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CHARACTERISTICS OF THE TOP TEN SNOWSTORMS AT FIRST ORDER STATIONS IN THE U.S.

Tamara G. Houston*
NOAA National Climatic Data Center, Asheville, North Carolina

Stanley A. Changnon
Changnon Climatologist, Mahamet, Illinois

1. INTRODUCTION

Snowstorms are one of the most damaging weather extremes (Changnon and Hewings, 2001). Concurrent weather conditions such as freezing rain and high winds often exacerbate these damages. Four percent of all weather related insured property losses in the U.S. are a result of snowstorms, averaging $408 million (USD) in insured property losses per year (Changnon and Changnon, 2006). A report by Adams et al. (2004) found that the economic impact of snowfall on the U.S. economy, both positive and negative, range from $50 to $400 billion (USD) per year.

Previous snowstorm studies have typically focused on the synoptic conditions associated with snowstorms, the development of snowstorm climatologies, and case studies of particular events. Additionally, studies by Branick (1997), Schwartz and Schmidlin (2002), Changnon and Changnon (2006), and Changnon et al. (2006) examined significant snowstorms and identified the spatial and temporal characteristics of damaging snowstorms and blizzards. This study builds on these previous studies by identifying the top ten 1- or 2-day snowfall totals at individual First Order Stations (FOS) in the eastern two-thirds of the conterminous U.S. from 1948 to 2001. Concurrent weather conditions such as low temperatures, high winds, and other weather conditions reported during top ten events were analyzed to examine the frequency of their occurrence. By knowing the types of conditions that can occur during a heavy snowstorm at a particular location, those impacted by these storms can be better prepared the next time a significant snowstorm threatens.

2. DATA AND ANALYSIS

In order to assess the frequency and types of potentially damaging conditions associated with locally significant snowfall events, hourly weather conditions during top ten snowstorms (TTS) at select FOS were analyzed. Daily observations of snowfall from FOS were used to identify the top ten snowstorms at each station, and hourly observations of temperature, precipitation, wind speed, and other concurrent weather conditions were used to assess the characteristics of these storms.

A snowstorm was defined as an event in which snow fell over a 1- or 2-day period. This definition is consistent with the findings of Changnon (1969) and Changnon et al. (2006) who found that 84 percent of all 2-day snow events lasted less than 24 hours but, due to a fixed once-a-day observation time, were reported over two observational days. Research has also shown that snowstorms begin to produce significant damages when heavy snowfall occurs within 48 hours or less (Changnon, 1969; Branick, 1997).

The 1- or 2-day snowstorms were determined based on the following criteria. A subset of daily snowfall totals of 25.4 mm or greater at 121 National Weather Service (NWS) FOS from 1948 to 2001 was obtained from the National Climatic Data Center's (NCDC) Cooperative Summary of the Day dataset (NOAA, 2004a). From this subset, if one day reported snow with no snow reported on the day before or after, this snowstorm was considered for the TTS list. If two adjacent days reported snowfall, this 2-day total was considered for the TTS list. If three consecutive days reported snowfall, the two adjacent days with the greatest snowfall total was considered as a 2-day event. The remaining day was also considered but as a separate event. If four or more consecutive days reported snowfall, the three consecutive days criterion was followed to identify the first snowstorm for consideration. Then if the next two adjacent days reported snowfall, or if only one day remained, then this snowstorm was also considered for the TTS list. Additional snowstorms were identified until snow was no longer reported. The snowstorms at each station were then ranked to determine the TTS at that station.

Once the TTS were determined for each station, hourly data for each event were obtained from NCDC's Surface Airways Hourly and Airways Solar Radiation dataset (NOAA, 2004b). This data included dry bulb, wet bulb, and dew point temperatures, wind speed and direction, visibility, and other concurrent weather conditions such as fog and freezing rain. Hourly precipitation was also obtained from NCDC's Hourly Precipitation dataset (NOAA, 2004c) in order to examine water equivalent totals during each event.

