A New Approach to Parameterize Ice-Phase Microphysics by Predicting Multiple Particle Properties

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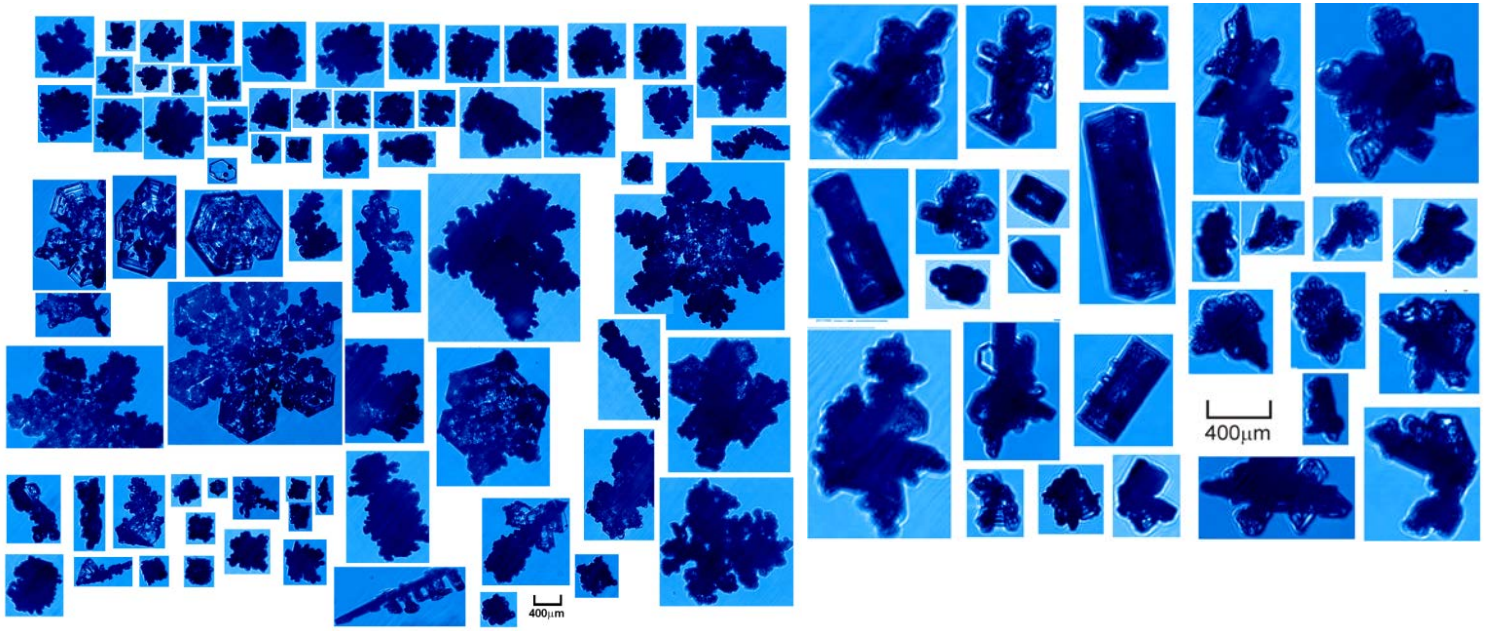
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Microphysics schemes have traditionally represented ice using **pre-defined classes** (*cloud ice, snow, graupel, hail, etc.*) with **fixed properties** (bulk *density, V-D, etc.*).

Example of observed ice particles:



Photos c/o Alexei Korolev (ARMP, EC)

Some conceptual problems:

- there is a continuum of ice particle characteristics in nature

- conversion processes/thresholds are needed between pre-defined ice-phase classes but are often unphysical and/or poorly constrained (*e.g., ice autoconversion*)

- models typically exhibit large sensitivity to parameterization of conversion processes and specification of ice characteristics

A shift (in parameterization of ice phase)**:**

Representation using pre-defined *classes*
to
Prediction of particle *properties*

- Predicted rime mass fraction – Morrison and Grabowski (2008)
- Predicted graupel density – Mansell et al. (2010); Milbrandt and Morrison (2013)
- Predicted crystal axis ratio (habit) – Harrington et al. (2013); Sulia et al. (2013)

What if we fully exploit the new paradigm of predicting ice particle properties?

