Urbana, Illinois: 20th Century Snowfall Variations and Non-Climatic Influences

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ABSTRACT

Previous studies using *in situ* data to examine historical variations in snow have focused on seasonal total snowfall amount or number of days with snow cover, with little or no attention given to adjusting the data for inhomogeneities. A suite of snowfall parameters, including total snowfall amount, greatest 1-day and 2-day snowfall amount, length of snow season, number of days with snowfall, and median daily snowfall, is used successfully to give a more complete picture of 20th Century snowfall variations at Urbana, Illinois.

Snowfall amount is most sensitive to inhomogeneities in the data, number of days with snow is less sensitive, and snow season length is least affected. Changes in observation time appear to be the most important inhomogeneity, along with exposure changes. Station relocations did not appear to have as large an effect.

Key words: historical snow variations, snowfall parameters, inhomogeneities, case study, observation time changes.

INTRODUCTION

Snow is a significant factor in the economy and water resources of the United States. Its impact can disrupt transportation and cause extensive damage and loss of life, and snow removal costs can break city budgets. Lack of snow in normally snowy climes can bring economic hardship to the recreation and water management industries. Snow is also an important player in the climate picture, both reflecting climatic changes and fluctuations as well as exerting an influence on climate. It is clear that a better understanding of the history of snowfall will benefit this nation, for both climatic and economic reasons.

Visible satellite observations provide the most accurate information on snow cover extent, however this data source extends back only about 30 years (Robinson *et al.*, 1993). *In situ* observations are available in the U.S. for several thousand Cooperative Network stations, with some going back more than 100 years. However, previous studies using *in situ* data have examined primarily seasonal total snowfall amount or number of days with snow cover (e.g., Groisman and Easterling, 1994; Frei *et al.*, 1997), with little or no attention given to adjusting the data for inhomogeneities.

The 20th Century snowfall record for Urbana, Illinois, is examined in this paper as a case study to illustrate (1) the utility of using several parameters to examine historical variations of snowfall and (2) the importance of non-climatic influences.

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DATA

Daily snowfall data from the National Climatic Data Center's (NCDC) TD-3200 data base formed the basis for several snowfall parameters:

TOTAL SF: total snowfall amount;
MAX 1-DAY: greatest 1-day snowfall amount;
MAX 2-DAY: greatest 2-day snowfall amount, where it snowed both days;
DATE FIRST: date of first snowfall ≥ 0.254 cm. (0.1 in.) during the August-July snow season;
DATE LAST: date of last snowfall ≥ 0.254 cm. (0.1 in.) during the August-July snow season;
LENGTH: length of the snow season (number of days between DATE FIRST and DATE LAST);
NUMDAYS: number of days with snowfall ≥ trace;
MAX MEDIAN: greatest median snowfall amount (for the days with snowfall, the median [MED] snowfall amount was calculated for each month; MAX MEDIAN is the maximum MED); and
AVE MEDIAN: average median snowfall amount (the average of the monthly MED values).

The daily snowfall values were put through NCDC's ValHiDD quality control process (Reek *et al.*, 1992). Additional checks were made for factor of 10 errors (snowfall checked against concurrent precipitation), extreme outliers, and hail included in the snowfall measurement (snowfall value identified as hail if concurrent minimum temperature ≥ 4.4° C [40° F]).

Urbana, Illinois (Cooperative station number 118740) was chosen for study because of its long digital record (1903-1996), high degree of completeness (1116 months out of 1128 possible months had no missing days [99% complete]), and small amount of missing data (0.058% of the days were missing).

Total snowfall amount (TOTAL SF) was computed for a given year-season only if there were no days missing for the season in question. The other parameters were tolerant of missing data.

ANALYSIS

20th Century Snowfall Variations and Trends

The data were plotted and examined for trends using least squares linear regression, two-phase linear regression (Solow, 1987), and the nonparametric Wilcoxon signed-rank test. The trend tests were performed over the period common to all parameters (1924-25 to 1963-64) and over the longest uninterrupted data period for each parameter (Tables 1 and 2, respectively, for annual data, and Tables 3 and 4 for seasonal data). The Wilcoxon tests yielded no significant trend for all parameters and seasons.

Plots of the seasonal and annual (i.e., August-July) TOTAL SF (Figures 1a and 1b) generally agree with regional and continental-scale studies of snow cover extent by Hughes and Robinson (1996), Frei *et al.* (1997), and Brown (in WMO, 1998, page 66). On a broad canvas, TOTAL SF indicates that the first two decades had more snowfall in Urbana when compared to the 1920's-40's. Snowfall amount increased in the 1950's-60's, with record amounts falling in the late 1970's. The 1980's-90's have had less snowfall, which is also consistent with the 1972-present satellite snow cover record (annual TOTAL SF is significantly positively correlated with seasonal mean satellite snow cover, as seen in Table 5). Annual and winter (Dec-Feb) TOTAL SF had statistically significant increasing linear trend (cm./yr.) over 1925-64 and 1915-87 (Tables 1 and 3).

