A New Bulk Microphysical Parameterization in WRF (& MM5)

and what's so bad with the old scheme anyway?

Techniques to force a single-moment bulk scheme to act more like a double-moment (or higher-order) scheme

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Goals / motivation

Develop a physically-based (and efficient) bulk microphysical parameterization that:

- improves quantitative precipitation forecasts (when compared to similar, existing schemes)
- improves forecasts of water phase everywhere: aloft = aircraft icing; surface = FZDZ/SN
- incorporates recent microphysical observations (AIRS/IMPROVE/SLDRP/… field projects)
- is sufficiently optimized/fast for real-time modeling needs (WRF-Rapid Refresh)
- uses clean, well-documented code that can be modified rapidly to increase complexity or perform sensitivity studies

Outline

Properties/physics of the water species

- cloud water, rain, cloud ice, snow, and graupel
- terminal velocity
- hydrometeor collection

Physical processes & code improvements

Tests in 2 dimensional idealized cases

Tests in 3 dimensional case studies

- comparisons to aircraft data for icing events
- convective (squall line) case

Future work

Microphysics species' characteristics

Cloud water

gamma distribution w/ shape factor dependent on droplet concentration

does not sediment

"autoconverts" to rain using Berry & Reinhardt with dependence on droplet concentration

Cloud ice

gamma distribution

"pristine" ice (D < 125 microns)

initiation T-dependent (Cooper)

prognosed N_i

slowly sediments at ~10-30 cm/s

Rain

gamma distribution

variable equiv y-intercept:

- 2×10^9 m^{-4} (drizzle)
- 8×10^6 (melted snow)

accurate fallspeed relation

Snow

sum of two gamma distributions (Field et al, 2005)

size distrib depends on ice content and temperature

non-spherical geometry ($m = aD^2$)

variable snow density ($1/D$)

Graupel

gamma distribution

variable equiv y-intercept depends on mixing ratio (simulate hail and snow-like graupel):

- 2×10^6 m^{-4} (graupel)
- 1×10^4 (hail)

Ice/snow size spectra (UK-C130 aircraft)

Mid-latitude stratiform cloud around UK

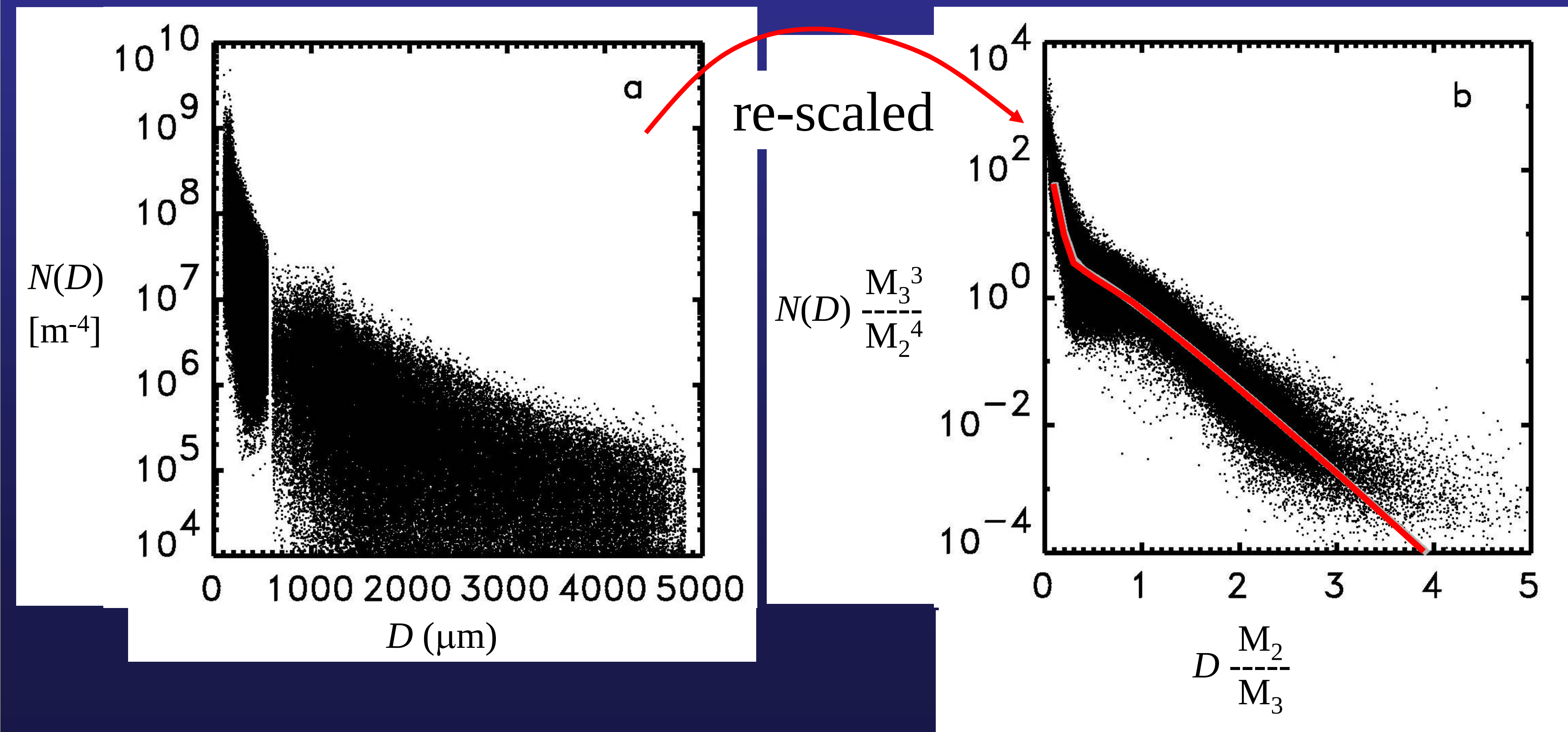
~9000 10 second (~1.1 km) ice particle size distributions

2DC/2DP particle probes (100 μm to 6 mm)

a moment, M_x, is defined as $\int D^x N(D)\, dD$

Sum of exponential + gamma distributions (Field et al. 2005):

