Milbrandt & Yau Multimoment Scheme

Brad Carlberg
AGRON 590
7 October 2014

Background

- Six hydrometeor categories
  - Follows Ferrier scheme
  - Cloud, rain, ice, snow, graupel, hail
- Multiple moments
  - Single moment
  - Double moment
  - Triple moment

What's the difference?

- Single moment scheme
  - Predicts mixing ratio or specific humidity
- Double moment scheme
  - Includes particle number concentration
- Triple moment scheme
  - Adds radar reflectivity

Background

- Control simulation
  - Pine Lake, AB 14 Jul 2000
  - Good hail producer
  - Supercellular storm
- Triple Moment scheme modeled very well

Background

- Assumptions
  - Squall line and supercells have similar characteristics
  - All hydrometeors assumed to be spherical except ice
    - Ice assumed to have rosette bullet shape
- Limitations
  - No in-situ measurements of control storm
  - In sensitivity experiments, triple-moment scheme was used as control

Bulk Parameterizations

- Most microphysical schemes use 3-parameter gamma distribution:

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

- Where:
  - $N_x(D)$ is total number concentration per unit volume
  - D is hydrometeor diameter
  - N_{0x} is total number concentration
  - α is the spectral shape parameter
  - λ is the slope parameter

Bulk Parameterizations

- Single moment schemes hold N_{0x} and α constant
- Many double moment schemes hold α constant while varying N_{0x} and λ
- Milbrandt and Yau also varies α
  - Diagnose in double moment
  - Predictive equation in triple moment

Single Moment

- λ varies:

$$\lambda_x = \left[\frac{\Gamma(1 + d_x + \alpha_x)}{\Gamma(1 + \alpha_x)} \frac{c_x N_{Tx}}{\rho q_x} \right]^{1/d_x}.$$

- By predicting q:

$$\frac{\partial q_x}{\partial t} = -\frac{1}{\rho} \nabla \cdot (\rho q_x \mathbf{U}) + \mathrm{TURB}(q_x) + \frac{1}{\rho} \frac{\partial}{\partial z} (\rho q_x V_{Qx}) + \left. \frac{dq_x}{dt} \right|_S, \qquad (8)$$

Double Moment

- Adds prognostic parameter N_{0x} :

$$N_{0x} = N_{Tx} \frac{1}{\Gamma(1 + \alpha_x)} \lambda_x^{1+\alpha_x}.$$

- By predicting N_{Tx} :

$$\frac{\partial N_{Tx}}{\partial t} = -\nabla \cdot (N_{Tx}\mathbf{U}) + \mathrm{TURB}(N_{Tx}) + \frac{\partial}{\partial z}(N_{Tx}V_{Nx}) + \left.\frac{dN_{Tx}}{dt}\right|_S, \qquad (9)$$

Double Moment

- α can be fixed or diagnosed
- Diagnostic equations for hail:

$$\alpha_h = \begin{cases} c_{1h} \tanh[c_{2h}(D_{mh} - c_{3h})] + c_{4h} & \text{for} \quad D_{mh} < 8 \text{ mm} \\ c_{5h} D_{mh} - c_{6h} & \text{for} \quad D_{mh} \geq 8 \text{ mm}. \end{cases}$$

- Diagnostic equations for hydrometeors:

$$\alpha_x = c_{1x} \tanh[c_{2x}(D_{mx} - c_{3x})] + c_{4x},$$

Triple Moment

- Prognostic parameter, α, is obtained by reflectivity equation: $$Z_x = M_x(6) = \frac{G(\alpha_x)}{c_x^2}\frac{(\rho q_x)^2}{N_{Tx}},$$

- where $$G(\alpha_x) = \frac{(6+\alpha_x)(5+\alpha_x)(4+\alpha_x)}{(3+\alpha_x)(2+\alpha_x)(1+\alpha_x)}.$$

- By predicting Z:

$$\frac{\partial Z_x}{\partial t} = -\nabla \cdot (Z_x \mathbf{U}) + \mathrm{TURB}(Z_x) + \frac{\partial}{\partial z}(Z_x V_{Zx}) + \left.\frac{dZ_x}{dt}\right|_S,$$

Why Not Use 3-Moment?

