An Efficient Semi-Double-Moment Bulk Microphysics Scheme
(For Operational Applications)

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Premises

- Operation NWP models are approaching the convective scale [i.e. $\Delta x \sim O(1\text{ km})$]
- Importance of BULK MICROPHYSICS SCHEMES (BMS) for operational models is increasing
- **There is a continued need to develop sophisticated yet efficient BMSs**

Bulk Method

- Hydrometeor spectrum is partitioned into representative categories (e.g. *cloud* (droplets), *rain* (large drops), *ice* (pristine crystals), etc.
- For each category:
  - the size distribution is described by an analytic function (e.g. gamma function)
  - one or more variables (moments) can be prognosed – e.g. mass content (***Q***), total number concentration (***N***), reflectivity (***Z***)
  - tendency equations for the (progostic variables) based on microphysical processes are formulated and computed

Bulk Method

HISTORICALLY:

- early schemes were generally single-moment (predicting q_x)
- increasing complexity meant increasing the number of hydrometeor categories (but still single-moment)
- with increasing computer power, multi-category single-moments schemes became double-moment, with several (10-14) prognostic variables

→ **double-moment BMSs have been too expensive for operational NWP**

REQUIREMENTS for an operational BMS:

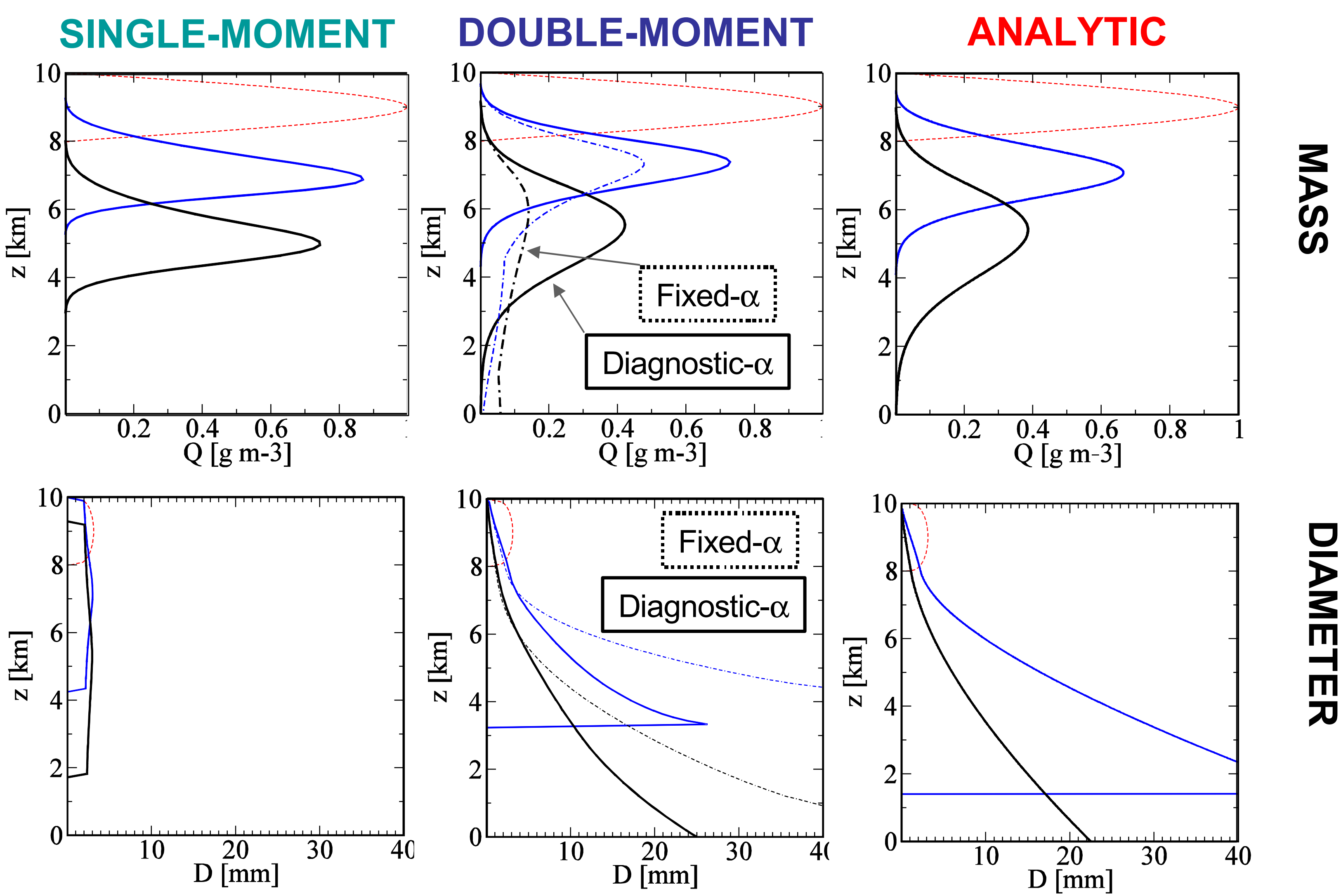
- Efficiency – must be useable in real time
- Versatility – should have as few case-dependent parameters as possible
- Should closely reproduce more detailed BMSs

