Problems with Heavy Snow Data at First-Order Stations in the United States

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ABSTRACT

Various interests desire information and data on heavy snowfalls to define their spatial and temporal occurrences. Historical data at the nation's 208 first-order stations for events with 15.2 cm or more snowfall in 2 days or less was assessed, and revealed various serious data problems at 118 stations with climatological quality data available for 90 stations. The data problems are described as guidelines for those seeking to utilize heavy snowfall data, and stations with quality data are listed.

1. Introduction

Weather data from first-order stations (FOS) manned by trained personnel of the National Weather Service are generally considered to have high quality for climatological applications. Most of these stations have been in operation since late in the nineteenth century, and their data are widely used as input for structural design, operational planning, and research. A recent project assessed data at FOS in the contiguous United States for snowfall events that produced 15.2 cm (6 in.) or more snowfall in one or two consecutive days. This level of snowfall was chosen because past studies found that when 15.2 cm or more snow fell in periods of 6 h up to 2 days, major socioeconomic impacts occurred (Changnon 1969), and Branick (1997) assessed national snowstorm periods using 15.2-cm or greater amounts as a definition for heavy snowfalls in the United States. This paper describes the evaluation of the heavy snowfall data at FOS and the surprising data problems encountered at many stations related to methods of snow data collection.

Assessment included data of 208 FOS to detect any shifts in storm frequency associated with station moves or operational changes. Temporal evaluations were performed for each FOS with initial attention to frequencies before and after station moves or observational/operational changes to detect discontinuities (Easterling and Peterson 1995). Snowfall measurement is difficult and can be inaccurate, and resulting data need careful analysis (Doesken and Judson 1997)

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2. Assessment of first-order station heavy snowfall data

Data for 208 FOS with long records were evaluated. First-order stations generally have high quality data, but certain changes over time could have affected the continuity of measured snowfall amounts. One such factor is the move of the station and a potential change in exposure or local/regional climate conditions. Most FOS were moved from in-city sites to rural airport sites during the 1930–50 period, and this shift could have altered the amount of snow measured. Second, the 24-h measured amounts can vary depending on whether the station summed the four 6-h measured values during each day, or just used the once-a-day measurement. Another factor affecting the quality of FOS snow data was the establishment of the Automated Surface Observing System (ASOS) during the 1990s.

Assessment of the FOS snowfall data and resulting annual averages for snowstorms at the 208 FOS revealed a lack of long-term (1901–2001) digital data for most (195) stations, but all 208 FOS had digital data for 1948–2001. Data problems discovered in the 1948–2001 data fell under two general categories. First were those resulting from shifts in storm frequencies over time due to observational shifts, station relocations, and the adoption of ASOS during the 1990s. The second type of problem found related to inadequate sampling of heavy snow event frequencies.

a. *Frequency changes due to station relocations and/or operational changes*

The records of each FOS were examined to detect possible shifts in snowstorm frequency associated with station moves or shifts in observational approaches. Most moves of consequence, from in-city locales to airports, occurred prior to 1948, as revealed by the station records. Assessments were made to detect unusual shifts in values at times of recorded station shifts. If the values after the shift exceeded one standard deviation of the existing frequency, they were considered too altered to be representative of the past climate conditions. This analysis found that 21 stations had statistically significant changes in storm frequencies associated with station shifts or operational changes. Examples of the data shifts from station moves are described below for three stations. Some FOS had shifts due to periods when the daily total was based on the sum of hourly measurements, an action that inflated the daily totals. A comparison of the daily totals based on once a day measurements with those based on the sum of four measurements per day (taken every 6 h) was made for six stations, and this showed 8% to 15% more snow per day when the four values were summed.

Atlanta, Georgia, with snowfall data for 1930–2001, exhibited an abrupt 43% increase in its snow day (2.5 cm) frequency during 1951–60. Thereafter the frequency remained higher than that of 1931–50, and the shift was related to a station relocation and operational changes made during 1951–60. Analysis of the Sheridan, Wyoming, records for 1920–2001 revealed a 56% reduction in snowstorm (15.2 cm) frequency during 1981–85. As a result, the 1986–2000 period had the lowest frequencies of the 1920–2001 period, and the shift was due to a station relocation and operational changes. At Helena, Montana, the frequency of 15.2-cm snow days decreased after 1940 when the station was moved from the in-city locale to the airport. The average before 1940 was 13 storm days per 5-yr period, but after 1940 it was 8 days per 5-yr period, 38% less. The changes at these western stations may reflect local climate differences due to topography or different exposures of the measurement sites.

