# Warning the Public about Hail: Determining the Potential for Short-Term Damage Mitigation

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ABSTRACT

Previous attempts to mitigate hail damage have focused primarily on protective efforts, such as insurance programs, which require long-term planning. Very little research has been done to determine what actions can be taken to prevent hail damage just before it occurs. In this study, hail reports taken from the National Climatic Data Center (NCDC) Storm Events Database were compared with NWS warnings for Colorado, Massachusetts, Oklahoma, and South Carolina during the years of 1999-2008. Warning accuracy and average lead time were determined for all hail reports during 1999 and 2000 as well as damaging hail reports between 1999 and 2008. It was found that in general, under the county warning system, sufficient lead time existed for mitigating action by the public. While less than 50% of NWS Severe Thunderstorm Warnings resulted in hail reports, it is likely that many hail events were not reported in the NCDC data base. Using data from the Severe Hail Verification Experiment (SHAVE), an average hail swath size of 863 square kilometers (333.2 square miles) was calculated from 14 hail swaths across the United States. The average polygon warning size covered more area than the average hail swath size, while county warnings covered a much larger area and would prompt an unnecessary number of people to take mitigating action. There are serious limitations as to the data sources available to make decisions for damage mitigation. A more thorough, more accurate data base would improve the economic cost-benefit analysis of various possible mitigation methods.

## 1. INTRODUCTION

Though a relatively rare weather phenomenon, hail has the potential to cause significant damage. Previous research has documented hail climatologies, assessed hail damage to property and crops, and evaluated hail suppression programs (Changnon 1977). More recent advances in technology have improved the ability of forecasters to identify storms capable of producing hail. Despite these developments, the cost of hail damage to property continues to reach all time highs and without changes in response by the public, hail related damages are projected to increase even further (Changnon et al 2000).

This project aims to serve as an initial investigation into the following questions: What can be done to reduce or prevent hail damage to property? Are current warnings of hail accurate and timely enough for individuals or emergency managers to take necessary action? More specifically, this paper will quantify the average warning lead time for hail as provided by the NWS.

The paper is organized by first summarizing historical methods used in the mitigation of hail damage. The data sets utilized for this project and the general methods applied to the data are listed in Section 3. Results are described in Section 4 and possible applications of the results are discussed in Section 5. Finally, the limitations of the data available for this project and suggestions for improvements in future related research are considered in Section 6.

## 2. BACKGROUND DAMAGE PROTECTION METHODS

Individuals have typically focused on mitigating costly hail damages by insuring their property at risk. The following protection strategies summarize what currently is done to lessen the negative economic impact from hail damage. These all require long-term planning and an understanding of risk well before a storm capable of producing hail occurs.

### *2.1 Crop Insurance*

Hail causes approximately $1.3 billion in crop damages annually (Changnon 1999). Ironically, the same climatic conditions (such as seasonal patterns and moisture distribution in the High Plains) which make regions most favorable for agriculture also contribute to destructive weather events such as hail (Changnon et

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al. 1999). There are two main types of protective crop insurance in the United States: Hail insurance which is provided by private companies and Multiple Peril Crop (MPC) Insurance which is run by the federal government and covers a wider variety of potential loss causes (Insurance Information Institute 2009 b). As of 2007, there were 271.7 million acres of land covered by crop insurance, larger than the combined area of Texas, Oklahoma, and Kansas (Insurance Information Institute 2009 b). Hail insurance can be applied for at any time during the growing season from the time that 50% of the crop is visible until the expected harvest date (Insurance Information Institute 2009 b).

Insurance companies define a loss ratio as the amount of money paid out in losses divided by the amount of money collected in premiums (Changnon et al. 1999). While historically the average loss ratio is around 66% (Insurance Information Institute 2009 b), insurance companies only make money during individual years with loss ratios below 70% (Changnon et al. 1999).

