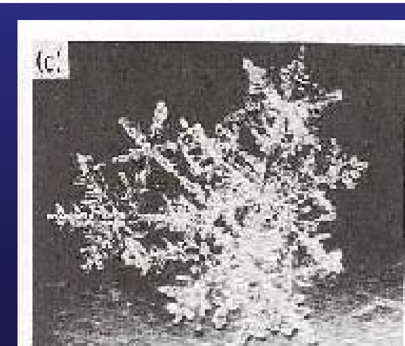
-3) No clear separation of physical processes for small and large crystals

Pristine ice crystals, grown by diffusion of water vapor



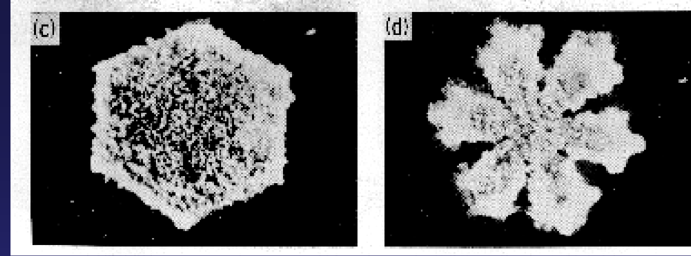


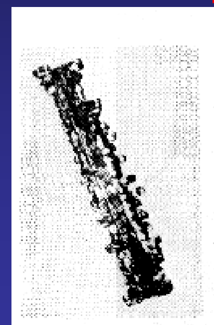
Snowflakes, grown by aggregation

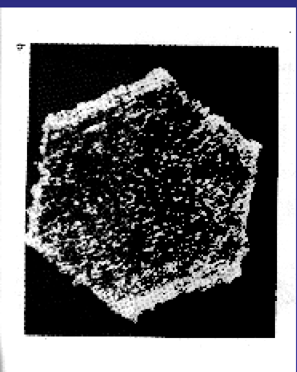


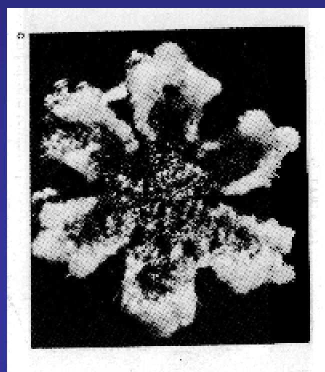
Pruppacher and Klett

Rimed ice crystals (accretion of supercooled cloud water)

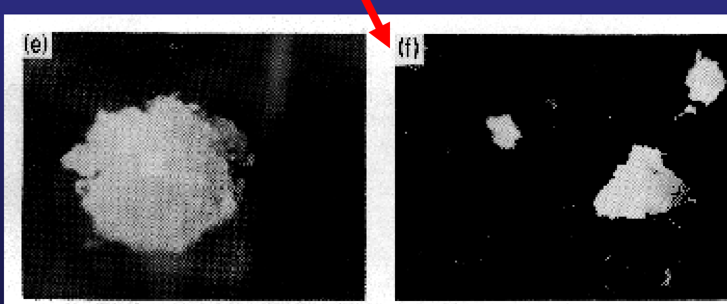


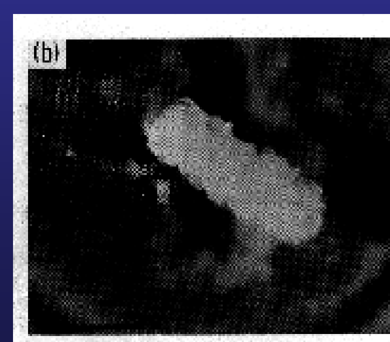






Graupel (heavily rimed ice crystals)





Pruppacher and Klett

Most schemes used today include the logic of “cloud ice-snow-graupel/hail” to represent different size/shape particles.

Such a logic follows approaches proposed 20+ years ago (Rutledge and Hobbs, Lin et al.) that transplanted ideas from warm-rain microphysics into ice physics.

