EMBRYO DIFFERENCES BETWEEN SIMULATED HIGH AND LOW PLAINS HAILSTORMS

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I. INTRODUCTION

Previous observational studies have shown that marked differences exist in the embryo composition of hailstones collected at the ground between hailstorms of the High Plains of Colorado and Lower Plains of Oklahoma. Knight (1981) found a strong relationship between the temperature at cloud base and the collected hail embryo type at the surface. The colder (warmer) cloud bases of the High Plains (Oklahoma) were associated with more hail reaching ground with graupel (frozen drop) embryos. Although Knight postulated why, our study attempts to provide insights to this behavior using a three-dimensional non-hydrostatic cloud model with sophisticated two-moment microphysics.

II. MODEL SETUP

A 10-class two-moment microphysics scheme was used (an early version of the Straka and Gilmore 2008 scheme) that includes two distinct classes of the most common embryo types (frozen drops & graupel) as well as hail. A flow chart of the process rates is included herein (Fig. A1). Frozen drops or graupel become hail for sufficiently large riming of cloud water (following formulas in Straka and Mansell 2005, in bulk form) or when the mass-weighted density of ice riming one of the three rain categories exceeds a threshold density (following Ferrier et al. 1994).

The NCOMMAS model domain was initialized and run with soundings that were taken in close proximity to hailstorms from the High Plains & Oklahoma (see, e.g., Fig. 1). The very low p-values strongly suggest differences in mean sounding values between regions for all but the convective inhibition (CIN; Table 1). The simple thermal bubble method was used for triggering the storm in each case.

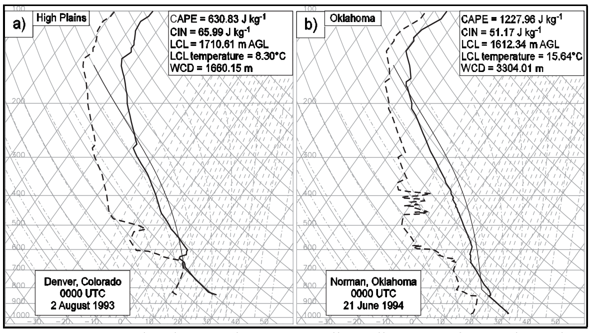

FIG. 1: Example skew-T log-P sounding diagrams for each region. Warm cloud depth (WCD) is that layer between the LCL and freezing.

III. ANALYSIS

In order to determine differences in the mean simulated hail growth behavior between environments, Student's test statistics and p-values were generated for important model and environmental sounding variables. Linear regression was also used to test the presence of and the degree of relationship between model and sounding variables within a single environment and between environments. Transformations were required to normalize some of the data distributions prior to calculating the test statistics.

IV. RESULTS AND CONCLUSIONS

The depth of the cloud layer between the cloud's base and freezing level (the WCD) is directly correlated to the total production of warm rain mass by the storm (Fig. 2). It is more physically meaningful than using the LCL temperature. The total mass flux of rain upward through the freezing level is proportional to both the total warm mass rain produced (not shown), and the environmental CAPE (Fig. 3a). A larger flux of rain corresponds to more frozen drops produced (not shown) and consequently more hail with frozen drop embryos (Fig. 3b). Because the rain mass flux values are generally higher in Oklahoma (owing to larger CAPE and warm rain production), this likely explains why more hail from frozen drops are produced in Oklahoma storms compared to High Plains storms.

