Winter Storms: An Overlooked Source of Death, Destruction, and Inconvenience in the Carolina Piedmont Region

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ABSTRACT

Monetary losses due to catastrophic winter storms in the Southeast region of the U.S. have been found to be comparable to losses from Northeast winter storms, despite the fact that the Southeast experiences far fewer events. The impacts of winter storms, however, go far beyond dollar signs: driving becomes difficult and hazardous, electricity and heat are lost, schools and business are forced to close, emergency management services are stressed, and communities experience an overall loss of productivity. Sadly, the conditions resulting from winter storms, often coupled with poor decision making, can also lead to death. Adequate planning and preparation for winter storms requires an understanding of the full range of their impacts and the circumstances surrounding them. We studied the impacts of over 30 winter storms that occurred in two metropolitan areas of the Southeast (Raleigh-Durham, NC and Greenville-Spartanburg, SC) between 1995 and 2007 using information obtained from *Storm Data* and archived newspaper articles.

Keywords: Winter storms; impact assessment; economic loss; casualties; Southeast U.S.

INTRODUCTION

Monetary losses due to catastrophic winter storms in the Southeast region of the U.S. have been found to be comparable to losses from storms experienced in the Northeast region, despite the fact that the Southeast experiences far fewer events (Changnon, 2007). One explanation is that Southeast winter storms have higher precipitation rates than Northeast storms, which can exacerbate the stress placed on tree limbs, power lines, and building structures due to accumulating snow and ice (Call, 2007). Higher precipitation rates can also cause traffic conditions to deteriorate more quickly. While economic losses due to winter storms have been investigated, there is a paucity of information regarding the societal and human impacts of winter storms, particularly in regions that are less accustomed to their occurrence. For example, warm season weather events, such as tornadoes, heat waves, and tropical cyclones, often receive substantial coverage from the media and are topics of high priority in the research community. We feel that in the context of hazard mitigation and economic assessment, the impacts of winter storms in the region have, by comparison, been largely overlooked. Although winter storms are relatively uncommon in the Southeast compared to other areas of the country, a number of notable events have occurred and for a variety of reasons have become etched in our memory (e.g., the January 2000 “Carolina Crusher” and the “Blizzard of ‘96”). During periods of quiescence between major winter storms or active winter seasons, we are liable to forget just how destructive

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these storms can be and how a severe winter season can have crippling effects that continue to be felt well after the last of the precipitation has melted.

The objective of this paper is to identify the social and economic impacts that result from winter storms in the Southeast U.S. This research is guided by the following set of questions: 1) What are the societal impacts of winter storms in the region? 2) What are the human, social, and physical factors that influence these impacts? 3) What are the specific vulnerabilities to winter weather in the region and how do they vary demographically? 4) What is the relationship between precipitation intensity and impact? Under what circumstances do minor events (meteorologically speaking) have significant societal impacts?

METHODOLOGY

Identifying and Classifying Winter Storms

For this initial study of the impacts of winter storms in the Southeast U.S., we chose two major urban areas located centrally within the region: Raleigh-Durham, NC (RDU) and Greenville-Spartanburg, SC (GSP) (**Fig. 1**). These two urban areas are located in the Carolina Piedmont, which experiences on average three to five winter storms per year. We identified winter storms using hourly weather observations from first-order stations at the RDU and GSP airports and daily snowfall data from the nearest Cooperative Observer station for the period 1995-2007. Our reasoning for limiting the study to this time period is discussed in the next section. Using weather station data to identify winter storms, as opposed to local storm reports from *Storm Data*, allowed us to objectively determine the event duration and intensity (Branick, 1997). This was important, since we were interested in sampling both minor and significant winter storms. We were also able to more precisely capture the diurnal pattern of precipitation to assess its effect on storm impacts. Moreover, the storm type could also be classified more objectively using the present weather observations rather than subjective post-storm assessments.

Winter storms were identified from the hourly weather observations if measurable precipitation was recorded with at least one observation of a winter precipitation type (i.e., snow, sleet, freezing rain, freezing drizzle). The storm was terminated if there was more than a 24-hr lapse in consecutive precipitation observations. We determined the storm type based on the proportion of winter precipitation recorded over its full duration. A storm was classified as snow (freezing rain) if the total snowfall (freezing rain) accounted for at least 60% of the total storm precipitation and duration. There is still debate as to the quality of sleet observations at first-order automated weather stations. It was suggested that sleet observations be classified as snow for the purposes of this study (J. Cortinas, personal communication). Since sleet comprised less than 20% of all winter precipitation observations at RDU and GSP from 1995 to 2007, we do not feel this significantly affected the results of the winter storm classifications. Using the above criteria, we identified 35 winter storms (14 snow, 14 ice, 7 winter mix) at RDU and 32 winter storms (10 snow, 13 ice, 9 winter mix) at GSP. A detailed listing of events is provided in the Appendix.

