Connecticut Snowfall Distributions

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ABSTRACT

This research project was conducted in order to determine if there are certain snowfall distributions over the state of Connecticut. Using snowfall data from ten Connecticut locations, normal probability plots, lognormal probability plots and histograms were constructed. The results of these statistics tests led to the conclusion that there are three regions in Connecticut with unique snowfall distributions. The first zone is in northern Connecticut, which has a normal distribution of snowfall. Next, coastal Connecticut has a lognormal distribution of snowfall. Finally, southern interior Connecticut has a bimodal distribution of snowfall.

Key words: annual snowfall, lognormal distribution, normal distribution, bimodal distribution.

INTRODUCTION

I will begin with a brief summary of three distinct climate zones in Connecticut and its effect on snowfall. This is a more generalized version of the eight Connecticut climate zones discussed by Goldstein, in his article "Accounting for Differences; the Climate Zones" which appeared in *The Hartford Courant.*

The first climate zone, in northern Connecticut, includes the northern counties of Litchfield, Hartford, Tolland, and Windham. Here, snow falls frequently during the winter. However, annual snowfall amounts in this region vary greatly due to changes in elevation. In the northwest portion of Connecticut, locations above 1500 feet (457.5 m) in elevation receive an average of nearly 100 inches (254 cm) of snow per year. Lower terrain in the southern portion of the region, with elevation around 500 feet (152.5 m), averages 50 inches (127 cm) of snow every year. Annual snowfall amounts drop to near 40 inches (101.6 cm) in the Connecticut River Valley. The increased snowfall in the higher terrain can be attributed in part to two reasons. First, colder temperatures, which in a span of 1000 feet may decrease around 5 degrees Fahrenheit (1 degree Celsius per 100 meters) and therefore keep most winter precipitation in the form of snow. Second, lifting of the winds as they approach the hills (orographic lifting) enhances precipitation over the higher elevations.

The second climate zone, the coastal plain, encompasses the Connecticut coast, including the cities of Bridgeport, New Haven, and Groton. The relatively mild waters of Long Island Sound make the winter months in this region considerably milder than in the northwest hills. Temperatures along the shore may be as much as 10 to 15 degrees Fahrenheit (5.5 to 8.3

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degrees Celsius) above those in the northwest hills. For this reason, during many winter storms (especially Nor'easters) precipitation in coastal areas will quickly change from snow to rain with a mild wind coming off the ocean. Annual snowfall totals in this region average between 20 and 30 inches (50.8 and 76.2 cm).

The third climate zone includes the southern interior portion of Connecticut. More specifically, this zone encompasses interior portions of Fairfield, New Haven, Middlesex, and New London counties, including the cities of Danbury and Middletown. Here, contributions of both the northern and coastal zones influence the accumulation of snow. A strong flow off the ocean can quickly change precipitation to rain in this region while more northern locations experience snow. However, this region is just far enough away from the coast and has an elevation high enough (averaging between 200 and 500 feet, or 61 to 152.5 m) that it may also snow here while it rains along the coast. Annual snowfall totals range from between 30 and 40 inches (76.2 and 101.6 cm), although this may vary greatly depending on storm tracks throughout the winter.

TECHNIQUE

Keeping these climate zones in mind helps to categorize the sites obtained in the data. Snowfall data for ten Connecticut locations were obtained from the Northeast Regional Climate Center at Cornell University. The sites included coastal locations and interior stations with the longest records. The coastal sites were Norwalk, Bridgeport, New Haven, and Groton. Northern locations included Storrs, Cream Hill, and Norfolk. Southern interior sites included Mount Carmel, Danbury, and Middletown. The average number of years of snowfall data used for each site was 51. The minimum was 28 years at New Haven, and the maximum was 74 years at Storrs.

The raw snowfall data was ordered and years with incomplete snowfall data were omitted. All snowfall totals were rounded to the nearest inch and plotted on log-probability paper. From this, we should see that a straight-line plot would indicate a lognormal distribution of the data. Shoreline locations exhibited a distinct pattern, showing a fairly linear plot. This may have indicated a lognormal distribution of coastal snowfall, but further investigation was needed. Southern interior locations showed a log-probability plot similar to what would be seen in a bimodal distribution. Meanwhile, northern locations showed neither tendency on their log-probability plots.

Normal probability plots, lognormal probability plots and Lilliefors tests were applied to all data. The results confirmed the lognormal distribution hypothesis for the shoreline snowfall data. The ln values of the snowfall data were plotted against the probability of a given snowfall amount to create a lognormal probability plot like the one seen in Figure 1.