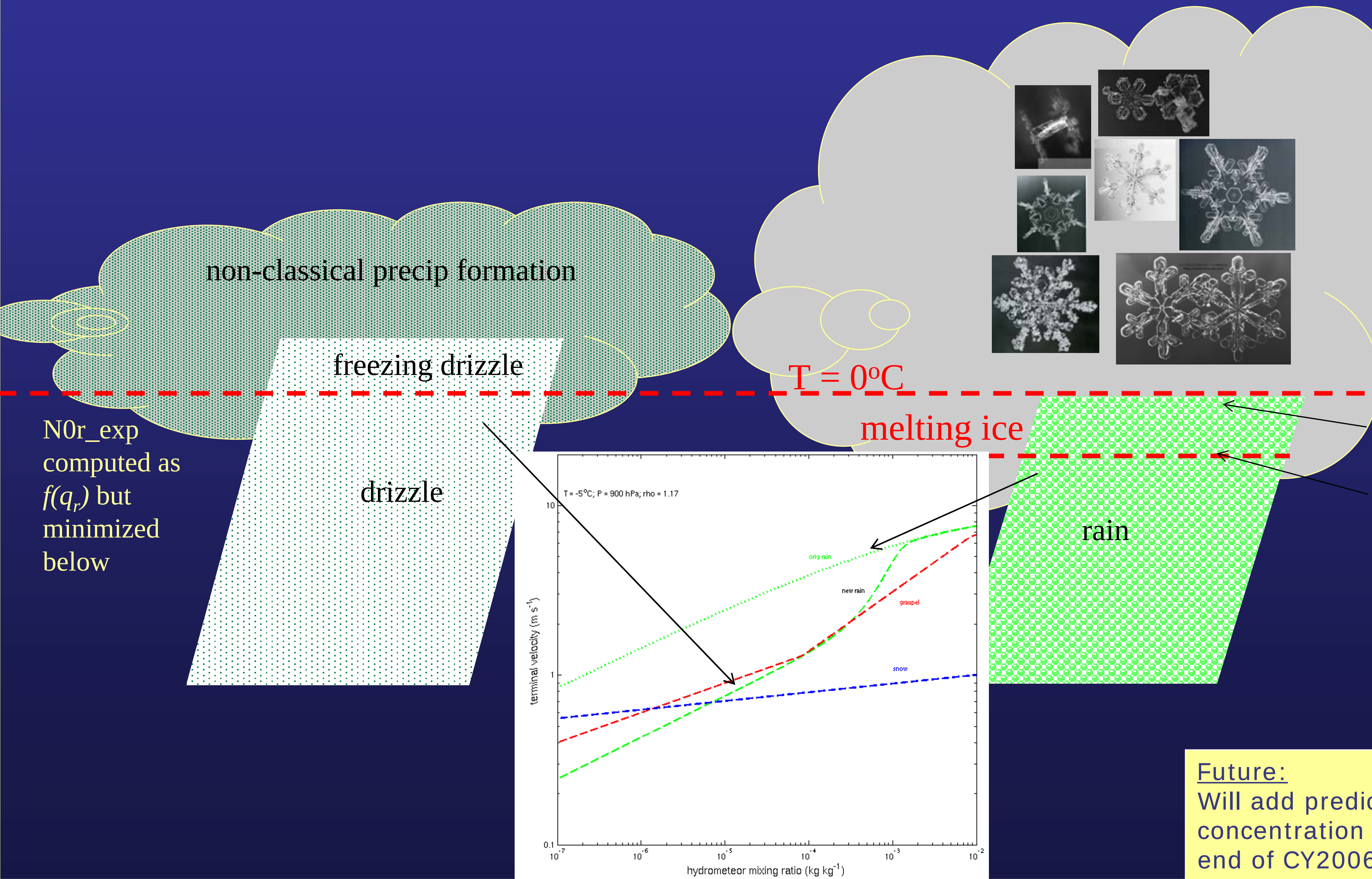
$$N(D) = \frac{M_2^4}{M_3^3}\left[\kappa_0 e^{-\frac{M_2}{M_3}\Lambda_0 D} + \kappa_1\left(\frac{M_2}{M_3}D\right)^{\mu} e^{-\frac{M_2}{M_3}\Lambda_1 D}\right]$$



Rain - details

Y-intercept (equiv exponential distrib), N_0, uniquely diagnosed; melted ice versus collision/coalescence. This was done to attempt to simulate freezing drizzle events while not ignoring classical rain (melting ice).

N0r_exp varies from 2 x 10^9 (drizzle-like) down to 2 x 10^6 m^{-4} (convective rain) producing median volume diameters from 50 microns to no larger than 3 mm.



mvd=50µm
linear increase to melted equiv (~1-2 mm);
then constant N0r_exp below

Future:
Will add predictive number concentration for rain by end of CY2006

Graupel - details

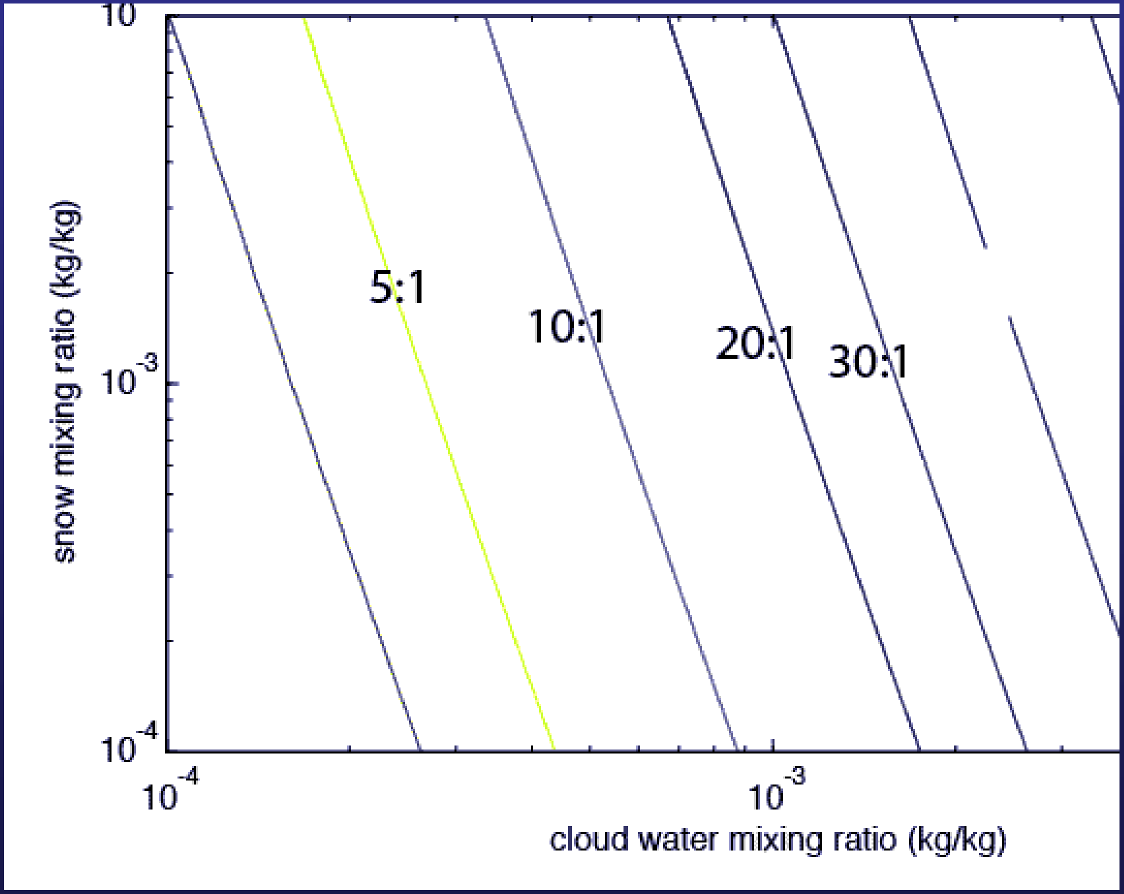
Generalized gamma distribution: $N(D) = N_0 D^{\mu} e^{-\lambda D}$

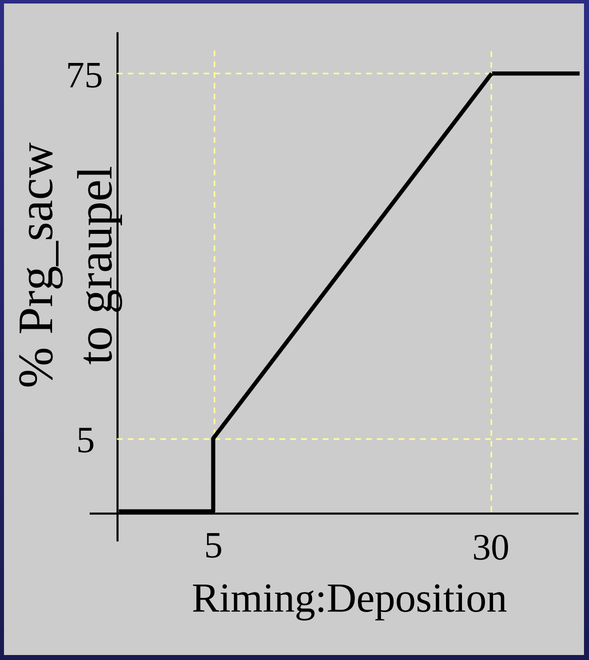
Y-intercept (equiv exponential distrib), N_0, diagnosed as $f(q_g)$:

$N_0 = \max(10^4, \min(100*q_g, 10^6))$

shifts from snow-like graupel towards hail category using single species

rimed snow converting to graupel remains ad-hoc and needs more research:

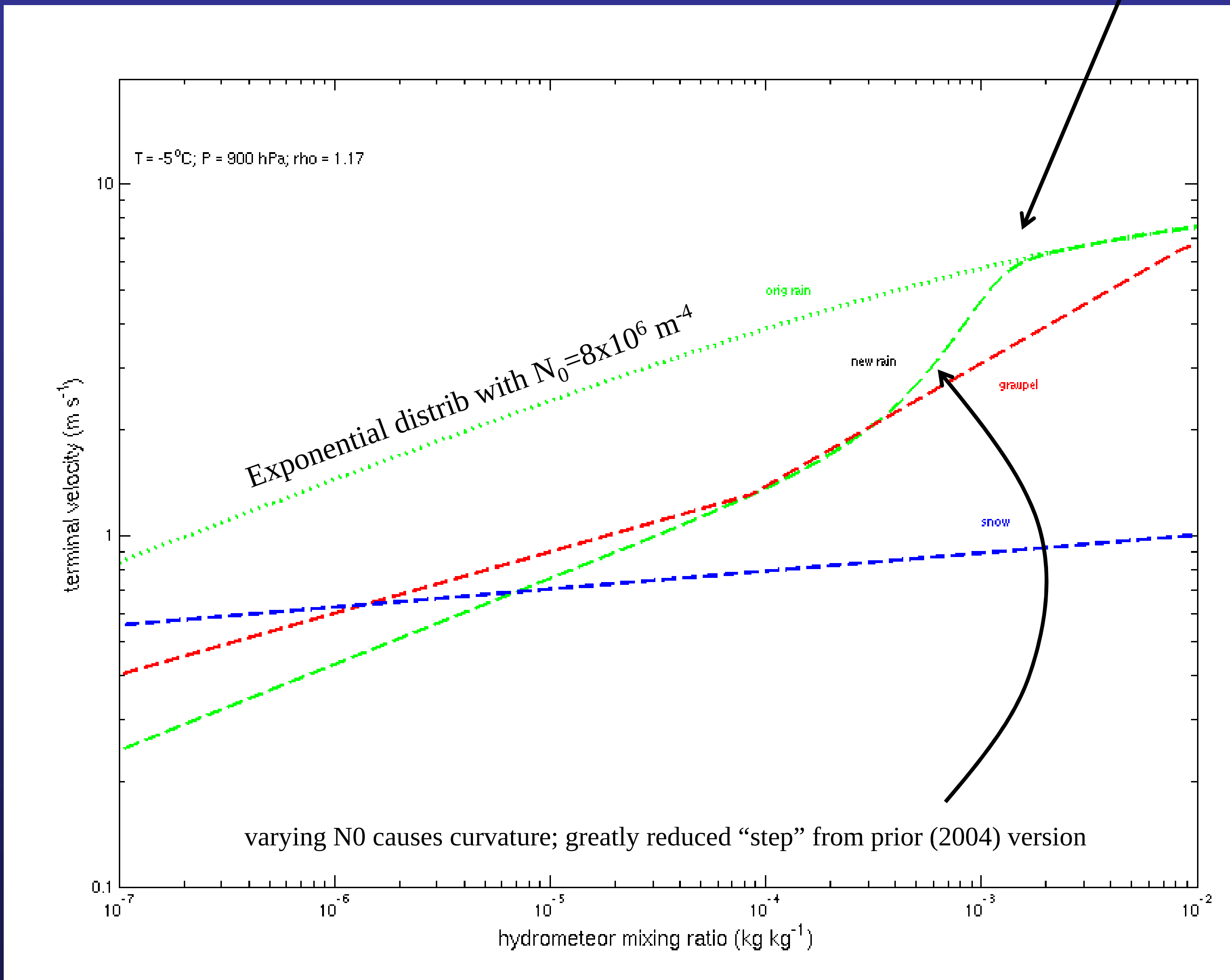




Terminal velocity

Power law for cloud ice, rain, snow, graupel: $v_t = av_x D^{bv_x} \times e^{-fv_x D}$

(exponential causes the flattening)



Cloud ice:

$$v_t = 2247 D^1$$

Snow:

$$v_t = 40.0 D^{.55} e^{-125.0D}$$

Graupel:

$$v_t = 130 D^{.7}$$

Rain (Ferrier, 1994):

$$v_t = 4854 D^1 \times e^{-195.0D}$$

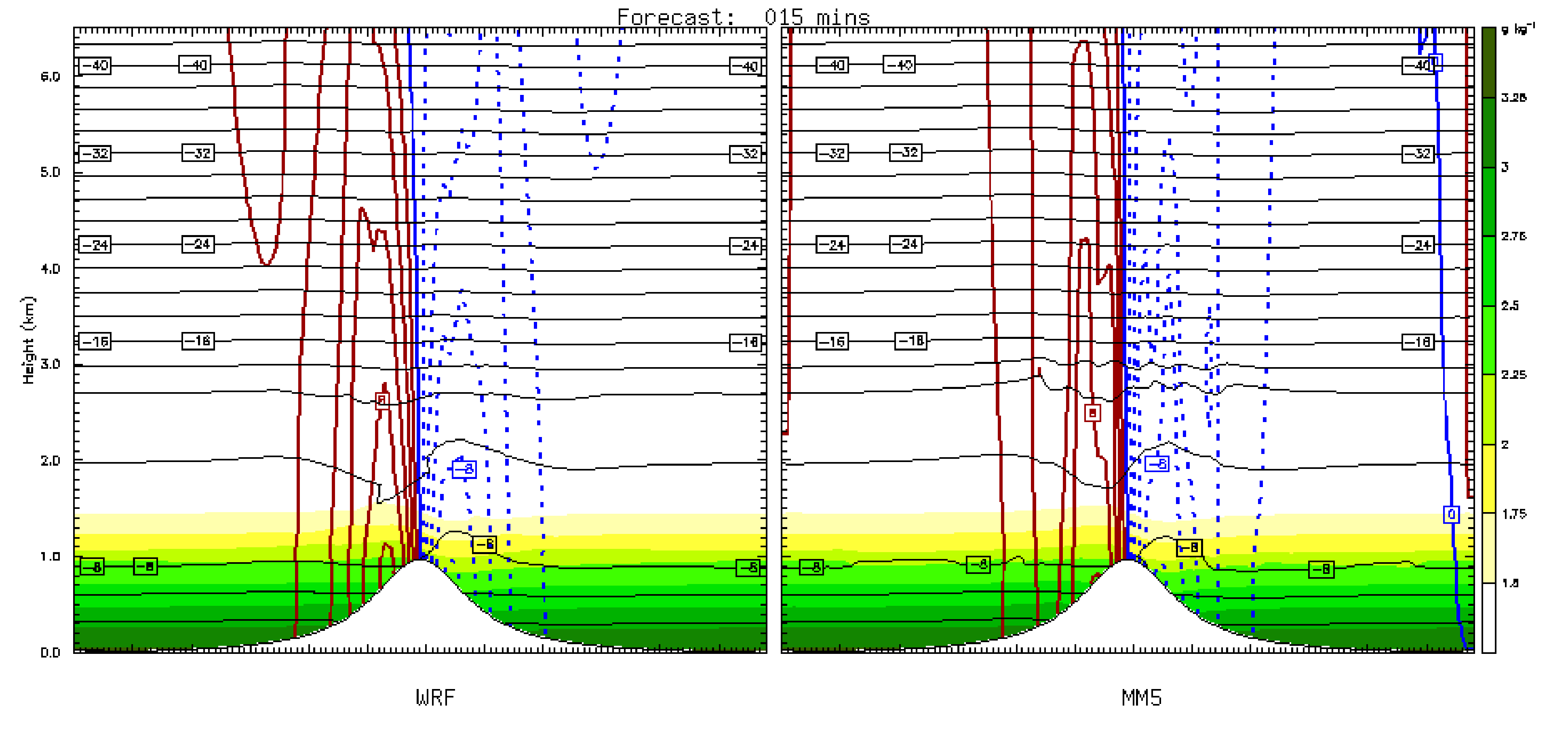
Summary of physical process improvements

- Generalized gamma replaces exponential distributions plus Field et al. (2005) snow distrib.
- Snow is considered non-spherical and its density varies with size as observed.
- Rain evaporates only after cloud water evaporates.
- Cloud ice, snow, and graupel sublimate and rain evaporates using more accurate Srivastava & Coen (1992) method.
- Cloud ice converts to snow using explicit, not ad-hoc method.
- Collisions between hydrometeors with similar fallspeed use explicit bin method in Collection Eqn (CE).
- Rain collecting cloud ice or snow properly sums the rain amount into graupel, not just the ice amount.
- Snow and graupel sublimate when above melting temperature (did not in old scheme).
- Graupel y-intercept parameter (and terminal velocity) attempt to mimic hail when high mixing ratio (strong updrafts).
- Rain y-intercept parameter mimics both precip formation mechanisms: classic melting ice & collision/coalescence.
- Autoconversion uses correctly computed Berry & Reinhardt characteristic diameters.
- Rimed snow conversion to graupel is no longer “all or nothing” but increases as riming:deposition increases.
- Snow fallspeed gets “boosted” by 10-50% when heavy riming.
- Cloud ice has differential number/mass-weighted terminal velocities.