Analysis of Winter Storm Impacts

We consulted two sources of information on winter storm impacts: 1) descriptive entries of impacts in the NCDC publication *Storm Data* and 2) archived newspaper articles from the *Raleigh News & Observer*, *Durham Herald Sun*, and *Spartanburg Herald Sun*. Online databases containing these sources[2] were utilized to more efficiently collect and analyze information on storm impacts. This limited our study to the period 1995 to 2007. Nevertheless, this period was long enough to provide an adequate sample of events and recent enough to obtain the maximum

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[2] Storm Data is available at http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwEvent~Storms. Newspaper archives were made available through the UNC-Chapel Hill library at http://www.lib.unc.edu/reference/hum/newspapers.html

amount of impact information. We began searching the online newspaper databases three days before the event began to determine if any preventative actions or mitigation strategies were employed and stopped searching when there was no mention of the event or its impacts for at least two consecutive days. Impacts were grouped into seven categories for discussion, largely based on categories initially defined by Call (2007): 1) Business, commerce, and industry; 2) Property damage and insured losses; 3) School closings and delays; 4) Utilities, including electric, cable, telephone, gas, public water; 5) Transportation, including road conditions; 6) Emergency management and government response; 7) Deaths and injuries.

RESULTS

Impacts to Business, Commerce, and Industry: *Who Benefits and Who Loses?*

The closure of businesses and offices, and the cancelation and postponement of sporting and other events due to winter weather leads to lost revenue and an overall decrease in productivity. Even if businesses remain open, they may lose revenue if customers are unable to travel due to poor road conditions. While a loss of power and heat automatically prevents most businesses and offices from operating, the most cited reason for closure of businesses and cancelation of events was poor driving conditions. Some businesses, however, found ways to remain open even without heat and electricity. Following a severe ice storm, employees at a Home Depot in the RDU area used flashlights to escort customers through the store, accepted cash only for payment, and used hand-held calculators to ring-up customers.

Table 1 lists some of the different businesses and groups that either benefited or suffered financially as a result of winter storms. Although monetary losses and gains were nearly impossible to quantify with the information available, some general conclusions can be made. Businesses that likely suffer the most financially are those that require good weather (e.g., construction) and good road conditions (e.g., delivery companies). As discussed earlier, some businesses are able to remain open even without heat and electricity, but this is probably not advantageous, or even possible, for the vast majority of businesses and industries. In general, the businesses that benefit the most from winter storms are those associated with clean-up and rebuilding projects. Hotels and restaurants also benefit from those seeking heat and electricity. Following the January Blizzard of 1996, some RDU residents traveled as far as Wilmington, NC (1.5 hours away) to find a hotel with vacancy and electricity. It is interesting to note that most newspaper articles reporting on impacts to businesses and industries focused more on those that benefited from the storm than those that suffered. This is reflected in the list compiled for Table 1 below. Call (2007) noted a similar reporting pattern for severe ice storms in the Northeast U.S.

Property Damage and Insured Losses

The effect of winter storms on insured losses, which likely reflect only part of the total economic loss associated with winter storms (Call, 2007), has been examined by Changnon (2007). Using insurance claim data, he found that the total insured loss from winter storms in the Southeast between 1949 and 2003 was $6.6 billion, with 62 storms amassing at least $1 million each in damage. For this study, it was extremely difficult to ascertain reliable information on monetary damages and losses. Although *Storm Data* has traditionally been the primary government source of storm-related damage available to researchers, there exist a number of potential problems with the figures provided. These problems essentially relate to inconsistencies in reporting procedures and lack of available data for a large number of storms [see Ashley and Mote (2005) for a more detailed discussion]. Extracting data on monetary damage from newspaper articles was also problematic. In many cases, reliable estimates of total damage costs are not known until many months after the storm. Since we stopped checking the online archive if more than two consecutive days passed without mention of a recent storm, we likely missed this information (assuming it was reported in the newspapers we examined). We are planning a follow-up study that focuses on the monetary losses associated with winter storms in the Southeast. We also plan on utilizing information from the Property Claim Service's catastrophe database to determine the impact of winter storms on local insurance industries.

Table 1. List of businesses and groups that benefited and suffered financially from winter storms.