3. CHARACTERISTICS OF TOP TEN SNOWSTORMS

Overall a total of 1,182 TTS were analyzed (28 TTS did not have hourly data available). The following

* Corresponding author address: Tamara G. Houston, NOAA's National Climatic Data Center, 151 Patton Ave., Asheville, NC 28801; e-mail Tamara.Houston@noaa.gov.

sections describe the general characteristics of TTS such as the frequency and timing of events, precipitation types and temperatures during TTS, the occurrence of blizzards and blowing snow during TTS, as well as the occurrence of other significant weather conditions.

3.1 *Frequency and Timing of TTS*

The snowfall totals of the number one TTS at each station varied considerably depending on where the storm occurred. In general, there was a latitudinal increase in totals from south to north with higher totals downwind of the Great Lakes and in mountainous areas. The greatest TTS total was 1168.4 mm at Sault Ste Marie, MI on 9-10 December 1995. This event helped break the station's all time record monthly snowfall total with a monthly total of 2507.0 mm. The smallest snowfall total for a number one storm on a TTS list was 139.7 mm at Jackson, MS from a storm that occurred on 13 January 1982.

Studies have shown that snowstorms have occurred as early as September, are most frequent in January, and end as late as June (Doesken & Judson, 1997; Hirsch et al., 2001; Changnon et al., 2006). TTS are no exception. Five TTS occurred during the month of September and one occurred in the month of June. All six of these snowstorms occurred at stations along the Rocky Mountains and had 1- or 2-day snowfall totals ranging from 279.4 mm to 584.2 mm. The month with the most TTS was January (26.8 percent of all TTS) followed by March (19.6 percent) and February (18.8 percent). Figure 1 shows that TTS occurred most frequently in January in most regions assessed, but peaked in February in the Northeast and in March in the West North Central region.

The annual (January - December) number of TTS are shown in Figure 2, revealing that 1978 had the most with 59 TTS from 23 separate storms, a majority of which occurred in the Central region. The year 1983 was second with 47 TTS from 19 storms followed by 1987 with 45 TTS from 15 storms and 1966 with 41 TTS from 16 storms. Since snowfall is a winter phenomenon that crosses from one year to the next, annual frequencies were also determined based on a July to June year. Using this criterion, the winter of 1977-78 had 52 TTS from 19 separate storms followed by the winters of 1978-79 and 1982-83 which had 42 TTS each from 14 and 18 storms, respectively. The temporal distribution has a mid-period peak and does not have a long term upward or downward trend.

3.2 *Damaging Types of Precipitation*

The most frequent hourly liquid equivalent precipitation total during a TTS was 0.3 mm which included melted snow as well as other forms of liquid precipitation such as rain and melted ice. Eighty-eight percent of the time, hourly liquid equivalent precipitation totals were 2.3 mm or less. The highest hourly liquid precipitation total was 17.0 mm at Bristol, TN on 21 November 1952. During that hour, heavy snow fell and contributed to a 1-day snowfall total of 411.5 mm which is the number one storm on Bristol's top ten list. Regionally, hourly precipitation totals were slightly higher in the Northeast and Southeast than in the other regions.

During TTS, heavy snowfall (i.e. visibility less than 400 m) occurred seven percent of the time while snowfall intensity was light (i.e. visibility greater than 805 m) approximately 75 percent of the time. These percentages were also true regionally except in the Northeast and Southeast where heavy intensities occurred 14 and nine percent of the time, respectively, and light intensities occurred in both regions 65 percent of the time.

3.3 *Temperatures*

The temperature during a winter storm plays a significant role in determining whether a location will receive rain, freezing rain, or snow and also determines how dense the snow will be. Approximately 50 percent of the time, snowfall occurred when the dry bulb and wet bulb temperatures were between -4.4° C and 0.6° C. The warmest dry bulb and wet bulb temperatures during a TTS was 7.2° C and 5.0° C respectively at Albuquerque, NM on 29 March 1973 where a 2-day total of 271.8 mm of snow was reported. These temperatures occurred in the early afternoon during a brief thunderstorm and light snow. The coldest dry bulb and wet bulb temperature reported during a TTS was -27.2° C at Sault Ste Marie, MI on 16 January 1982 where a 2-day total of 368.3 mm of snow was reported. Snow continued into the next day (which was beyond the 2-day definition of an event for this study) where the dry bulb and wet bulb temperature dropped to -30.6° C with light snow. Overall, this storm produced $104.6 million (USD, 2006) in insured property losses in 24 states throughout the Midwest, Southeast, and Northeast.