- Works well enough to use as control for sensitivity experiments

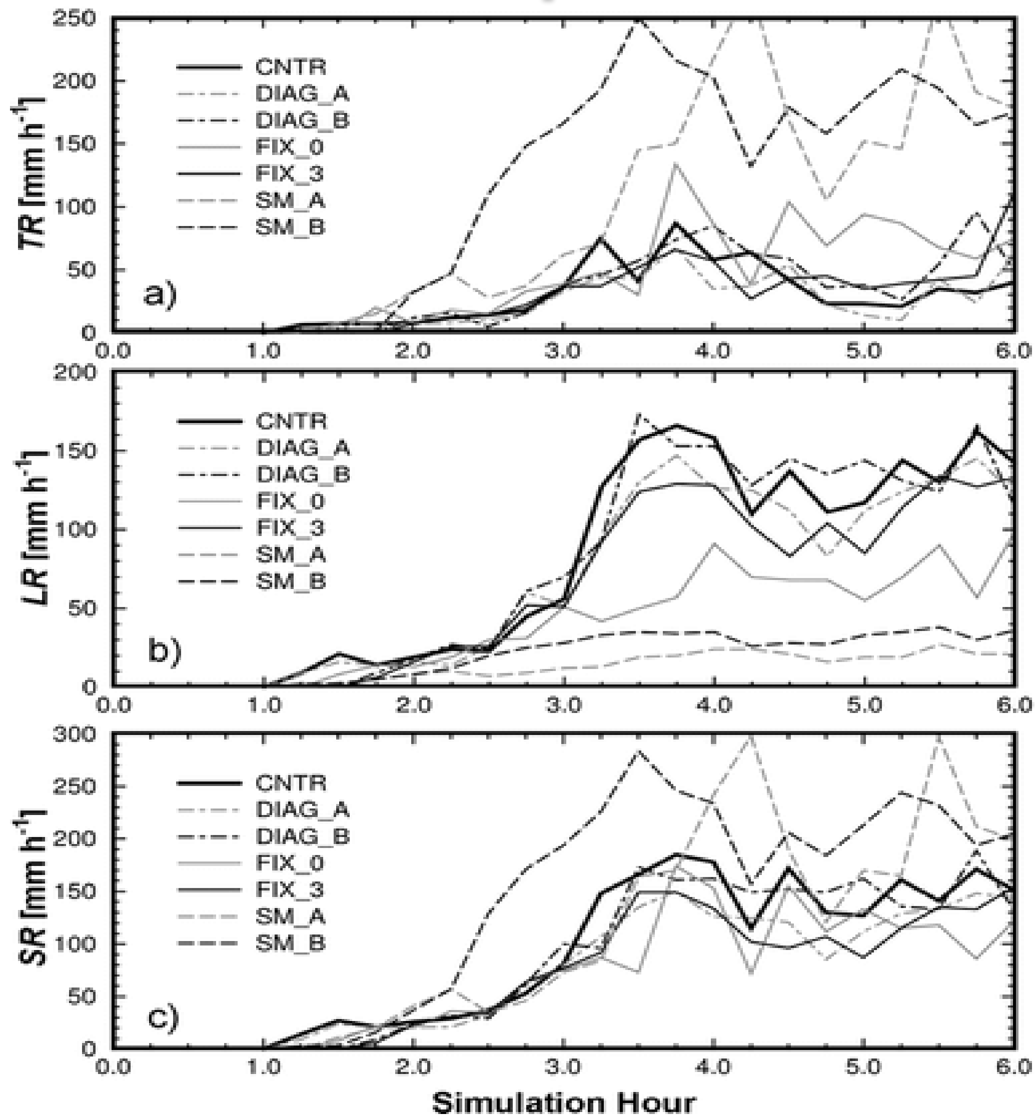
- Quite simply,

  computationally expensive

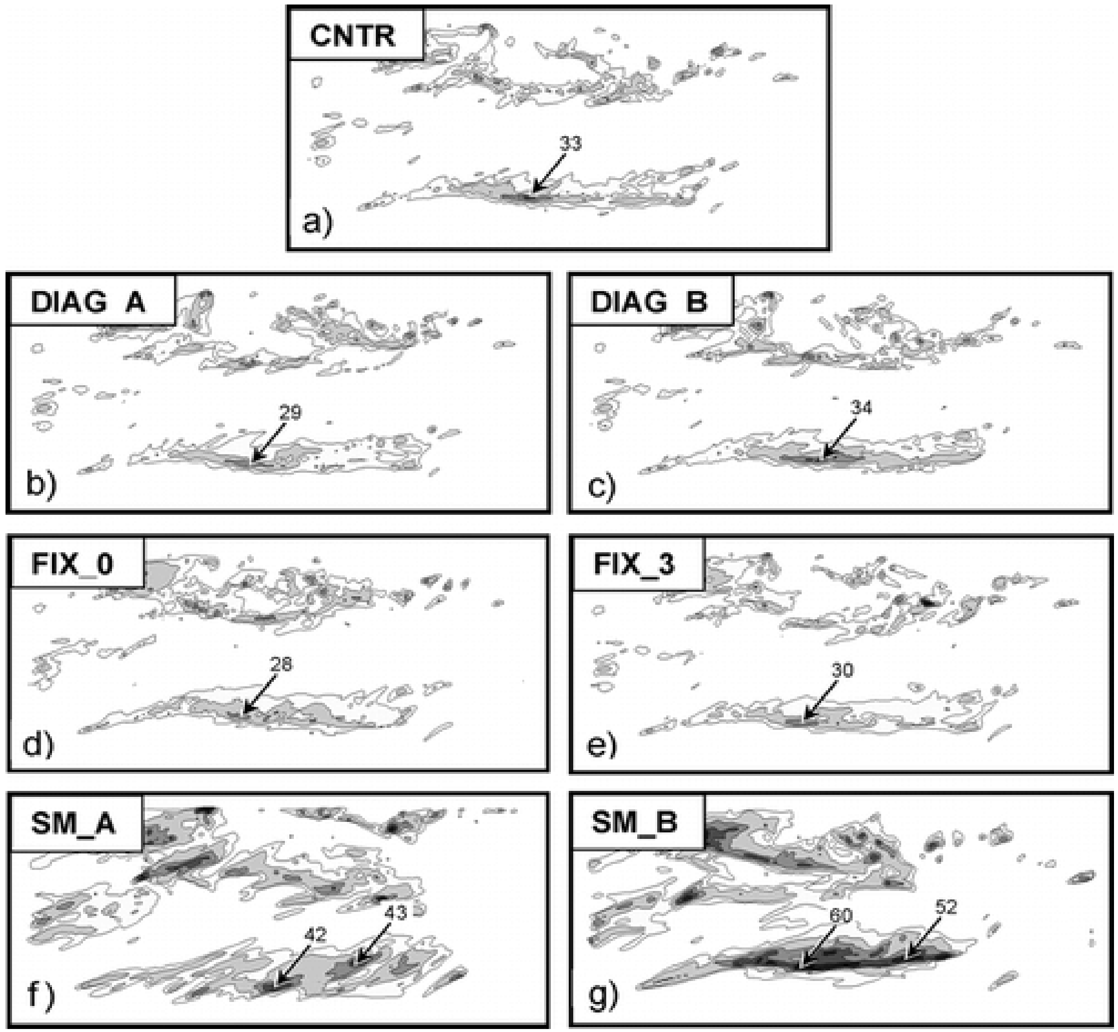
Sensitivity Experiments

- CNTR: 3-Moment (full version)
- DIAG_A: 2-Moment diagnostic ($\alpha \geq 3$)
- DIAG_B: 2-Moment diagnostic ($\alpha \geq 0$)
- FIX_0: 2-Moment fixed ($\alpha = 0$), ($\alpha r = 2$)
- FIX_3: 2-Moment fixed ($\alpha = 3$), ($\alpha r = 2$)
- SM_A: 1-Moment fixed N_{0h}
- SM_B: 1-Moment diagnostic N_{0h}

Maximum Precipitation Rates



6-hr Accumulated Precipitation



Overall Comparison

Reproduced characteristic of CNTR	DIAG_A	DIAG_B	FIX_0	FIX_3	SM_A	SM_B
Total precipitation pattern	✓	✓	✓	✓		✓
Total precipitation amounts	✓	✓	✓	✓		
Liquid/solid precipitation distribution	✓	✓		✓		
Updraft/downdraft		✓		✓		
Mesocyclone intensity	✓	✓		✓		
Storm propagation	✓	✓	✓	✓		
Cold pool strength	✓	✓		✓		
Overall storm structure	✓	✓	✓	✓		
Maximum total reflectivity (Z_e)	✓	✓		✓	✓	
Peak hail mass contents (Q_h)	✓	✓	✓	✓		
Mean-mass hail diameter (D_{mh})		✓				
Maximum hail sizes at surface						

Conclusions

- Milbrandt and Yau introduced a new multimoment scheme