Benefits	Losses
• Grocery stores • SUV and snow tire sales • Tow truck companies • Hardware stores: popular items purchased include shovels, batteries, ice scrapers, sleds, sand, quick-melt solutions, salt, firewood, snow removal equipment, chain saws, and generators • Car washes • Hotels: for stranded motorists, travelers from airports, people/families without electricity • Restaurants (with electricity) • Car repair shops • Tree and landscaping companies • Credit card companies: customers taking cash advances prior to a storm • Movie rentals	• Grocery stores: supply shortages due to consecutive storms in short succession; spoiled foods due to lack of power • Crops/agriculture • Delivery companies • Construction companies • Utility companies: Overtime pay required for local and out-of-state line crews • Retail stores • Blood drives • Day laborers

School Closings and Delays

A large percentage of the storms examined in this study (78%) affected public school schedules in the RDU and GSP areas. Even storms that produced most of their precipitation over the weekend typically lead to a closing or delay the following Monday. In some cases, the timing of a storm affected end-of-term exams and standardized testing schedules, which appeared to cause more logistical problems than cancelation of ordinary instructional days. Though most school cancelations due to winter weather lasted only one day, there are notable exceptions. These include the January Blizzard of 1996, which kept students out of school for a full week in most districts, and the December 2002 ice storm, which resulted in three days of missed classes and restructuring of the end-of-term exam schedule. The most common reason cited for closing or delaying schools was poor driving conditions, but in a few cases a lack of power and heat and mechanical problems with school buses due to the cold weather were the primary reasons.

According to newspaper reports in the RDU area, colleges and universities were more likely to remain in session or cancel only early morning classes, even if K-12 schools in the area had already canceled for the entire day. One of the reasons offered was that the larger universities in the area (e.g., University of North Carolina and North Carolina State University) would in most cases only cancel classes if the public transportation systems stopped service. Conversations with local transit workers seemed to suggest that only the worst of storms would cause severe disruption of public transportation. Nevertheless, we uncovered numerous reports of university classes being held despite hazardous driving conditions and power outages.

One of the more intriguing results from examination of impacts on school operations was the difference in perceived coordination among school districts between RDU and GSP. The public school system in Spartanburg County, SC, is divided into seven independent districts, and very rarely did all districts make similar decisions regarding whether to cancel or delay classes. In contrast, the Wake County, NC, public school system, which is also comprised of seven school districts, appeared to implement system-wide cancelations, delays, or early dismissals. Based on information provided in the newspaper articles, we believe that differences in the roadway infrastructure between the two counties (i.e., more rural roads in Spartanburg County that are not sanded or plowed) may force some districts to forego sending buses or having parents drive students to school because of more hazardous driving conditions. Another difference observed between the two counties was how they recovered lost instructional time due to closings and delays. In most cases, Spartanburg County utilized previously allocated teacher workdays to recover the time, while Wake County had already "built in" a number of snow days to the spring academic calendar to account for possible cancelations during the winter. As an aside, the concept of snow days has recently been broadened in Wake County to include time missed due to hurricanes and severe weather.

Impacts on Utilities

Perhaps the most visible impact of winter weather is the disruption of utilities, namely electrical power. Other utilities are also adversely affected, such as telephone, internet, cable, and water. Based on newspaper reports, approximately 60% of winter storms at GSP and 50% of winter storms at RDU resulted in power outages to at least 10,000 customers. During a minor winter storm in December 2005, approximately 500 customers lost power when a single tree limb severed a power line in a residential community in Chapel Hill, NC. In cases where regional estimates were available, the number of customers without power often exceeded 100,000. During some of the more prolific events, Duke Energy, the largest utility provider in the Carolinas, reported outages of over 1 million. In fact, the December 2002 ice storm was called "the worst in Duke Energy's 100 year history" – over 1.5 million customers in the Carolinas lost power during the storm. This single event alone cost Duke Energy over $47 million. Fortunately, the company was able to absorb the cost out of its annual budget, eliminating the need to increase utility rates. For most events, electrical power was restored to at least 75% of customers within 24 hours, with all power typically restored within 48 hours. There were, however, notable exceptions. Following the January Blizzard of 1996, a number of communities in the RDU area went without electricity for two weeks. In this case, bitterly cold temperatures and an additional round of winter precipitation following the event made it extremely difficult for crews to repair damaged lines and transmission towers. Following the December 2002 ice storm, 10% of Duke Energy customers in Durham County, NC were still without power 10 days after the storm.

Newspaper reports typically cited trees falling on electrical wires as the cause of most power outages. In some cases, trees may have been predisposed to damage due to preceding weather events. For example, a moderate winter storm in January 1997 resulted in numerous downed trees and damage to power lines in the RDU area. An assessment of storm damage later revealed that a large number of downed trees were likely weakened many months earlier when Hurricane Fran passed through the area. In other cases, increases in snow density (i.e., "wet" snow) may have placed added stress on trees and power lines, making them more vulnerable to damage. In addition to power outages, damaged electrical wires can cause a host of other hazards and problems. Live wires that have fallen to the ground can lead to electrocution and fires. A loss of electricity can hinder 911 and other emergency operations, affect various municipal services (e.g., water and sewage), and prevent medical equipment and facilities from operating normally unless back-up generators are utilized. Without television and LAN-line telephones, most individuals relied on portable radios to receive information during power outages. During some of the more severe storms we studied, however, a number of clear-air radio stations were off the air because of damage to their antennas. Interestingly, damage to cell phone towers were not mentioned in any of the newspaper articles, suggesting that cell phone service was typically not affected.