Annual and winter NUMDAYS (Figures 2a and 2b) show a similar pattern to TOTAL SF, except for the first two decades. Annual NUMDAYS had a statistically significant increasing linear trend (days/yr.) over 1925-64 (Table 1), and a significant two-phase trend over the period 1904-96 with the change point (from increasing trend to decreasing) occurring in 1962 (Table 2). A similar significant two-phase trend appears in the data for spring NUMDAYS (Table 4).

TABLE 1. Tests for trend, August-July season, common uninterrupted data period (1924-25 to 1963-64). *Bold italic* values are significant at the 0.05 level.

	Linear Regression (Least Squares)		Two-Phase Regression		
Parameter	Trend	P-Value	Type +	Year	F-Statistic
TOTAL SF	***0.876***	***.009***	***I1***	***1958***	***4.82***
MAX 1-DAY	0.053	.550	--	1958	2.08
MAX 2-DAY	0.099	.322	--	1958	1.06
DATE FIRST	0.002	.992	--	1959	0.12
DATE LAST	0.233	.303	--	1943	0.10
LENGTH	0.231	.418	--	1956	0.07
NUMDAYS	***0.293***	***.028***	--	1948	0.47
MAX	-0.033	.159	--	1943	0.04
AVE MEDIAN	-0.000	.955	--	1955	0.27

TABLE 2. Tests for trend, August-July season, longest uninterrupted data period (1903-04 to 1995-96). *Bold italic* values are significant at the 0.05 level.

	Linear Regression (Least Squares)		Two-Phase Regression		
Parameter	Trend	P-Value	Type +	Year	F-Statistic
TOTAL SF	(1924-25 to 1963-64 [Table 1] was the longest uninterrupted period for total				
MAX 1-DAY	-0.003	.900	--	1936	1.99
MAX 2-DAY	0.010	.710	--	1937	1.21
DATE FIRST	-0.101	.104	--	1917	0.56
DATE LAST	0.111	.102	--	1967	2.32
LENGTH	***0.212***	***.017***	--	1942	1.76
NUMDAYS	0.051	.176	***C1***	***1962***	***5.29***
MAX	0.000	.868	--	1909	0.70
AVE MEDIAN	0.003	.445	***C2***	***1909***	***4.94***

TABLE 3. Tests for trend, seasonal total snowfall amount. *Bold italic* values are significant at the 0.05 level.

	Linear Regression (Least Squares)		Two-Phase Regression		
Season / Period	Trend	P-Value	Type +	Year	F-Statistic
Common Uninterrupted Data Period					
Winter 1925-64	***0.696***	***.008***	***I1***	***1958***	***8.05***
Spring 1925-64	0.229	.123	--	1952	0.84
Autumn 1924-	-0.048	.622	--	1958	0.29
Longest Uninterrupted Data Period					
Winter 1915-87	***0.462***	***.001***	--	1921	2.00
Spring 1903-79	0.015	.815	--	1917	0.49
Autumn 1919-	0.025	.740	--	1925	0.70
Autumn 1964-	-0.119	.459	--	1974	0.68

\+ Two-Phase Regression, Type: year1=beginning year, year2=year of change in trend, year3=ending year

I1: linear trend increasing year1 to year2, increasing at a greater rate year2 to year3.

C1: linear trend increasing year1 to year2, decreasing year2 to year3.

C2: linear trend decreasing year1 to year2, increasing year2 to year3.

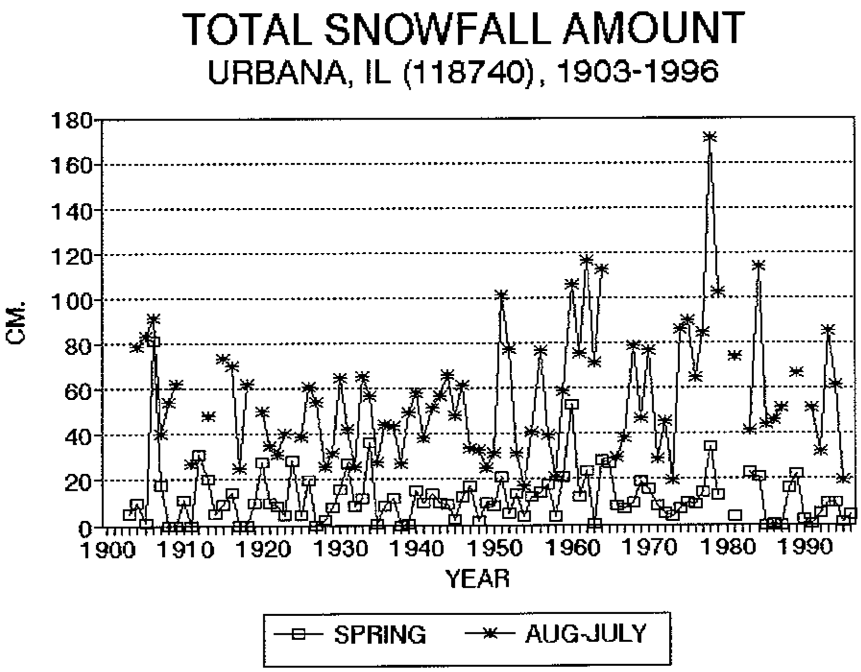

Figure 1a. Variations in 20th Century total snowfall amount at Urbana, IL, for spring (March-May) and annual (August-July).