Rutledge and Hobbs, JAS 1984

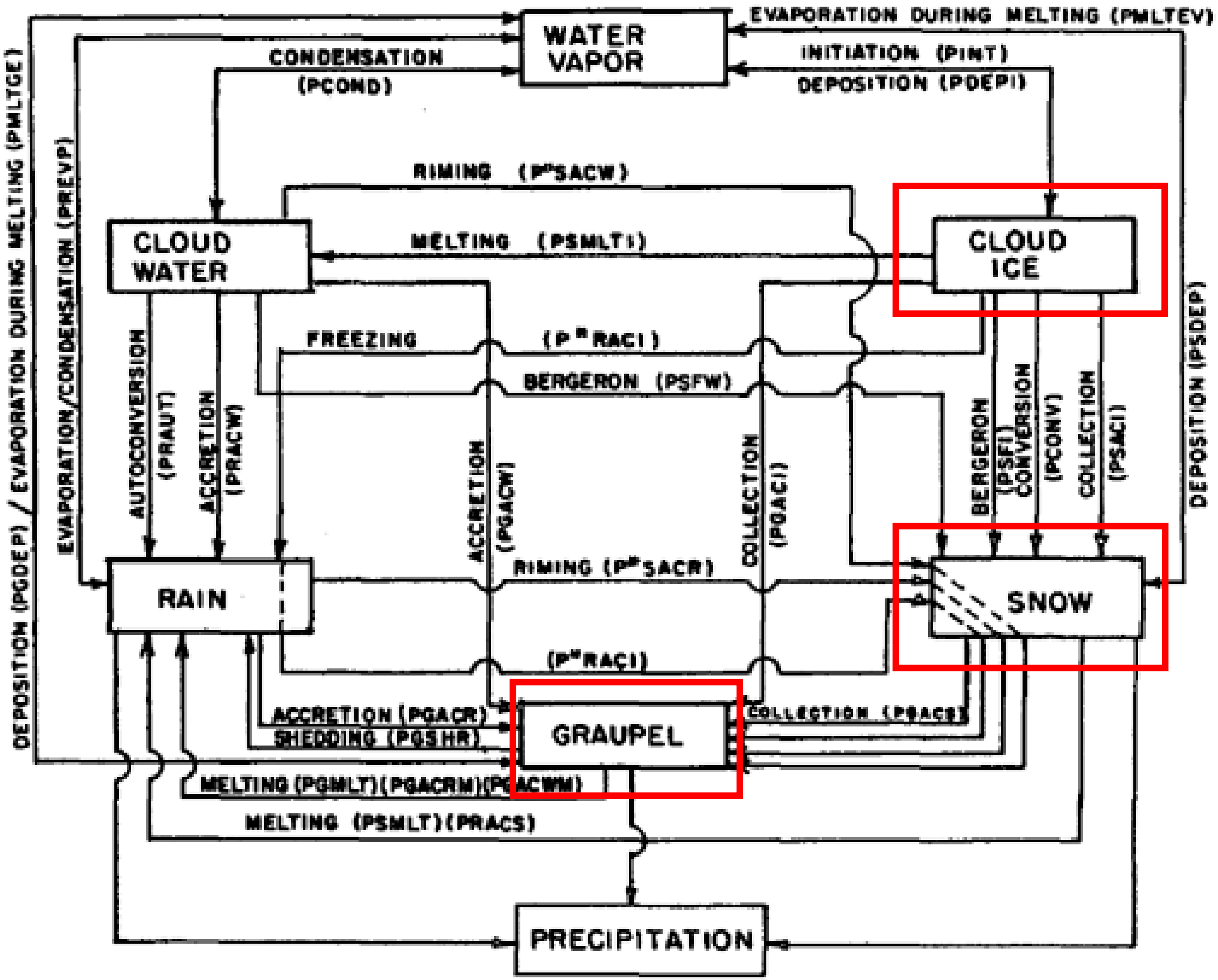


FIG. 1. Schematic depicting the cloud and precipitation processes included in the model for the study of narrow cold-frontal rainbands.

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Does it make sense?

Not really!

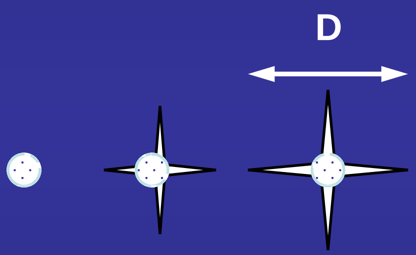
-For warm rain, clear separation does exist between cloud water and drizzle/rain, cloud water grows by diffusion of water vapor, drizzle/rain grows by collision/coalescence. For ice, the boundaries are not obvious and transitions from one category to another take place through a combination of diffusion, aggregation, or riming (accretion of liquid water) growth.