APPROACH to developing an efficient BMS:

- BOTTOM-UP – add sophistication to simple schemes
- TOP-DOWN – simplify detailed schemes

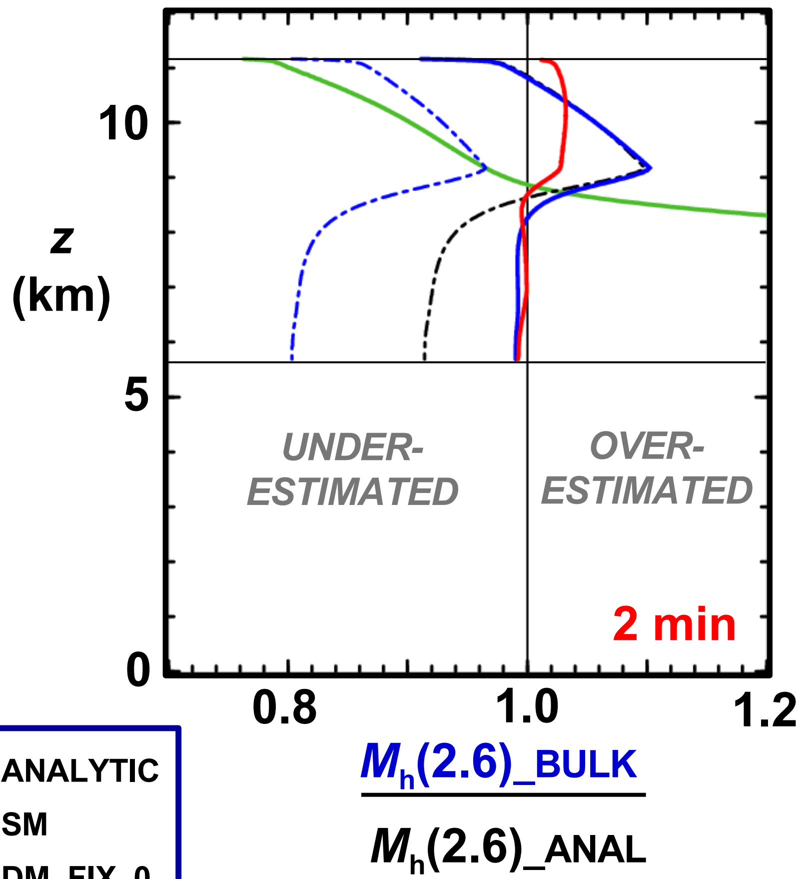
Pure sedimentation of hail

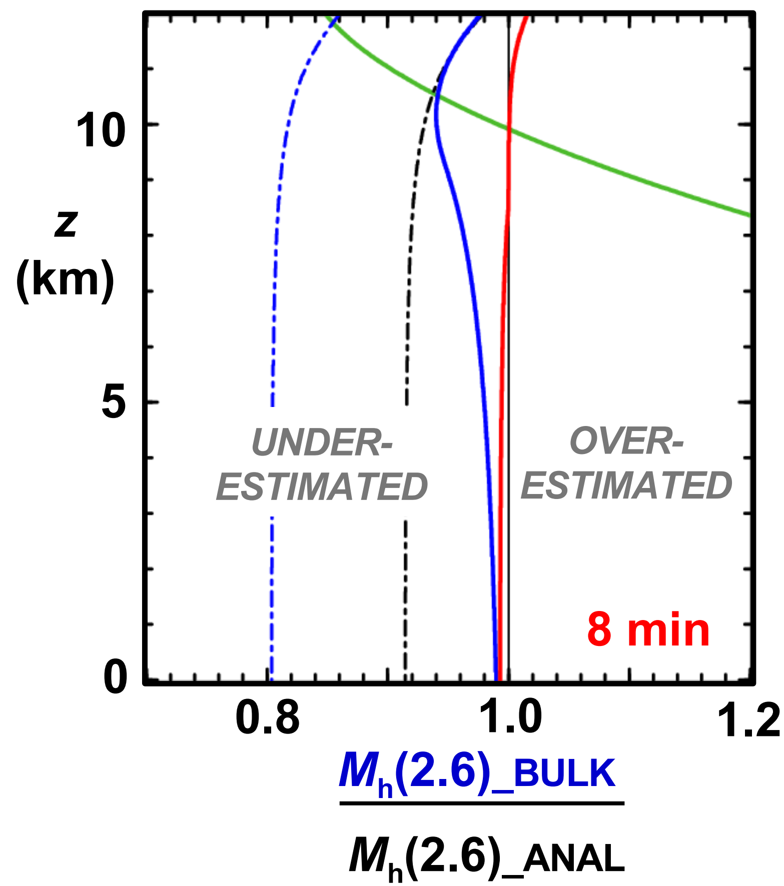
(no other processes)

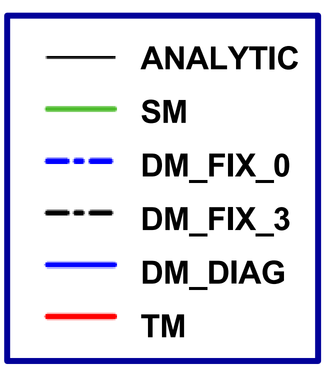