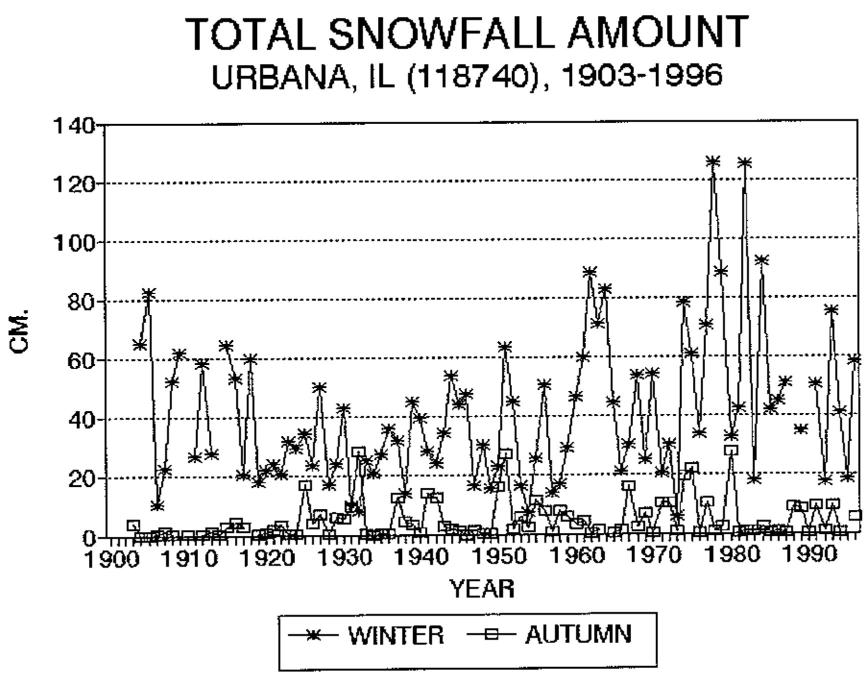

Figure 1b. Same as Figure 1a, except for winter (December-February) and autumn (September-November).

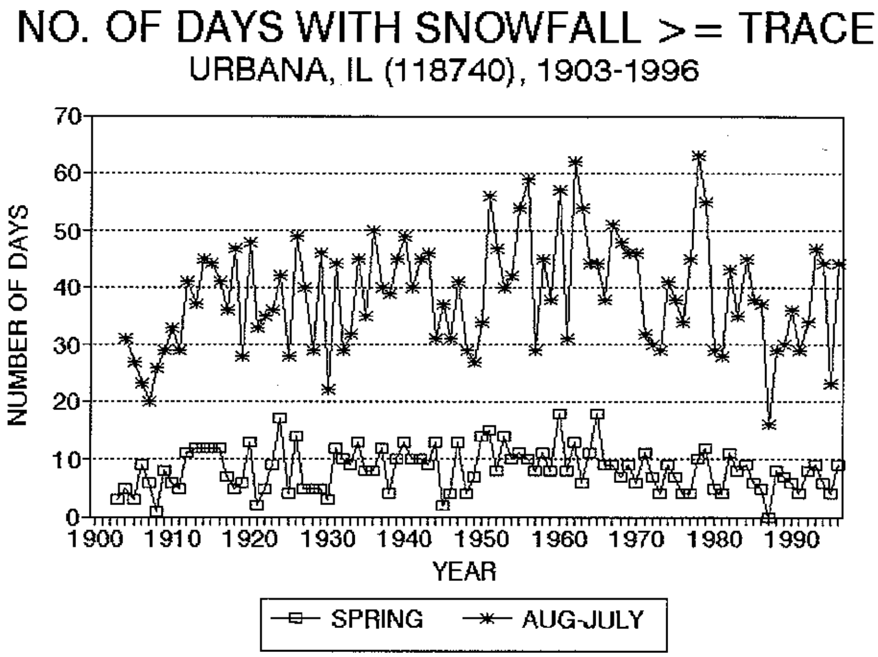

Figure 2a. Variations in 20th Century number of days with snowfall at Urbana, IL, for spirng (March-May) and annual (August-July).

