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Parameterizations of Microphysics for Mesoscale models: Applications to quantitative precipitation forecasting

Greg M. McFarquhar[1], Jimy Dudhia[2], Henian Zhang[1], and Robert Black[3]

[1]Dept. of Atmospheric Sciences, University of Illinois, Urbana, IL
[2]National Center for Atmospheric Research, Boulder, CO
[3]NOAA/AOML/HRD, Miami, FL

1. Research Goals

Our CAMEX funded research has focused on examining microphysical parameterizations implemented in numerical models, improving them, and obtaining a better understanding of how they affect the structure and evolution of hurricanes in models. This should eventually lead to improved quantitative precipitation forecasts (QPFs) for hurricanes. In particular, our four stated research goals were to 1) improve parameterizations of microphysics for tropical cyclones, 2) incorporate the improved parameterizations into the Penn State/NCAR mesoscale modeling system (MM5), 3) determine the sensitivity of hurricane simulations and precipitation estimates to the representation of microphysics, and 4) evaluate the simulations with observations obtained during CAMEX-4. We have made substantial progress on the first three goals, and plan to compare our simulations against observations in the next year.

2. Past Year Accomplishments

We looked at the theoretical basis for the representation of hydrometeor fall velocities. In mesoscale models, hydrometeors are sorted according to 5 or 6 categories (e.g., cloud water, rain, cloud ice, snow, graupel and possibly hail) and a mass-weighed fall velocity, V_m, is calculated to determine fallout for each hydrometeor classification. We choose to look at V_m first because previous studies indicated that ice phase microphysics, and V_m in particular, can significantly influence the structure and evolution of the storm (e.g., cooling due to melting affects magnitude of downdrafts, which can contribute to formation of new convective rings). The representation of V_m may be related to a common problem found in MM5, namely the overabundance of graupel aloft.

To represent V_m we require information on how the following vary with diameter: the number concentration of each hydrometeor category, N(D); the fall velocity of individual particles, V(D); and the mass of individual particles, m(D). We are preparing a note for submission to *Mon. Wea. Rev*. where we describe a number of issues associated with the representation of V_m, namely that N, V, and m are frequently defined in terms of different diameters (i.e., maximum dimension, melted-equivalent diameter, and area-equivalent diameter). Further, there can be substantial variations and uncertainties in the parameterization coefficients used to describe N(D), V(D), and m(D), and the effects of these uncertainties on model simulations are unknown. Figure 1 shows an example of how a and b coefficients used to describe the fall velocities of individual particles, V(D) = aD^b, vary for graupel; substantial variation in V_m is associated with the variation of these coefficients. Values of a and b currently used in MM5 are designated by a plus sign.