Dew point temperatures ranged from -7.8° C to 0° C 67 percent of the time during TTS. The warmest dew point temperature of 3.3° C occurred during the "Storm of the Century" in Atlanta, GA on 13 March 1993 where 106.7 mm of snow was reported. The coldest dew point temperature was -33.3° C which occurred during a snowstorm in Helena, MT on 10 January 1971 where a total of 307.3 mm of snow was reported.

During TTS, the dry bulb temperature peaked at -1.1° C to 0.6° C for each region except for the East North Central and Northeast regions. The frequency distribution in both of these regions tended to be more uniform over a wide range of temperatures. In the other regions that had higher frequencies near the freezing point, the frequency distribution peaked more sharply. Dew point temperatures peaked at lower temperatures in the East North Central, Northeast, and Central regions than in the other regions.

3.4 *Blizzards and Blowing Snow*

Of the 1,182 TTS, 80 TTS from 56 separate storms were considered blizzards by the NWS definition

(NOAA, 2007). Thirty TTS blizzards were from storms that caused catastrophic damage (based on insured property losses of $1 million (USD) or greater (Changnon, 2005)). TTS blizzards were reported in each month between October and April and occurred most frequently (25 percent of the time) in the month of March. Fifty-five percent of the TTS blizzards occurred in the West North Central region which includes the nation's maximum blizzard zone states of North Dakota and South Dakota, as well as the western part of Minnesota (Schwartz and Schmidlin, 2002).

Ninety percent of the time hourly wind speeds were 11.2 m/s or less during TTS. Only three percent of the time did winds during a TTS exceed 15.6 m/s, the threshold for defining a blizzard. The highest hourly wind speed reported during a TTS was 26.4 m/s at Rapid City, SD on 30 April 1967 where a total of 345.4 mm of snow was reported. Approximately 54 percent of the time, the prevailing wind direction during a TTS was from the northern quadrant.

Regionally, the Southwest had higher frequencies of lower wind speeds and lower frequencies of higher speeds than other regions. Wind speeds were 15.6 m/s or greater six percent of the time in the blizzard prone West North Central region. In the other regions, wind speeds were 5.4 m/s to 7.6 m/s approximately 40 percent of the time.

3.5 *Other Significant Weather Conditions*

Many types of weather conditions occurred at the same time as snowfall during the TTS. These conditions included: thunderstorms, rain, freezing rain, fog, smoke, haze, and blowing snow and included the various types of precipitation (rain, rain showers, drizzle, ice crystals, ice pellets, etc.) and intensities (light, moderate, and heavy). Sixty percent of hours reporting snow also reported one additional concurrent weather condition, six percent reported two additional concurrent weather conditions, and less than 0.5 percent reported three additional concurrent weather conditions. Regionally, the South had the highest percentage of additional concurrent weather conditions with one or more condition occurring 76 percent of the time, while in the Southwest, one or more concurrent weather conditions were reported 52 percent of the time.

The most common concurrent weather condition during a TTS was fog (52 percent of the time) followed by blowing snow (40 percent of the time). Fog was the primary concurrent condition in the Central, Southwest, South, and Southeast regions and blowing snow was the primary concurrent condition in the West North Central and East North Central regions. In the Northeast, fog and ice were dangerous additions to hours when heavy snowfall was occurring.

4. CONCLUSIONS

This study assessed the frequency of various weather conditions that occurred during hours when heavy snowfalls occurred. The results revealed that TTS have occurred as early as September and as late as June, with January being the peak month of occurrence. The year 1978 had the greatest number of TTS. The most frequent hourly liquid equivalent precipitation total during a TTS was 0.3 mm with 88 percent of all hours having values of 2.3 mm or less. Seven percent of the time, snowfall intensity was heavy.