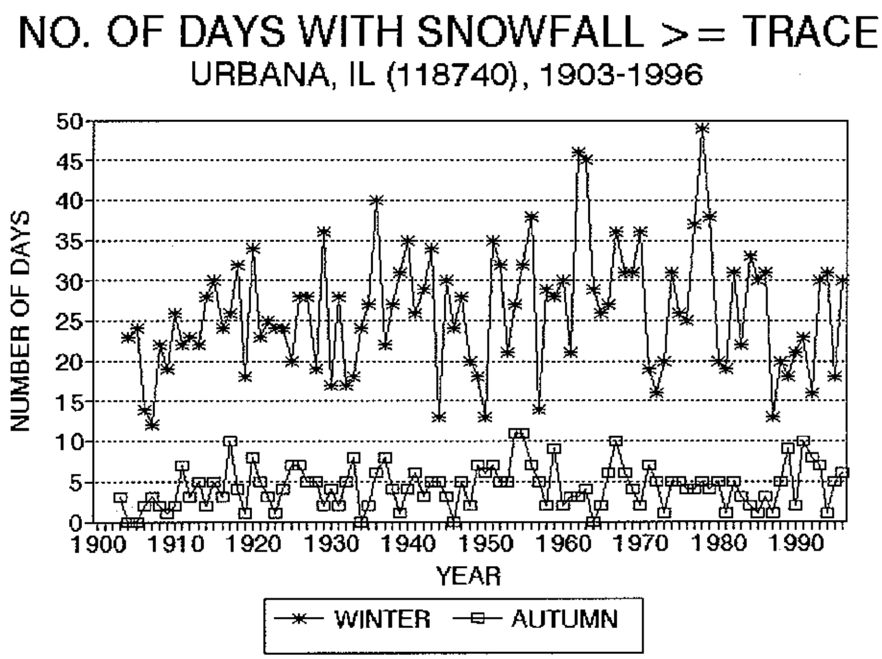

Figure 2b. Same as Figure 2a, except for winter (December-February) and autumn (September-November).

TABLE 4. Tests for trend, seasonal number of days with snowfall ≥ trace. *Bold italic* values are significant at the 0.05 level.

	Linear Regression (Least Squares)		Two-Phase Regression		
Season / Period	Trend	P-Value	Type +	Year	F-Statistic
Common Uninterrupted Data Period					
Winter 1925-64	0.179	.106	--	1958	1.04
Spring 1925-64	0.091	.079	--	1934	0.20
Autumn 1924-	0.023	.530	--	1956	1.00
Longest Uninterrupted Data Period					
Winter 1904-96	0.044	.131	--	1978	2.54
Spring 1903-96	-0.004	.787	***C1***	***1960***	***4.77***
Autumn 1903-	0.015	.140	--	1917	1.95

\+ Two-Phase Regression, Type: year1=beginning year, year2=year of change in trend, year3=ending year
I1: linear trend increasing year1 to year2, increasing at a greater rate year2 to year3.
C1: linear trend increasing year1 to year2, decreasing year2 to year3.
C2: linear trend decreasing year1 to year2, increasing year2 to year3.

Heavy extreme annual snowfalls (MAX 1-DAY and MAX 2-DAY) occurred more often at the beginning and end (1970's-80's) of the century than at other times (Figure 3). This is consistent (both graphically and in Table 7) with the time variability of TOTAL SF. No significant trends were detected (Tables 1 and 2) for MAX 1-DAY & 2-DAY.

The time series of DATE FIRST and DATE LAST show no significant trend (Tables 1 and 2), although inspection of the graph (Figure 4) suggests the snow season ended earlier more often in the beginning of the century than in recent decades (top curve).

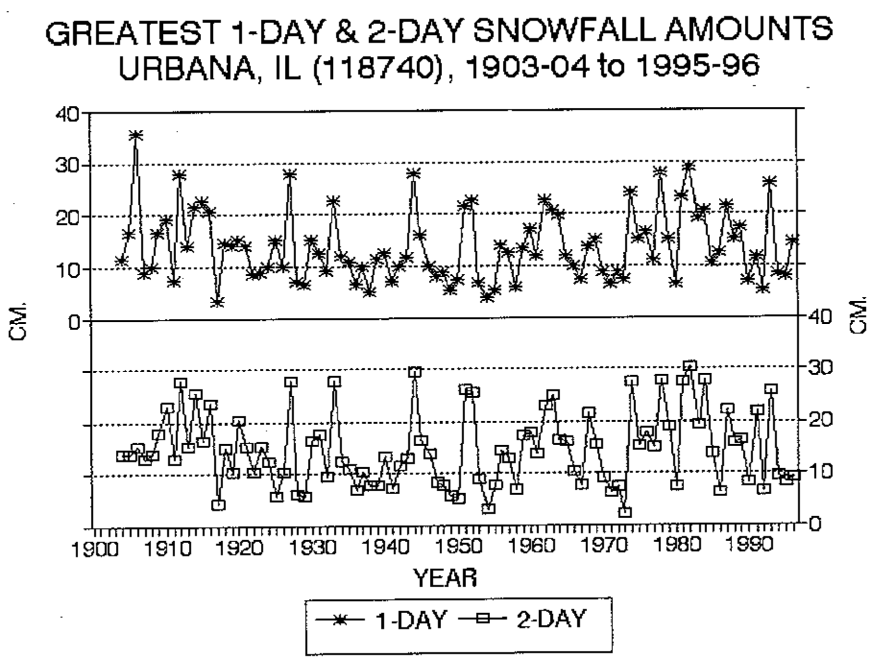

Figure 3. Variations in 20th Century daily snowfall amount at Urbana, IL. Top: greatest one-day amount. Bottom: greatest two-day amount, where it snowed both days.