The new approach: No pre-defined ice classes; instead *predict multiple particle properties* (mean density, size, rime mass fraction, etc.) to evolve ice-phase characteristics

– Predicted Particle Properties (P3)

Some conceptual advantages:

- avoids unphysical/poorly constrained thresholds for conversion between pre-defined ice-phase classes
- smooth evolution of ice particle characteristics
- fewer prognostic variables → *fast code!*
- more consistent application of microphysical processes
- particle properties are real physical quantities that can be observed, conversion thresholds are not → *better linkage with observations (see Radar Science breakout session Wed)*

Our initial development: P3 with a single ice category (P3-1C)

- The goal: A *flexible* and *efficient* scheme for application in high-resolution cloud, NWP and climate models

- Prognostic variables: q_c, q_r, N_r, q_i*, N_i, q_{rim}, B_{rim}

- The four prognostic ice variables provide information on all modes of growth (deposition, aggregation, riming)

- Allows four degrees of freedom for predicting evolution of the particle properties

$$*q_i = q_{dep} + q_{rim}$$

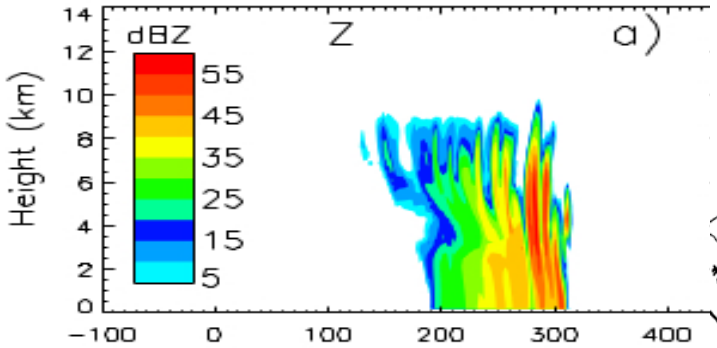
q_i, q_{rim}, B_{rim}, N_i are used to evolve all relevant ice particle properties and size distribution parameters.

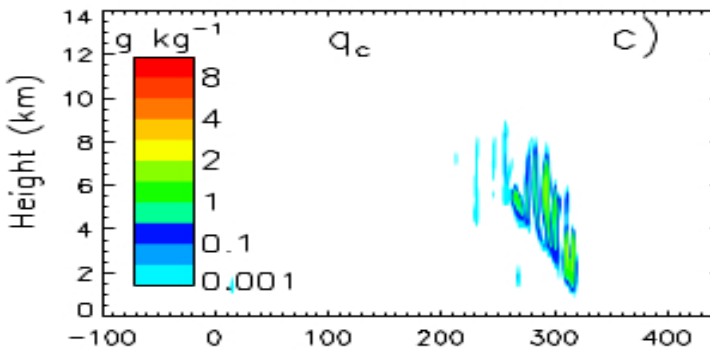
→ follows from a conceptual model of the changes in mass, projected area, and size during ice particle growth via deposition, aggregation, and riming