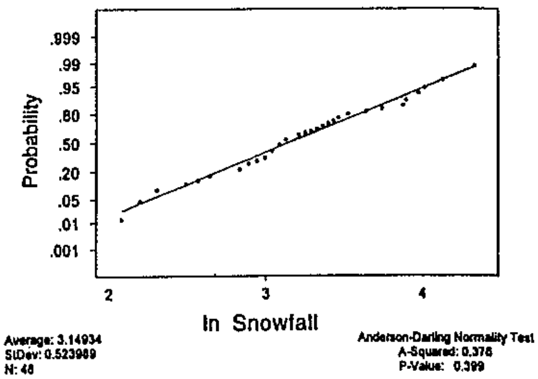

Figure 1. Bridgeport log normal probability plot.

On this plot, the solid line is the cumulative distribution function of the data, with the black dots being the actual data points. The P-value displayed on the bottom right-hand corner of the plot gives a numerical value for which the data will either confirm or reject the hypothesis of lognormality. A P-value of 0.05 or above confirms lognormality, while a P-value below 0.05 rejects it. Looking back at Figure 1, we see that the Bridgeport P-value is 0.399, which confirms the lognormal distribution.

The next test performed was the Lilliefors test. In this plot, the stepped line indicates the empirical distribution function of standardized data. The dashed lines represent the cumulative distribution of the standard lognormal distribution, with a 5% tolerance. If the stepped line remains within the bounds of the dashed lines, this gives a visual confirmation of the hypothesis of lognormality. A look at the Bridgeport Lilliefors plot (Figure 2) gives a visual confirmation of the lognormal distribution hypothesis. It should be noted that this test is not as sensitive as the normal probability plot.

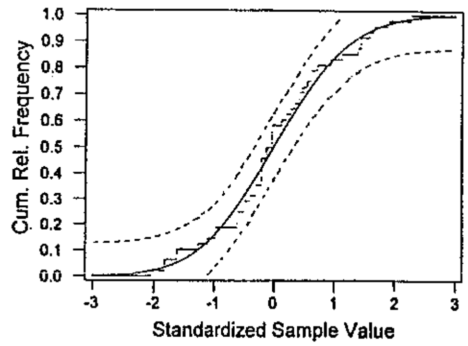

Figure 2. Bridgeport Lilliefors plot.

RESULTS

One point to mention is that heading east along the Connecticut shoreline, the lognormal fit of the snowfall data is less pronounced. The P-values for New Haven and Groton are 0.260 and 0.121 respectively, which may be explained for this reason. On the New Haven and Groton probability plots, the greatest deviation of the ln snowfall data (black dots) from the cumulative distribution function (solid line) occurs for ln values of about 2.3 and below (approximately 10 inches, or 25.4 cm of snow and below). For ln values above 2.3, the plots stay linear for all locations.

The minimum amount of snowfall for any year in the Bridgeport data was 8 inches (20.32 cm); in New Haven it was 6 inches (15.24 cm); in Groton it was 3 inches (7.62 cm), with 10% of the years in the Groton dataset having annual snowfalls of 8 inches (20.32 cm) or below. Due to the nature of the ln function, we have as great an increase from values of 1 to 10 as from 10 to 100. This explains the deviation from ln values below 2.3 and the more linear nature of the plot for ln values above 2.3.

This effect becomes even more pronounced in Norwalk, in the southwest corner of Connecticut. Here, the minimum annual snowfall recorded in the dataset was 1 inch (2.54 cm) with 11% of the snowfall data below 10 inches (25.4 cm). This much of the snowfall below 10 inches (25.4 cm) makes the P-value on the probability plot drop to 0.0. However, for ln values above 2.3, the plot becomes linear.

Another factor to consider is the uncertainty in measuring an annual snowfall of below 10 inches (25.4 cm). On the shoreline, this often means that over the course of the winter there were a series of light snowfalls (up to 2 inches, or 5.08 cm), since during many storms the snow changes to rain. These measured amounts can vary due to the precision of the tool being used. Because of this uncertainty and the nature of the ln function for values below 2.3, the lognormal tests were performed again with totals below 10 inches (25.4 cm) discarded. The results from these lognormal probability plots showed that all shoreline locations confirmed the lognormal distribution hypothesis with higher probability levels. In addition, Norwalk confirmed the lognormal distribution hypothesis.

Furthermore, the lognormal distribution is most useful in situations when the distributed quantity covers a wide range of values, with a ratio of 10 or above from large to small values of snowfall (Hinds 1982). All shoreline locations had a ratio over 10. Norwalk was the highest (64), followed by Groton (24), then Bridgeport and New Haven (10 each).

For northern Connecticut, normal probability plots confirmed a normal distribution of snowfall. The P-values for the normal distribution were 0.385, 0.067, and 0.673 at Storrs, Cream Hill, and Norfolk respectively. The Lilliefors test also confirmed normality. It was thought that a histogram might visually confirm the Gaussian distribution. The three show the fairly symmetrical distribution around the mode (see the Storrs histogram, Figure 3). This feature is not as pronounced in Cream Hill, which passed the test with a lower P-value.

