P1.53 HURRICANE OBSERVATIONS OF PARTICLE SIZE AND PHASES AND THEIR IMPLICATIONS FOR MESOSCALE MODELING OF MICROPHYSICAL PROCESSES

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1. INTRODUCTION*

Microphysical processes feed back on the dynamics of tropical cyclones. Willoughby et al. (1984) showed that hurricane simulations with parameterized ice microphysics had a different structure and evolution compared to those with liquid water microphysics. They, together with Lord and Lord (1988) showed that the extent and intensity of mesoscale downdrafts associated with latent heat release is determined by the horizontal advection of hydrometeors from the convection, together with fall speeds of snow and graupel and conversion rates between hydrometeor species.

Here, we examine how the size, density and shape of snow and graupel affects their fallout in hurricanes, and develop better model representations of such processes based on a unique data set acquired near the melting layer in hurricanes. This study is timely because: 1) most current microphysical schemes are based on hydrometeor observations obtained in mid-latitudes, and it is not known whether these adequately represent hurricanes; 2) the basis for such bulk schemes was developed about 20 years ago when coarser resolution models were in use; with finer resolution models, more physical basis can be added to parameterizations, such as the relationship between microphysical properties and updraft strength; 3) observations of tropical cyclones are now available (e.g., Black and Hallett 1986, 1999) making such a study possible.

A new self-consistent strategy for representing fall-out of hydrometeors in mesoscale models is introduced here. In-situ microphysical data obtained in hurricanes are used to examine the nature of snow and graupel size distributions. Differences from mid-latitude size distributions are shown to have significant impacts on the fallout of hydrometeors due to greater numbers of smaller particles than previously hypothesized. A physically based parameterization scheme, where particle size distributions and fall out depend on the vertical air motion, will also be introduced.

2. MODEL REPRESENTATION OF FALLOUT

In bulk parameterization schemes, solid hydrometeors are typically sorted into three categories: snow, graupel and cloud ice. A mass-weighted terminal velocity, V_m, is calculated for snow and graupel since only mass concentrations are prognosed. V_m is obtained by analytic integration, assuming an exponential distribution for number density $N(D)=N_0\exp(-\lambda D)$, a bulk particle density ρ, and a fall speed relation $V(D) = aD^b$, where a, b are obtained from observations (Locatelli and Hobbs 1974; Mitchell 1996).

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Potter (1991) noted an inconsistency in how this integration was performed to calculate V_m for many bulk schemes. Velocities for snow and graupel are typically represented in terms of maximum particle diameter, whereas exponential size distributions are frequently represented in terms of melted equivalent diameter. Further, the bulk density is usually expressed in terms of volume equivalent diameter. In this presentation, we will show that this inconsistency in diameter has a substantial impact on estimates of V_m. We then derive a new parameterization scheme that calculates conversion rates between hydrometeor species using a consistent diameter definition for all terms, such as the conversion of cloud water to snow by riming. As the release of latent heat depends on these mass transfer rates, changes in these schemes may affect hurricane simulations.

Another uncertainty in determining how microphysical processes affect the release of latent heat in hurricanes is determining which a, b coefficients best describe the fall speeds of snow and graupel, and how these depend on the characteristics of a hurricane. Most schemes in the Penn State/National Center for Atmospheric Research mesoscale model (MM5) describe the fall speed of snow particles using relationships observed for unrimed radiating assemblages of plates, side planes, bullets and columns. But, in tropical cyclones, most snow particles exhibit some degree of riming because ice particles begin as rimed particles in convective regions, and then grow somewhat by diffusion in stratiform regions; hence relationships for unrimed radiative assemblages may not be applicable. We will describe how the possible spread of a,b values for hurricanes might impact V_m, and hydrometeor conversion terms. We will also show that step-variations in a,b coefficients, associated with different particle sizes, do not have a large impact on V_m provided that coefficients are chosen in accordance with sizes where the majority of mass occurs.

3. HURRICANE OBSERVATIONS

Formulations of V_m are also very sensitive to the nature of particle size distributions that occur in hurricanes. However, typical meoscale parameterization schemes are based on cloud observations acquired in mid-latitudes and their applicability for tropical cyclones is not known. We investigated this, using cloud observations in hurricanes.