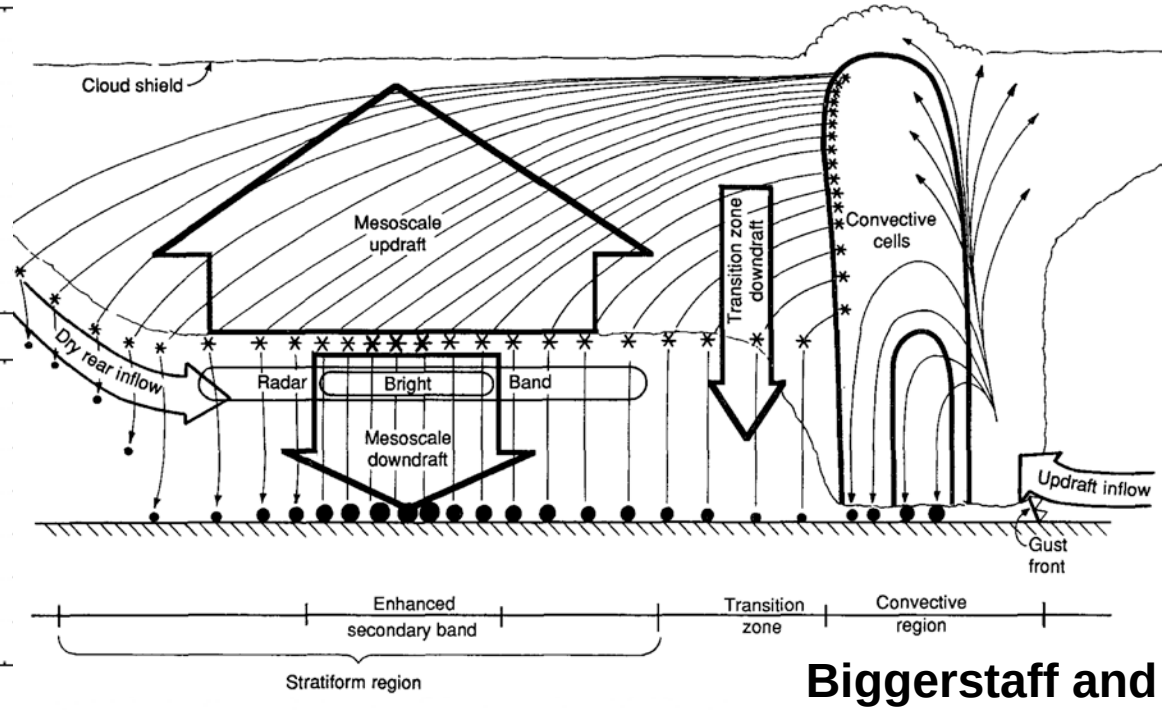
Skipping lots of details…

WRF 2D idealized squall line

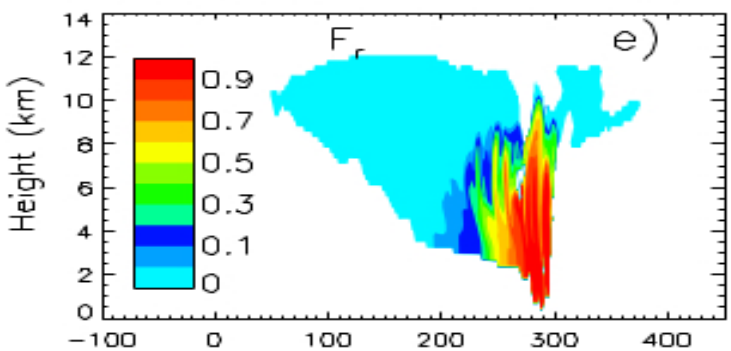
- WRFv3.4.1
- Dx = 1 km, 80 vertical levels, 500 x 20 km domain
- Weisman-Klemp initial sounding
- Convection initiated from a thermal
- No radiation or surface fluxes
- Moderate low-level environmental shear (12 m/s difference in 0 to 2.5 km horizontal wind)