-The ice scheme should produce various types of ice (cloud ice, snow, graupel) just by the physics of particle growth; partitioning ice particles a priori into separate categories introduces unphysical “conversion rates” and involves “threshold behavior” for various parameters (e.g., sedimentation velocity).

Conceptual model of particle evolution during growth (similar to Heymsfield 1982)

Stage 1: Unrimed crystal

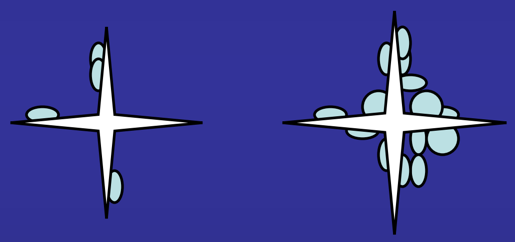
- Particle size D and mass increase by vapor deposition



- Vapor depositional growth

Stage 2: Partially-rimed crystal

- Particle size increases by vapor deposition
- Mass increases by vapor deposition and riming

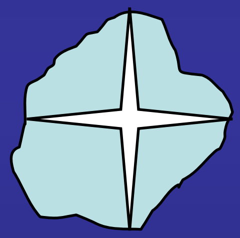


- Riming of crystal interstices and faces

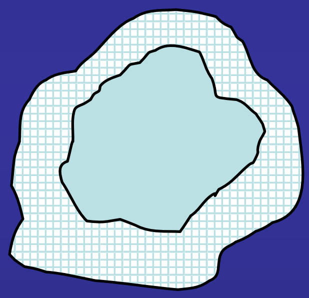
- Vapor depositional growth

Stage 3: Graupel

- Particle size increases by vapor deposition and riming
- Mass increases by vapor deposition and riming



- Complete filling-in of interstices and faces with rime



- Further growth by riming and vapor deposition

Prediction of masses grown by both riming and vapor deposition are needed to explain growth evolution of particle.

A new two-moment three-variable bulk 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}

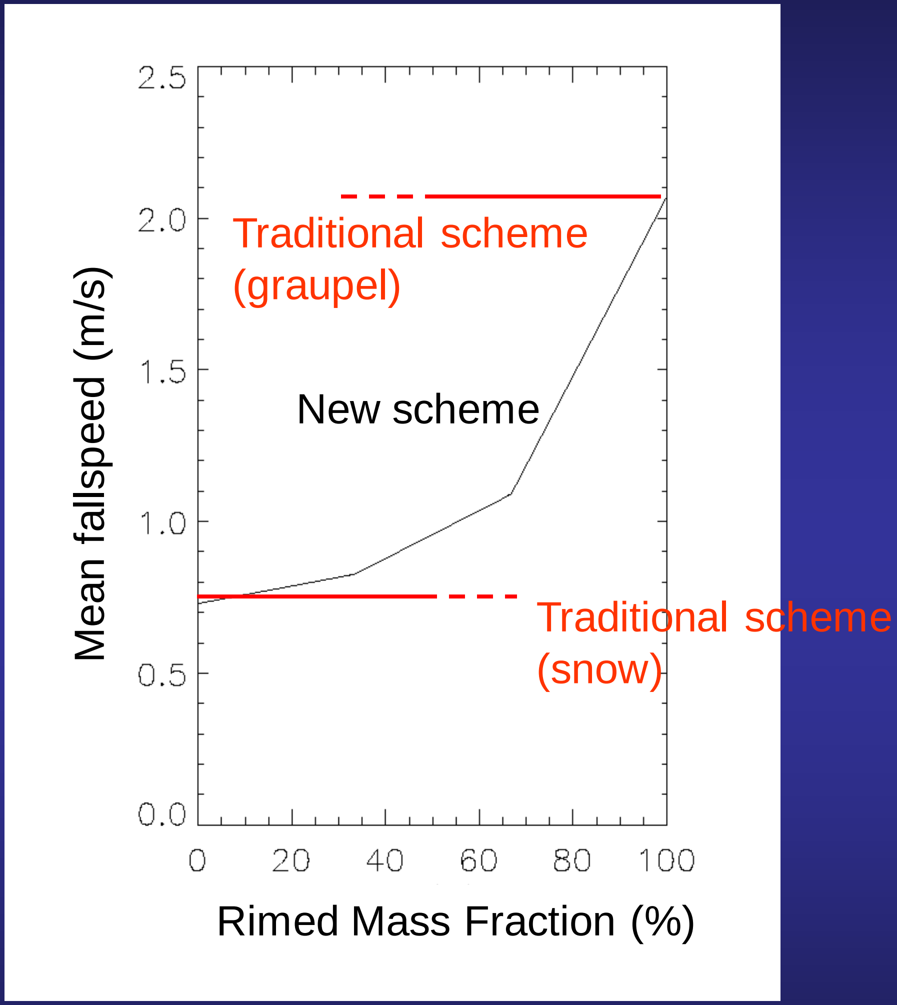
3 prognostic variables instead of 6 or more in the 2-moment traditional approach!