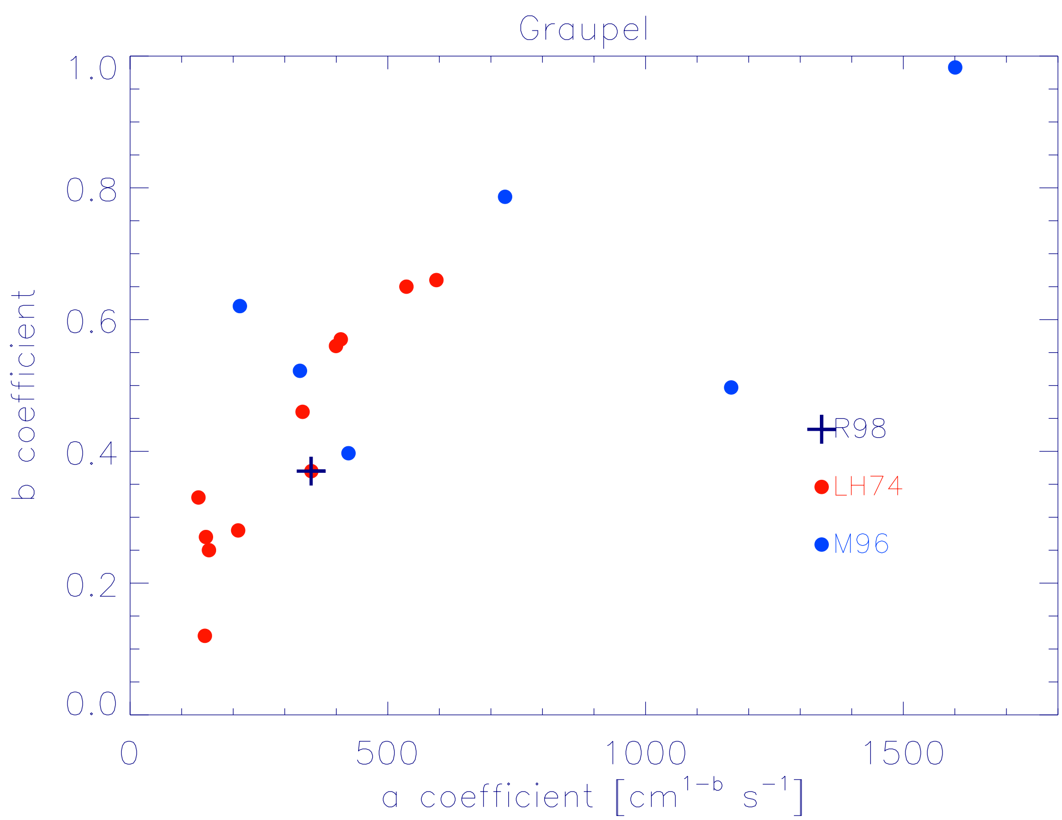

Figure 1: Variation of a and b coefficients used to describe fall speeds of graupel particles, as tabulated by LH74 and M96. Plus sign indicates a and b coefficients used to describe graupel fall speeds in Reisner et al. (1998) scheme of MM5 model.

We also showed that estimates of V_m vary by almost a factor of 2 depending on the intercept parameter, N_0, used to describe exponential size distributions for each hydrometeor classification. Values for N_0 used in current parameterization schemes are mainly based on measurements collected in mid-latitude synoptic and frontal cloud systems; it is not known whether these measurements are appropriate for tropical cyclones. Because of this, we used microphysical data collected in tropical cyclones to determine characteristic hydrometeor size distributions. Figure 2 shows histograms for N_0 describing graupel size distributions, determined using data collected in Hurricanes Tina (1992), Norbert (1984), Emily (1987), and during CAMEX-3. N_0 can vary by over 2 orders of magnitude, and the median value of $1.6 \times 10^7\ m^{-4}$ is larger than the typical value of $4 \times 10^6\ m^{-4}$ used in MM5; similar variations of N_0 for snow were also noted.

