Exploring the Role of Super Cold Water Within A Severe Hailstorm

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**Cover Photographs Courtesy of: Charlie Knight, Nancy Knight, and the NCAR Photography Dept.
ABSTRACT

The region of supercooled water within a storm system is presently not well understood. However, beginning with the atmospheric technology explosion of the mid 20th century, new instruments have been developed almost daily. This rapid growth is drawing the field of science one step closer to fully understanding topics such as supercooled water. Understanding some of the characteristics such as the location, nature and behavior of the supercooled water particles within a storm region will be the general focus of this paper.

INTRODUCTION

With over seventy percent of the earth's surface being composed of water, there are not too many processes that occur, either man-made or natural, that do not involve this compound. Hailstorms are no exception. The various particulate matter that falls from the clouds is usually water in one of its three fundamental states. Within the clouds, however, unusual transformations take place. One of those transformations is the process of supercooling which affects a specific region in a storm system. The water in this region changes temperatures falling below the freezing point without actually freezing. The name given to this water is supercooled water. The focus of this paper is the contributions made by the region of supercooled water to a storm system. In addition, various particle sizes and paths will also be identified and discussed.

INSTRUMENTS

In this study of supercooled water, instruments ranging from airborne samplers to ground based radar were used. Only the most frequently
used instruments will be discussed (See Table 1 for specifics on some instrumentation). A separate description of each will follow in this section.

Table 1:

<table>
<thead>
<tr>
<th>Sample Variable(s)</th>
<th>Instrument</th>
<th>Range</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal Cloud Water and Droplets</td>
<td>Johnson-Williams Liquid Water Concentration</td>
<td>0 - 6 g/m²</td>
<td>+/- 20%</td>
</tr>
<tr>
<td>Precipitation Particle Sizes and Concentrations</td>
<td>Williamson Foil Impactor</td>
<td>1 - 20 mm</td>
<td>0.2 mm</td>
</tr>
<tr>
<td></td>
<td>PMS, Inc. 2-D Cloud Probe</td>
<td>Size 25 - 800 µm</td>
<td>+/- 25 µm</td>
</tr>
<tr>
<td></td>
<td>Hail Spectrometer</td>
<td>Size 4.5 mm - 4.5 cm Concentration 0 - 100/ m³</td>
<td>+/- size class</td>
</tr>
<tr>
<td>Aircraft Tracking</td>
<td>Trimble TNL3000 GPS/LORAN</td>
<td>Planet Earth</td>
<td>30 m</td>
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</table>

The T-28 Aircraft

For years now, various aircraft have been used to collect weather data. Helicopters are used to hold stationary positions while observing severe weather from a distance. The pictures and visual observations that are obtained can be very helpful. High altitude reconnaissance planes such as the ER-2 and the SR-71 are equipped with high resolution long-range cameras in order to take overhead views of storm complexes. This data further assists researchers in helping to understand storm dynamics. The data obtained for this paper came primarily from a modified T-28 aircraft. Owned and operated by the South Dakota School of Mines and Technology (SDSM&T), the armor coated T-28 aircraft traveled through various storm centers. While passing through the storm centers; hail, rain, snow,
and graupel were all encountered. For the propose of both short-term and long-term analysis, instruments were attached to the T-28 aircraft itself. Some of those were as follows: the Williamson Foil Impactor, the Hail Spectrometer, and the 2-D Cloud Probe. All of these instruments will be described later. The research flights in this particular study were under the direction of NCAR scientists at the NCAR Foothills Laboratory in Boulder, Colorado (Detwiler et al, 1993).

The Williamson Foil Impactor

The Williamson Foil Impactor is used to calibrate airborne particle sizes within severe storms. The device operates by exposing a roll of aluminum foil through a 38 X 38 μm opening. The aluminum foil roll scrolls across this open window at a rate of 38 mm per second (Walsh 1993). The Williamson Foil Impactor hangs from the aircraft (in this case the SDSL T armoured T-28) recording data when activated by the on board crew. The impactor is generally turned on only when the aircraft enters the clouds associated with the storm complex. While inside the clouds, the Williamson Foil Impactor records the impressions of drops that actually strike the foil (fig. A). Behind the foil roll is a calibrated drum that leaves small indentations on the foil when the drop strikes it. These indentations represent the drop images. Each indentation is exactly 250 μm apart. At the time of analysis, the number of indentations can be counted for an approximation of the drop size. The difficult part of the analysis arises in the actual determination of what each drop represents. Only with practice and a trained eye can one discriminate images on impacted foil.

The Hail Spectrometer

Providing data for approximately twenty-five years, the Hail Spectrometer probe measures hail particle sizes. The general range of measurement is usually those particles between 0.45 and 4.5 cm in diameter. This
probe is attached to an aircraft and records data as the plane moves through storms. The probe operates by using a method known as the optical array method. The optical array method basically deploys a high intensity laser beam to produce an image. Particle sizes are determined from the portion of the beam blocked out by precipitation particles. All of the data, upon collection, is grouped together into various size arrays for post analysis. The benefits of this probe have been, and still are very numerous. The instrument, unlike airborne drop samplers such as the Williamson Foil Impactor, requires no tedious post hand analysis. All of the sampled data is stored in an array as it is collected.