Morrison and Grabowski 2008, *JAS*

- Instead of separate ice categories determining ice characteristics a priori, in the new scheme characteristics are determined by a particle mass-size (m-D) and projected area-size (A-D) relationship that freely evolves during the simulation as a function of the particle size and predicted rimed mass fraction – allows smooth transitions between ice types and avoids thresholds and arbitrary (tuned) conversion parameters!

- This approach potentially also allows for better coupling with observations, since particle mass and projected area are real physical quantities that can be obtained from observations, conversion thresholds in the traditional approach are not.

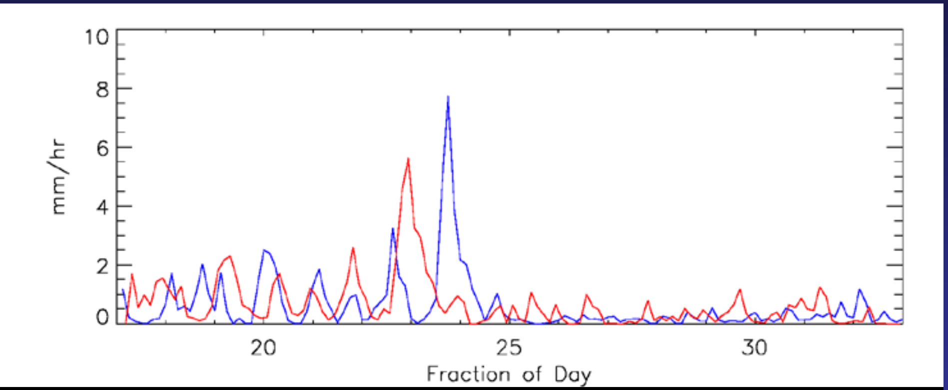
Example – mean particle fallspeed



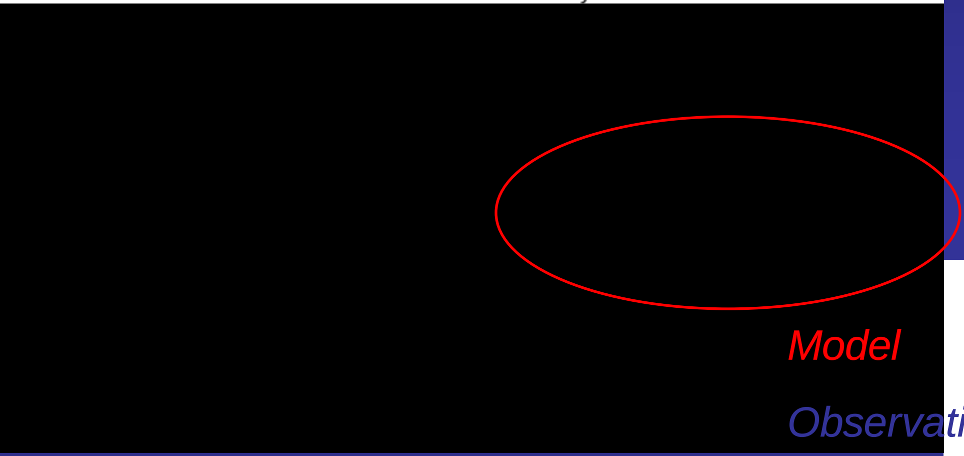
Mean mass-weighted fallspeed as function of rimed mass fraction, for q = 0.2 g/kg, N = 1 L^{-1}.