Summary of code improvements

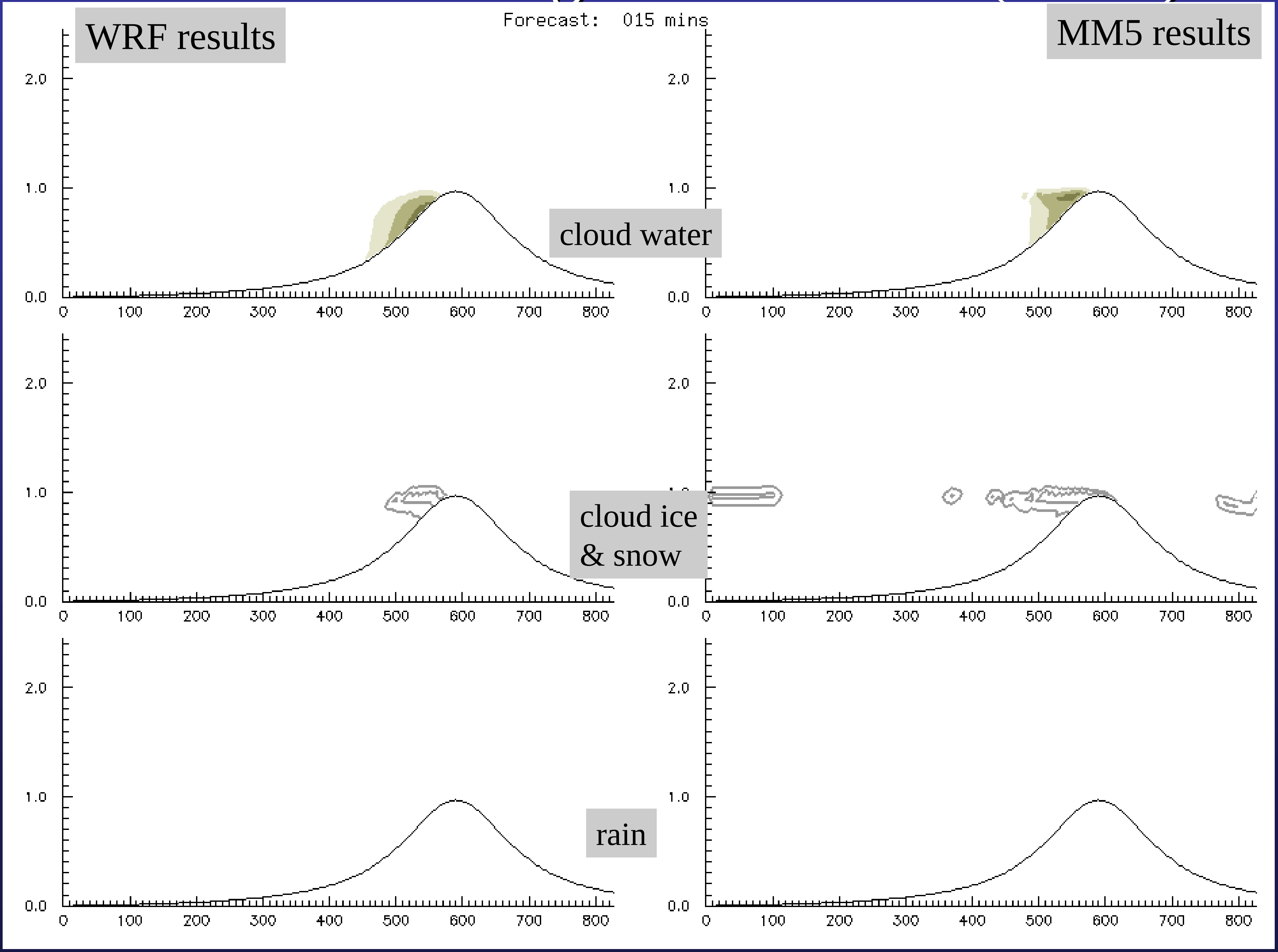
- Generalized gamma replaces exponential distributions.
- Look-up tables implemented for most costly calculations (SCE for rain and snow/graupel collisions).
- Very simple parameters to change mass-diameter (and other) relations.
- When skipping timesteps, rain evaporates (and cloud water condenses/evaporates) and hydrometeors sediment.
- Cloud water condensation uses more accurate iterative Newton-Raphson technique.
- “Clean slate” approach, no more legacy code, well documented, consistent variable naming, etc.

Tests in 2-d using MM5 & WRF (dynamics)



Thompson, G., R. M. Rasmussen, and K. Manning, 2004: Explicit forecasts of winter precipitation using an improved bulk microphysics scheme. Part I: Description and sensitivity analysis. *Mon. Wea. Rev.*, **132,** 519-542.

Tests in 2-d using MM5 & WRF (micro)



