EXPLORING THE RELATIONSHIP BETWEEN SATELLITE-RETRIEVED ICE CRYSTAL SIZE AND THUNDERSTORM INTENSITY

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I. INTRODUCTION

Since the launch of the first geostationary satellites in the 1970's, scientists have attempted to utilize the excellent temporal resolution to study the evolution of thunderstorms (e.g., Purdom 1976). In the 1990's, the addition of a shortwave infrared band allowed for estimates of shortwave infrared reflectance, which can be used to retrieve cloud-top particle size (Nakajima and King 1990). More recently, some studies have suggested that satellite-retrieved cloud-top water droplet and ice crystal size may provide information about thunderstorm updraft strength (e.g., Rosenfeld and Lensky 1998; Lindsey et al. 2006).

A GOES-East climatology of ice crystal effective radius was provided in Lindsey and Grasso (2007), and is shown here as Fig. 1. Average summertime ice effective radius values are significantly smaller in the High Plains and Rocky Mountain region of the U.S. compared to the Eastern part of the country. Lindsey et al. (2006) hypothesize that the primary reason for this difference is related to average thunderstorm cloud base height. Storms with higher cloud bases (such as those often found in the relatively dry High Plains) tend to generate a large number of small cloud droplets which freeze homogeneously before growing to more appreciable sizes.

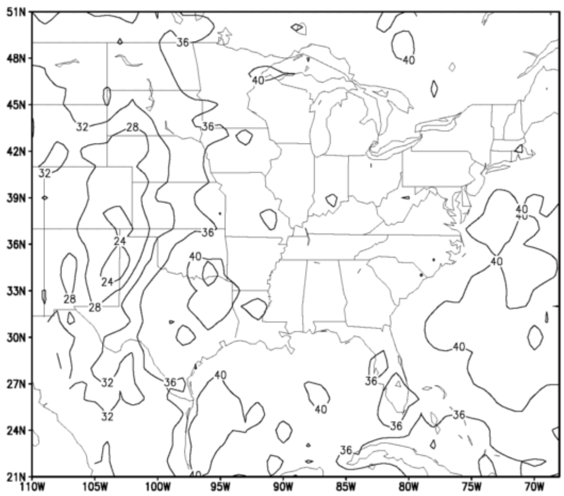

FIG. 1: Mean effective radius (μm) of ice clouds from a) GOES-East and b) GOES-West, during May, June, July, and August of 2000, 2003, and 2004, when the solar zenith angle was less than 68˚. From Lindsey and Grasso (2007).

Fig. 2 shows a result from Lindsey et al. (2006): mean soundings from a statistical composite analysis of clouds with relatively small ("reflective") and large ("non-reflective") ice crystals. Notice that the temperature lapse rate is greater for the small crystal storms; this suggests that more storms in more unstable environments tend to generate smaller cloud-top ice crystals.

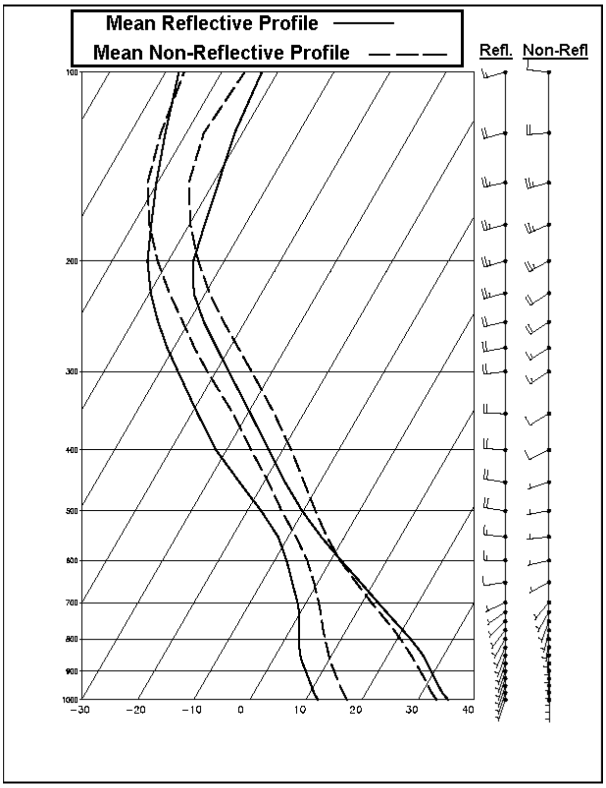

FIG. 2: Mean temperature (right) and dewpoint (left) profiles for the reflective (solid) and non-reflective (dashed) cases, along with mean wind profiles, plotted on a traditional skew-T/log-p diagram. A full wind barb represents 10 knots. From Lindsey et al. (2006).