The area within a storm that is affected by hail is often discontinuous and can vary widely (Leigh 2007) causing many cases where some parts of a field or crop will be destroyed and other parts will remain untouched (Insurance Information Institute, 2009 b). Also depending on where the hail falls, hailstone size may be of varying importance. Small hail can still result in substantial damage to crops while large hail which could easily cause property damage may be insignificant over fields if it is not during the growing season (Brooks 2006).

*2.2 Property Insurance and Roofing Materials*

In recent years, the costs of property damage from hail and weather hazards in general have increased significantly (Changnon et al. 1999). While losses of crops to hail damage have historically been of greater concern, damages to property reached record highs of approximately $1.2 billion annually during the 1990s, prompting insurance companies to seek mitigation techniques, and scientists to address the role of climate change in severe storms (Changnon 1999). Climate change may physically affect severe thunderstorms, however inaccuracies in historic damage databases make the trend difficult to detect (Brooks 2006) and shifting societal factors putting higher value property at risk (Changnon 1999) seems to dominate the trend.

State Farm Insurance Co. reports that 8 of the company's 25 highest pay out claims in history were due to property hail damage. Roofing is the most commonly damaged part of buildings affected by hail while the damage costs are greatly dependent on design and materials (Fronapfel 2000). In 1996, a testing standard (UL 2218) was developed to determine the resistance of different materials to simulated hail damage (State Farm Insurance 2009). The kinetic energy of hailstones based on diameter and terminal velocity is used to classify these resistances (Cullen 1997). Modified asphalt shingles are rated least susceptible to damage (referred to as Class-4) and have been tested to withstand impacts from hailstones with kinetic energies of 30 joules (Cullen 1997). According to Cullen, this kinetic energy would correspond to a hailstone with diameter just smaller than 2 inches. In a survey by Leigh (2007), 90% of respondents reported some type of roof damage and 50% reported substantial damage from hail larger than 2 inches.

Because materials such as modified asphalt are effective in preventing damages from hailstones smaller than 2 inches, they are becoming popular in high risk regions. However, while these durable materials can cost 10-20% more than basic roofing materials, many insurance companies even offer cash incentives or reduced premiums when customers opt for the hail resistant shingles (Fronapfel 2000).

*2.3 Automobile Insurance*

In order to protect automobiles from hail damage, comprehensive car insurance can be purchased which covers damages not related to collisions, such as those from severe weather. According to the Insurance Information Institute (2009 a) Americans spend on average about $154 annually for this type of coverage. Automobile damage can comprise a large percentage of the total insured losses from a hailstorm. Because individual insurance companies are interested in tracking these losses for their own purposes, there is not a lot of publicly available data on automobile hail damages (Hohl et al. 2002). In Switzerland, mean damages to automobiles from hail averaged $1900 US during their storm season and $1300 US during the rest of the year (Hohl et al. 2002). Hohl's research on this topic focused on assessing damage after storms passed and estimating potential losses for insurance companies, rather than on ways to prevent the damage from occurring.

In the United States, hail damage to automobiles between the Rocky Mountains and the Mississippi River can be so expensive that Stewart Smith Specialty Risks, Inc. has created an insurance program specifically for car dealerships. They explain that a single hail storm is capable of causing 0.5-1 million dollars in damages at an individual car dealership (Esters, 2009). The policy, Hail Exchange insurance, covers repairs or replacement of up to 100 vehicles without a specific dollar limit (Esters 2009).

*2.4 Cloud Seeding*

Cloud seeding is a unique approach because its goal is to reduce hail damage, primarily to crops, without requiring any direct action or prevention by individuals. While studies regarding cloud seeding for hail suppression have reported varying opinions on its effectiveness (Smith et al. 1997), there is enough support for the process that as of 1996 there were 45 cloud seeding projects documented across 9 states (North Dakota Atmospheric Research Board 2009). The general principle behind cloud seeding involves limiting the amount of water available in a cloud. With seeding, this water is divided up which limits the amount available for each hailstone and results in smaller hail size (Leigh 2007). The lead time required for hail suppression is significantly shorter than for the insurance option. While the preparation is a longer process, the actual seeding should be performed about 3-5 minutes before precipitation occurs (Smith et al. 1997).