ADVANTAGES OF MULTI-MOMENT

Ratio of Growth Rates: $\dfrac{CL_{ch\_}\text{BULK}}{CL_{ch\_}\text{ ANAL}} = \dfrac{M_h(2.6)\text{\_BULK}}{M_h(2.6)\text{\_ANAL}}$



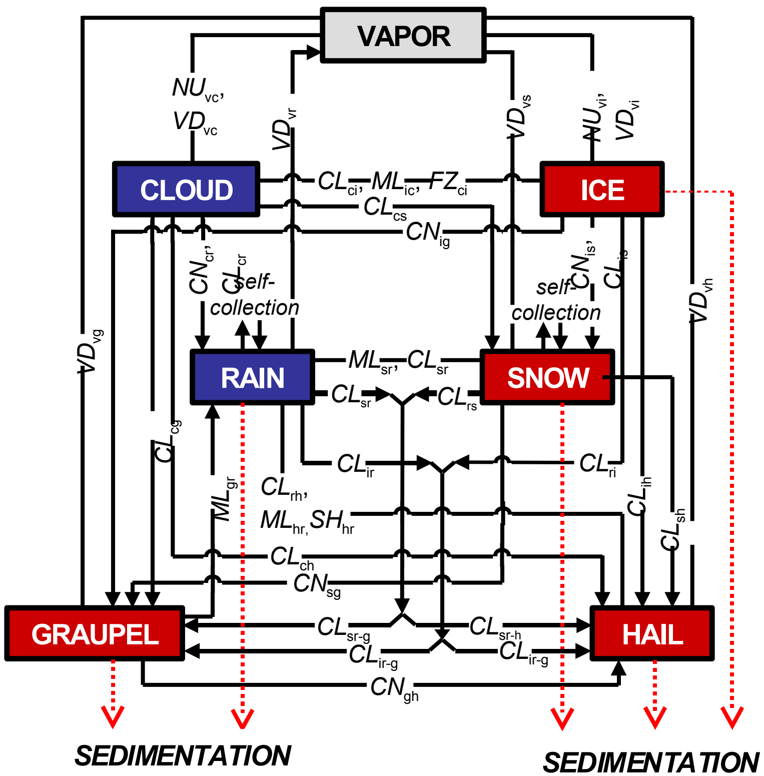




(e.g. A **ratio of 0.95** ⇒ growth rate **underestimated by 5%**)