Application to TWP-ICE

- Same setup as TWP-ICE intercomparison (Fridlind et al.) (Jan. 18-Feb. 3), 10 mb ARM forcing, ocean surface
- 2D EULAG model, Δx = 1 km, 97 vertical level w/ stretched coordinate, periodic lateral boundary, 200 x 25 km domain
- (Very) preliminary results shown here, currently working on more detailed model-obs comparison using lidar-radar simulator (A. Kardas, S. McFarlane)



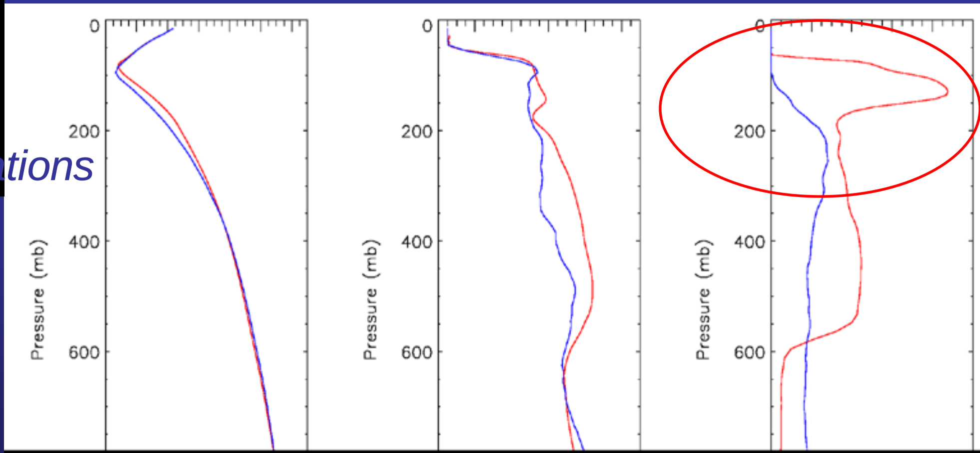
Modeled and observed timeseries of domain-mean surface rain rate and TOA upwelling LW flux.*



Modeled and observed time- and domain-mean temperature, water vapor, and cloud fraction# profiles.*