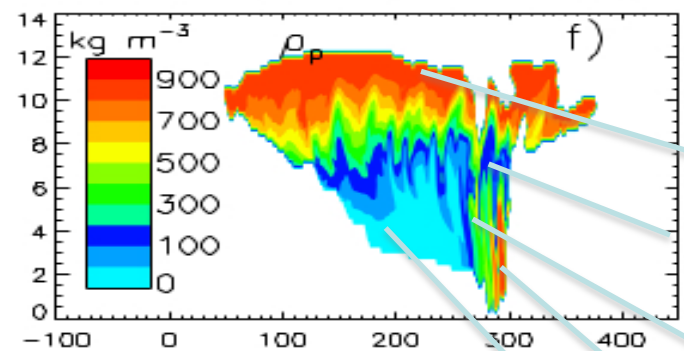


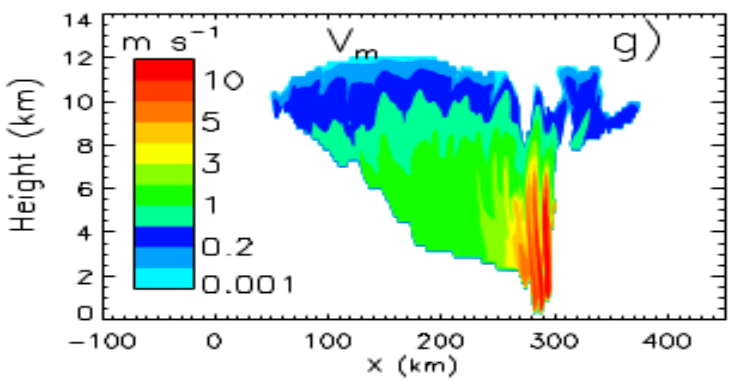


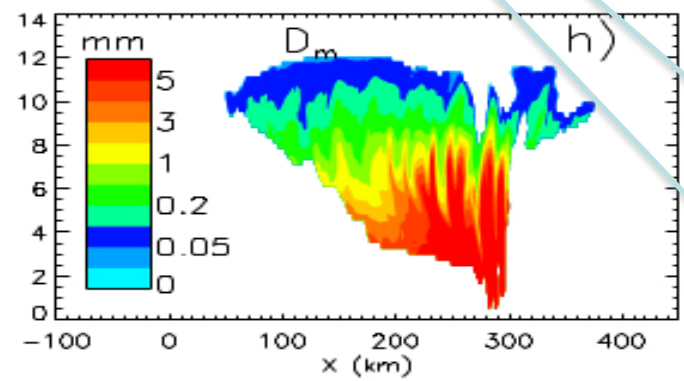


Biggerstaff and Houze (1991)









Small dense ice

Low-density graupel

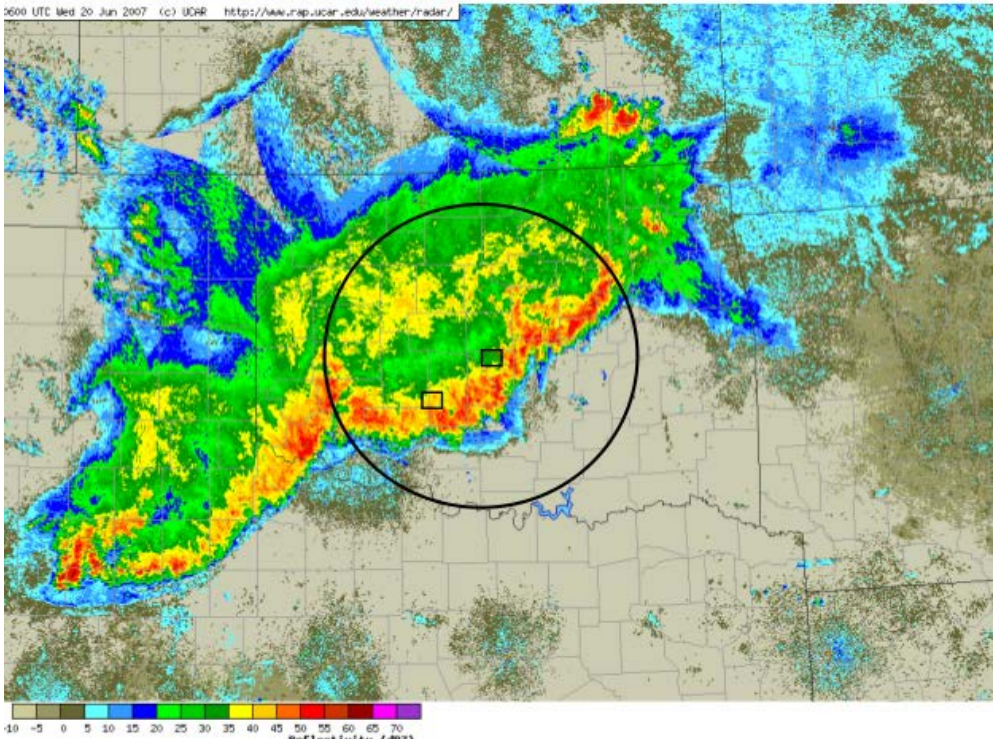
Medium-density graupel

Hail

Large unrimed ice (aggregates)