In an effort to restore power following some of the more severe storms, local and regional power companies will request that line crews from other states and regions be brought in to help. For example, nearly 3,000 workers were brought in from six states, some as far away as Michigan, to help the 2,000 utility workers already deployed by Duke Energy following the December 2002 ice storm. These workers spent nearly two weeks restoring power to over 1.5 million customers.

Impacts on Transportation

Winter precipitation that accumulates on roadways can lead to hazardous driving conditions and hundreds of accidents in just a short period of time. Although reliable estimates were difficult to determine for the RDU and GSP areas, statistics at the national level indicate that over 85,000 accidents per year may be attributed to icy/snowy road conditions. Of these accidents, over 1,200 (1.5%) are fatal (Kocin and Uccellini, 2004). Though these numbers are significant, they are much less than the millions of customers who experience a loss of electricity each year due to winter storms. Not surprisingly, there has been much debate as to which sector is impacted the greatest by winter weather – transportation or utilities. Plausible arguments exist in both cases (see Rooney, 1967; Kocin and Uccellini, 2004; Call, 2005; Call, 2007).

According to the North Carolina Highway Patrol, call volume over a 24-hour period can more than double during a winter storm compared to a typical 24-hour period. This places a tremendous burden on emergency workers. Most accident calls take place during and immediately after the period when the precipitation is heaviest, which can sometimes occur at the early stages of the storm. If this happens to coincide with a time when many cars are on the roads (e.g., "rush hour" or holiday weekend), the impact can be severe: highways become large parking lots, stranding motorists and making it exceptionally difficult for emergency and transportation equipment to reach those in need.

Different types of roadways are impacted in different ways by winter storms. As mentioned before, highways and interstates are prone to severe traffic jams and delays due to their high volume and higher likelihood of experiencing a major accident. Unless pre-treated with a chemical solution or salt, highways and interstates can experience significant accumulation of precipitation if traffic volume prohibits plows from clearing them. Major urban arterial and connector roads are often in better condition compared to other roadways since they are typically the first municipal roads to be plowed and have sufficiently high traffic volume to induce compaction and melting. However, if traffic lights are inoperable, delays, traffic jams, and accidents may cause significant inconvenience. Secondary (local) roads are typically in the worst condition following a winter storm since they are rarely pre-treated or plowed and may be blocked by downed trees and power lines. Icy conditions on bridges also pose a significant hazard on secondary roads and are a major source of fatal traffic accidents due to winter storms. During a storm in February of 2003, a school bus returning students home after an early dismissal skidded off a bridge in rural Spartanburg County. Three students suffered minor injuries.

In general, both major and local roadways are severely impacted when the temperature drops significantly, rendering pre-treatment solution and salt ineffective, and when the accumulation rate is greater than the rate of clearing from plowing. Following an event, cold temperatures can cause melt-water on the roads to re-freeze (i.e., "black ice") while road surfaces can be damaged from plow scrapes and numerous freeze-thaw cycles. In contrast, impacts to transportation are often minimized during early and late season events when paved surfaces are able to warm sufficiently to prevent accumulation of winter precipitation (**Fig. 2**). Airports are also negatively impacted by winter storms. While the airports at RDU and GSP typically remained open during most winter storms (there were some exceptions – e.g., RDU airport lost power on two occasions and was closed for nearly a week following the January 2000 snowstorm), there were inevitably large numbers of delays and cancelations.

Emergency Management and Government Response

According to Call (2005), massive government intervention is a key factor in mitigating the impacts of winter storms. This includes having a preparedness plan and the resources in place prior to the winter season as well as responding efficiently and effectively to the impacts as they unfold. In some cases, however, state governments and local municipalities simply do not have the resources available to cope with the impacts resulting from severe winter storms. In those cases, governors will often declare a state of emergency and request federal aid. These measures are necessary in terms of increasing the mobility of emergency vehicles and utility crews and helping stranded residents get food and heat. Local municipalities also rely on the American Red Cross to help set up shelters (often in local school gymnasiums) and distribute food and medicine.