Model

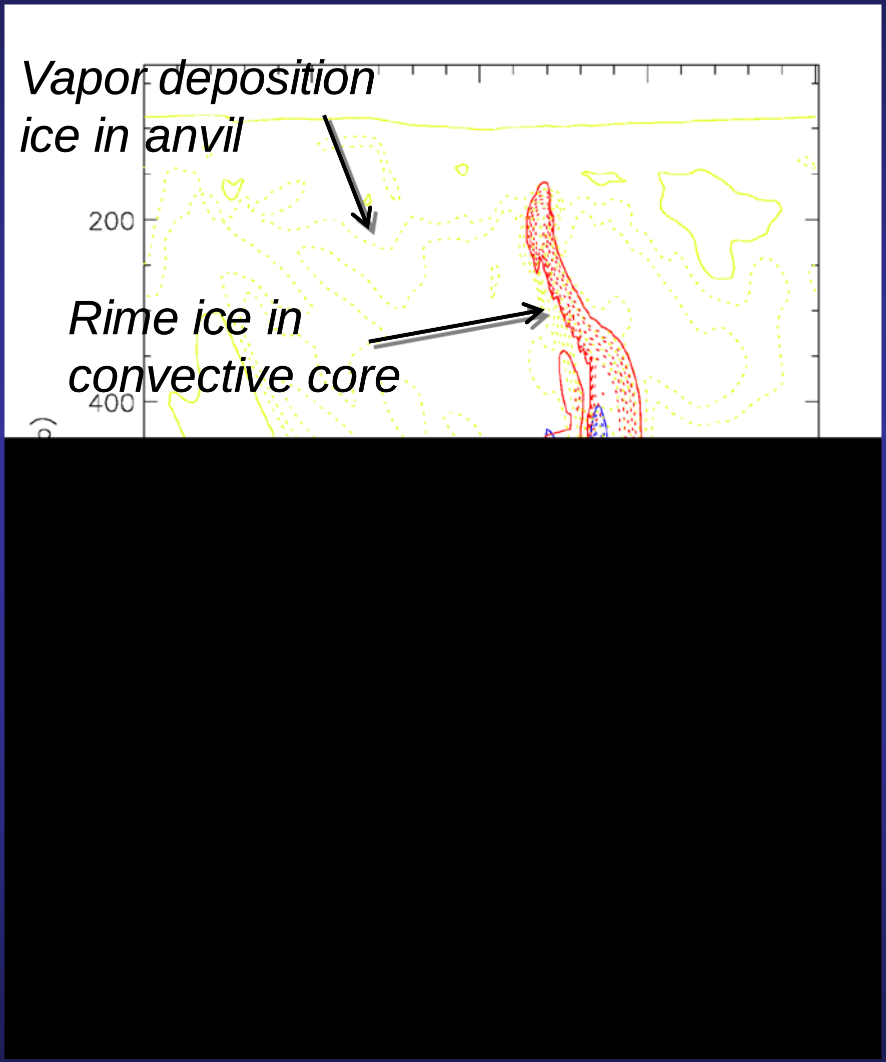
Observations



**From V2 10 mb TWP-ICE forcing files provided by S. Xie*

#Model cloud fraction defined by hydrometeor mix. rat. threshold of 0.001 g kg^{-1}

Example of X-Z snapshot of cloud water (blue), rain (green), vapor deposition ice (yellow), and rime ice (red) mixing ratios* at 15 UTC Jan. 23.

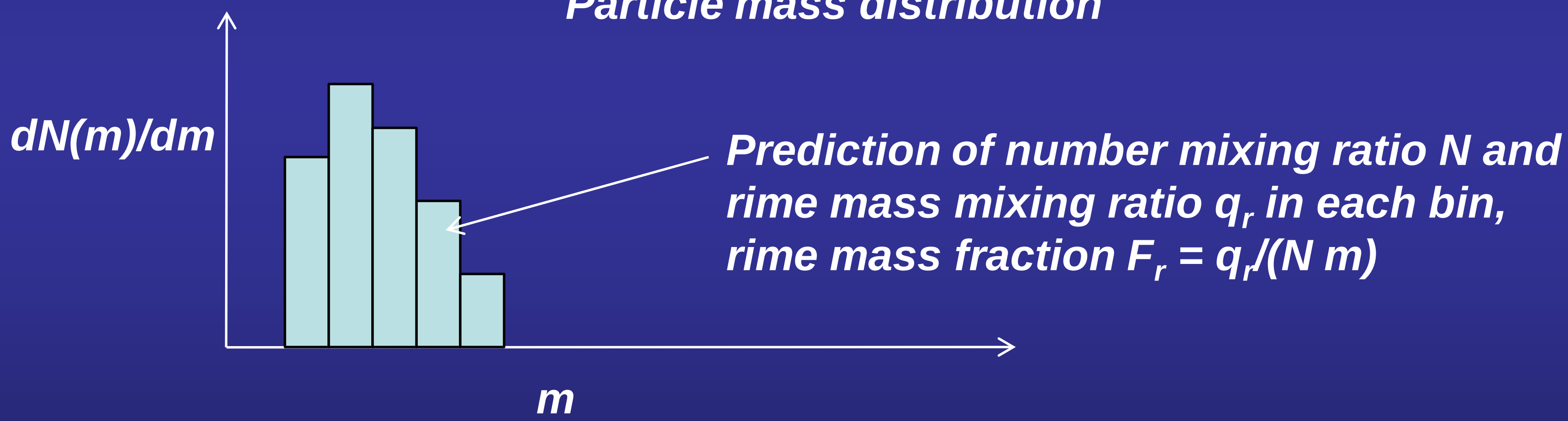


*Contour intervals 0.01, 0.05, 0.1, 0.5, 1, 2, 3, 4, 5 g kg^{-1}.

