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THE SEVERE HAIL VERIFICATION EXPERIMENT

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1. Introduction

Severe weather diagnosis applications that have a high temporal (5 minute) and spatial (1 km) resolution require verification data on the same scales. However, no source for such high-resolution data exists on a wide scale in the United States climate record. Additionally, temporal and spatial inaccuracies in the U.S. official climate record of severe weather events, the National Climate Data Center's *Storm Data* publication, are well documented. Because the official record of storm events is highly dependent on the National Weather Service warning system, reports of severe weather are usually on the temporal and spatial scale of an NWS warning, which typically last up to an hour and cover one or more counties. Storm-scale severe weather events frequently occur on a smaller spatial scale than the typical NWS warning, and the fine details of these events are usually missed during the verification process. Trapp et al (2006) and Witt et al (1998) cite many examples of how utilizing the severe weather reports in *Storm Data* for scientific research can be problematic.

With the onset of WSR-88D base data distribution over the internet (Droegemeier 2002) and cheap, fast computing performance, it became possible to merge and process data from the entire CONtinental United States (CONUS). The Warning Decision Support System – Integrated Information (WDSS-II; Lakshmanan et al. 2007; Hondl 2002) has the capability to generate 3D radar data grids on the CONUS scale at a resolution of approximately 1 km (0.5 km, or better for some products) both horizontally and vertically and 1 to 5 minutes temporally in real-time (Lakshmanan et al. 2006). Such a system is co-located at the National Severe Storms Laboratory and Storm Prediction Center, with experimental products shared on the web site http://wdssii.nssl.noaa.gov (Smith and Lakshmanan 2006). When these high-resolution data are coupled with geographic information, it becomes possible to make a detailed assessment of when and where storm damage occurred at a much finer scale than *Storm Data* provides.

The Severe HAil Verification Experiment (SHAVE) was designed to take advantage of this ability to blend high-resolution radar data with geographic information. The primary objective of the experiment was to collect high temporal and spatial resolution data that describe the distribution of hail sizes in hail swaths produced by severe thunderstorms. These data enable several goals, including:

- to utilize the high-resolution verification data in the development of techniques for probabilistic warnings of severe thunderstorms,
- to evaluate the performance of a multi-sensor, multi-radar hail detection algorithm;,
- to correlate changes in the hail size distribution with storm evolution, and
- to enhance climatological information about hail in the United States.

The high spatial and temporal resolution of the dataset collected during the project facilitates the development of decision-making tools that improve forecasts and warnings of severe hail as well as improving the historical record of hail events. In 2006, the project began on May 15, 2006 and continued through August 12, 2006. It utilized the real-time hail swath products from the CONUS WDSSII system to enhance data collection via verification telephone calls to select data points along a storm's path immediately following storm passage. Because the presence of hail is diagnosed via radar on the CONUS scale, it is possible to collect data from anywhere in the contiguous 48 states on a daily basis throughout the summer, which minimizes project "down days." Data were collected by a team of University of Oklahoma meteorology students working closely with scientists from the National Severe Storms Laboratory / University of Oklahoma Cooperative Institute for Mesoscale Meteorological Studies.

2. Data collection facilities

SHAVE was conducted in NOAA's Hazardous Weather Testbed (Norman) as part of the Experimental Warning Program, a collaboration between NSSL researchers, academia, and NWS operational forecasters to improve warning and verification techniques. During 2006, the project was located in the Storm Prediction Center's Science Support Area (SSA). The setup was as follows:

- *Computing cluster*: described in the introduction (section 1) and in detail by Lakshmanan et al 2006.
- *Display machines*: The laboratory contains six computers with adequate display, processing, and memory capabilities to run the WDSSII display (wg), Google Earth Pro, and Mozilla Firefox. These machines connect to the computing cluster to retrieve data, and may also submit collected data back to the cluster for processing. Each participant utilized one of these machines during data collection.
- *Collaboration Display*: a 42" plasma screen monitor that shows details on (a) the current storm's reflectivity and hail swath profile, (b) the cross-section of the hail swath currently being examined, and (c) lists of telephone numbers being called. As the name implies, it facilitates collaboration among participants who may be on and off the telephone at different times.
- *Telephone Lines*: Five telephone lines with headsets were available for use in the SSA.
- *Geographic Information*: The geographic information utilized in this project comes from a number of sources. Google Earth provides information on business locations and phone numbers, which is especially useful for collecting information over densely populated areas. Information on farmsteads and rural homes is available in county directories that are available from several different vendors. Other data sources, such as local government web sites and online GIS tools, may also be accessed as supplemental information.

3. SHAVE Operations

a. Daily activities

A typical day during the project begins with the decision about whether or not to commence operations by the project scientists. On most days, this coincides with the issuance of the SPC 1630 UTC Day 1 Convective Outlook. Several factors play into this decision, which may include:

- if hail-producing storms will form in areas that can be easily surveyed,
- the expected time of day of potential storms,
- potential storm types,
- staff availability or staff fatigue.