A major operational shift affecting snow observations at many FOS occurred during the 1990s when the weather measurements at all FOS were shifted from observations by NWS personnel to a sensor-based system during 1995–96. The installation of ASOS resulted in many changes in snowfall measurements that depend on human measurements and are not done by the ASOS equipment. Assessment of the 208 first-order stations in the nation with digital snowfall data through 2001 revealed three different outcomes in snowfall measurements resulting from the shift to ASOS.

TABLE 1. Selected first-order stations with annual average frequencies of snowstorms that are lower than those of surrounding cooperative substations.

First-order station	Average	Averages of surrounding stations	Difference, percent of FOS
Evansville, IN	0.4	0.5–0.6	25–50
Columbus, OH	0.7	0.8–0.9	14–28
LaCrosse, WI	1.4	1.7–1.8	21–28
Springfield, IL	0.6	0.8–0.9	33–50
Sioux City, IA	1.2	1.3–1.4	8–16
St. Louis, MO	0.7	0.8–1.1	14–42
Oklahoma City, OK	0.2	0.3–0.4	50–100
Topeka, KS	0.7	0.8–0.9	14–28
North Platte, NE	1.0	1.5–1.6	50–65
Pierre, SD	1.1	1.4–1.6	27–31
Pittsburgh, PA	1.1	1.6–1.7	31–35
Richmond, VA	0.7	0.8–0.9	12–22
Asheville, NC	0.5	0.6–0.7	16–30
Miles City, MT	0.7	0.9–1.1	22–36

In one outcome, some stations had no snowfall measurements after 1995 or 1996 and through 2001, and this occurred at 46 stations. In the second situation, the snow-day values in 1996, 1997, 1998, and sometimes in 1999, were zero or drastically reduced over those in prior years, but thereafter snow-day frequencies increased in either 1999 or 2000 when human observers were again used to measure snow. This major data reduction for 3–4 yr was found in the records for 38 stations. No ASOS effect could be discerned at 124 stations. No effect could be detected at 69 stations in the South and Southwest where snow-day occurrences are very infrequent. No effect was present at 55 stations in northern, heavy snowfall locations where human observations of snowfall had been continued when ASOS was implemented.

b. *Inadequate sampling of snowstorm occurrences*

One phase of each station's evaluation involved comparison of the annual average snowstorm frequency with those at three or more surrounding stations within 50 km. These spatial comparisons revealed that 51 FOS had averages that were markedly less than those of surrounding cooperative substations with none of the FOS having averages that were equal to or greater than any surrounding station (Changnon 2005).

Table 1 shows averages for 14 FOS selected to illustrate the problem. The stations shown are from varying climate areas, and the table shows the range of the averages of the surrounding cooperative substations (manned by volunteers), and the range of percentage differences. Most of the 51 FOS values were between 14% and 50% lower than surrounding values. It was impossible to make such comparisons for FOS in the mountainous western third of the nation where topographic influences cause sharp spatial differences in storm occurrences.

Two reasons for fewer snow events at the FOS were identified: (a) urban effects on the atmosphere led to fewer in-city snowstorms, and (b) differences in exposures of measurement sites. Prior studies have shown that large urban areas, as a result of their heat islands, convert some snow to rain, and as a result, experience 10% to 30% less snowfall than do surrounding rural areas (Landsberg 1961). Many FOS are in or near large urban areas, and this is not the case for most cooperative substations. Heat island–related decreases in seasonal snowfall were found at Chicago, Illinois, and St. Louis, Missouri (Changnon 2004). Some major cities with notable heat islands like Kansas City, Missouri; Oklahoma City, Oklahoma; and St. Louis had lower snowstorm values, but some large cities like Cleveland, Ohio, and Milwaukee, Wisconsin, had averages that matched surrounding values.

The Washington urban heat island has been documented as having an influence that decreases total snowfall in Washington, DC (Woollum and Canfield 1968). Their study of the historic snowfall data in the Washington area showed a decrease of 20% due to the urban heat island. The possible urban effect on snowstorms in Washington was investigated by comparing values of two nearby first-order stations that had measured snowfalls from 1963 through 2000. One is at Washington, DC's Reagan National Airport and the other is 31 km west at Dulles Airport. Both had comparable ASOS problems during 1997–98. The average annual frequency of snowstorms was 1.0 at Dulles and 0.7 at National. Their peak snowfall event values and those for 5- and 10-yr return intervals are shown in Table 2. The National Airport values are 10% to 20% less than the Dulles values. These could be illustrative of how differences can exist over short distances during a 38-yr period, possibly due to natural variability or to urban influences. National Airport is in the center of a large urban area and Dulles is in a largely rural, partially suburban environment. Two nearby rural-area cooperative substations with quality snowstorm data, one 26 km east-northeast of National Airport and one 34 km south, both had annual averages of 1.0 storms, further revealing the 0.7 average at Washington National is low and unrepresentative of regional frequencies. The urban heat island effect appears to be a factor behind the lower values at Washington, DC, and at certain other FOS, but these FOS have not been identified by in-depth case studies. Some FOS are at airport sites free of any urban heat island effect.