Original Multi-Moment Version

The full research version of the BMS used is the detailed, six-category, **multi-moment** scheme of Milbrandt and Yau (2005a,b; *JAS*)



Full version:

CLOUD	double-moment	(Q_c, N_c)
RAIN	triple-moment	(Q_r, N_r, Z_r)
ICE	triple-moment	(Q_i, N_i, Z_i)
SNOW	triple-moment	(Q_s, N_s, Z_s)
GRAUPEL	triple-moment	(Q_g, N_g, Z_g)
HAIL	triple-moment	(Q_h, N_h, Z_h)

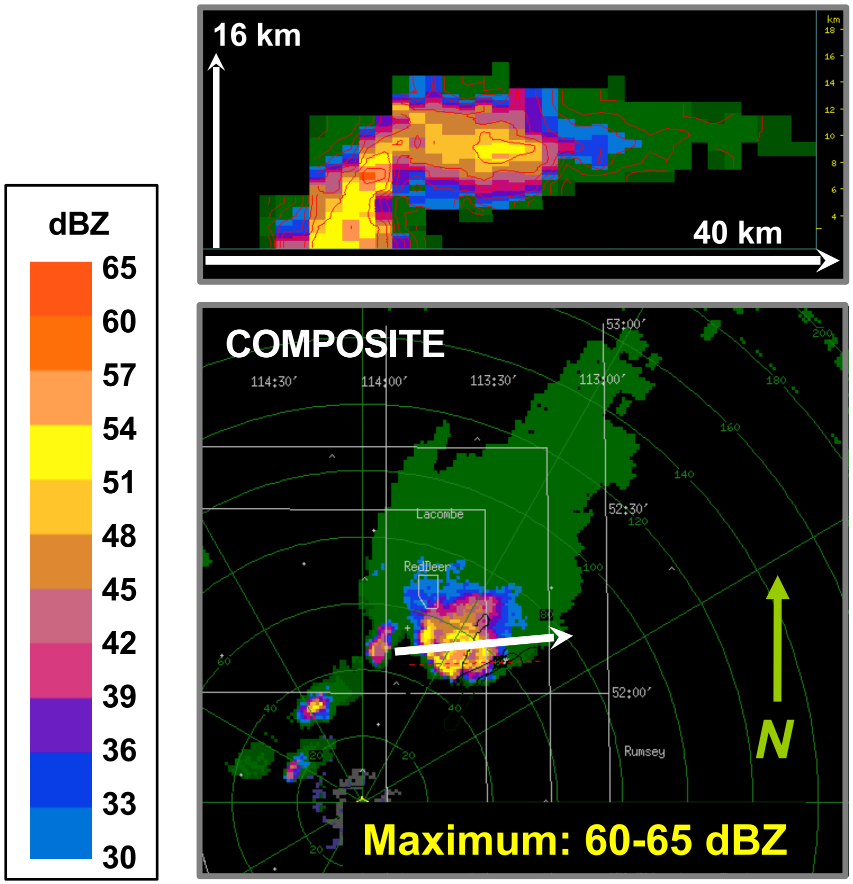
→ **17 prognostic variables**

Each category is represented by a 3-parameter gamma distribution:

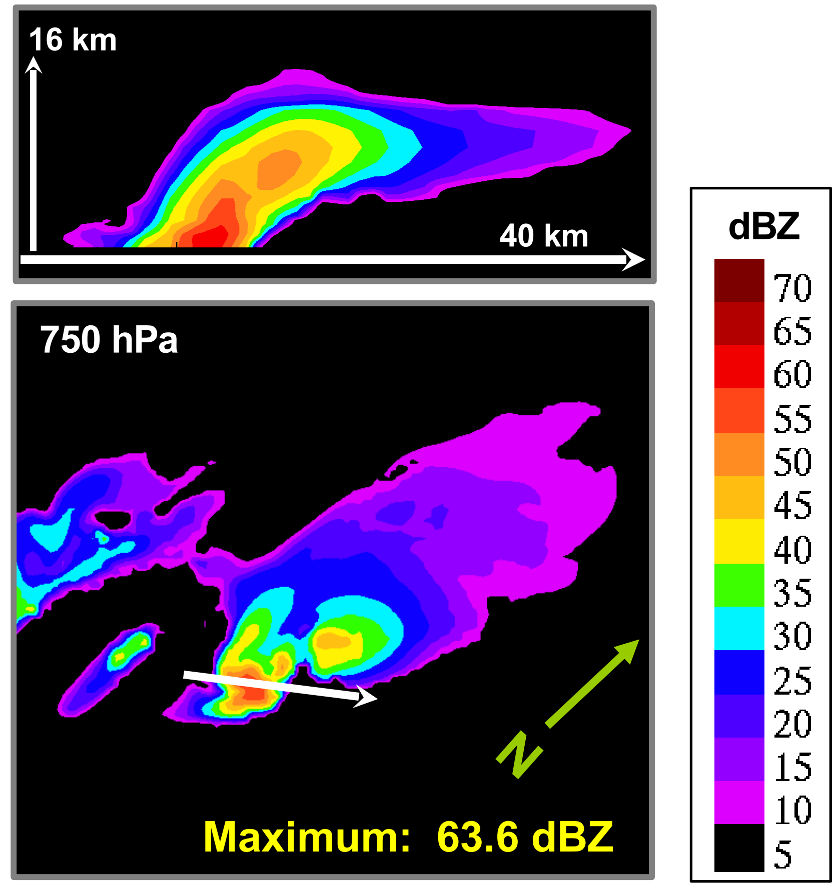
$$N_x(D) = N_{0x} D^{\alpha_x} e^{-\lambda_x D}$$

Original Multi-Moment Version

RADAR:
0030 UTC [6:30 pm, LDT]



1-km TRIPLE-MOMENT Simulation:
4:30 h [6:30 pm, LDT]



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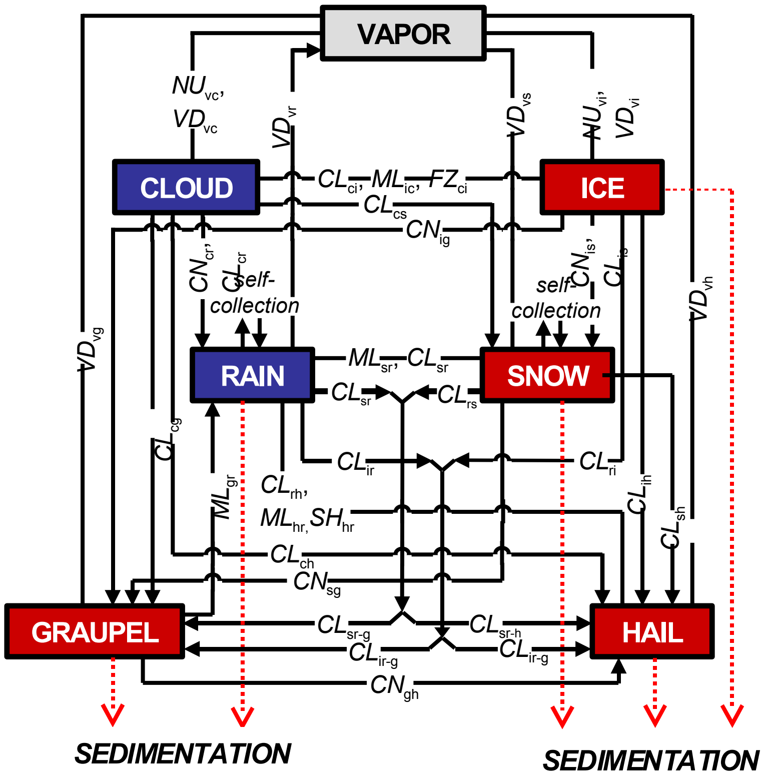

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→ **17 prognostic variables**