The amount of money spent on hail suppression varies from project to project. The North Dakota Cloud Modification Project is funded mostly by participating county taxes as well as partially by the state. The North Dakota Atmospheric Research Board (2009) asserts that statewide, the project costs about $3.2 million annually the reduction in crop damages results in $34.4 million savings annually. Crop-hail insurance loss ratios during the North Dakota Cloud Modification Project were approximately 45% less than would be expected from past insurance records, however hail damaging less than 10% of a crop is not considered in insurance payments so this data cannot always be assumed to correspond directly to hail damage totals (Smith et al. 2007).

## 3. DATA AND METHODOLOGY

Information on all reported hail cases occurring between 1999 and 2008 was collected from the National Climatic Data Center (NCDC) Storm Events Database for Colorado, Massachusetts, Oklahoma, and South Carolina. The first two years of hail events, 1999 and 2000, were then compared by county, date, and time to all issued thunderstorm and tornado warnings archived in the NOAA Performance Management Interactive Product Database. Using this database, hail cases were classified into one of the following categories: before a NWS warning, during a thunderstorm warning, after a NWS warning, during a tornado warning, or without any warning. Hail reports occurring more than three hours before a warning was issued or after a warning had expired were assumed to occur without any warning present.

Data obtained during the Severe Hail Verification Experiment (SHAVE) was used to supplement the NCDC hail reports. The primary goal of SHAVE is to sample both severe and non-severe hail swaths at a higher spatial and temporal resolution than has been done previously (Smith, T.M. et al., 2007). The resulting hail information, displayed across the continental US in Google Earth format, was used in this study to determine an approximate hail swath size as estimated from fourteen well-sampled hail swaths collected across eleven different states occurring between 2006 and 2008. The width and length of each event was measured across each location verified to have experienced hail, and the area was calculated assuming the hail swath approximated the shape of an ellipse.

## 4. RESULTS

### *4.1 Warning Accuracy*

No public response to mitigating hail damage can take place if the public is not first made aware that severe hail is likely to occur. This makes accurate warnings and low false alarm rates critical in determining the practicality of short term damage mitigation. Unfortunately there is not a specific warning for large or damaging hail, but its presence is one possible reason for a severe thunderstorm warning to be issued. Historically a thunderstorm is considered severe in the United States if it is accompanied by at least one of the following characteristics: wind gusts greater than 50 knots, hail larger than .75 inches, or a tornado (*Brooks 2006). However, starting 1 July 2009 all fourteen states in the NWS Central Region changed from .75 inches to 1 inch diameter hail as the new Severe Thunderstorm Warning criteria (Brothers 2009).

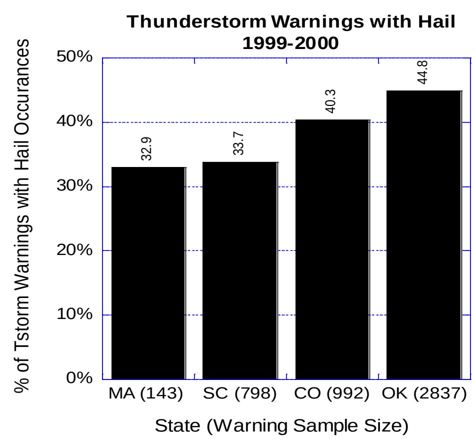


**Figure1:** The percentage of NWS Severe Thunderstorm Warnings verified by NCDC hail reports during 1999 and 2000. Results are listed by state with the sample size of NWS Severe Thunderstorm Warnings listed.

The first question addressed in this project was to determine how often a severe thunderstorm warning resulted in at least one hail report. Figure 1 shows the percentage of NWS Severe thunderstorm warnings issued during 1999 and 2000 that were verified to have experienced hail from each of the four states in the sample. Severe thunderstorms were least likely to produce hail during a warning in Massachusetts, where the number of total hail reports for the 2 year period was also the lowest (68 hail cases). Oklahoma had the highest frequency of hail during 1999 and 2000 and also the highest percentage of hail events reported a thunderstorm warning (44.8% of 1685 hail cases). This shows that in every state considered, less than half of the Severe Thunderstorm warnings issued resulted in reported hail of any size, though there were likely cases when hail occurred during a thunderstorm warning but was not reported. The percentage of warnings verified by hail increased as both the number of total hail cases and the sample size of total warnings increased.