Extension to bin microphysics model

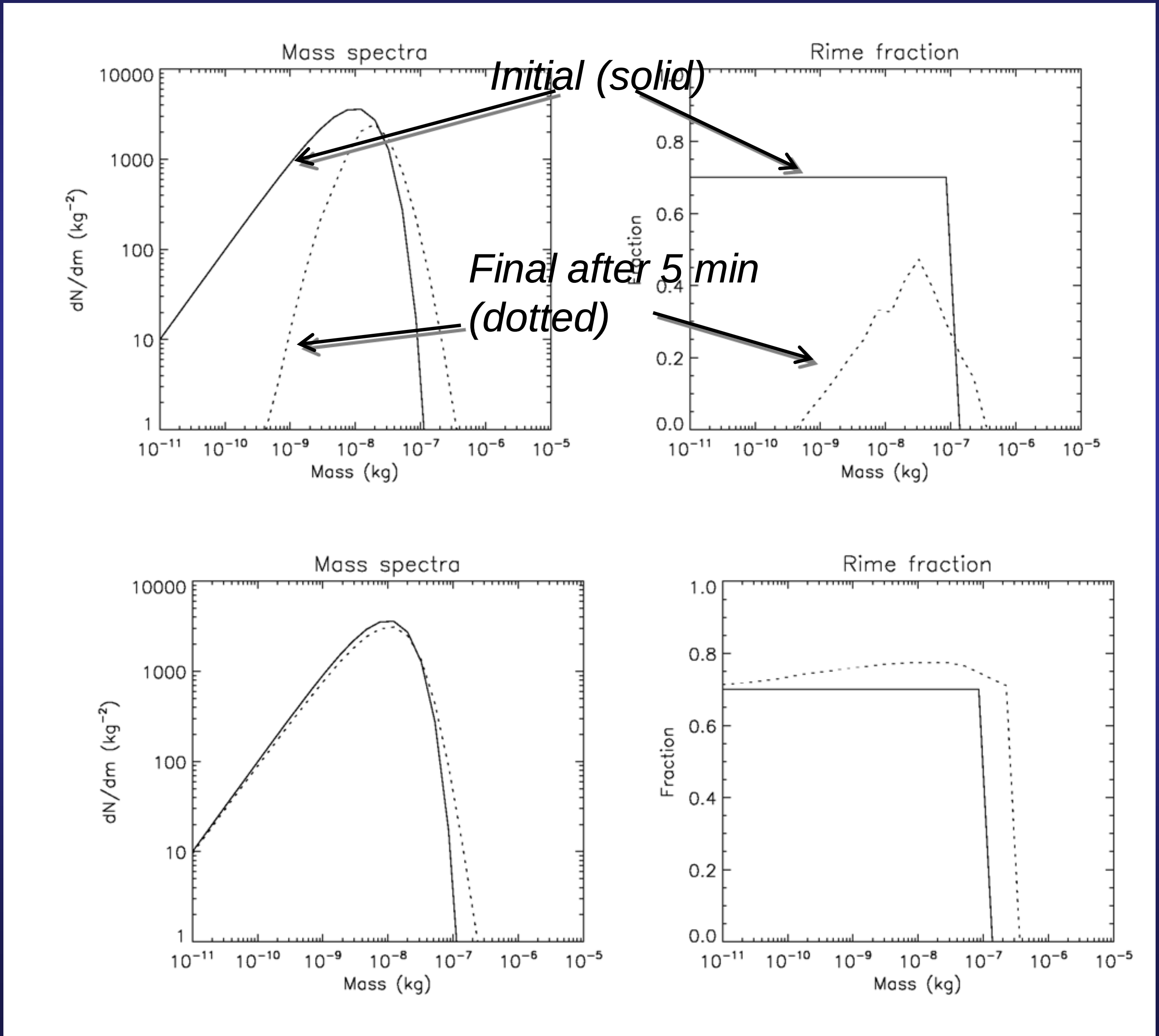
- Development of multi-component bin-resolving microphysics model that predicts number and rime mass mixing ratio in each (mass) bin.

Particle mass distribution



- Mass-conserving flux-based method to calculate transport and growth of q_r in the mass space due to riming.

Mass spectra and rime mass fraction for idealized tests of growth by either vapor diffusion (top) and riming (bottom)



Summary

- A new approach for treating ice microphysics in models has been developed that moves away from the traditional paradigm of separate species for cloud ice-snow-graupel. The new scheme is based on conceptual model of crystal growth does not rely on arbitrary thresholds and conversion rates between ice species.

- Preliminary results for TWP-ICE suggest scheme produces generally reasonable results but there is excessive high cloudiness.

- This approach is extended to new multi-component bin microphysics model that predicts number and rime mass mixing ratio in each mass bin, allowing for diagnosis of rime mass fraction as function of particle mass (size).

- Numerical techniques developed for this scheme can be used to predict spectral evolution of additional model components (e.g., mass mixing ratio of dissolved aerosol).


Thank you