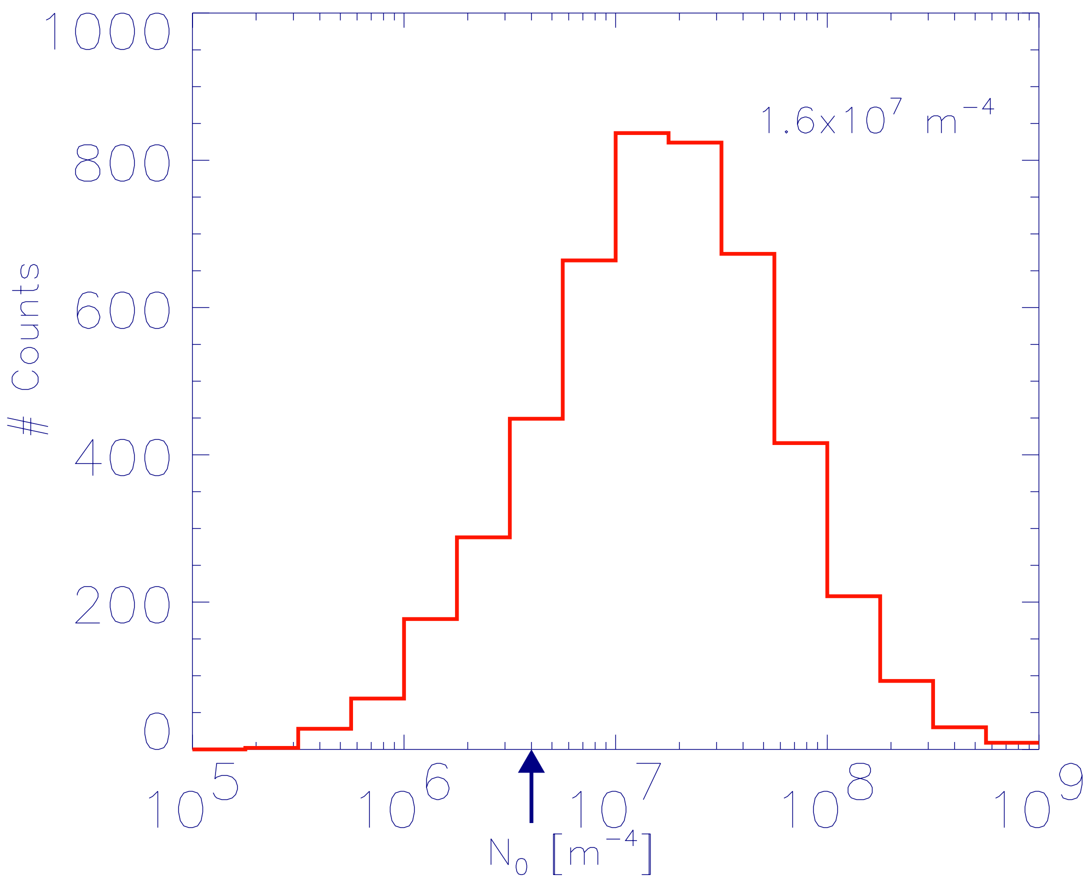

Figure 2: Histograms for intercept of exponential (N_0) characterizing graupel size distributions observed in tropical cyclones. N_0 values represent 5 to 10 s averaged size distributions, and arrow shows N_0 values currently assumed for graupel in MM5 microphysical parameterization scheme.

We also conducted preliminary simulations of Hurricane Erin (2001) using MM5 version 3.4 to estimate the impact of varying microphysical parameters on the structure and evolution of the storm, and on the amount of precipitation falling at the ground. We performed course simulations (27 km resolution) and medium-range simulations (9 km resolution) using data from the National Center for Environmental Prediction (NCEP) to force the model; simulations were started at 0Z on 7 September 2001 and continued until

0Z on 11 September 2001. Our simulations showed that the course simulations were more sensitive to the choice of convective and boundary layer scheme than to the choice of microphysical scheme. However, for 9 km simulations, the distribution of precipitation at the ground did exhibit some sensitivity to parameters that describe particle fall speeds; however, areal averaged precipitation estimates were similar for the different simulations.

3. Future Plans

We will conduct high resolution simulations of Erin with a horizontal resolution of 3 km; at these scales the simulations should exhibit larger sensitivity to microphysics. We will use these 3 km simulations to determine how uncertainties in parameterization coefficients scale up to uncertainties in hydrometeor distributions at different levels in the storm; crucial to this work will be an assessment of which range of coefficient values we feel are most appropriate for representing conditions in tropical cyclones (which we will estimate using microphysical data collected in past hurricanes). We will also continue our investigations with the 9 km resolution simulations, as they may have more immediate impacts for real-time quantitative precipitation forecasts (of course, after it is determined whether these simulations adequately represent the precipitation field).

We will also evaluate our simulations against observations acquired during CAMEX-4. In particular, we will compare simulated reflectivity against that observed by EDOP, PR2, and other instruments. Although AMPR will not provide quantitative estimates of hydrometeor mixing ratios to compare against our simulations, this comparison will help determine whether we have the three-dimensional structure of the storm correct.

4. Expected papers

i) We expect to submit a note detailing the difference in diameters that can be used to describe N(D), m(D), and V(D) in the next couple of months.

ii) We will try to meet the March 2003 deadline for submitting our first paper on the simulation of Erin, detailing sensitivities to various microphysical parameters. Potential authors include G. McFarquhar (PI), Jimy Dudhia (co-I), Henian Zhang (graduate student at Illinois performing simulations), Robert Black (describing microphysics of past hurricanes), Gerry Heymsfield (EDOP data for evaluating simulations), and Robbie Hood (AMPR data for evaluating simulations).