In addition to the likelihood of a given warning resulting in hail, the likelihood of a given hail event to occur during a thunderstorm warning must also be considered. Figure 2 shows that a high percentage of thunderstorm warnings resulting in hail do not necessarily indicate how often hail events in a given state occur during a warning. On average between the four states, 72.5% of reported hail cases occurred during a NWS Severe Thunderstorm warning and 6.87% occurred during a NWS Tornado Warning. Therefore, over one quarter of reported hail events appear to have occurred in counties which were not under a Severe Thunderstorm warning at the time. Figure 3 shows the percentage of damaging events which were warned. For every state except Colorado, the damaging hail cases were more likely to occur during a warning.

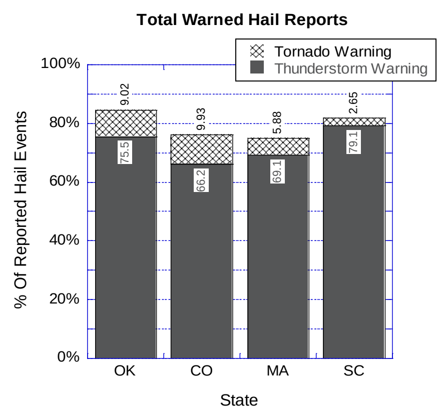


**Figure 2**: The percentage of all NCDC hail reports during 1999 and 2000 which occurred during either a NWS Severe Thunderstorm or Tornado warning.

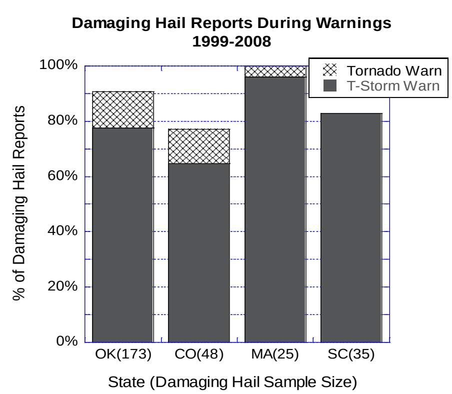


**Figure 3**: The percentage of NCDC hail reports between 1999 and 2008 which occurred during either a NWS Severe Thunderstorm of Tornado Warning

For the two states with the largest samples of reported hail cases, Oklahoma and Colorado, the percentage of hail cases occurring during both thunderstorm and tornado warnings was broken down by hail size to determine when the most significant hail was occurring. From Figures 4 and 5 it is clear that as hail size increases, it is less likely to have occurred during a thunderstorm warning and more likely to have occurred during a tornado warning. In the time period sampled for this study, warnings were issued by complete county, not localized polygons. The fact that very large, and therefore potentially damaging, hail often was falling during tornado warnings would create problems for many people in a warned county who are focused on taking tornado precautions but instead receiving unexpected damage from large hail.

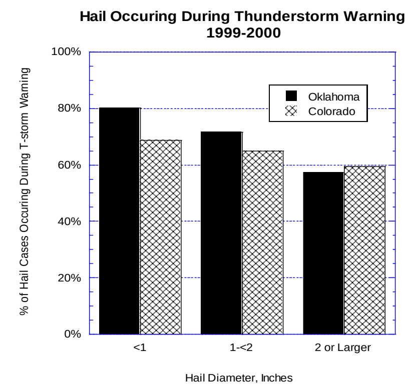


**Figure 4**: The percentage of NCDC hail reports for OK and CO during 1999 and 2000 which occurred during a NWS Severe Thunderstorm Warning. Hail reports during a thunderstorm warning decrease as hail size increases