Thought federal aid is sometimes needed to help mitigate the impacts of winter storms, local municipalities themselves can also provide important services. The NC Department of Social Services provided food and kerosene vouchers for residents in the days after the December 2002 ice storm. They also provided food stamp reimbursement for spoiled food. The Director of Public Services for the city of Raleigh established a designated winter weather management team comprised of street maintenance workers, leaf collectors, electric workers on other assignments, and employees from the city's Park and Recreation Department. In the case of the January 2000 snowstorm, former North Carolina governor Jim Hunt ordered prison workers to help shovel business and school parking lots so they could reopen. Even though winter weather mitigation plans are not formally included in many municipal budgets, there appears to be effective communication among city officials, emergency managers, and clean-up crews before, during, and after the storm. Nevertheless, severe winter storms can affect the discourse of city budget meetings. Following the December 2002 ice storm, Raleigh mayor Charles Meeker declared that he would ask the city council to consider purchasing an additional sand truck and plow – with a price tag of more than $100,000.

While the media typically reports on the good deeds of citizens and the competent workers helping to restore a community following a winter storm, there are often hard lessons to be learned as well. The record-breaking snowfall experienced during the January 2000 storm at RDU exposed a number of inadequacies in the city's snow removal strategies. The impact of this storm on the city in terms of snow removal costs was staggering – more than $15 million. Following the storm, the city of Raleigh re-evaluated its plowing and snow removal strategies; the revised plan has been deemed a success following subsequent storms. A lack of preventative measures was also criticized by residents in Chapel Hill, NC following the December 2002 ice storm. While a number of municipalities in the Carolinas allowed power companies to implement aggressive tree-trimming around power lines in an effort to reduce power outages (**Fig. 3**), Chapel Hill mayor Kevin Foy vehemently opposed it. Pictures of power lines wrapped around large tree branches soon circulated, along with reports that tree trimming could have prevented or shortened the duration of hundreds of thousands of power outages in the area.

Deaths and Injuries

To assess the number of deaths and injuries associated with winter storms at RDU and GSP, we elected to use only information from the newspaper archives. Although *Storm Data* is the most frequently used source of casualty information for weather events, much of this information is extracted from newspaper articles (whose information is not provided) and typically does not give precise information on where the casualty occurred (Lopez, 1993). Based on an examination of the state-wide casualty figures provided by *Storm Data*, the "urban" figures we provide for RDU and GSP likely reflect approximately 55% of the total casualties from North Carolina and South Carolina for the period 1995 to 2007.

We identified a total of 43 deaths related to winter storms (24 in RDU and 19 in GSP). Over 69% of fatalities were traffic-related. In a number of cases the exact circumstances were not known, or it was difficult to determine if poor road conditions or weather were the primary causes of the crash. The most commonly cited causes were skidding on a slick road and striking another car or object (in most cases it was the passenger who was killed), skidding off a bridge, head-on-collision due to an inoperable traffic light, and individuals struck while standing next to a disabled vehicle. Approximately 29% of reported deaths were classified as “indirect” and included smoke inhalation and burns due to house fires, carbon monoxide poisoning, and respiratory distress. In addition, two young boys drowned while walking across an ice-covered pond in the RDU area. The remaining deaths were due hypothermia and exposure. All of these victims were at least 60 years of age and two were homeless.

Injuries resulting from winter storms were widespread and included mostly broken bones from falls and slips, as well as trauma resulting from sledding accidents, traffic accidents, falling branches, and snowball fights. There were also numerous reports of individuals treated for exposure, hypothermia, burns, and carbon monoxide poisoning. Determining an accurate number of injuries resulting from winter storms is a difficult task, although improvements in hospital admission surveillance systems are beginning to provide some insight. Broder et al. (2005) examined emergency department admissions records at UNC-Hospitals in Chapel Hill, NC during and following the severe ice storm of December 2002 and identified 130 injuries related to the storm. The most common types of injuries were trauma from falling debris and carbon monoxide poisoning. Interestingly, only 18% of storm injuries were related to slips and falls on the ice.

Under What Circumstances Do Minor Events Have Significant Societal Impacts?

In this section, we highlight a few storms from RDU and GSP that were, meteorologically-speaking, rather minor events, but produced significant societal impacts. Although one could ultimately devise a categorical scheme to describe the impacts of winter storms in the region, we feel that when considering the details of a storm, each in fact has a distinctive “footprint” that overrides simple generalization.

29-30 January 1995 (<0.1 in. freezing rain/sleet at RDU)

Weather forecasts for this event called for mostly rain throughout the day on 29 January and into the early morning hours of 30 January. A brief transition to freezing rain and sleet was expected in the mid to late morning hours, with only trace amount accumulating on cold ground and objects. Since surface and road temperatures were above freezing prior to the event, little accumulation of winter precipitation was expected. Nevertheless, the NWS in Raleigh issued a Winter Storm Advisory. In response, Wake County filled over a dozen trucks with salt and sand. However, the freezing precipitation began earlier than expected, at the height of the “morning rush” (07-09 LST). Traffic already on the roads made it difficult for trucks to adequately treat them. Although the precipitation was light, slick spots developed quickly, causing nearly 100 accidents on major roads and highways. Two fatal accidents were reported in the Raleigh area. Accidents and congested roadways forced many businesses, government offices, and some regional school systems to close, although no power outages were reported.