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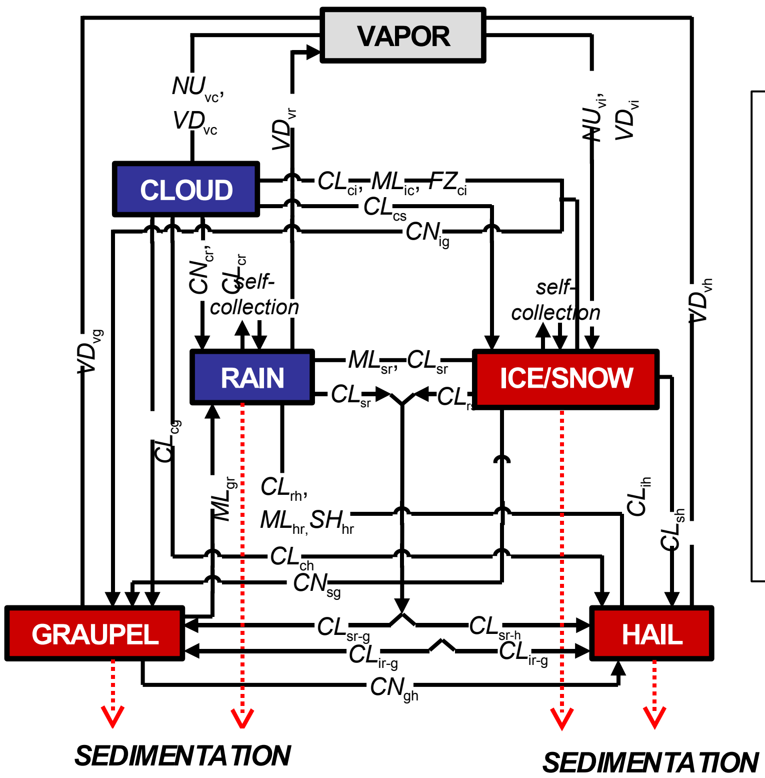
$$N_x(D) = N_{0x} D^{\alpha_x} e^{-\lambda_x D}$$

Proposed Semi-Double-Moment Version

Prototype **operational version** of the Milbrandt-Yau BMS being developed for the high-resolution Canadian NWP system for the 2010 Winter Olympics (Vancouver)



Proposed version:

CLOUD	single-moment	(Q_c)
RAIN	double-moment	(Q_r, N_r, *diag-* α_r)
ICE/SNOW	double-moment	(Q_i, N_i)
GRAUPEL	single-moment	(Q_g)
HAIL	double-moment	(Q_h, N_h, *diag-* α_h)

→ **8 prognostic variables**

Proposed version:

HYBRID ICE/SNOW Category:

Combines separate categories for small crystals (***ice***) and large crystals/aggregates (***snow***) into one double-moment category

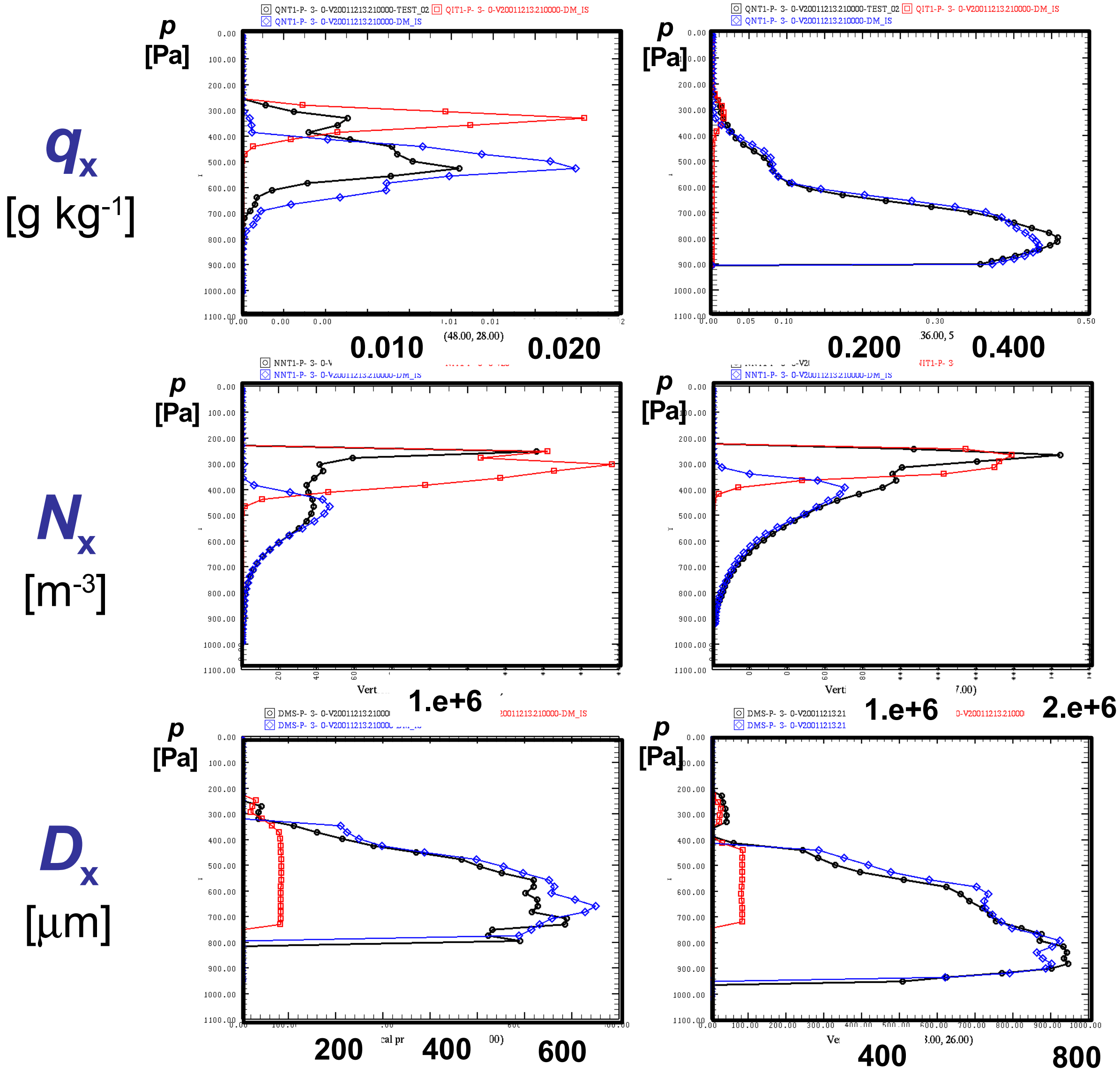
ICE/SNOW	double-moment	(Q_i, N_i)	(fixed α_s=0)