An assessment of temperatures showed that dry bulb temperatures during TTS ranged from -27.2° C to 7.2° C and most frequently occurred near the freezing point. Fifty-one percent of all values were from -4.4° C to 0.6° C. Approximately 54 percent of the snow hours had winds from the northern quadrant. Wind speeds less than 11.2 m/s prevailed 90 percent of the time. Seven percent of TTS were classified as a blizzard with over half of the blizzards occurring in the West North Central region.

Weather conditions occurring during the hours when heavy snow fell were assessed, and the most frequent conditions in the U.S. were fog (52 percent of the time) and blowing snow (40 percent of the hours), both of which reduce visibility.

A listing of the TTS at each station and their concurrent weather conditions along with additional snowfall data and information found in Changnon (2005), Changnon and Changnon (2006), and Changnon et al. (2006) can be obtained from two products available from NCDC. A CD-ROM titled "Snowstorm Data: Long-Term Data Sets about Snowstorms in the United States" and a publication titled "Snowstorms Across the Nation: An Atlas about Storms and Their Damages" can be obtained from the NCDC web site at http://www.ncdc.noaa.gov or by calling NCDC Customer Service at +1-828-271-4800.

5. REFERENCES

Adams, R., L. Houston, and R. Weiher, 2004: The value of snow and snow information services. Report prepared for NOAA's National Operational Hydrological Remote Sensing Center. http://www.economics.noaa.gov/library/documents/benefits_of_weather_and _climate_forecasts/econ_value-snow-final_report.doc

Branick, M. L., 1997: A climatology of significant winter-type weather events in the contiguous United States, 1982-94. *Wea. Forecasting*, **12**, 193-207.

Changnon, S. A., 1969: *Climatology of severe winter storms in Illinois.* Illinois State Water Survey, Bulletin 53, 45 pp.

Changnon, S. A., 2005: *Developing data sets for assessing long-term fluctuation in snowstorms in the U.S.* Changnon Climatologist, 21 pp.

Changnon, S. A., and D. Changnon, 2006: A spatial and temporal analysis of damaging snowstorms in the United States. *Natural Hazards* **37,** 373-389.

Changnon, S. A., and G. Hewings, 2001: Losses from weather extremes in the U.S. *Natural Hazards Review,* **2**, 113-123.

Changnon, S. A., D. Changnon, and T. R. Karl, 2006: Temporal and spatial characteristics of snowstorms in the contiguous United States. *J. Appl. Meteor. Climatol.,* **45,** 1141-1155.

Doesken, N. J., and A. Judson, 1997: *The snow booklet: a guide to the science, climatology, and measurement of snow in the United States.* Department of Atmospheric Science, Colorado State University, 876 pp.

Hirsch, M. E., A. T. DeGaetano, and S. J. Colucci, 2001: An East Coast winter storm climatology. *J. Climate,* **14**, 882-899.

NOAA, 2004a: *Cooperative summary of the day, DSI 3200 – 1948-2001*, National Climatic Data Center, Federal Building, 151 Patton Ave., Asheville, NC, 28801-5001.

NOAA, 2004b: *Surface airways hourly and airways solar radiation, DSI 3280 – 1948-2001*, National Climatic Data Center, Federal Building, 151 Patton Ave., Asheville, NC 28801-5001.

NOAA, 2004c: *Hourly precipitation data, DSI 3240 – 1948-2001*, National Climatic Data Center, Federal Building, 151 Patton Ave., Asheville, NC 28801-5001.

NOAA, 2007: National Weather Service directives system: 10-513 WFO winter weather products specification. http://www.nws.noaa.gov/directives/sym/pd01005013curr.pdf Cited 16 August 2007.

Schwartz, R. M., and T. W. Schmidlin, 2002: Climatology of blizzards in the conterminous United States, 1959-2000. *J. Climate*, **15**, 1765-1772.