3D squall line case:
June 20, 2007 central Oklahoma

- WRFv3.4.1, Δx = 1km, Δz ~ 250-300 m, 112 x 612 x 24 km domain, initial sounding from observations
- no radiation, surface fluxes
- convection initiated by u-convergence (squall line)



Composite reflectivity

600 UTC
20 June, 2007

WRF microphysics schemes tested:

P3-SINGLE CATEGORY (P3-1C)

MILBRANDT-YAU* (MY2)

MORRISON-HAIL (M-HAIL)

MORRISON-GRAUPEL (M-GRPL)

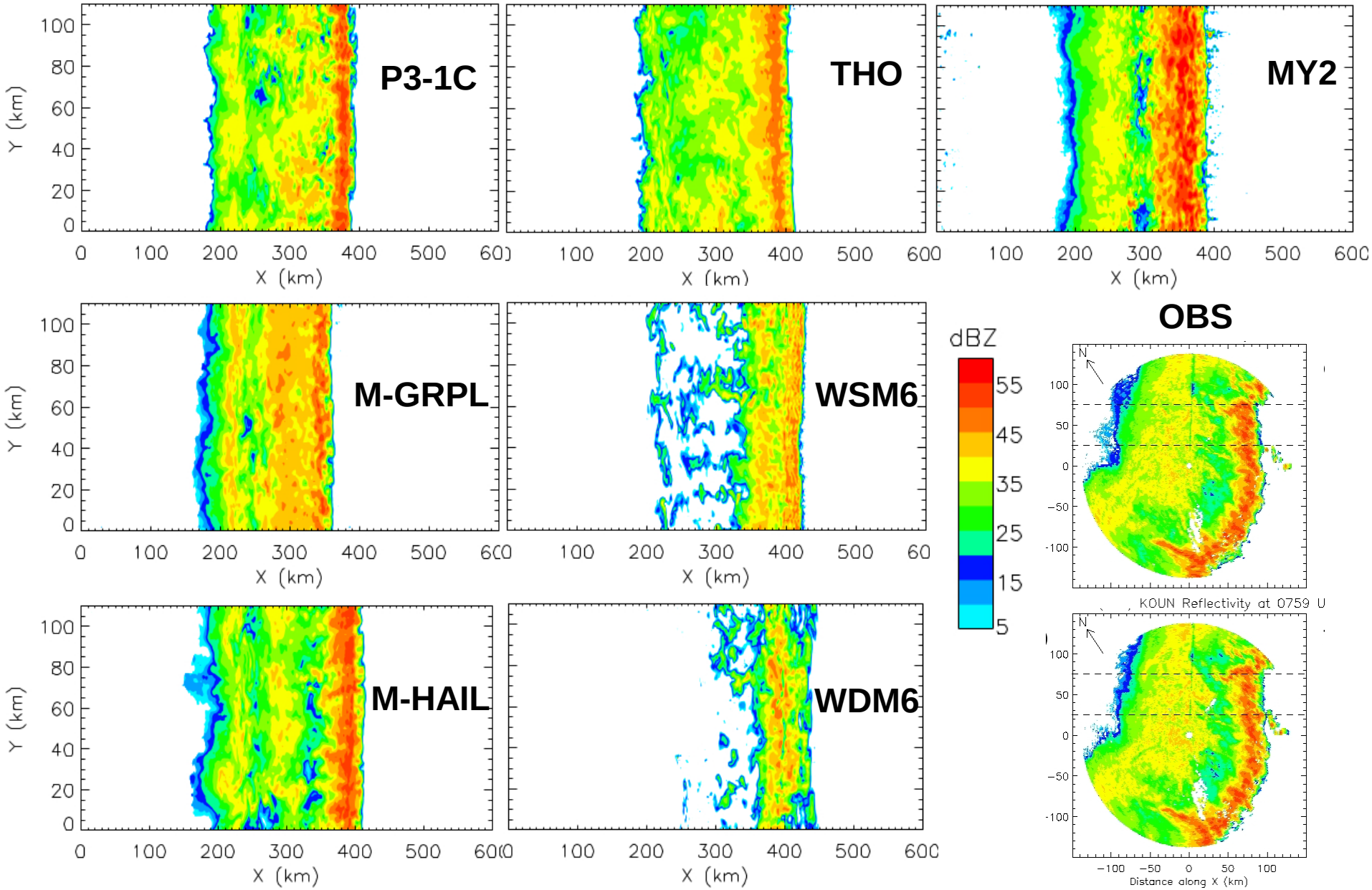
THOMPSON (THO)