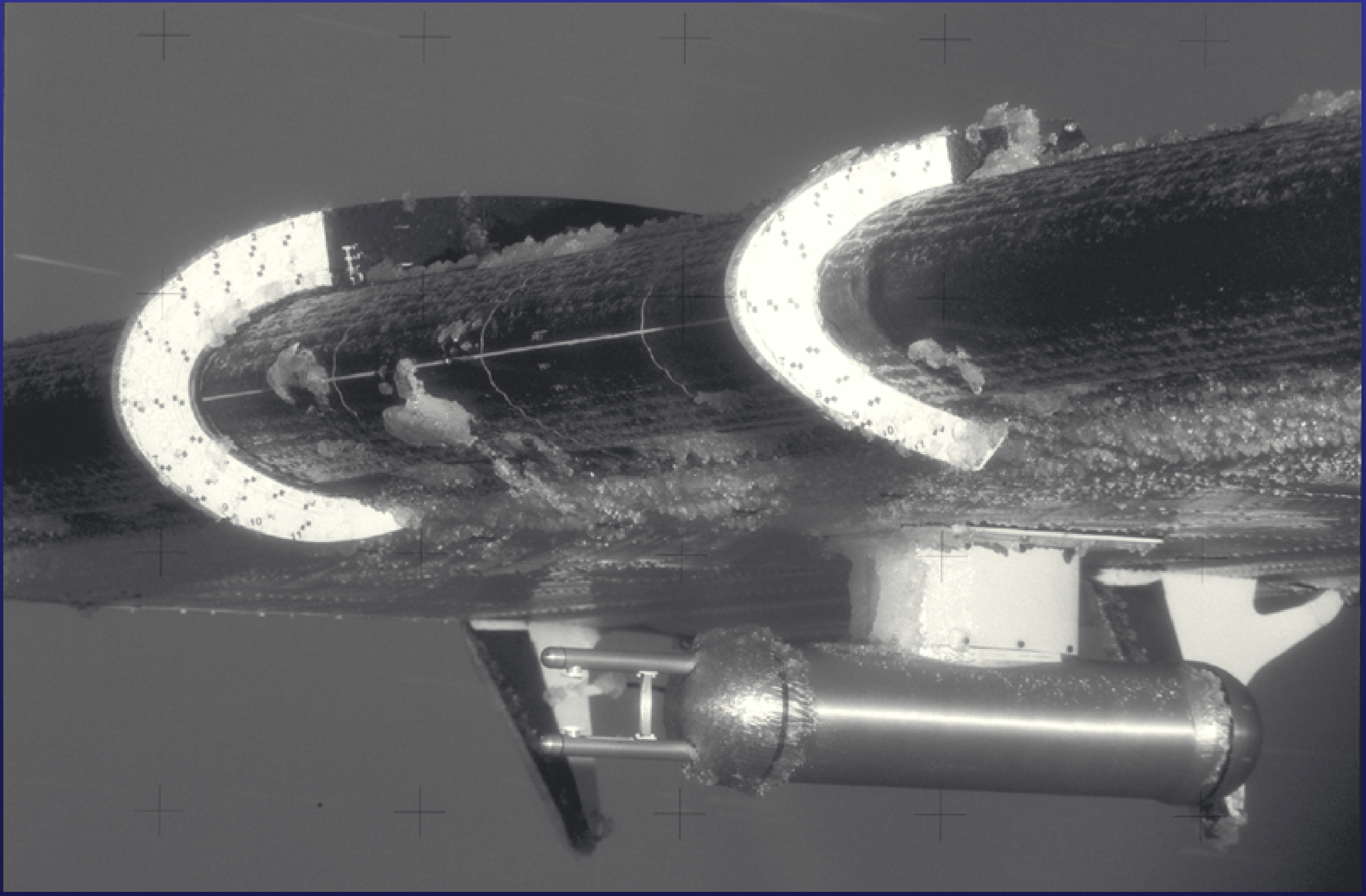
Tests in 3-d using MM5/WRF

- 14 Feb 1990 (WISP)
  shallow, post-frontal, upslope cloud w/widespread FZDZ.
- 30 Jan 1998 (NASA-SLDRP)
  shallow stratoCu, primarily CLW w/slight FZDZ.
- 04 Feb 1998 (NASA-SLDRP)
  deep and dynamic snowstorm w/classic FZRA.
- 01 Feb 2001 (IMPROVE-1)
  deep PacNW frontal system, abundant precip.
- 28 Nov 2001 (IMPROVE-2)
  deep PacNW frontal system plus orographics.
- 13 Dec 2001 (IMPROVE-2)
  deep PacNW frontal system plus orographics.
- 13 May 2005
  squall line through KOKC (OUN dual-pol radar + disdrometer data)
- plus NOAA-GSD and Jim Bresch (MMM) realtime runs
- plus DTC "phase-2" Rapid Refresh core tests (~240 simulations)

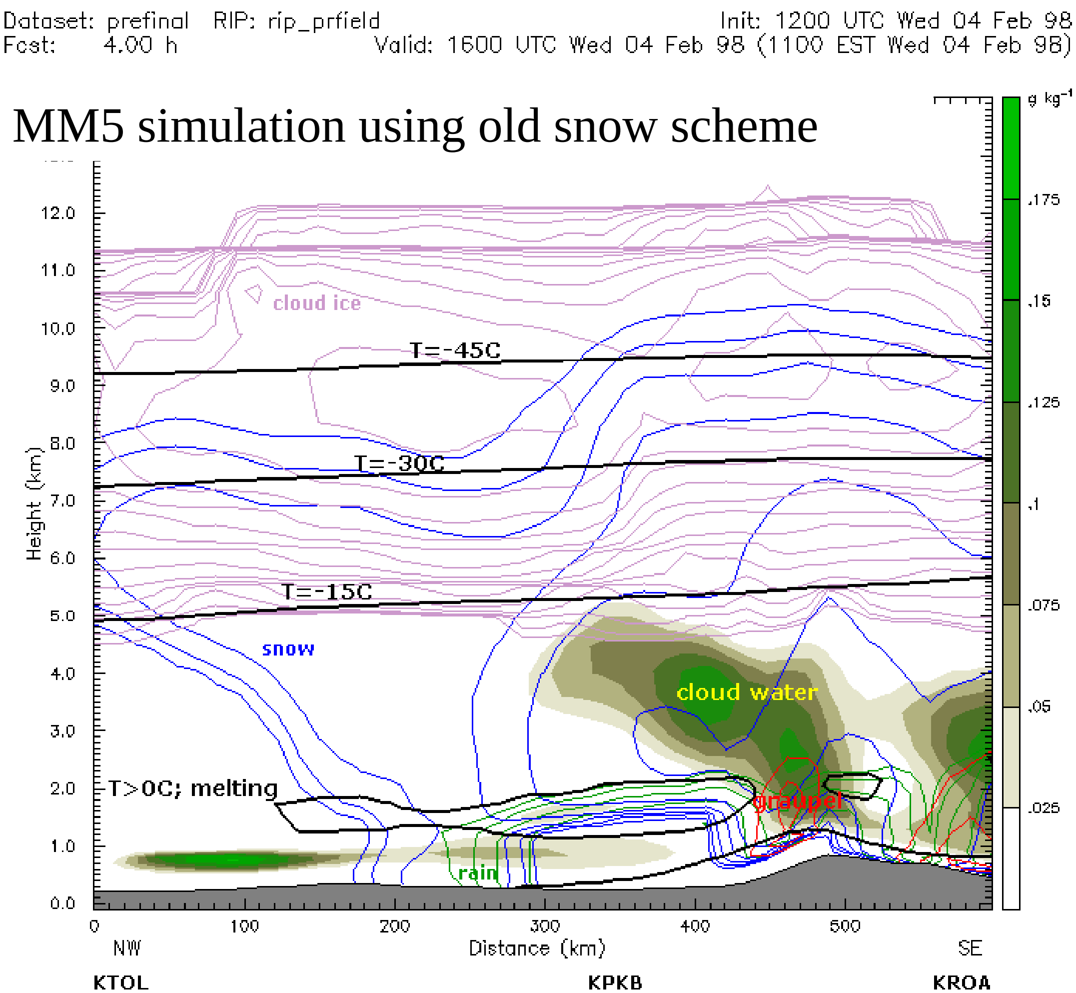
Thompson, et al., 2006: Explicit forecasts of winter precipitation using an improved bulk microphysics scheme. Part II: Case studies. *Mon. Wea. Rev.*, **in preparation**.