The 2-D Cloud Probe

The intricate 2-D Cloud Probe is manufactured in Boulder, Colorado by Particle Measuring Systems Inc. The 2-D Cloud Probe works on a principal similar to the Hail Spectrometer. Utilizing the optical array method, this probe stores data into either a 32-element or 64-element array. The two dimensional data is extremely helpful when trying to determine what type of particles are in a particular storm system. The major difference between this airborne sampling probe and the Hail Spectrometer probe is that the 2-D Cloud Probe only measures particles that range in size from 25 to 800 μm. This provides a fair range and also makes up for the very small particles that might be missed by one of the other probes. Each probe greatly assists scientists in helping to understand the microphysics of the atmosphere.

RADAR

Arriving on the scientific scene in the 1940's, radar technology has been a major contributor of information through the years. Since it emits pulsed energy, radar allows one to see imposing weather threats from a
measured distance. Just recently, Doppler radar has been gradually replacing the more conventional radar units. For this particular study, two different kinds of Doppler radar were used. Each is described below.

The CP-2 Radar

NCAR maintains and controls the CP-2 Radar System. Housed in a Radome and presently located in Marshall, Colorado, the CP-2 Radar is a multi-parameter Doppler radar system. The CP-2 operates at both X- and S-band wavelengths. At X-band 3 cm wavelength, there are separate vertical and horizontal antennas. In contrast, the S-band obtains its dual components with just a single antenna operating on the 10 cm wavelength. Some of the many advantages of Doppler radar are that it measures both horizontal and vertical wind components, internal structural features such as severe rotations (i.e. possible tornadoes), and provides for a trajectory analysis of data to be performed. Because of its multiparameter capabilities, the CP-2 radar is capable of determining the following: Differential Reflectivity ($Z_{DR}$), Linear Depolarization Ratio ($LDR$), Dual-Wavelength Ratio ($DWR$), and Horizontal Polarization Reflectivity ($Z_{H}$) (fig. B). The DWR data and Doppler capabilities place the CP-2 radar a step above other research radar systems. The afore mentioned parameters assist scientists in determining the structure and microphysical properties of any nearby imposing weather threat.

The Mile High Radar

In addition to the above radar system, NCAR operates the Mile High Radar (MHR) System. Presently located about 15km away from Colorado’s Stapleton International Airport, the MHR provides complete coverage of both the airport and front range mountain regions (Pratte, et al 1985). Like most modern day radar units, the MHR system is capable of measuring both radar reflectivity (fig. C) and radial velocity wind compo-
nants (fig. D). It contains only one antenna and operates at the 10cm wavelength. Although human operators monitor the MHR's daily activities, ordinarily control is left to, "general-purpose 680 X 0 microcomputers, a programmable floating-point signal, and two small workstation computers (Pratte, et al 1985)." Presently, the data that is obtained from the MHR is used by several different organizations including the Research Applications Program at NCAR, the Forecast Systems Laboratory of NOAA, the United States Federal Aviation Administration (FAA), and the United States National Weather Service (NWS). Since the radar is located in a relatively close position to the airport, the FAA is generally able to combine this radar information with Stapleton's own radar data to help facilitate air traffic without many problems. When Denver International Airport opens (in mid to late December of 1993), it will most likely utilize radar data from the new NEXRAD (WSR-88D) Radar system in addition to its own ground based radar. Chances are good that the MHR system will provide research datasets on a continuing basis.

**ANALYSIS**

Because each particular piece of hardware has something to offer, the best analysis can only be performed using as many of them as possible. The various instruments and radar described above provide a firm base to begin an analysis.

The first order of business was to identify the track that the aircraft (armored T-28) flew (fig. 1). This was very important in order to determine what type of particles were falling and possibly in what manner and where they were falling. After obtaining this information, the CP-2 and MHR systems provided an ample clue as to where the supercooled water might be located. This was done using the ZDR scan (fig. 2). By analyzing this data, it can be determined that the values of zero indicate probable hail outflow locations. And by the same token, those values closest to zero
without actually being zero represent regions of supercooled water. With a general idea of where to look, attention was focused on the data obtained by the airborne samplers.