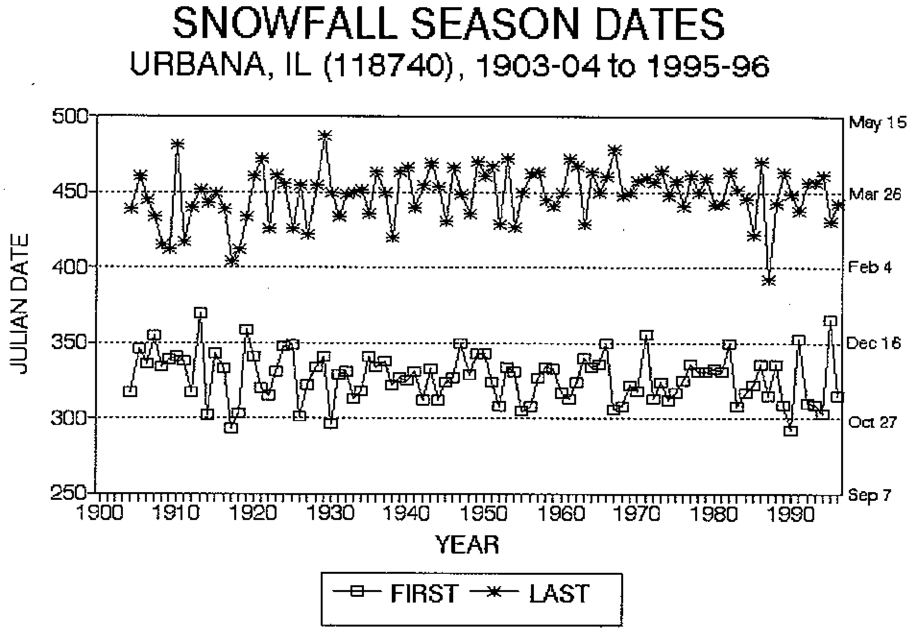

Figure 4. Variations in 20th Century snowfall season start (bottom) and ending (top) dates for Urbana, IL. Julian date of 213 corresponds to August 1, 365 to December 31, 366 to January 1, and 577 to July 31.

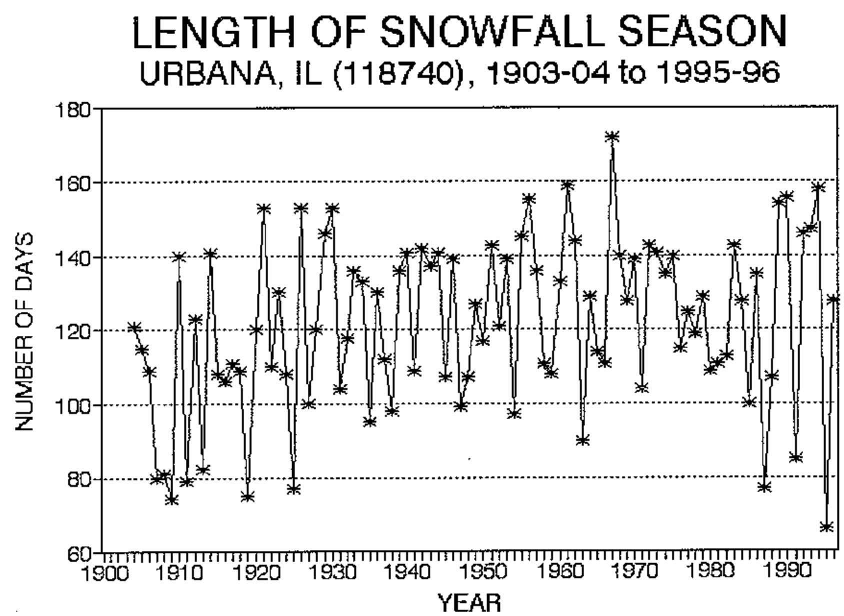

Figure 5. Variations in 20th Century snowfall season length at Urbana, IL.

Snowfall season LENGTH shows a significantly increasing trend (days/yr.) over the 20th Century (Table 2), however a more complex history can be seen in the graph (Figure 5). Shorter seasons, with large interannual variability, occurred more often at the beginning and end of the century than in the middle decades.

The annual maximum of the median daily snowfall for snowy days (MAX MEDIAN) does not have significant trend, although the graph (Figure 6, top curve) shows interdecadal variability with smaller maximums during the 1950's and 1960's.

AVE MEDIAN has significant two-phase trend (Table 2), strongly decreasing from 1904 to 1909 and increasing thereafter. Although the values of this parameter are small (due to the nature of the statistic), there is considerable variability over the century (Figure 6, bottom curve).