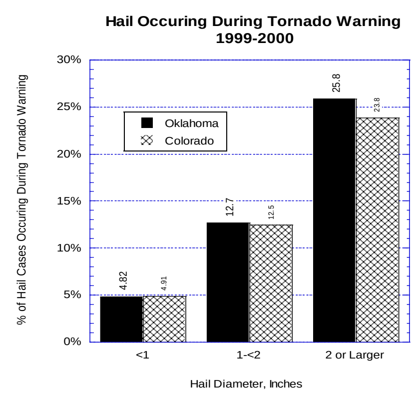


**Figure 5**: The percentage of NCDC hail reports for OK and CO during 1999 and 2000 which occurred during a NWS Tornado Warning. Hail reports during a tornado warning increase as hail size increases.

Finally, Figure 6 shows the hail reports that did not occur during either a NWS Thunderstorm or Tornado Warning. Hail which was reported after the warning ended may have occurred during the warning but was reported afterwards. For the hail reported before a NWS Thunderstorm Warning or without any warning, there is no potential for short term damage mitigation.

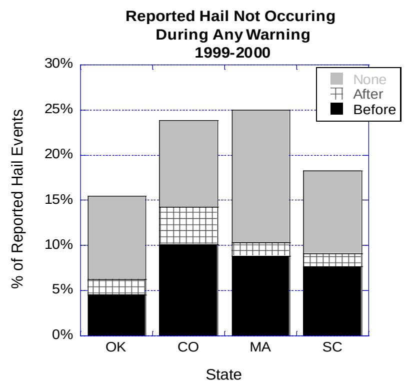


**Figure 6**: All NCDC hail reports during 1999 and 2000 which occurred before, after, or without a NWS Warning.

*4.2 Lead Time*

There is obviously no opportunity for the public to take action to prevent hail damage if the public is not warned and remains unaware of the threat. Also, for the hail cases that occurred during tornado warnings, the risk of tornado likely will outweigh any concerns regarding hail damage for many people depending on the usual false alarm rate and how they perceive warnings. Of course, individuals should never leave their shelters during a tornado warning. However, during a severe thunderstorm warning, action could be taken to prevent damage if enough lead time is present between the time the warning is issued and the time hail occurs.

Using the data available, the best estimate for lead time of hail cases which occurred during a NWS warning was determined by measuring the time between the beginning of the warning and the time of the hail report as recorded in the NCDC database. Table 1 lists the four states in order of increasing average lead time for all hail cases. South Carolina, the state with the highest percentage of hail occurring during a thunderstorm warning, had the shortest available lead time during those warnings.

| State Name | Avg. Lead Time | Standard Deviation | % Unwarned Hail Reports |
|---|---|---|---|
| South Carolina | 17.8 Min | 12.5 | 15.5% |
| Colorado | 21.0 Min | 14.9 | 23.8% |
| Oklahoma | 21.4 Min | 14.3 | 25.0% |
| Massachusetts | 21.7 Min | 14.5 | 18.2% |

**Table 1**: The four sample states shown in increasing average hail lead time during NWS Severe Thunderstorm Warnings. Also shows the % of hail reports which occurred outside of any NWS warning.

Average lead times across the four states varied by less than four minutes, which is unlikely to make a significant difference when it comes to preventative action. A shorter average lead time with a lower percentage of un-warned storms could provide South Carolina residents with greater potential for action than a state with longer average lead time and a higher percentage of un-warned storms, such as Colorado. Figure 7 shows that lead time generally was longer for damaging hail reports occurring during a warning than for hail reports without damage. A minimum lead time necessary would need to be determined for any specific damage prevention method to determine the true significance of varying lead times from state to state.

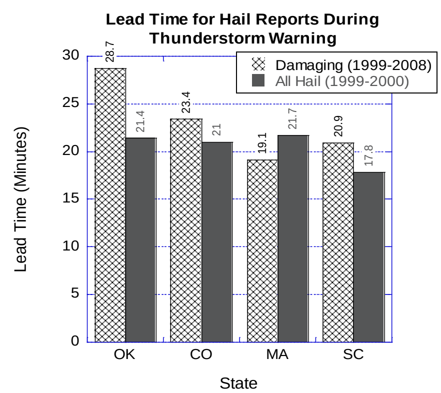


**Figure 7**: Lead time for all hail reports (1999-2000) and damaging hail reports (1999-2008) during NWS Severe Thunderstorm Warnings by state.