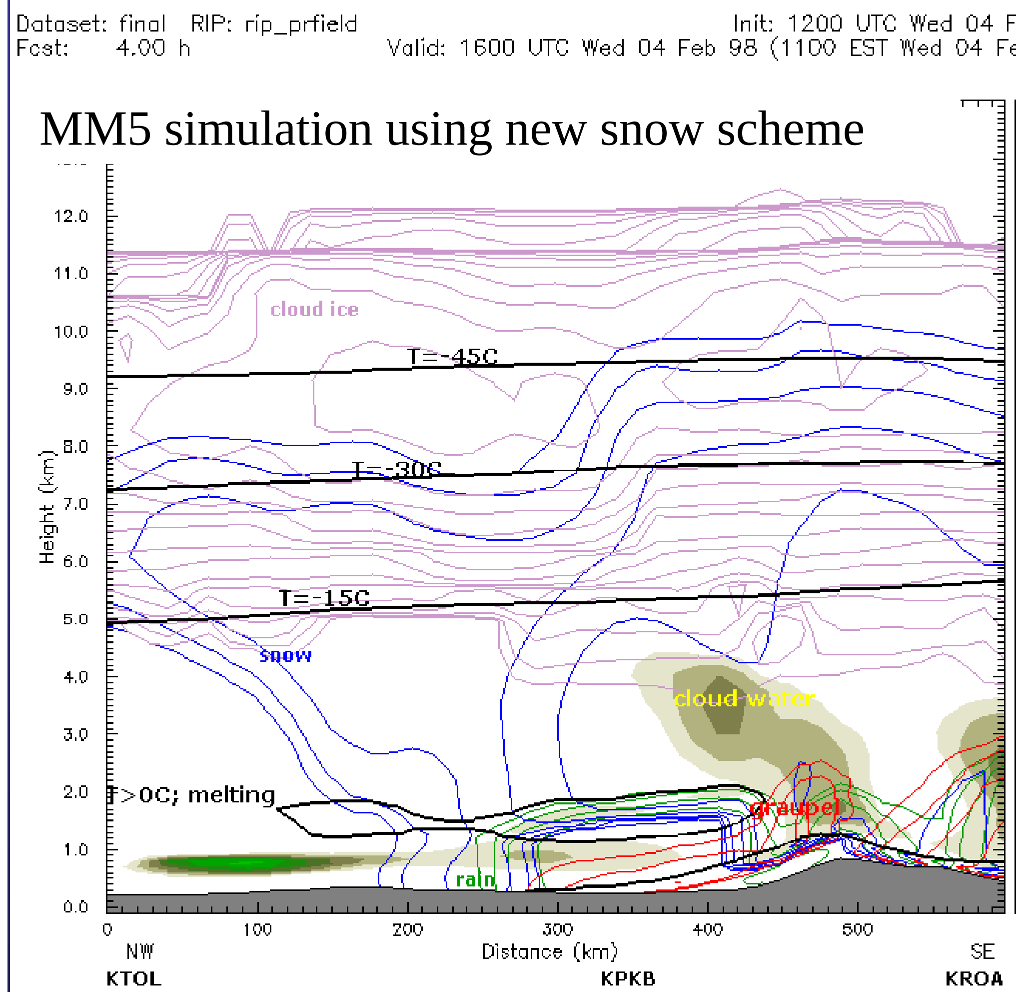
04 Feb 1998 NASA-SLDRP case

- Widespread, deep glaciated cloud (nor'easter)
- Classic "warm-nose" with freezing rain near OH/WV border (Parkersburg, WV)
- Twin Otter experienced a 'significant performance degradation'



04 Feb 1998: Old snow/new snow comparison



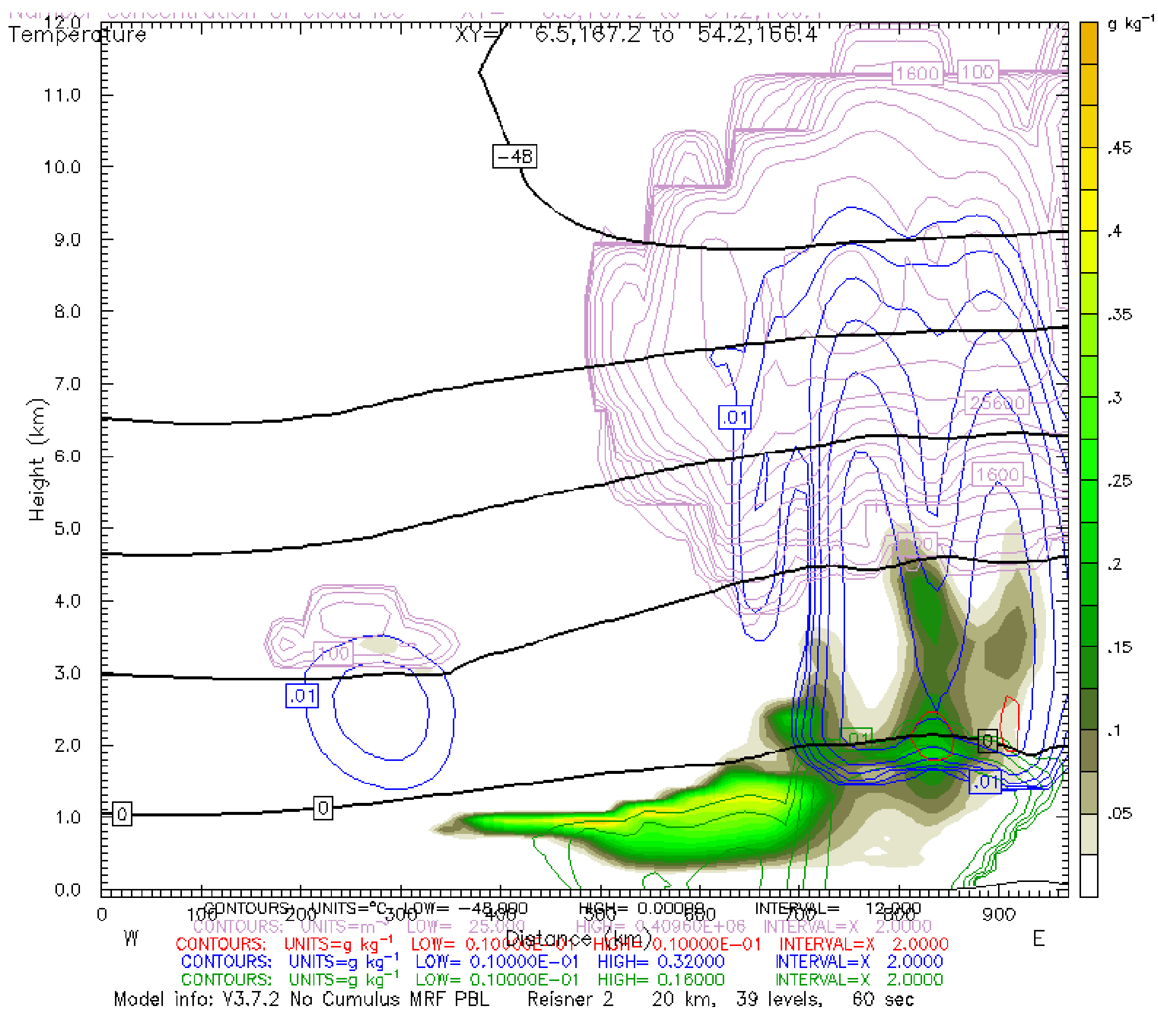


Deep/mostly-glaciated cloud simulation:

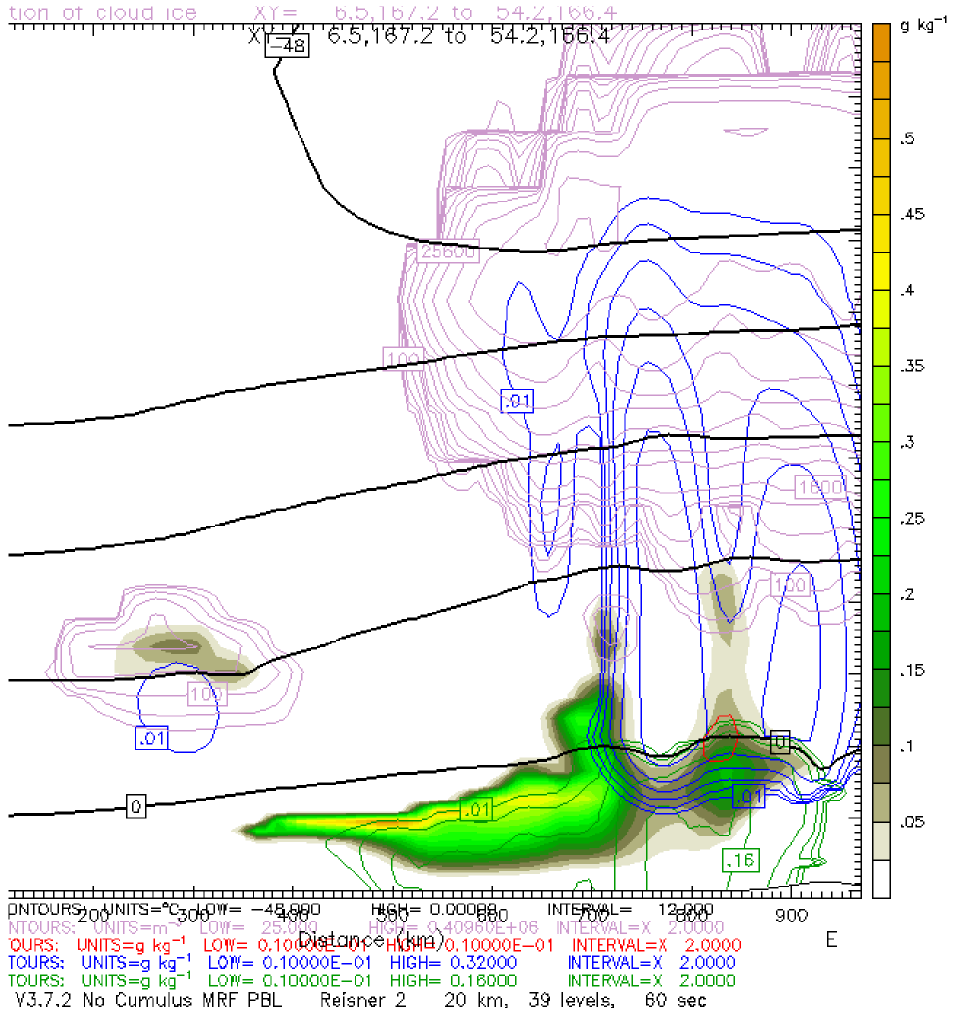
decreased supercooled liquid cloud & decreased RH_{ice} aloft using new snow scheme versus old!