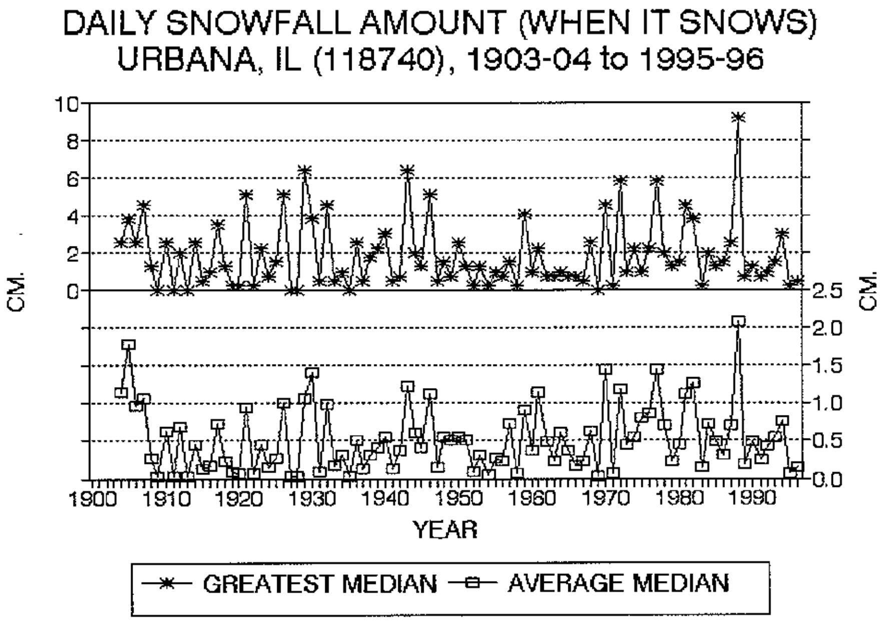

Figure 6. Variations in 20th Century median daily snowfall amount at Urbana, IL. Monthly median daily snowfall computed for those days with snowfall. Top: greatest of the monthly median values for each "year" (August-July). Bottom: average of the monthly median values for each "year".

Inter-Parameter Relationships

Correlation coefficients were computed to identify interrelationships between the snowfall parameters and the satellite snow cover area data set, and amongst the snowfall parameters (Tables 5-7).

TABLE 5. Correlation coefficients for mean areal extent of satellite snow cover (by season) vs. Urbana snowfall parameter (annual). *Bold italic* values are significant at the 0.05 level.

	Satellite Snow Cover Extent - by Season			
Parameter	Autumn (SON)	Winter (DJF)	Spring (MAM)	Oct-May
TOTAL SF	***0.51***	***0.54***	***0.68***	0.09
MAX 1-DAY	0.31	0.31	***0.55***	0.07
MAX 2-DAY	0.36	0.14	***0.50***	-0.01
DATE FIRST	0.25	-0.01	-0.13	0.25
DATE LAST	-0.01	0.29	-0.06	0.31
LENGTH	-0.18	0.20	0.05	0.04
NUMDAYS	***0.57***	***0.61***	***0.55***	0.29
MAX MEDIAN	0.26	-0.13	-0.26	-0.30
AVE MEDIAN	0.31	-0.09	-0.13	-0.26

Sample size = 19 for TOTAL SF, 24 for other annual parameters.

The similarity in the annual and winter plots for TOTAL SF and NUMDAYS is reflected in the statistically significant positive correlations (Tables 6 and 7) between the two parameters for these two seasons, as well as for autumn (Sep-Nov) and spring (Mar-May). TOTAL SF is also significantly correlated with MAX 1-DAY and 2-DAY, LENGTH, and AVE MEDIAN snowfall (Table 7). Annual TOTAL SF is significantly correlated with seasonal mean satellite snow cover extent (Table 5), and

TABLE 6. Correlation coefficients for concurrent seasons. *Bold italic* values are significant at the 0.05 level.

	Satellite Mean Snow Cover Area VS.		NUM DAYS VS.
Season	TOTAL SF +	NUM DAYS #	TOTAL SF @
Autumn	-0.03	0.01	***0.38***
Winter	***0.51***	***0.57***	***0.50***
Spring	***0.45***	***0.46***	***0.51***

\+ Sample size = 22.
\# Sample size = 24.
@ Sample size = 89 for autumn and winter, 92 for spring.

seasonal TOTAL SF is significantly correlated with seasonal satellite snow cover extent for the winter and spring as well (Table 6). This could reflect Urbana's location relative to the track of snow-producing storms. [In an extensive study of 304 winter storms in Illinois that produced 15.24 cm (6 inches) or more of snowfall, Changnon (1969) concluded that with few exceptions severe winter storms were associated with transitory cyclones moving primarily out of the Alberta region of Canada or from the general area of Colorado, to the west of Illinois. It would be safe to say that lesser snowfall amounts are also typically connected to this synoptic-scale process as well.] It should be noted that satellite snow cover extent averaged over Oct-May is not significantly correlated with any snowfall parameter (Table 5), probably due to its large temporal (8 months) and spatial (North American continent) domain.