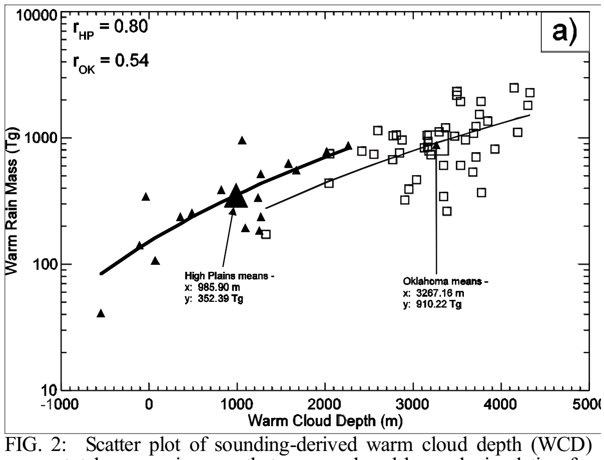

FIG. 2: Scatter plot of sounding-derived warm cloud depth (WCD) versus total warm rain mass that was produced by each simulation for both High Plains (triangles) and Oklahoma (open squares) storms. The large symbols signify distribution means. Linear regression lines are curved due to the chosen plotting method and due to a required data transformation. Correlation coefficients are also given.

Parameter	Mean of 29 High Plains cases	Mean of 101 Oklahoma cases	p-value for difference in means
CAPE (J kg^{-1})	656	1319	<.0001
CIN (J kg^{-1})	62	55	0.2
LCL (m)	1930	1319	<.0001
LCL T (°C)	5	15	<.0001
WCD (m)	1044	3133	<.0001

TABLE 1: Means proximity sounding parameters and the probability of falsely declaring the means of the distributions as distinctly different.

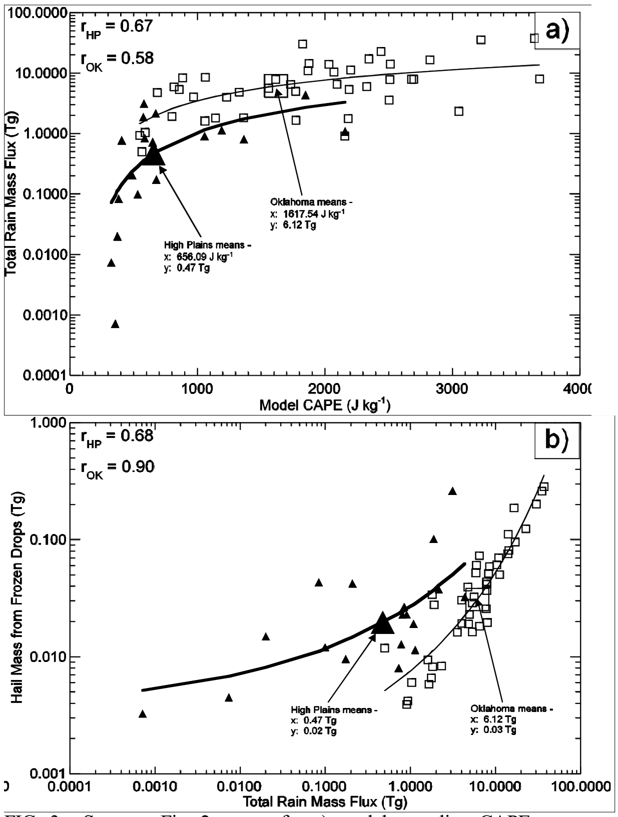

FIG. 3: Same as Fig. 2 except for a) model sounding CAPE versus simulation total rain mass flux through the freezing level and b) simulation total rain mass flux through the freezing level versus simulation total hail mass production with frozen drop embryos.

One drawback of the current work, however, is that the embryo history is lost due to only having a single hail category. That is, we cannot tell whether the greater hail production from frozen drop embryos in the simulated Oklahoma storms actually reach ground in similar proportion. In future work, it will be important to use a microphysics scheme with a separate hailstone categories for each dominant embryo type so that the amount and size of those hailstones can be followed to the ground. This may allow an understanding of why hailstones with frozen drop embryos are observed to reach ground with a larger size than those with graupel embryos (e.g., Knight 1981).