WRF SINGLE-MOMENT (WSM6)

WRF DOUBLE-MOMENT (WDM6)

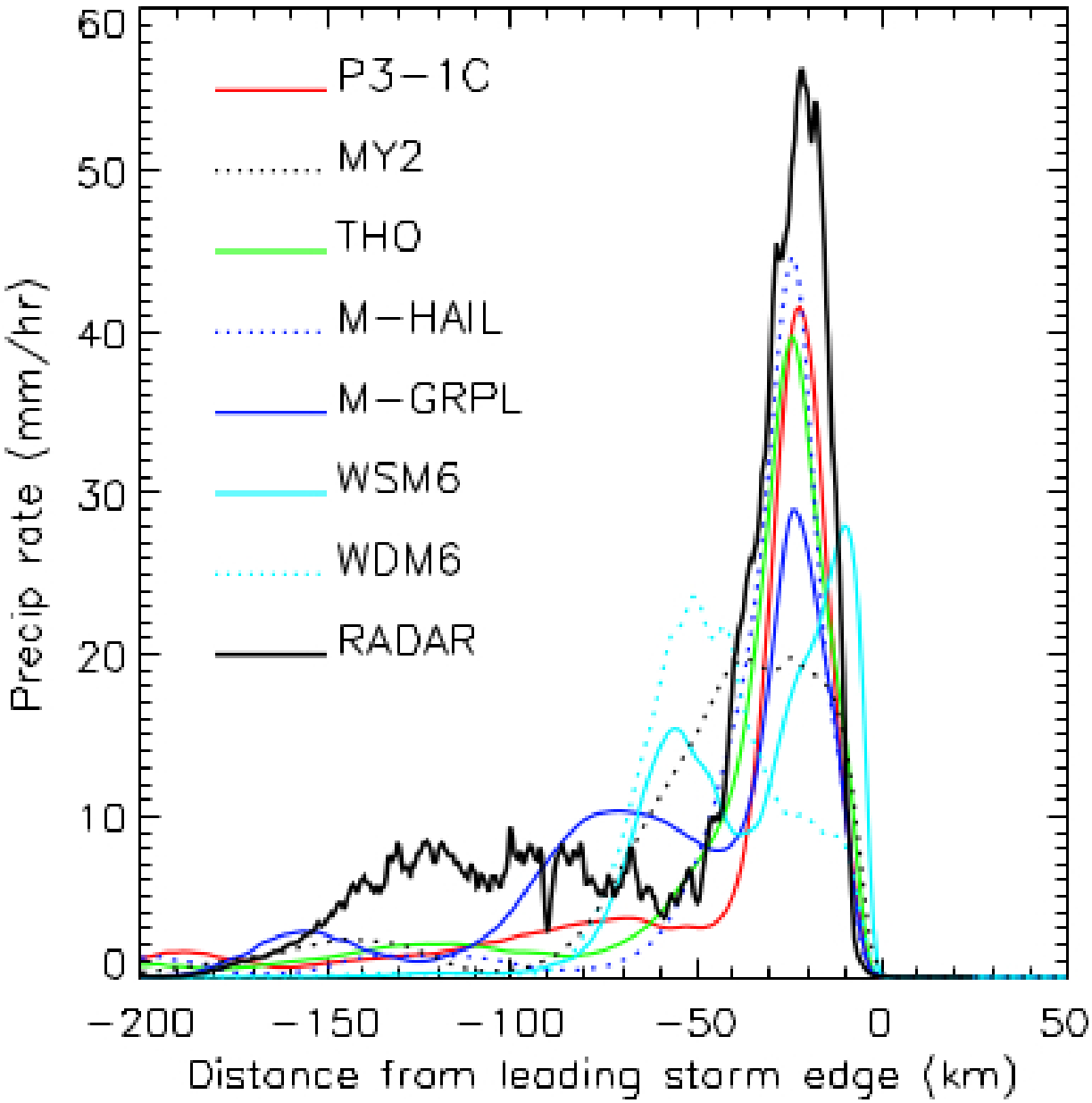
* tuned 13 variable version (“MY2b”)