TABLE 7. Correlation coefficients between Urbana snowfall parameters (annual). *Bold italic* values are significant at the 0.05 level.

	TOTAL SF	MAX 1-DAY	MAX 2-DAY	DATE FIRST	DATE LAST	LENGTH	NUM DAYS	MAX MEDIAN
MAX 1-DAY	***0.70***							
MAX 2-DAY	***0.68***	***0.86***						
DATE FIRST	-0.21	-0.09	-0.13					
DATE LAST	0.14	-0.06	-0.09	0.05				
LENGTH	***0.25***	0.02	0.02	***-0.65***	***0.72***			
NUMDAYS	***0.45***	0.13	***0.21***	***-0.24***	***0.29***	***0.39***		
MAX MEDIAN	0.11	-0.01	0.01	-0.09	***0.23***	***0.23***	-0.13	
AVE MEDIAN	***0.31***	0.11	0.09	-0.12	***0.25***	***0.28***	-0.19	***0.89***

Sample size = 82 for TOTAL SF, 93 for other parameters.

Annual and seasonal NUMDAYS, like TOTAL SF, is significantly correlated to seasonal satellite snow cover extent (Tables 5 and 6). Annual NUMDAYS is also significantly correlated to MAX 2-DAY, DATE FIRST, DATE LAST, and LENGTH (Table 7).

Annual MAX 1-DAY and MAX 2-DAY are strongly related to each other (Table 7), as expected by definition. They are also significantly correlated with satellite snow cover extent during spring, but not in the other seasons (Table 5).

Both DATE FIRST and DATE LAST are significantly correlated to LENGTH (Table 7), which is expected by definition of length of season. MAX MEDIAN is strongly correlated with AVE MEDIAN, also as expected by definition of the parameters. DATE LAST and LENGTH are both significantly correlated with MAX MEDIAN and AVE MEDIAN.

Is Homogeneity Important?

Double mass plots were generated to assess the effects of inhomogeneities on the snowfall parameters. Data from two nearby stations ("control") on either side of Urbana, Pana (station number 116579) and Hoopeston 1NE (114198), were compared to Urbana ("target") over the period with no missing data at either station (1924-25 to 1978-79). A known inhomogeneity (lateral location change of 169 km. [105 mi.]) was forced into the "control" time series by concatenating 1925-1951 data from Pana to 1952-1979 data from Hoopeston. Plots of "control" vs. "target" were made for each parameter. The plots indicate that all of the parameters are affected by inhomogeneities, to varying degrees. The numbers in the body of each graph identify years of observation time changes (see below) determined from station history metadata and from Changnon and Boyd (1963).

Year	Urbana	Pana*/Hoopeston**
1925*	7 pm (Oct-Mar), 7 am (Apr-Sep)	5 pm
1935	7 pm	5 pm
6-21-1939	7 pm	6 pm
5-5-1945	7 pm	7 pm
1952**	7 pm	6 pm
1-1-1956	MID	6 pm
1-1-1966	7 am	6 pm
7-1-1969	7 am	7 am
11-8-1972	MID	7 am

Previous research suggests changes in observation time should have a significant impact on snowfall amount. A study of hourly surface observations at Springfield, Illinois indicated snowfall was more likely to occur in the late morning to early afternoon hours. This is consistent with Changnon (1969) regarding the onset of heavy snowstorms in Illinois (> 15.24 cm). Therefore, measurements made around 7 a.m. may record different amounts than those at 6 p.m. after the snow has had time to settle and/or drift.

Autumn (Figure 7a) and spring TOTAL SF have greater deviations from the straight line than winter (Figure 7b) and annual TOTAL SF. A discontinuity in the late 1930's had a major impact on