Lead time for each state was broken down into size categories and then averaged to determine in general, how lead time varies with increasing hail size.

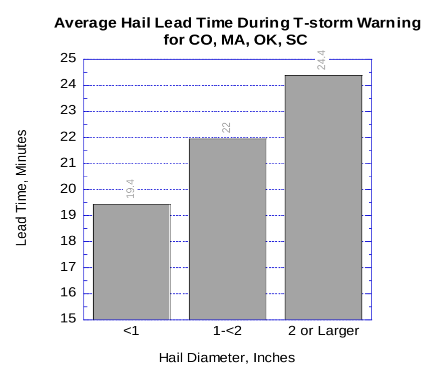


**Figure 8**: Lead time for hail reports from1999 and 2000 during NWS Severe Thunderstorm Warnings. Hail reports were divided up by size range and then combined for all four sample states.

In Figure 8, lead time clearly increases as hail diameter increases. Areas affected by hail larger than 2 inches had on average five minutes longer lead time than areas with hail smaller than 1 inch. This is reasonable because very large hail often requires a more mature storm and may take longer to develop. Also forecasters may have a clear idea of where a storm that quickly started producing small hail is likely to move, and quickly extend their severe thunderstorm warnings over counties that may later receive larger hail from the same storm. This is valuable because individuals would be more likely made aware of hail risk by the time it gets large enough to cause damage.

For each state in the sample, lead times for hail cases during thunderstorm warnings were divided up into ten minute intervals to obtain information not available from the average. For all of the four states, the largest group of hail cases fell into the interval between ten and twenty minutes. Over 70% of hail cases that were warned had over ten minutes of lead time. It appears that when hail occurs during a thunderstorm warning, there is a high chance that sufficient lead time has been provided to take some sort of action to protect property from damage.

However, with the change in severe hail classification diameter from .75 inch to 1 inch, warnings will no longer be issued for any storms expected to produce hail less than 1 inch in size and which contain no other severe characteristics. Storms that begin producing very small hail but continue to develop and produce larger, damaging hail along the way may not have warnings issued as early. With this change, people in the path of the storm may not realize it is producing hail or have as long of a lead time to take action. The number of thunderstorm warnings issued will also likely decrease, and the public should be made aware that severe thunderstorm warnings due to hail size are likely to be more severe than in the past. For geographic areas with frequent small hail, thunderstorm warnings may have frequently been ignored, so it is important for individuals to understand how this change will affect their reactions to warnings.

*4.3 Swath Area*

Determining the area affected by hail swaths is critical in deciding who actually would want to take action during a warning. Even if every single thunderstorm warning resulted in hail and every single hail storm occurred during a warning, only a certain portion of land area within the warning would actually experience hail. The SHAVE cases used to determine hail swath size were assumed to be representative of storms across several different parts of the US, and appropriate to use in calculating an average. SHAVE chooses storms to sample by those that were expected to have relatively high maximum expected size of hail (MESH) and were not likely to overlap other storms, making sampling difficult (Ortega 2009).

As seen in Table 2, an average hail swath size from the 14 SHAVE samples was calculated to be 863 square kilometers (333.2 square miles). The average polygon warning was slightly larger, while the average area warned under county based warnings was over six times larger. These results seem to further support the 2007 change by the NWS to issue storm based polygon warnings rather than county-wide warnings. Based on the average area of hail swaths from the sample of SHAVE cases, it appears that polygon severe thunderstorm warnings typically cover enough area to include the total area likely affected by hail. The average county based warning covers significantly larger area and if action were recommended to an entire county to prevent hail damage, a large number of people would likely act unnecessarily. Further study of hail swath size in relation to the new polygon warning system is recommended to aid in verification.

| | Avg. Area Affected |
|---|---|
| County Warning | 2008.1 square miles* (5201 sq. km) |
| Polygon Warning | 494.0 square miles* (1279.5 sq. km) |
| Hail Swath | 333.2 square miles (Std Deviation 466.35) (863 sq. km) |

(*Berman 2005)

**Table 2:** Area of land affected by average county warning & polygon warning (as determined by Berman 2005), and average hail swath (as determined by 14 well sampled SHAVE cases).