- Includes single-, double-, and triple-moment variations
- Each variation adds a prognostic variable
  - λ – single moment
  - N_{0x} - double moment
  - Z – triple moment

Conclusions

- Triple-moment scheme performed best
  - Uses too much computer power
- Double-moment version outperformed single-moment version
  - Especially when α was diagnosed

Questions

????

References

- Milbrandt, J.A. and M. K. Yau, 2005: A Multimoment Bulk Microphysics Parameterization. Part I: Analysis of the Role of the Spectral Shape Parameter. *J. Atmos. Sci.*, **62**, 3051–3064.
- Milbrandt, J.A. and M. K. Yau, 2005: A Multimoment Bulk Microphysics Parameterization. Part II: A Proposed Three-Moment Closure and Scheme Description. *J. Atmos. Sci.*, **62**, 3065–3081.
- Milbrandt, J.A. and M. K. Yau, 2006: A Multimoment Bulk Microphysics Parameterization. Part III: Control Simulation of a Hailstorm. *J. Atmos. Sci.*, **63**, 3114–3136.
- Milbrandt, J.A. and M. K. Yau, 2006: A Multimoment Bulk Microphysics Parameterization. Part IV: Sensitivity Experiments. *J. Atmos. Sci.*, **63**, 3137–3159.
- Warner, T.T., 2011: *Numerical Weather and Climate Prediction*, Cambridge University Press, 526 pp.