The goal of this study is to find a physical mechanism to explain the statistical results shown in Fig. 2, and to determine whether a satellite measurement of ice crystal size contains any information about thunderstorm updraft strength.

II. METHODOLOGY

Since detailed observation of internal thunderstorm processes is essentially impossible, it is necessary to pursue alternate methods of understanding the link between storm dynamics and microphysics. Thus far, we have made use of two different numerical models: a one-dimensional parcel model and a three-dimensional cloud-resolving model.

The parcel model is that used in Heymsfield et al. (2005) - it allows for cloud droplet and ice growth, as well as homogeneous nucleation. Its major advantage is that cloud droplets and ice crystals are represented in 1-µm bins, so assumptions about size distributions are not necessary. Limitations include no droplet growth by collision-coalescence and no heterogeneous nucleation. The effects of ice on water vapor and cloud droplet depletion in the mixed-phase portion of the cloud is represented by using a model addition discussed in Heymsfield et al. (2005). Using this parcel model, we can vary the cloud base height and updraft strength, and examine the evolution of cloud droplet and ice crystal concentration and sizes.

The second model used in this study is the Regional Atmospheric Modeling System (RAMS). It is a non-hydrostatic 3-D cloud-resolving model, with explicit 2-moment bulk microphysics (Saleeby and Cotton 2004). This version of RAMS microphysics package predicts the mass mixing ratio and number concentration of 7 hydrometeor types, including cloud water. We will be performing idealized model runs in which we initialize the model domain with a uniform vertical sounding and release a warm bubble to initiate deep convection. By altering the initial sounding, storms with low and high cloud bases can be simulated, and by adjusting the temperature lapse rate, the strength of the storms can be varied.

III. Results and Conclusions

Fig. 3 shows an early result from the Heymsfield homogeneous nucleation model. Two cloud parcels were released, one at 16 ˚C (low base) and one at -6 ˚C (high base). Each of these runs was repeated for updraft speeds of 10 m/s and 30 m/s. Cloud droplet mean diameter increases as each parcel rises, then homogeneous nucleation commences near -35 ˚C. Droplets in the low base runs grow appreciably larger than in the high base case, and after homogeneous nucleation, the low base ice crystals are significantly larger than in the high base case (not shown). It is also noteworthy that there is virtually no sensitivity to updraft strength. Whether this is an artifact of the model's limitations (listed above) is not known. Additional model results will be performed and shown in the full version of this paper.

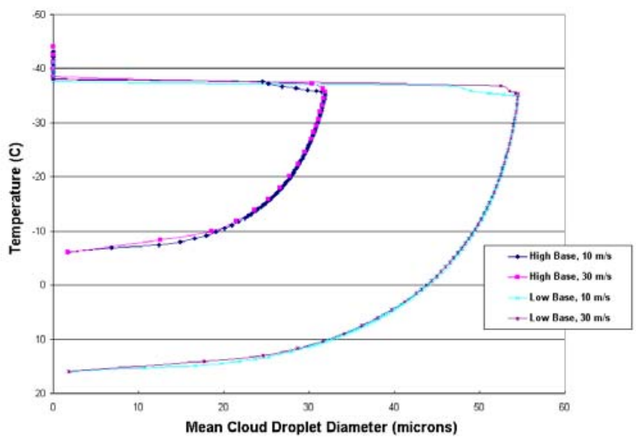

FIG. 3: Results from the parcel model. Four experiments are plotted: 2 with updraft speeds of 30 m/s with cloud bases at -6 ˚C and 16 ˚C, and 2 with updraft speeds of 10 m/s with the same cloud bases. The mean cloud droplet diameter (in µm) is plotted as a function of temperature (˚C). Pre-existing ice is not used in these runs.

Runs are currently being performed with RAMS, but at the writing of this abstract, the results are too preliminary. It is anticipated that the treatment of collision-coalescence and riming in RAMS will be sufficient to expand on the results of the Heymsfield homogeneous freezing model.

IV. AKNOWLEDGMENTS

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