They also determine the preferred storm types for interrogation. Notification of whether or not operations will occur is posted on the project web site. Participants report to the operations area at the time specified in the notification message, and operations commence with storm availability.

The Operations Coordinator will call an end to operations based on several conditions:

- it is getting late in the day in all of the areas that contain storms (past 9pm local time for the target area),
- there are no storms in the CONUS and no more are expected to form,
- storms are located over areas where data collection is not possible,
- the staff is fatigued, or
- intense operations are expected the following day(s).

The Operations Coordinator makes a log entry about the storms surveyed and any issues with operations during the day (ideally, this will be done this during operations as well) so that any problems may be addressed before operations on the following days.

b. Data Collection Team Duties

The data collection team consists of a mix of students and scientists from OU and NSSL. There is always a scientist either on-duty or on-call during operations. A typical duty day has three to five people collecting data with one person serving as operations coordinator. The coordinator makes decisions on the type of storms to investigate as well as which storms in particular should be examined. They may take part in data collection as well, depending on workload. The rest of the team collects data from the public about hail size and duration.

The duties of the Operations Coordinator (OC) include:

- selecting storms and hail swath cross-sections for interrogation,
- helping maintain communication among all participants during operations,
- maintaining a log of data collection activities (which storms, reasoning)
- monitoring computer systems for any problems, and
- calling an end of operations.

The other members of the data collection team have duties that include:

- checking operations potential via the SHAVE web site each day,
- utilizing hail swath cross section information to select communication targets,
- calling targets, utilizing survey questions,
- entering and checking data, and
- communicating with the OC and each other to ensure the best data collection strategies.

4. Data Collection

a. Strategies

Our desire was to collect a diverse dataset of storm types in varying environmental conditions. Some variations may include:

- supercells,
- splitting supercells, especially left-moving supercells
- quasi-linear convective systems,
- "pulse" thunderstorms that form in a high CAPE, low vertical wind shear environment, and
- storms that form in cold-core upper air systems .

This experiment was blind with regard to whether or not a Severe Thunderstorm Warning had been issued by the National Weather Service (NWS) for a particular storm - we sampled both warned and unwarned storms. Data were made available to those NWS offices that desired to examine the data in real-time, although we encouraged those NWS offices that did utilize our data feed to continue to collect information from their own storm spotter networks as per their normal operations. There was no guarantee that SHAVE would sample storms in a given NWS County Warning Area on a particular day, and even if we did, it is likely that we would only do so for a short time or may miss something that a regular spotter would see (such as a tornado or wind damage which were outside the scope of this project).

The guidelines for collecting data on a specific storm were:

1. The OC selects a storm and logs the relevant information about storm type.
2. The OC determines a cross-section, usually perpendicular to the storm path, along which targets will be called. However, the team monitors this cross section to ensure that the storm has cleared the area before data collection starts along that line. The phone calls are made as soon as possible following storm passage in order to minimize the effects of melting and to increase the chance that people will recall the start and end time of the falling hail.
3. The team coordinates with each other to collect hail information that is spaced approximately 1 km apart along the cross section line, utilizing the hail survey.
4. As the storm continues to move, the OC determines a new cross-section to collect data and the process repeats.

The spacing of cross sections is dependent on the speed of a storm and the availability of call targets. For example, when storms are over populated areas, the database of business phone numbers available in Google Earth Pro is very useful for correlating potential hail areas with verification targets. In this situation, the OC's job is primarily to determine the storm of interest and to set up cross sections for examination. The OC monitors the progress of the team to complete each cross-section and select a new cross-section. Most of the relevant data concerning call history, hail reports, and current cross-section should be available on the Collaboration Display.

1. "Hello, I'm calling from the National Severe Storms Laboratory. We are calling people in your area for a scientific study on hail storms. I was watching the storm that just passed your location on radar and I was wondering if you got any hail during the storm?"
2. "If you could look outside and estimate the size of the biggest hail stone you see...
   Is it is as big as a pea? A coin? (which coin?) A golf ball? A tennis ball? A baseball?"
3. "Are there very many stones that size? What is the average size of the stones?"
4. "Can you see more than half the ground between the hail stones? How much hail on the ground? (or, what percentage of the ground can you see through the hail stones?) "How deep are the hail drifts?"
5. "How long ago did it start and how long did it last?"
6. If it is safe to go outside, or if they have already picked up the hail, ask them to physically measure some stones if they are comfortable doing so.
7. "I appreciate your help. Thank you for your time."

Table 1: An example of the basic survey script.