01 Feb 2001: old/new scheme comparison

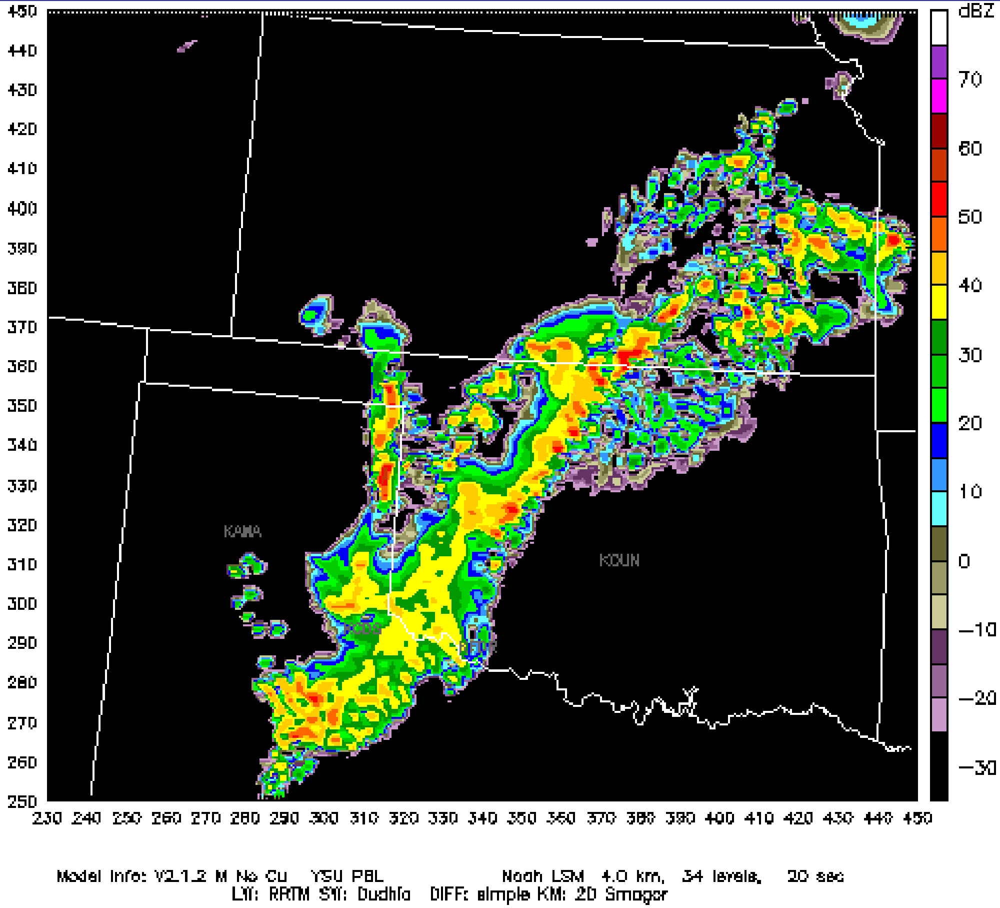
MM5 simulation using old bulk scheme

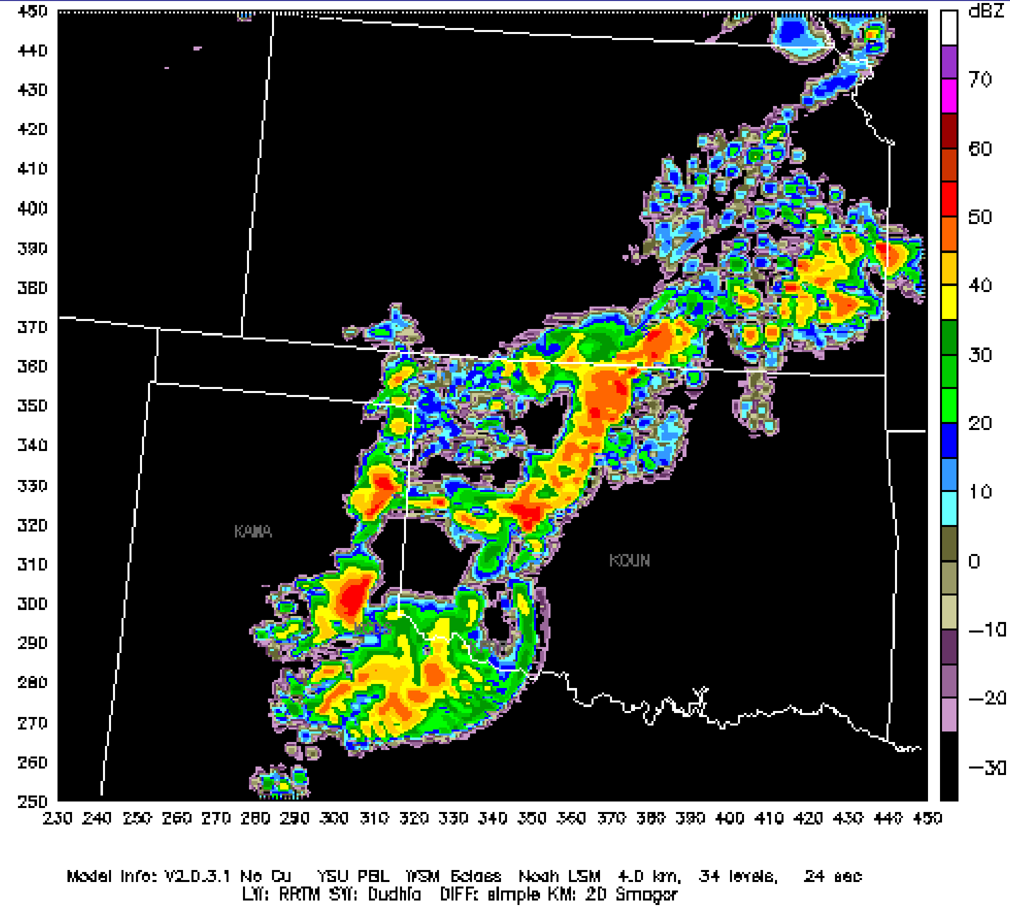


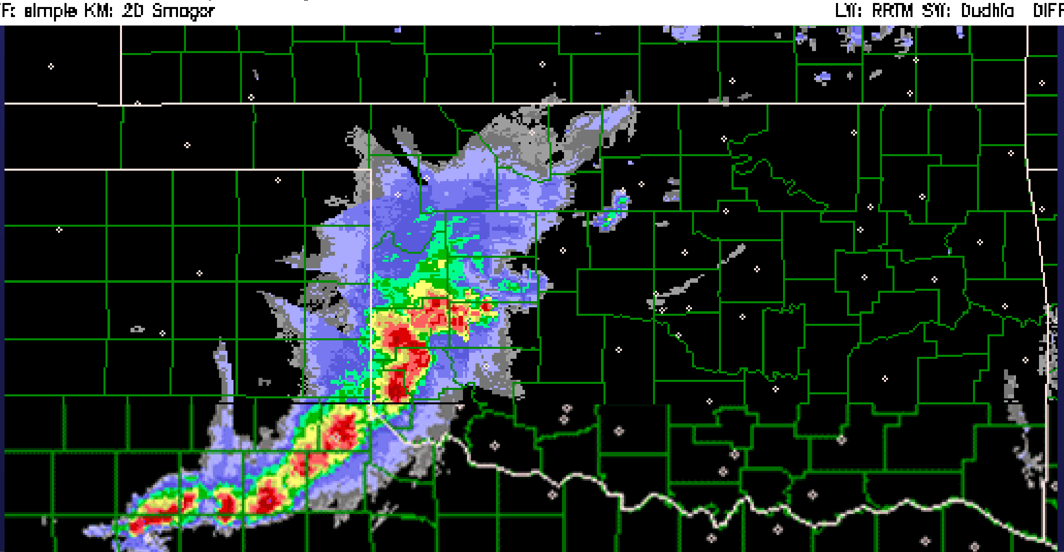
MM5 simulation using entirely new bulk scheme