19 January 2005 (1 in. snowfall at RDU)[3]

A quick burst of snow (~1 in.) in the Raleigh area lead to the early release of businesses and schools around mid-day on 19 January. However, a number of human and meteorological factors turned this seemingly minor event into an infamous one. The quick burst of snow, coupled with very cold surface and air temperatures, resulted in large, dry flakes that effectively covered the roadways. With the simultaneous closure of businesses and schools, area roadways quickly became jammed – a situation known as the “Super Rush” (Call, 2007). Interestingly, even with gridlock on the roads, a large number of accidents (some serious) were reported due to cars skidding and sliding. It was later determined that the icy road conditions were the result of a

[3] Additional information for this event was provided by the Raleigh National Weather Service forecast office: http://www.meas.ncsu.edu/nws/

three-step process: 1) snowflakes on the roads partially melted due to heat released from automobile exhaust; 2) the resulting slush became compacted from the slow-moving traffic; 3) very cold ground and air temperatures caused the compacted slush to freeze into a thin layer of ice. The combination of traffic gridlock, slick roads, and numerous accidents lead to commutes of up to 8-hr for trips that normally take about 30 min.

9-10 March 1999 (2-3 in. winter mix at GSP)

During the early morning hours of 9 March, light snow began falling across the upstate of South Carolina. By the morning rush hour, the snow had transitioned to a mix of sleet and freezing rain which lasted until late morning. In total, approximately 2-3 in. of frozen and freezing precipitation had accumulated across the region. Although power remained on, area schools canceled classes, making it one of the latest snow days in recent memory. Nearly 150 accidents were reported, mainly on major roads, highways, and interstates during the rush hour period. Fortunately, none were fatal or serious. Flight operations were stressed for a period of time at GSP airport, mainly due to deteriorating weather conditions across the Midwest. One of the greatest concerns, however, was the budding peach crop. South Carolina is the second largest producer of peaches in the country (after California), and early March is typically when the peach crop transitions from a tight bud to a breaking bud. During the transition, the crop is more susceptible to damage from cold temperatures and freezing precipitation, but a delay in the planting of the crop in early winter of 1998 meant that the bud was still tight enough to prevent major damage. Agriculturalists in the area stated that a late season winter storm such as this has the potential to cost the peach industry millions of dollars in lost revenue.

2-3 January 2002 (1-2 in. snowfall at GSP)

Although the event of 2-3 January 2002 was relatively minor from a meteorological standpoint, was well-forecasted, and anticipated – Spartanburg County spent an estimated $2 million in preparation – the socioeconomic impacts were substantial. Road crews pretreated most of the major roadways with salt and sand, but cold temperature, persistent light snowfall, and heavy traffic following the New Year's holiday rendered such action ineffective. Amazingly, in just a 12-hr period, approximately 900 accidents were reported in the upstate region of South Carolina, some of which were fatal. Emergency operations were stressed in dealing with the amount of incidents and damage. A later report stated that this contributed to a 50% spike in crime over the two day period. Roughly 50,000 customers in the GSP area lost power at some point during the storm, forcing many businesses to close.

FUTURE WORK AND RECOMMENDATIONS

The goal of this research was to uncover the range of impacts associated with winter storms in the Southeast U.S. For this preliminary study, we examined descriptive entries in the NCDC publication *Storm Data* as well as archived newspaper articles from two metropolitan areas in the Carolina Piedmont. We hope to expand this study to include other locales in the Southeast, especially in rural areas. We also hope to uncover the regional scope of the impacts associated with winter storms, particularly with regards to casualties, utility disruptions, and monetary losses. In this way, we may be able to compare the impacts from Southeast storms to those observed during Northeast winter storms (Call, 2005; 2007). Other areas of study include changes in storm impacts over time and the effect of weather forecasts and storm warnings/advisories on the resulting socio-economic impacts.

