SATELLITE DETECTION OF SEVERE CONVECTIVE STORMS BY THEIR RETRIEVED VERTICAL PROFILES OF CLOUD PARTICLE EFFECTIVE RADIUS AND THERMODYNAMIC PHASE

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(Dated: April 27, 2007)

I. INTRODUCTION

A new conceptual model is presented that facilitates the inference of the vigor of severe convective storms producing tornadoes and large hail, using satellite-retrieved vertical profiles of cloud top temperature (T) – particle effective radius (r_e) relations. The driving force of these severe weather phenomena is the high updraft speed, which can sustain the growth of large hailstones and provide the upward motion that is necessary to evacuate the violently converging air of a tornado. Stronger updrafts revealed by the delayed growth of re to greater heights and lower T, because they leave less time for the cloud drops to grow by coalescence. The strong updrafts also delay the development of mixed phase and eventual glaciation to colder temperatures. Analysis of case studies making use of these and related criteria show that they can be used to identify clouds with sufficiently strong updrafts to possess a significant risk of large hail and tornados, although the strength and direction of the wind shear probably will prove to be major modulating factors. It is observed that the severe storm T-r_e signature is an extensive property of the clouds that develop ahead in space and time of the actual hail or tornadic storm, suggesting that the probabilities of large hail and tornados can be obtained at lead times of 1-2 hours. Such an application will require using retrieved microstructure from geostationary satellites. Their temporal coverage can make up to some extent for their poor spatial resolution. This extended abstract contains selected parts of the full paper of Rosenfeld et al. (2007).

II. A CONCEPTUAL MODEL OF SEVERE STORM MICROPHYSICAL SIGNATURES

The vertical evolution of cloud top particle size can be retrieved readily from satellites, using the methodology of Rosenfeld and Lensky (1998) to relate the retrieved effective radius (r_e) to the temperature (T) of the tops of convective clouds. The T-r_e relations are obtained from ensembles of clouds having tops covering a large range of T. This methodology assumes that the T-r_e relations obtained from a snap shot of clouds at various stages of their development equals the T-r_e evolution of the top of an individual cloud as it grows vertically. This assumption was validated by actually tracking such individual cloud elements with a rapid scanning geostationary satellite and comparing with the ensemble cloud properties (Lensky and Rosenfeld, 2006). Based on the shapes of the T-r_e relations (see Fig. 1), Rosenfeld and Lensky (1998) defined the following five microphysical zones in convective clouds: (1) Diffusional droplet growth zone; (2) Droplet coalescence growth zone; (3) Rainout zone; (4) Mixed phase zone; (5) Glaciated zone. All these microphysical zones are defined only for convective cloud elements. Multi-layer clouds start with small re at the base of each cloud layer. This can be used to distinguish stratified from convective clouds by their microstructure. Typically, a convective cloud has a larger r_e than a layer cloud at the same height, because the convective cloud is deeper and contains more water in the form of larger drops.

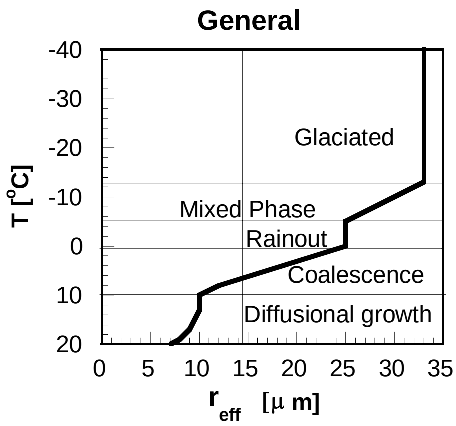

Figure 1: The classification scheme of convective clouds into microphysical zones, according to the shape of the T-r_e relations (after Rosenfeld and Woodley, 2003). The microphysical zones can change considerably between microphysically continental and maritime clouds, as illustrated in Fig. 6 of Rosenfeld and Woodley, 2003.

A highly microphysically continental cloud with a warm base (e.g., >10°C) has a deep zone of diffusional cloud droplet growth even for weak updrafts (Fig. 2). The onset of precipitation is manifested as the transition to the mixed phase zone, which occurs at progressively greater heights and colder temperatures for clouds with stronger updrafts. The glaciation temperature also shifts to greater heights and colder temperatures with increasing updrafts. From the satellite point of view the cloud is determined to be glaciated when the indicated r_e reaches saturation. This occurs when the large ice crystals and hydrometeors dominate the radiative signature of the cloud. Some supercooled water can still exist in such a cloud, but most of the condensates are already in the form of large ice particles that froze heterogeneously and grew by riming and fast deposition of water vapor that is in near equilibrium with liquid water. Such was the case documented by Friedland et al. (2004) in convective clouds in Florida, where satellite-retrieved T-r_e relations indicated a glaciation temperature of -29°C (not shown).