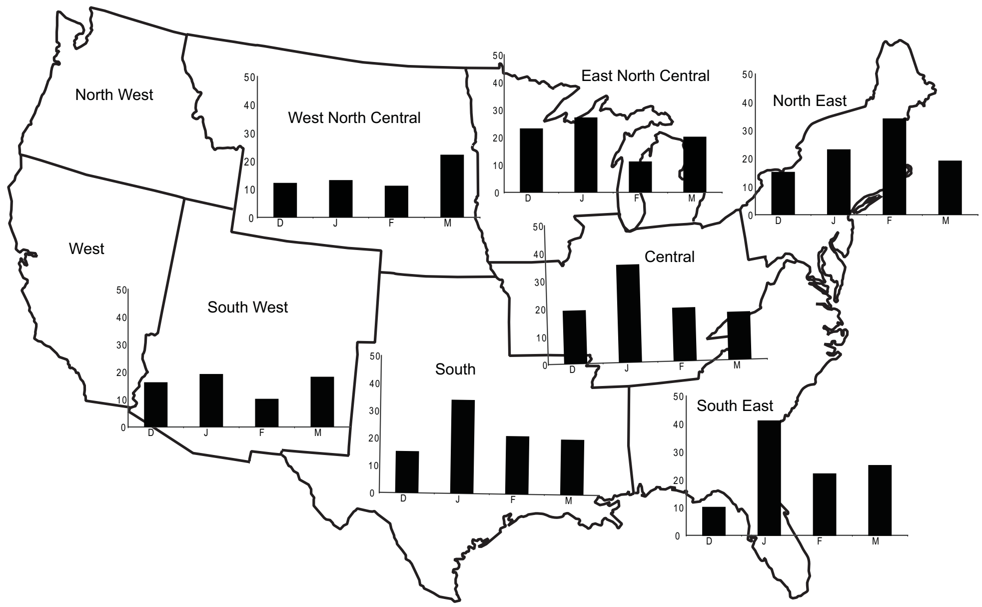

Figure 1. Map of the nine US climate regions. Within each region (excluding Northwest and West) is the frequency of TTS in percent for the months of December through March (D, J, F, M).

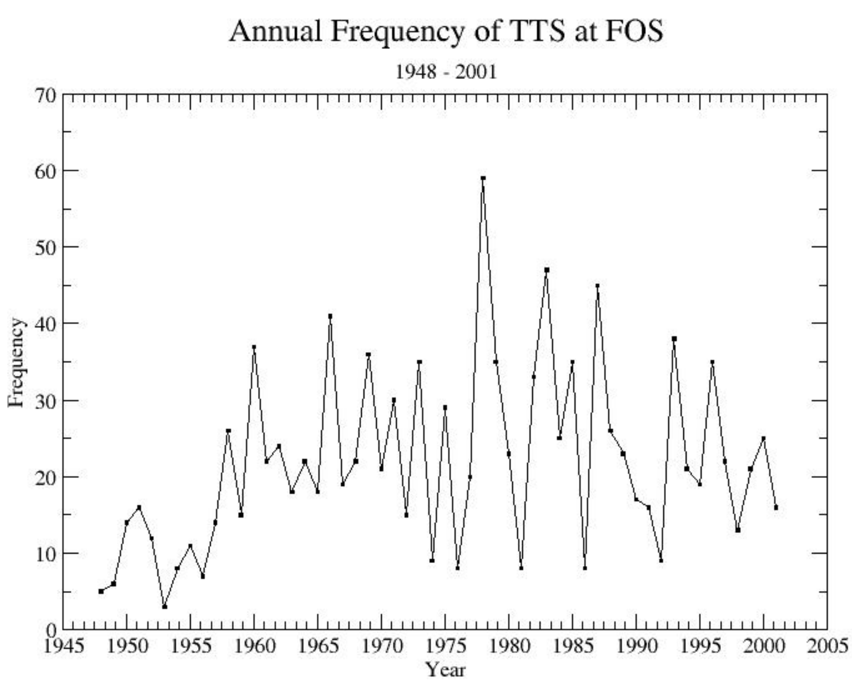

Figure 2. Number of TTS per year.