Based on the results we have uncovered in this study, we put forth the following recommendations in the hopes of promoting further discussion and research into the impacts of winter storms:

- Determine how municipalities can better prepare for and respond to winter storms

- Determine if the policies currently in place are sufficient in handling school closings and delays in a safe and efficient manner
- Assess the effectiveness of chemical solutions currently used to treat roadways (**Fig. 4**)
- Assess whether media coverage of roadway treatment before an event is providing motorists with a false sense of security
- Assess whether media outlets are providing sufficient warning of the dangers of carbon monoxide poisoning, as well as other environmental hazards
- Assess how communication between power companies and customers can be improved; are power companies relaying accurate information on outage duration to their customers?
- Assess whether aggressive tree-trimming by power companies helps in reducing the number and duration of power outages

APPENDIX: LIST OF WINTER STORMS

Table A1: List of storms for RDU

Date	Type	Precipitation	Impact
29-30 Jan 1995	Freezing Rain	0.3	High
7-8 Feb 1995	Snow	1.0	Moderate
10 Feb 1995	Snow	0.4	Low
6-8 Jan 1996	Winter Mix	6.8	Extreme
7-8 Mar 1996	Snow	0.9	Low
8-9 Jan 1997	Freezing Rain	3.6	Moderate/High
13-15 Feb 1997	Winter Mix	0.3	Low
23-25 Dec 1998	Freezing Rain	6.4	High
2-3 Jan 1999	Freezing Rain	0.1	Low/Moderate
9 Mar 1999	Winter Mix	0.5	Low/Moderate
18 Jan 2000	Snow	2.5	Moderate
22-23 Jan 2000	Winter Mix	3.4	Moderate
24-25 Jan 2000	Snow	20.3	Extreme
29-30 Jan 2000	Winter Mix	10.4	High
19 Nov 2000	Snow	2.2	Moderate/High
21-22 Dec 2000	Snow	0.1	Low
12-13 Feb 2001	Freezing Rain	0.6	Moderate
2-3 Jan 2002	Snow	10.8	High
4-5 Dec 2002	Winter Mix	16.5	Extreme
16-17 Jan 2003	Freezing Rain	0.3	Moderate
16-17 Feb 2003	Freezing Rain	2.0	High
26-27 Feb 2003	Freezing Rain	4.6	High
8-10 Jan 2004	Snow	3.0	Low
25-27 Jan 2004	Snow	2.7	High
15-16 Feb 2004	Snow	2.2	Moderate/High
17 Feb 2004	Winter Mix	0.6	Moderate
25-27 Feb 2004	Winter Mix	8.2	High
19 Jan 2005	Snow	0.7	High
22-23 Jan 2005	Freezing Rain	0.4	Low
28-30 Jan 2005	Freezing Rain	4.2	Moderate/High
15-17 Mar 2005	Snow	0.2	Low

14-16 Dec 2005	Freezing Rain	1.3	Moderate
17-19 Jan 2007	Winter Mix	1.7	Low
21-22 Jan 2007	Freezing Rain	4.2	Moderate/High
1-2 Feb 2007	Snow	0.6	Moderate

Table A2: List of storms for GSP

Date	Type	Precipitation	Impact
10 Feb 1995	Freezing Rain	0.7	Low
6-8 Jan 1996	Winter Mix	9.3	Extreme
11-12 Jan 1996	Snow	3.1	Moderate/High
1-3 Feb 1996	Winter Mix	2.0	Moderate/High
16 Feb 1996	Snow	1.0	Moderate
18-19 Dec 1996	Snow	2.0	High
8-9 Jan 1997	Freezing Rain	7.2	High
13-14 Feb 1997	Freezing Rain	0.6	Low/Moderate
23-25 Dec 1998	Freezing Rain	7.2	High
2-3 Jan 1999	Freezing Rain	7.9	High
31 Jan-3 Feb 1999	Winter Mix	3.6	Moderate
9 Mar 1999	Winter Mix	3.1	High
22-23 Jan 2000	Winter Mix	9.5	High/Extreme
24-25 Jan 2000	Snow	0.2	Low/Moderate
29-30 Jan 2000	Winter Mix	7.2	High
19 Nov 2000	Snow	2.5	Moderate
13-14 Dec 2000	Freezing Rain	0.7	Low
19 Dec 2000	Snow	0.8	Low
21 Dec 2000	Winter Mix	0.3	Low
2-3 Jan 2002	Snow	1.6	High
4-6 Dec 2002	Freezing Rain	5.8	High
16 Jan 2003	Snow	1.5	Moderate
23 Jan 2003	Snow	3.0	Moderate
16 Feb 2003	Winter Mix	3.9	Moderate/High
3-6 Dec 2003	Freezing Rain	2.5	Moderate/High
8-10 Jan 2004	Freezing Rain	0.1	Low
25-27 Jan 2004	Winter Mix	7.1	High
25-27 Feb 2004	Snow	3.5	Moderate
8-9 Dec 2005	Freezing Rain	1.3	Moderate
14-16 Dec 2005	Freezing Rain	11.0	Extreme
18 Jan 2007	Freezing Rain	0.9	Moderate
1-2 Feb 2007	Freezing Rain	6.1	High