When storms are over rural areas for which county directory or reverse address lookup information from the internet is available, it is more challenging to collect data. The OC or a designated assistant OC correlates the non-digital or web site sources to a geographic display and passes the information to the team via a Google Earth KML file. The results are still be available on the Collaboration Display, but the team rely on more centralization to determine where to collect data.

If the workload on one storm is light due to slow movement or the availability of few call targets, then the team may split up to sample multiple storms.

b. Survey

In order to remove as many biases from the data as possible, a survey was utilized to ask similar questions to each person called. The survey software facilitated data collection as well as collaboration among the team. The software has the following layout:

1. *Login screen:* Each team member has a username/password combination unique to them.
2. *Data point selection screen*: This screen allows the team member to enter a full 10-digit telephone number that they intend to call. When they submit the number, it checks the database for several items:
   - has this number already been called by someone? If so, list the last time and the results, or if the call is in progress.
   - has this number asked us not to call again or been disconnected?
   - if already called, then insert the location information.
3. *Survey screen:* This screen contains the script to follow for surveys, as well as a place to enter answers for each question (Table 1). These questions are front-loaded with the most important information first. The data collection team members are free to deviate from the basic script as long as they do not ask leading questions or personal questions in order to clarify exactly what happened and how valid the data point is.

As soon as the survey was finalized, the data were submitted to the data server via the web interface, and instantly plotted in the Google Earth Pro and WDSSII displays.

5. Discussion

A large number of hail swaths were successfully documented during the experiment at a much higher resolution than is available in *Storm Data*. A few preliminary results are presented here. Figure 1 shows a well-sampled storm where SHAVE collected 35 data points along the hail swath compared to 2 data points that would typically go down in the climate record in *Storm Data*. These higher-resolution verification data are essential, as guidance applications and severe weather warnings that are more specific spatially and temporally than the present county-based NWS warning system are developed in the future. Additional analysis of a few specific cases may be found in Ortega et al. (2006) in these proceedings.

Table 2 shows the results of the phone calls made to the public during SHAVE. Although SHAVE operated on 83 days, the number of calls made on each day varied widely from a low of 1 to a high of 680. The success rate for collecting a "good" data point – one that we had confidence in, including those with times slightly off – was 40% for the entire project. Members of the public were generally receptive to talking about the storms that affected them (the "disconnected / do not call" category was