Table 2. Snowfall values (cm) derived for Washington National Airport and Dulles Airport based on data for 1963–2000.

		Once in	
	Peak value of record	10-yr value	5-yr value
Dulles	58.0	38.5	28.5
National	46.8	34.5	25.8
Differences	11.2	4.0	2.7

A second possible reason for the lower snowstorm frequencies at FOS than at nearby cooperative substations are differences in the exposure of snow measurement sites. Most cooperative substations are located inside communities and have numerous surrounding structures acting to diminish winds and hence the blowing and drifting of the snow on the ground. In contrast, since the 1930s or 1940s, most FOS have been at airport sites with notably fewer structures surrounding their measurement sites than found at cooperative substations. Such more open exposures allow more snow to be blown and scoured at FOS measurement sites. This situation would reduce the amount of snow measured at FOS, in comparison to that at many cooperative substations. Data from Missoula, Montana, were examined for an exposure assessment. Two nearby FOS have been jointly operated, one inside the city and one at the rural airport, from 1948 to 2000 (both using the same observational rules). The in-city station recorded 79 snowstorm events (average 1.5 yr^{-1}), whereas the airport station had only 57 storm events, an average of 1.1 yr^{-1}. Furthermore, the top ranked storm snowfalls differed with more snowfall at the city station. Its top three ranked snowstorm amounts were 51.0, 36.3, and 32.2 cm, as compared to 36.0, 32.5, and 30.3 cm at the Missoula airport. These results indicate an exposure difference with less snowfall and fewer storms at the more openly exposed rural airport site.

3. Summary

Assessment of the quality of the heavy snowfall data for the 208 FOS in the United States revealed the following outcomes: 84 stations had ASOS-related data problems, 21 had problems from station relocations/operational changes, and 51 had annual averages that appeared to be too low. Some of those with a problem in one category also had a problem in another category. The total number of stations with questionable snowstorm data for one or more reasons was 118. Data from these stations should not be used in studies of climate

TABLE 3. First-order stations in the United States with quality heavy snowfall data for 1948–2001.

State	Stations
Alabama	Mobile, Montgomery
Arizona	Phoenix, Tucson, Yuma
Arkansas	Little Rock
California	Auburn, Bakersfield, Bishop, Blue Canyon, Eureka, Fresno, Redding, Red Bluff, Sacramento, Stockton
Colorado	Colorado Springs, Denver, Grand Junction
Georgia	Athens, Augusta, Columbus, Macon
Idaho	Boise, Pocatello
Illinois	Chicago
Indiana	Ft. Wayne, South Bend
Iowa	Dubuque
Kansas	Goodland, Dodge City, Wichita
Louisiana	Baton Rouge, Lake Charles, Shreveport
Maine	Caribou, Portland
Michigan	Flint, Grand Rapids, Marquette
Minnesota	Duluth, International Falls
Mississippi	Jackson, Meridian
Missouri	Springfield
Montana	Billings, Butte, Kalispell, Missoula
Nebraska	Scottsbluff, Valentine
Nevada	Elko
New Hampshire	Concord
New Mexico	Roswell
New York	Binghampton, Buffalo, New York, Syracuse
North Carolina	Charlotte, Wilmington
North Dakota	Bismarck, Fargo, Grand Forks
Ohio	Akron
Oregon	Astoria
Pennsylvania	Williamsport
Rhode Island	Providence
South Carolina	Charleston, Columbia, Greenville
South Dakota	Aberdeen, Huron, Rapid City, Sioux Falls
Tennessee	Knoxville
Texas	Austin, Amarillo, Houston, Port Arthur, San Antonio, Waco
Utah	Salt Lake City
Vermont	Burlington
Virginia	Norfolk
Wisconsin	Madison, Milwaukee
Wyoming	Casper, Rock Springs

change or regional climatologies. They could be used in local areas as an approximate measure of the local snowfall climate. Ninety FOS were found to have high quality data, and these are listed in Table 3. Many states in areas of frequent snowstorms had one or two FOS with quality data. The Northeast region had 10 quality stations, the Midwest had 13, the High Plains had 12, and the Rocky Mountains had 15.

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