WRF Results: Reflectivity at height ~ 1 km, t = 6 h



Source (obs): Sarah Tessendorf (NCAR)

WRF results: Line-average surface* precipitation



Time-averaged from 6-7 h

*Radar-retrieval is for height of 1 km

Timing tests

scheme	run time per Δt* (sec)	# of prognostic variables
WSM6	0.457	5
P3-1C	0.486	7
THO	0.523	7
WDM6	0.535	8
M-HAIL	0.558	9
MY2	0.749	13

*Total time step run time, averaged from 4-7 hours simulation time.

An extension: predict multiple ice categories that each have multiple predicted (rather than fixed) properties

In contrast to traditional schemes, *categories are not differentiated by pre-defined type but instead how ice particles are initiated.* Categories can evolve to *any* ice type depending upon the growth history and conditions.

- allows more than one type of ice at the same time and location (but also more expensive due to additional prognostic variables)

Future work

- Testing of P3-1C for other cases (winter orographic precipitation, supercell, etc.) is currently underway. More extensive tests in a quasi-realtime setting are needed (e.g., NOAA HWT).

- Development of P3-Multi Category

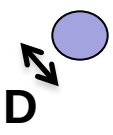
- Adding more predicted properties: liquid fraction, crystal axis ratio (habit), 3-moment (spectral dispersion)

Conceptual model of particle growth following Heymsfield (1982) with modifications:

Rime density ρ_r determines when complete "in-filling" occurs, and the change of D with m with further growth