Other modifications*:

- exponent in mass-diameter relation changed from 3 to 2
- diagnostic bulk density as a decreasing function of mean diameter (as in Thompson et al., 2008)
- diagnostic terminal fall velocity parameters (based on mean diameter)
- effective capacitance factor added to diffusional growth term (to compensate for overestimates of deposition rates by electrostatic capacitance analogy)

*(under construction)

Testing the **HYBRID** ice/snow category:



- Both small cirrus and large crystals/aggregates can be represented be a single, double-moment category
- vertical distribution of mass, concentration, and size (of the two-category approach) can be adequately reproduced

ICE
SNOW
HYBRID

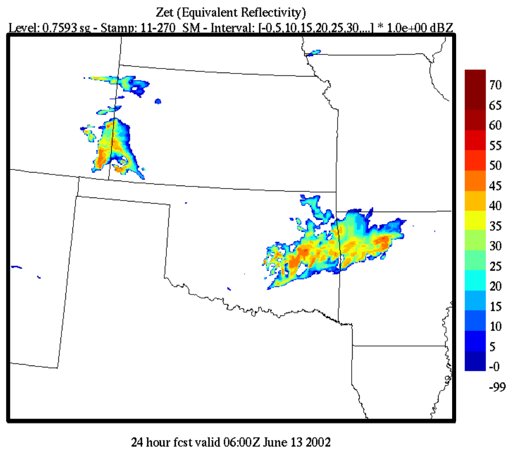
Workshop CASE 3: **Mid-latitude SQUALL LINE**

3-D Simulations conducted with GEM model

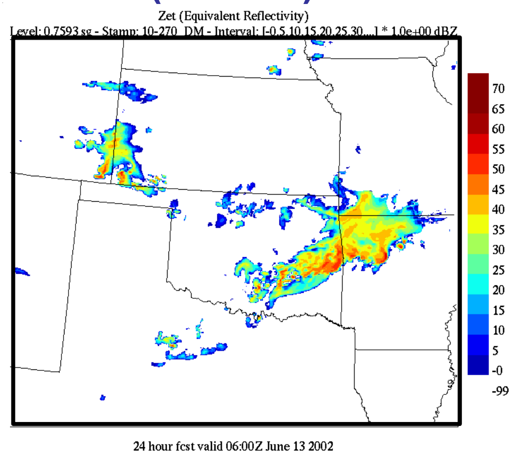
- Initialized from 0000 UTC 12 June 2002 CMC analysis
- Run with operational “regional” configuration (global, variable resolution, Δx ~ 15-km over North America
- Nested to Δx ~ 2.5-km grid at 1200 UTC (using various versions of Milbrandt-Yau scheme)