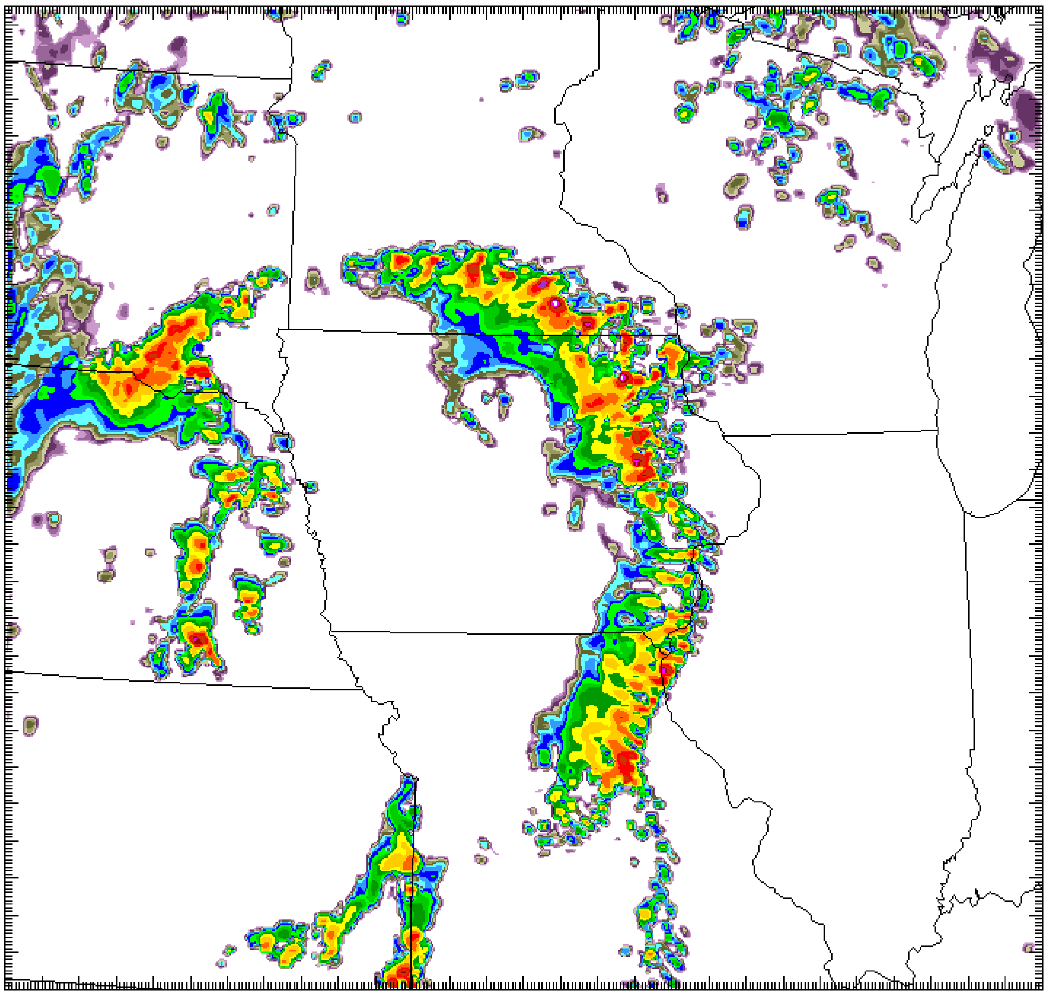
13 May 2005: Squall line (near OKC)



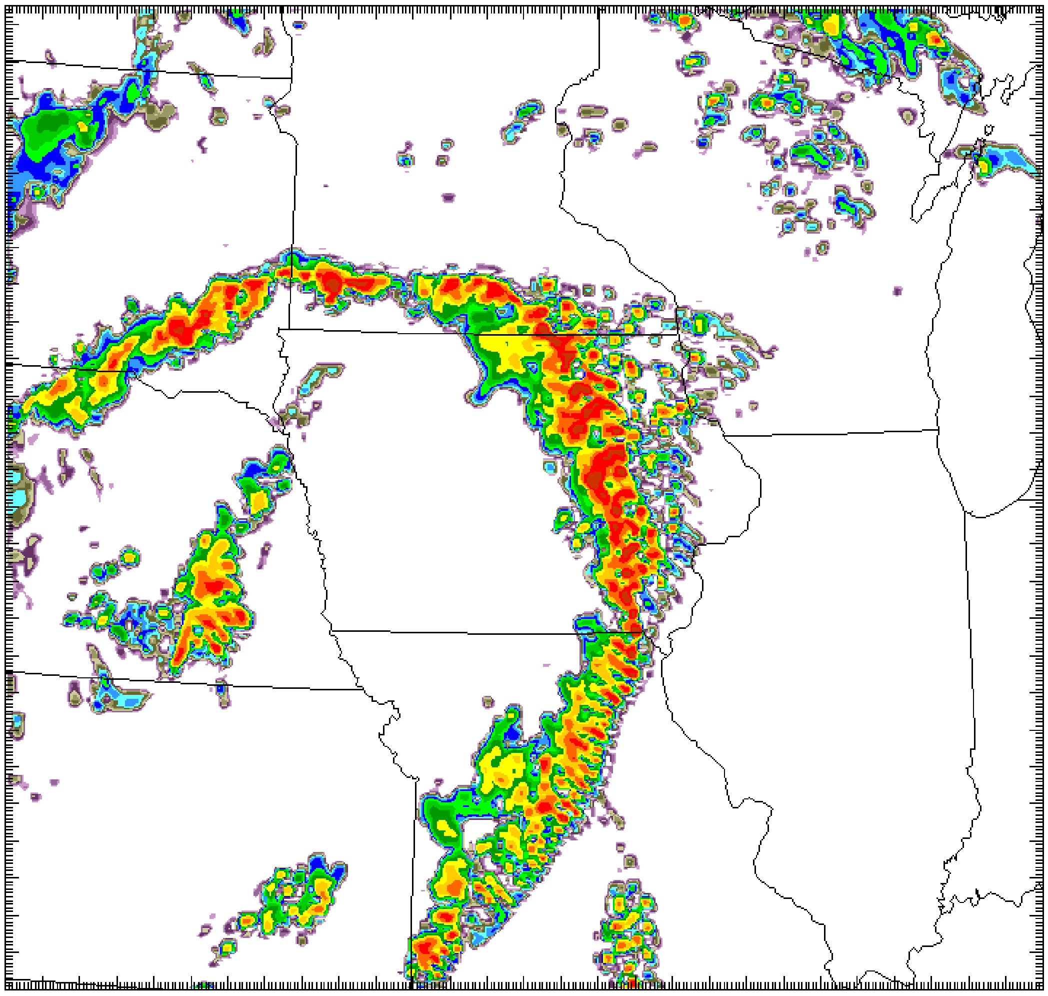




05 June 2005: Squall line



New scheme



WSM6 (Hong et al. 2004)

Future work

- verification and more testing (DTC "phase-2" Rapid Refresh core tests)
- upcoming additions/improvements:
  1) 2^{nd} moment for cloud water and rain
  2) initial aerosol variable will vary in space/time (connect to Chem module?)
  3) aerosol variable will influence cloud water condensation and ice nucleation
  4) addition of "Asian dust outbreaks" (for NSF-proposed ICE-L field project)
- needs:
  1) testing un-tested aspects (gamma shape parameter)
  2) better (and faster) sedimentation
  3) improve handling of rimed snow conversion to graupel
  4) addition of hail category for convective simulations?

Thank you

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