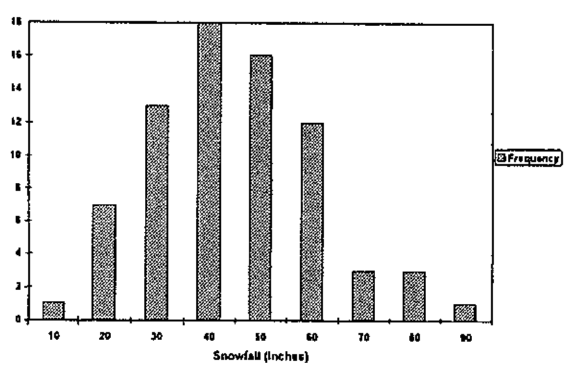

Figure 3. Histogram of Storrs, CT snowfall (1888-1997).

Although these three locations have the same type of snowfall distribution, the amounts the distributions cover are strikingly different. For example, the mean snowfall total in Norfolk is 96.6 inches (245.36 cm) with snowfall totals between 66.1 and 127.1 inches (167.89 and 322.83 cm) within one standard deviation. Nearby Cream Hill has a mean snowfall total of 70.3 inches (178.56 cm) with amounts of 47.7 and 92.9 inches (121.16 and 235.97 cm) falling within one standard deviation. By contrast, the mean snowfall in Storrs is 40.3 inches (102.36 cm) with totals between 24.5 and 56.1 inches (62.23 and 142.49 cm) falling within one standard deviation. This has to do with the elevation of the three sites. Norfolk, at an elevation of approximately 1700 feet (518.5 m), has the most snowfall. Cream Hill, at 1486 feet (453.2 m), has slightly less snowfall. Storrs, at approximately 300 feet (91.5 m) in elevation, receives much less snowfall than the other two locations. The one thing that remains constant, though, is that the annual snowfall in all three locations is distributed normally.

One peculiarity observed in the Norfolk data is that it also passed the lognormal distribution tests. This is explained by the observation that when the ratio of snowfall range from high to low values is narrow (below 10), the lognormal distribution approximates the normal distribution. The ratio of Norfolk snowfall from from highest to lowest values is 4.3, well below 10.

Looking at southern interior Connecticut, we find a bimodal distribution of snowfall (see the Middletown histogram, Figure 4). This bimodal distribution exhibits both coastal and northern influences to the snowfall of this area. The first "mode" of snowfall occurs at the 13-24 inch (33.02-60.96 cm) snowfall bin at Middletown, the 15-22 inch (38.1-55.88 cm) snowfall bin at Mount Carmel, and the 21-30 inch (53.34-76.2 cm) snowfall bin at Danbury. These modes coincide with the modes established at coastal locations, which were 26-35 inches (66.04-88.9 cm) at New Haven, 17-24 inches (43.18-60.96 cm) Groton, 21-30 inches (53.34-76.2 cm) at Norwalk, and 11-21 inches (27.94-53.34 cm) at Bridgeport.

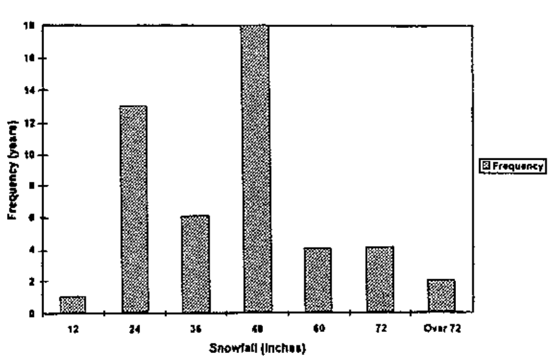

Figure 4. Histogram of Middletown, CT snowfall (1948-1996).

The second "mode" of snowfall occurs at the 37-48 inch (93.98-121.92 cm) snowfall bin at Middletown, the 31-38 inch (78.74-96.52 cm) snowfall bin at Mount Carmel, and the 41-50 inch (104.14-127 cm) snowfall bin at Danbury. This mode coincides with the modes established in more northern locations at a similar elevation. For example, Storrs, which is at a similar elevation to the three southern interior sites, has a mode of 31-40 inches (78.74-101.6 cm). This mode coincides with the second mode of southern interior snowfall. Meanwhile, Cream Hill and Norfolk, which are both more than 1000 feet (305 m) higher in elevation, have much higher modes and cannot be compared to the second mode of southern interior snowfall.