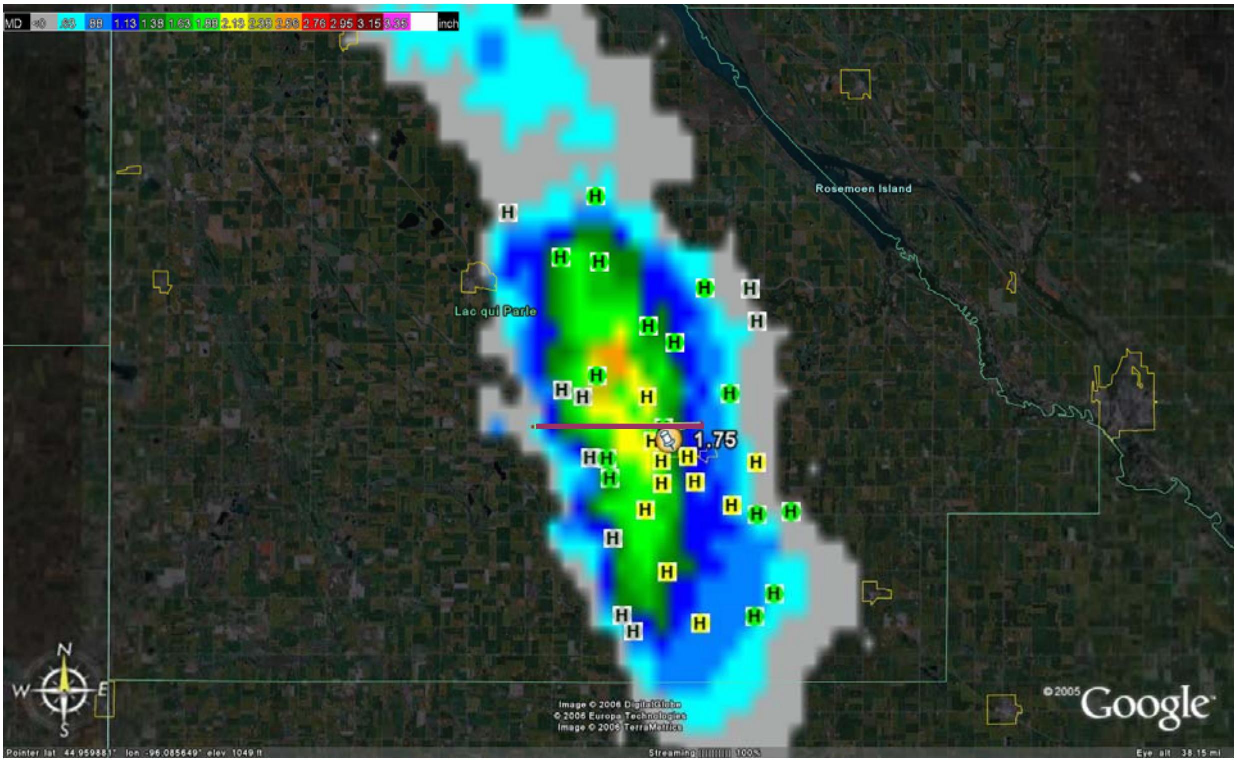

Figure 1: The NSSL Hail Swath algorithm showing radar-estimated maximum hail size over a 180 minute period for a storm that occurred in Lac qui Parie County, MN on July 27, 2006. The grey icons (no hail), green icons (hail up to 1" – 2.54 cm) and yellow icons (hail >1" to 2" – 2.54 cm to 5.08 cm) represent data points collected by SHAVE. The single "push pin" icon represents two data points collected in the county by the National Weather Service as part of warning verifications efforts and published on the Storm Prediction Center web site at http://www.spc.noaa.gov/climo. The purple line is 10 km long in the scale of the map.

dominated by "disconnected" numbers). One unknown is how well the general public can visually estimate hail size, but evidence based on the small number of measured reports that were collected seems to indicate that the estimates are reasonable (Figure 2). SHAVE also checked data points that did not seem reasonable by calling nearby (across the street, for instance) to get a second or third estimate of the hail size at a location.

Figure 3 shows the distribution of reported hail sizes during SHAVE. During the project period, the synoptic scale weather pattern over the CONUS was dominated by a large 500 mb ridge with relatively few severe storms compared to climatology. Because SHAVE focuses on the CONUS scale, we were still able to collect data even during slow convective activity periods, but the overall percentage of very large hail reports was small. According to the SPC storm logs (http://www.spc.noaa.gov/climo), there were 5532 severe hail reports (of which about 20 were credited to SHAVE) during the SHAVE operations period in 2006 compared to 5538 valid data points (hail or no hail, 1827 severe hail of ¾" or greater) collected by SHAVE that gave much more detail but on a relatively

Data collection days	**83**
Total phone calls	**13854**
"Good" data points	4880
"Good" except time	658
Hail w/ questionable location	42
Hail w/ questionable size	371
Busy / intercept operator	777
Wrong location	47
No answer or machine	5485
Disconnected / Do Not Call	1286
Other	307

Table 2: The results of the phone calls during SHAVE 2006.

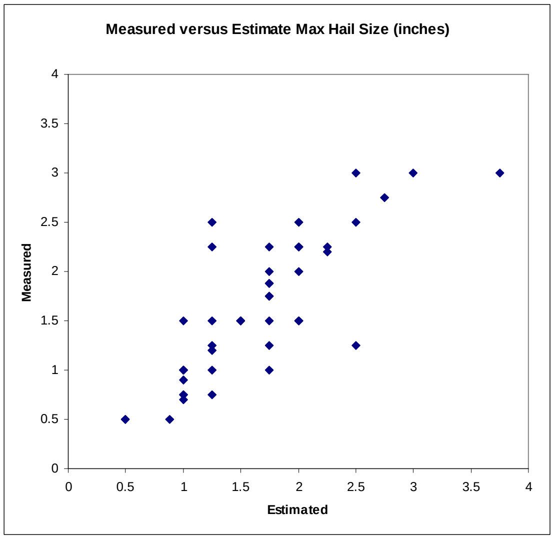

Figure 2: Scatter diagram of estimated hail size (inches) versus the hail size measured by the same observer after the visual estimate had been made.

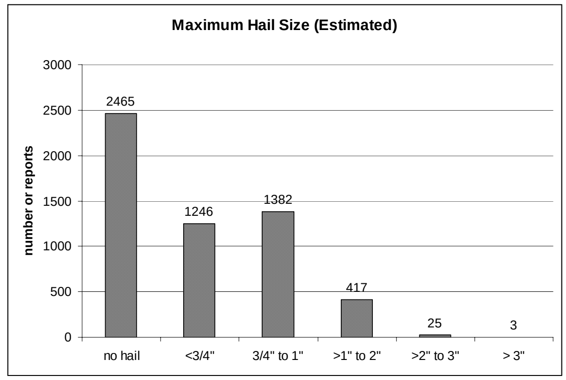

Figure 3: Hail size distribution for “good” data points.

smaller number of storms.

SHAVE has provided a successful proof-of-concept for enhanced warning verification, warning guidance application validation, and severe storm climatology studies. Data are collected on the storm scale without regard to county boundaries or whether or not the storm is warned by the NWS. We intend to continue analysis of data collected in SHAVE 2006 and plan to expand the project to additional hazards such as high wind events in 2007.

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