## 5. APPLICATIONS FOR DAMAGE PREVENTION

The purpose of this paper was to examine different aspects of severe weather warnings in relation to hail events in order to begin a foundation for further damage mitigation efforts. As implied throughout Section 2, most protection methods aim to reduce the financial liability associated with hail damage, but do nothing to limit actual damage. Prevention strategies require a much shorter lead time than insurance programs or structural changes, but are effective only if individuals and authorities are motivated to take the necessary action.

The results of this project show that in many areas of the United States, more than sufficient lead time is typically available during severe thunderstorm warnings for individuals to take preventative action. Even for events that were given very limited lead time, media could play a crucial role in recommending that the public take cautionary action before an official warning is actually issued. The role of weather in traffic management is also becoming a highly important area of research as population increases and traffic congestion increases across many urban areas (Pisano and Goodwin 2004). More accurate, specific warnings of hail with appropriate lead time provide an opportunity for meteorologists to work with emergency management to reroute or block traffic when appropriate. Previous studies have shown that weather-responsive traffic management decisions are particularly effective when used on relatively short stretches of highways (Pisano and Goodwin 2004). A detailed study examining the costs and benefits associated with applying mitigation practices such as these with accurate economic information would help authorities make decisions for when to take action.

## 6. CAVEATS AND DISCUSSION

### *6.1 Data Accuracy and Issues*

Storm Data is an inclusive database which contains information regarding storms across the entire United States. However because of its broad scope the database is known to contain fewer details and more errors than are ideal for this type of analysis (Witt et al., 1998). Several others have identified problems relying on Storm Data (NCDC) for severe thunderstorm characteristics (Trapp et al. 2006) but it still remains among the most accessible sources for such data.

On average across the four sample states, only 2.26% of hail events in the ten years between 1999 and 2008 had any associated damage costs reported. In Oklahoma, the state out of the four with the most frequent hail occurrence, only 186 instances of damage were reported in all ten years. Colorado experienced the next highest hail frequency and damage was reported only 48 times in all ten years. All of these damage reports appear to be glaring underestimations and further investigation suggested reporting biases by certain counties or areas that reported damage much more accurately than others.

For any type of economic analysis of hail damage or mitigation plans a much more detailed damage database must be developed. In 1977, Changnon Jr. recommended further study for economics and action related to property hail damage, requiring a better damage database, but it appears atmospheric scientists and economists are both still lacking this type of information. Insurance companies have determined that collaboration with atmospheric scientists will be necessary to mitigate all types of weather loses and learn about the way climate change may affect their industry, but little insurance data on hail damage is currently publicly available to researchers (Changnon et al., 1999).

### *6.2 Polygon Warnings*

It is important to consider that the data used in this project to perform verification of warnings with hail events was taken from 1999 and 2000, before the polygon storm-based warning system was in place. It has been anticipated that polygon warnings will generally better represent areas under significant threat of severe weather than county wide warnings have (Browning and Mitchell 2002). Because of this, it is recommended that a study similar to this one be performed for several areas across the United States to determine how these results change. Many storms may move across the intersection of several counties, but produce hail in only one of those counties. It is likely that the polygon warning method will result in fewer unnecessary warnings and a higher percentage of thunderstorms warnings resulting in hail. However, it is conceivable that with smaller warnings and the scattered nature of hail, there may be more reports of hail occurring within a given county, but outside of the warning area (Browning and Mitchell 2002). Detailed analysis of the SHAVE data in conjunction with an accurate warning database will certainly benefit future related research.

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