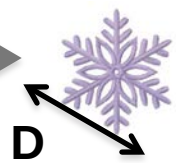
COMPLETE "IN-FILLING" WITH RIME AND FURTHER GROWTH

ICE INITIATION



$F_r = 0$
qi increase
Ni increase

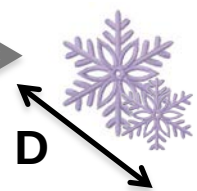
VAPOR GROWTH



mass increase
D increase

$F_r = 0$
qi increase
Ni constant

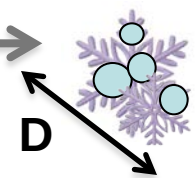
AGGREGATION



mass constant
D increase

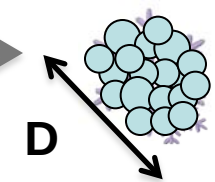
$F_r = 0$
qi constant
Ni decrease

RIME COLLECTION IN CRYSTAL INTERSTICES



mass increase
D constant

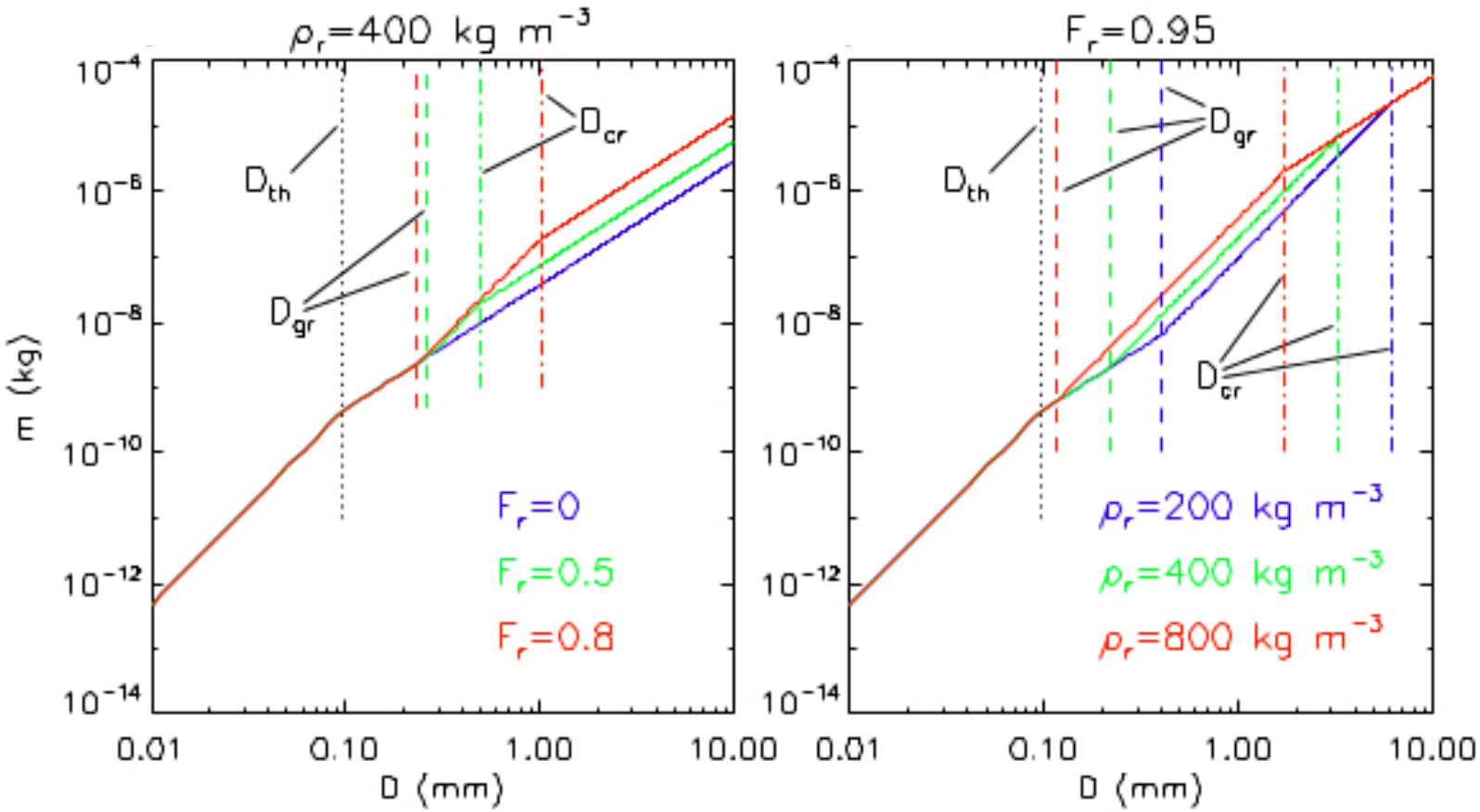
F_r increase
qi increase
Ni constant



mass increase
D increase

F_r increase
qi increase
Ni constant

Some important assumptions:

1) F_r does not depend on particle size
2) ρ_r does not depend on particle size
3) small ice particles are solid spherical ice
4) graupel/hail particles are spherical with a density less than or equal to solid ice
5) the mass-size (m-D) and projected-area size (A-D) relationships for unrimed ice are empirical
6) the A-D relationship for “partially-rimed” crystals is a linear-weighted average of the values for graupel/hail and unrimed ice for a given D

The conceptual model of particle growth, together with these assumptions, uniquely leads to a derivation of m-D, A-D, and size distribution parameters as a function of q_i, N_i, F_r, and ρ_r.