Providing an actual imprint of an airborne particle, the Williamson Foil Impactor contains the most conclusive evidence of supercooled droplets within the region identified by the $Z_{DR}$ radar scan. The impactor also provides detailed information relating to other airborne particles including: hail, graupel, and snow (fig. 3). [Table 2 is a Key to reading the information found in figure 3] *Note: The concentration values represent millimeter (mm) sized particles- i.e. C5 represents a 5 mm particle, C11 represents an 11 mm sized particle]. Here actual particle sizes and concentra-

<table>
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<th>Figure 3 Time(sec) Values</th>
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tions were obtained. To verify that this data was indeed correct, data obtained from the two optical devices (the Hail Spectrometer and the 2-D Cloud Probe) was compared. All seemed to indicate relative particles in similar time regions. In addition, another airborne in situ sampler was compared and showed similar results (fig. 4). This probe displays frozen precipitation on the last row, and liquid water (including supercooled water) on the row just above the last. By examining this probe and comparing it with the data obtained from the Williamson Foil Impactor, it can be seen that the “peak” values appear in the same general time frames.

Upon examination of various $Z_{\text{DR}}$ scans, it is clear that regions of supercooled water tend to exist within all types of severe storms. This even holds true for storms of varying seasons. With the confirmation of the presence of supercooled water, the next step was to determine its function in a storm. The radar data once again proved very useful. By utilizing both the CP-2 and the MHR data, a Dual-Doppler analysis was performed. This analysis allowed not only a constant altitude planned position indicator (CAPPI) to be generated (fig. 5), but also a vertical cross-section of the main storm complex (fig. 6). This helped determine what exactly happened within the storm. The CAPPI and its vertical cross-section were taken at a height of about 4 km. This was very close to where the T-28 aircraft was flying. The cross-section indicated that there was a strong amount of convergence (or rising motion) at lower levels of the storm. A low-level convergence zone tends to extend the life of supercooled water. Extended life of water at some temperature below 0° Celsius, occurs when strong updrafts create continued movements. This motion prevents the water from undergoing the process of crystallization to form ice (resulting in either graupel or hail). It is true that similar supercooled water, in other regions of the
storm, will act as the embryo for hail or graupel particle growth. Because of being surrounded by these strong updrafts, a "Recirculation Process" occurs. The Dual-Doppler analysis also indicated that within this Recirculation Process, it is likely that a fair amount of supercooled water droplets will in fact serve as embryos for the synthesis of either hail or graupel. Various concentrations for corresponding time periods in Figure 3 concur with this finding.

The final step of analysis involved a projection of where exactly particles will fall once generated in a storm complex. Following Newton's laws of gravity, the larger particles will tend to fall directly beneath where they are being formed. Taking into account the updrafts, downdrafts and cross-winds present within a severe storm, this location will generally be in an area behind the storms direction of travel. With present technology, determining a post analysis of where particular particles might fall would not be that hard. The difficulty arises when one attempts to predict where particles will fall as the storm is alive and progressing. In addition, if the storm is a multi-celled severe storm, then it will have more than one region where particles form and are discharged to the earth. Some isolated weak cells help contribute to an even more dangerous outflow in another location as the particles within them become part of the Recycling Process. With this knowledge, detection of the internal structure of various storms becomes more and more important. Only with active knowledge of various regions within a storm, as it is progressing, can one accurately identify locations of particle outflow.

CONCLUSION

Each day, the job of accurately predicting the weather becomes increasingly important. Not only for agencies such as the FAA and the NWS, but small underdeveloped countries and insurance agencies also need to know what type of weather will take aim on their villages, houses,
automobiles, etc. Accurate prediction of severe storms will also aid in preventing countless deaths and in the reduction of property damage costs in the years to come. What was described above relating to supercooled water was only a brief synopsis. Fully understanding this very unique feature within severe storms will help in precise detection of storm outflows and in the determination of precipitation intensity. Hopefully the determination of particle types can be accomplished while a storm is occurring, and will not just be available for post analysis. Severe storm microphysics is extremely complicated and a great deal of future research needs to be focused in this area.

ACKNOWLEDGEMENTS

I would like to say “THANKS FOR ALL YOUR HELP” to the following people who appear in Table 3:

Table 3:

<table>
<thead>
<tr>
<th>Advising/Knowledge/</th>
<th>Computer Related</th>
<th>Writing/Editing</th>
<th>Opportunity/Information/Support</th>
<th>Graphics/Photography</th>
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<tr>
<td>Ed Brandes</td>
<td>George Rabatin</td>
<td>Joann Dennett</td>
<td>Anna Reyna-Arcos</td>
<td>David McNutt</td>
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<td>Jothiram Vivekananda</td>
<td>Terri Eads</td>
<td>Mary Martin</td>
<td>Chryl Brunner</td>
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<td>Cathy Kessinger</td>
<td>Paul Burry</td>
<td>Harvey Moore</td>
<td>Joanne Dunnebecke</td>
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<td>Sandra Henry</td>
<td>Eric Butz</td>
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</table>

In addition to all of the above listed people, there are countless other people and organizations who have made my stay in Boulder, Colorado a time worth remembering. Among the many there are two more that I will men-
tion. They are the National Science Foundation and NCAR who make all of this possible. I’m glad that I had the opportunity to meet so many wonderful people and do so many exciting things! Best of luck to all!

REFERENCES


Figure 3
Figure 6

213700 GMT  vertical cross-section  062492

Height (km)

Distance (km)