Workshop CASE 3: Reflectivity at 2 km AGL, 0600 UTC 13 June 2002 (36-h fcst)

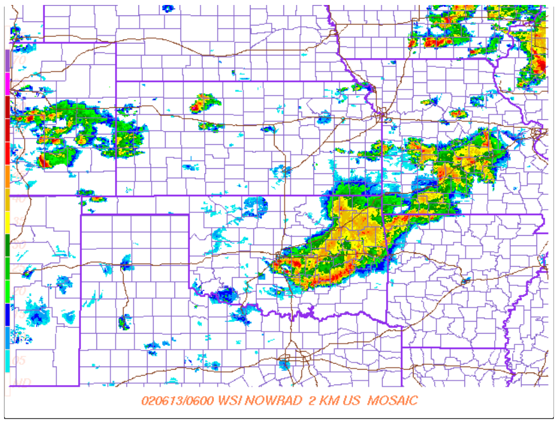
SINGLE-Moment



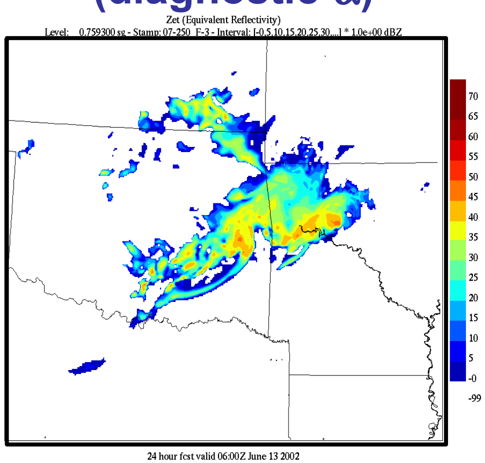
DOUBLE-Moment (fixed-α)



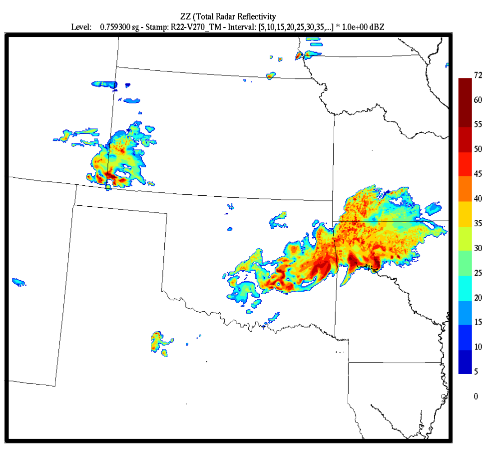
WSI RADAR



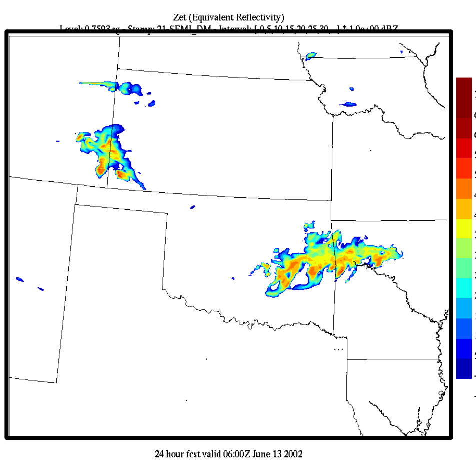
DOUBLE-Moment (diagnostic-α)



TRIPLE-Moment



SEMI-DOUBLE-Moment



CONCLUSIONS

- Sedimentation and source/sink term are computed much better by multi-moment schemes
- Fewer double-moment categories, rather than more single-moment categories, may be a better alternative for operational (high-resolution) bulk schemes
- Combining ***ICE*** and ***SNOW*** into a single, two-moment category is a feasible alternative to the traditional approach of using separate categories
- The proposed “semi-double-moment” configuration of the Milbrandt-Yau scheme – though good on paper – requires further work in order to reproduce the higher-moment simulations