The combination of coastal and northern influences can be shown on a normal probability plot. Herdan explains that when plotted on an arithmetical probability grid, the graph of the average particle sizes of a mixture comprised of two components whose means are sufficiently apart from one another will show up as a double inflection. This double inflection will first go clockwise, then counterclockwise (Herdan 1960). Applying this concept to snowfall, we see that the graph of two sufficiently different snowfall distributions (shoreline and northern) will also show up as a double inflection, first clockwise, then counterclockwise.

Looking at the Middletown normal probability plot (Figure 5), we see that a clockwise bend occurs at c1=21 (where c1 represents snowfall in inches). This corresponds with the first mode of Middletown snowfall (the coastal part of the distribution). The next bend, which is counterclockwise, occurs at c1=40, which agrees with the second mode of Middletown snowfall (the northern part of the distribution).

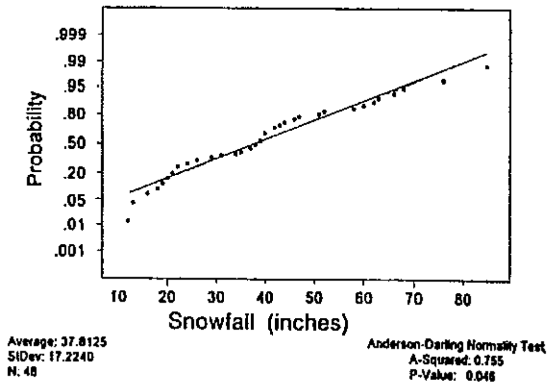

Figure 5. Middletown normal probability plot.

Furthermore, if the distance between the means of the two normal curves with a standard deviation, σ, is 2σ or greater, then the curve will have two modes (Herdan 1960). For Middletown, the mean of the first normal curve (between cl=13 and cl=21) is 18.1. The mean of the second normal curve (between cl=40 and cl=85) is 52.7. This difference is 34.6, which is greater than 2σ (34.4). Hence, this substantiates the hypothesis of a bimodal distribution at Middletown.

The Danbury normal probability plot has a clockwise bend at about cl=29, corresponding with the first mode of snowfall. The second bend, which goes counterclockwise, occurs at cl=45. This coincides with the second mode of snowfall. The mean of the normal curve up to the first bend (between cl=15 and cl=29) is 23.8, while the mean of the second normal curve is 62.8. This difference (39) is greater than 2σ (37), which justifies the bimodal distribution at Danbury.

The Mount Carmel normal probability plot shows the first clockwise bend occurring at cl=23. This agrees with the first mode of Mount Carmel snowfall. The second, counterclockwise bend occurs at cl=31, corresponding with the second mode of Mount Carmel snowfall. The mean of the first normal curve (between cl=11 and cl=23) is 17.1, while the mean of the second normal curve is 43.7. This difference is 26.6, greater than 2σ (26.2). This justifies the bimodal distribution in Mount Carmel.

Another interesting feature of the mixing of distributions in the southern interior portion of the state is that each of these locations actually passed one of the other distribution tests. Danbury and Middletown each passed the lognormal distribution tests with P-values of 0.218 and 0.065, respectively. Mount Carmel passed the normal distribution test with a P-value of 0.261. Once again, these locations exhibited the bimodal distribution that neither the coastal or northern locations showed. Therefore, they were placed in their own group.

CONCLUSION

This brings us to the conclusion that there are three unique Connecticut snowfall distributions, as shown on the map in Figure 6.

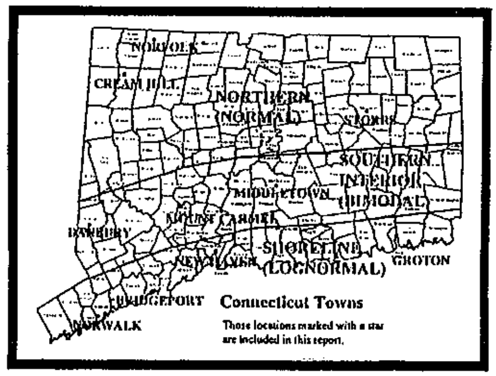

Figure 6. Connecticut snowfall regions and their distributions.

Coastal sections have a lognormal distribution, southern interior sections a bimodal distribution, and northern sections a normal distribution of snowfall. The exact boundaries of these zones cannot be determined, since these changes occur gradually. Furthermore, the influences of these zones do tend to overlap, as was seen in the southern interior locations.

Using these distributions, it may be possible to predict the probability of a given annual snowfall total at a Connecticut location. Further research can be done to refine these distributions in order to improve predictions for annual snowfall.

REFERENCES

Herdan, Gustav. *Small Particle Statistics.* Butterworths, London, 1960.

Hinds, William C. *Aerosol Technology.* John Wiley & Sons, New York, 1982.