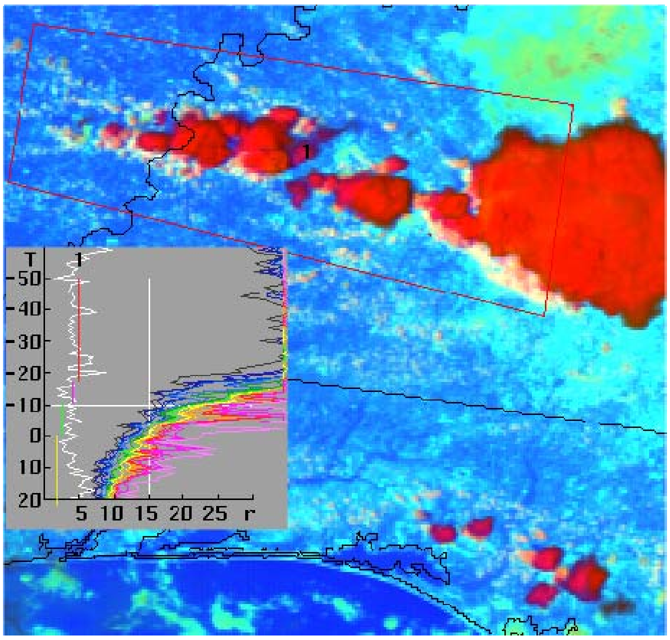

Figure 2: A T-re analysis for a non-severe convective storm. The image is based on the NOAA-AVHRR overpass on 28 July 1998, 20:24 UTC, at a domain of 232x222 AVHRR 1-km pixels. The cloud system is just to the north of the Florida Panhandle. Note the rapid increase of re towards an early glaciation at -17°C.

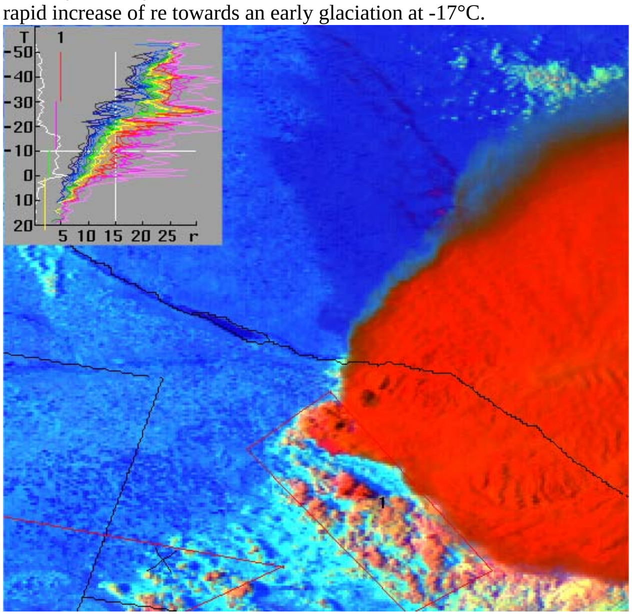

Figure 3: A T-r_e analysis for a tornadic storm with 4.5 inch hail. The image is based on the NOAA-AVHRR overpass on 29 June 2000, 22:21 UTC, at a domain of 282x264 AVHRR 1-km pixels. The cloud occurred in southwestern Nebraska. The locations of a reported F1 tornado at 23:28 is marked by X. Note that the tornado occurred in a region that had little cloud development 68 minutes to the tornadic event. This demonstrates that there is predictive value in the cloud field before any of the clouds reach severe stature. A hail swath on the ground can be seen as the dark purple line emerging off the north flank of the storm, oriented NW-SE. Two hail gushes are evident on the swath near the edge of the storm. The precipitation swath appears as darker blue due to the cooler wet ground. Note the linear profile of the T-r_e lines, and the glaciation occurs at the small r_e=25 µm, in spite of the very warm cloud base temperature near 20°C.

Further invigoration of the clouds would shift upward the onset of mixed phase and glaciated zones. But glaciation occurs fully and unconditionally at the homogeneous freezing temperature of -38°C (Rosenfeld et al., 2006). Any liquid cloud drops that reach to this level freeze homogeneously to same-size ice particles. If most cloud water was not rimed on ice hydrometeors, it would have a radiative impact on the retrieved effective radius and so greatly decrease the r_e of the glaciated cloud. Yet additional invigoration of the updraft would further shift upward and blur the onset of the precipitation, and reduce the r_e of the glaciated cloud above the -38°C isotherm, until the ultimate case of the most extreme updraft, where the T-r_e profile becomes nearly linear all the way up to the homogeneous freezing level. This situation is illustrated in Fig. 3. Examples of T-r_e lines for benign, hailing and tornadic convective storms are provided in Figs. 2 and 3. It is remarkable that the T-r_e relations occur not only in the main clouds, but also in the smaller convective towers in the area from which the main storms appear to propagate (see fig. 3). This means that the potential for severe storms can be revealed already by the small isolated clouds that grow in an environment that is prone to severe convective storms when the clouds are organized. Based on the physical considerations above it can be generalized that a greater updraft is manifested as a combination of the following trends in observable T-r_e features:

- Glaciation temperature is reached at a lower temperature;
- A linear T-r_e line occurs for a greater temperature interval;
- The r_e of the cloud at its glaciation temperature is smaller.

These criteria can be used for identifying clouds with sufficiently strong updrafts to possess a significant risk of large hail and tornados. The feasibility of this application is examined in the next section.

The T-r_e relations of a large data set was parameterized and analyzed for skill of detecting hail and tornadic storms. The results show a predictive skill of 2 hours that is better than the standard conventional methods.

III. REFERENCES

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