V. ACKNOWLEDGMENTS

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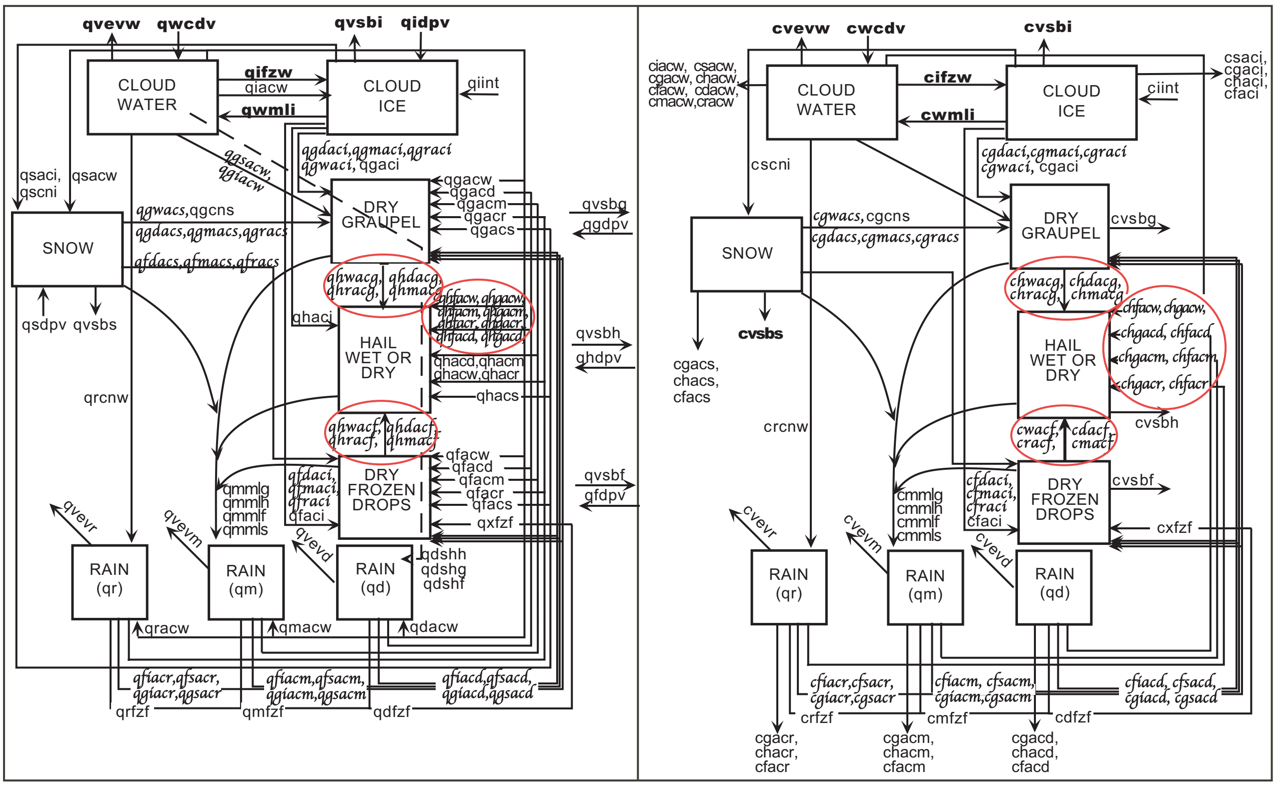

FIG A1: Flow chart of mixing ratio transfers (left panel) and number concentration transfers (right panel) between the 10 different microphysics species used in this study. There are five ice categories: cloud ice (i), snow (s), graupel (g), frozen drops (f), and hail (h). There are three rain categories: warm rain (r) melt water (m) and shed water (d). Sinks in number concentration do not necessarily have a corresponding source term. The rate naming convention is such that the second letter in the name always represents the gaining species and the last letter represents the loss species. Italicized 6-letter rates indicate three-body interactions whereby certain riming criteria are satisfied such that mass is transferred from two different categories to a third species; circled in red are those rates where riming graupel or frozen drop embryos become hail. See the appendix of Gilmore et al. (2004) for more on the naming convention.