Black and Hallett (1999, and references) describe in-situ observations collected using two-dimensional cloud (2DC) and precipitation (2DP) probes installed on the NOAA P-3 aircraft, which routinely flew radial legs through hurricanes at or just above the melting layer. These probes give size distributions covering sizes between 100 μm and 6.4 mm. We use observations collected in Hurricane Norbert 1984 to represent stratiform areas outside eyewalls since little strong convection was sampled then, and in Emily 1987 to represent unusually strong up and downdrafts documented in the eyewall during its rapidly deepening phase.

Snow and graupel were differentiated according to particle shape, with any presumed ice particle close to circular, defined using measures of image perimeter and area perimeter ratio, called graupel. Mass concentrations were estimated following Black (1990), who determined effective particle densities from regression equations linking radar reflectivity and ice content from airborne radar and in-situ data. Average size distributions for snow and graupel were generated, stratifying by mass content and measured air velocity, with motions less than 1 m s^{-1} identified as stratiform, and other motions as up or downdrafts. Exponential fits to each distribution were determined using a bootstrap technique, to give uncertainty estimates on all parameters.

Figure 1 summarizes the fits, plotting the intercept of the graupel exponential distribution, N_{0g}, as a function of graupel mass content, M_g. Since size distributions were parameterized in terms of melted equivalent diameter, specifying both M_g and N_{0g} gives the slope of the exponential distribution, λ_g. N_{0g} for both up and downdrafts are lower than for stratiform areas, indicating greater numbers of large crystals in these regions; these differences will have a substantial impact on how crystals sediment and on hydrometeor conversion rates.

Substantial differences, especially at high M_g, exist from graupel distributions measured in weak convective systems over southern England (Brown and Swann 1997). A decrease of N_{0g} with M_g in those observations roughly corresponds to a situation with a fixed number of graupel particles with increasing M_g. The hurricane observations correspond to a situation where the total particle number increases with mass content, but in such a way that the average particle size also increases with M_g as seen from the slope of the best-fit line.

Similar trends are found when the intercept of the snow distribution is plotted against mass content, except smaller differences between stratiform and convective regions exist. Substantial differences between hurricane observations and relationships used in MM5, based on observations in mid-latitude systems, still exist. In the presentation, it will be shown that these differences have a big impact on estimates of V_m because of the increased numbers of small crystals in the hurricanes. This in turn affects the conversion rates between hydrometeor categories and the release of latent heat.

4. SUMMARY

Existing parameterization schemes, used in mesoscale models to describe mass transfers between hydrometeor categories, have been modified to ensure that particle diameter is consistently defined for all terms. Using observations acquired near the melting layer in hurricanes, we investigated how varying microphysical characteristics might affect particle fall-out. More physical basis is added by changing the description of size distributions to represent the greater numbers of small particles contained in hurricanes and to differentiate according to different particle characteristics in stratiform and convective regimes. Because the release of latent heat critically depends on particle velocities, these findings may have important ramifications for better understanding microphysical effects on hurricane evolution.

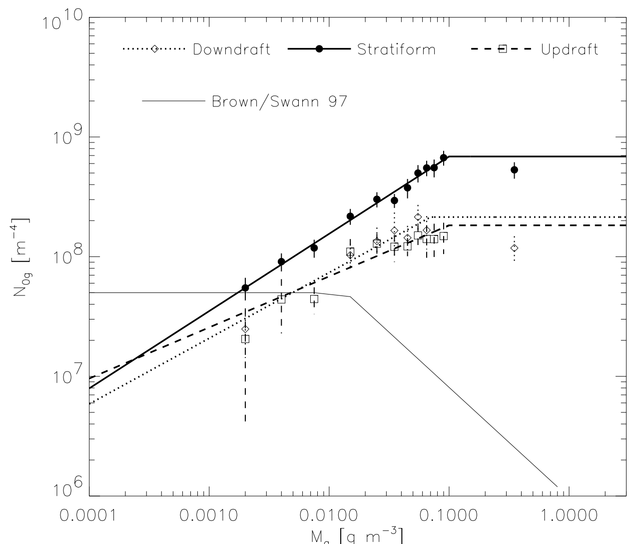

Figure 1: N_{0g} as function of M_g. Different symbols and thick line types correspond to distributions measured in updrafts, downdrafts, and stratiform regions. Thin solid line represents fits to Brown and Swann (1997) observations.

5. ACKNOWLEDGMENTS

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