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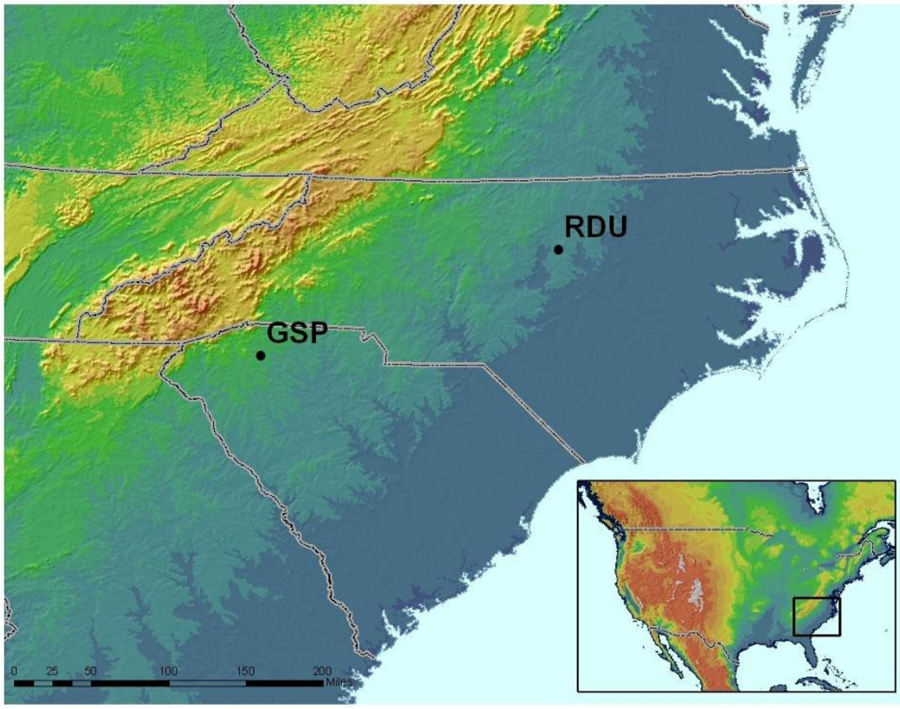

Figure 1: Topographic map of the study area and locations of RDU and GSP.

Figure 2: A local road in Wake County, NC following a moderate snowstorm. Note the accumulation of snow on trees and non-paved surfaces, while the warmer asphalt has prevented any accumulation.

Figure 3: Example of aggressive tree-trimming around power lines in Forsyth County, NC.

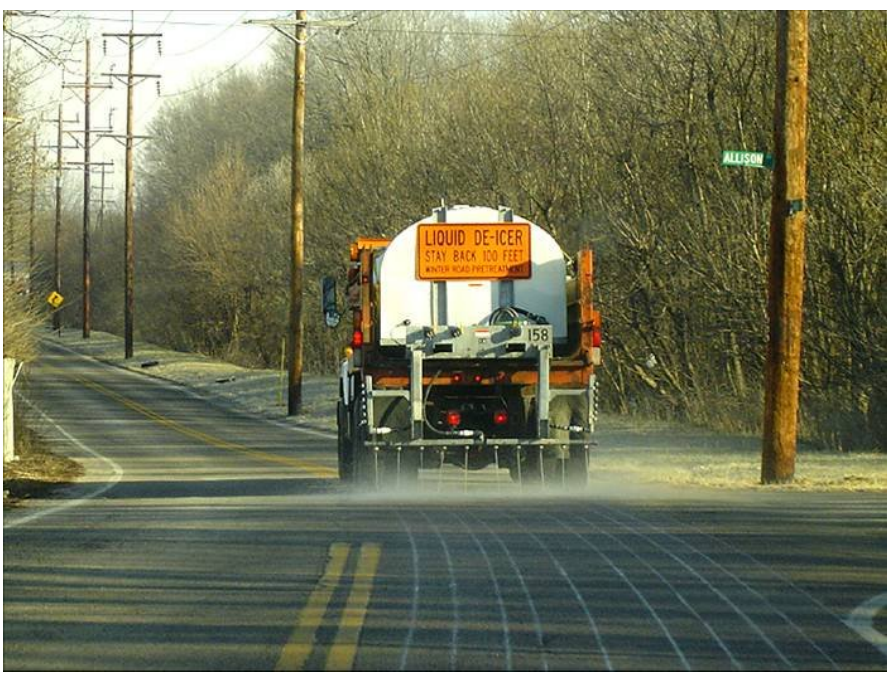

Figure 4: Department of Transportation truck sprays calcium chloride on an arterial road in Wake County, NC prior to an impending winter storm.