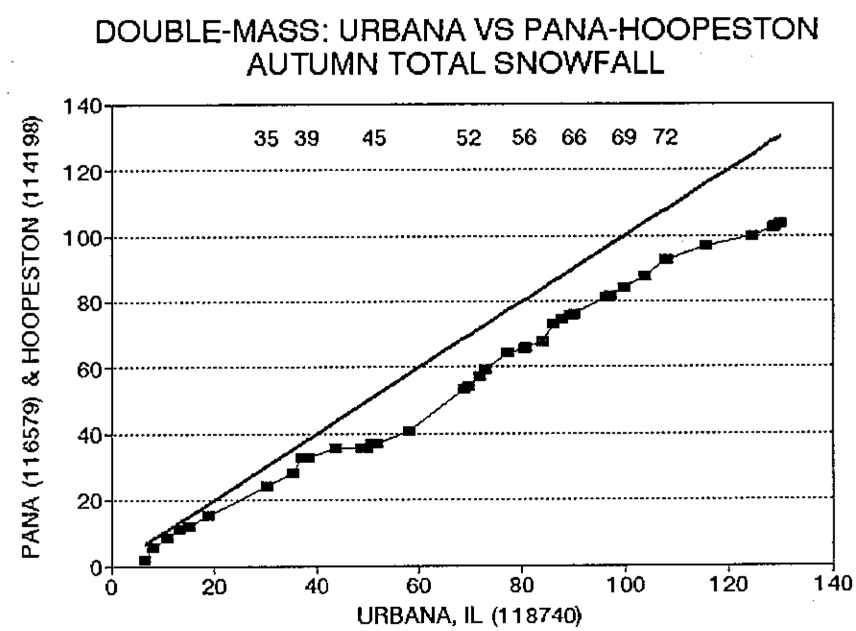

Figure 7a. Double-mass plot of Urbana vs. "control" station for autumn (September-November) total snowfall, based on 1924-1979 data.

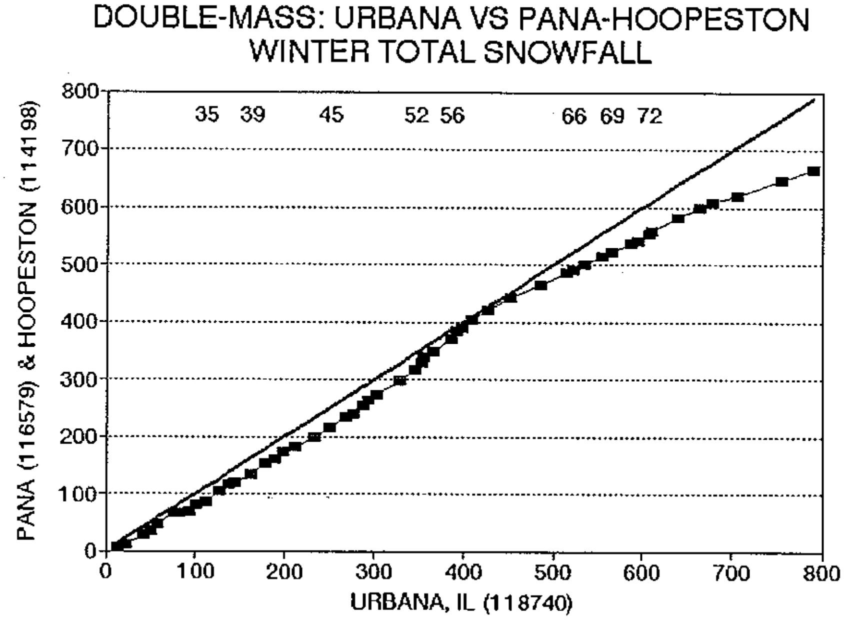

Figure 7b. Same as in Figure 7a, except for winter (December-February) total snowfall.

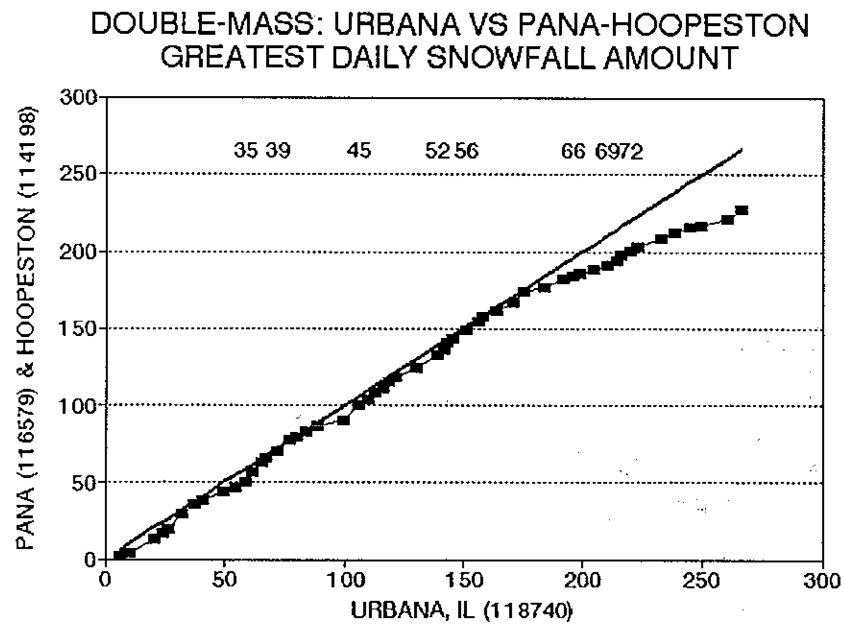

Figure 8. Same as in Figure 7a, except for annual (August-July) greatest daily snowfall amount.

autumn TOTAL SF, while discontinuities in the 1960's and 1970's adversely impacted both autumn and winter TOTAL SF. The plots for MAX 1-DAY (Figure 8) and MAX 2-DAY are similar to winter TOTAL SF. AVE MEDIAN (Figure 9) and MAX MEDIAN show the greatest sensitivity to discontinuities, with jumps at almost every marked year.

For NDAYS, the seasonal plots are similar to the annual plot (Figure 10), with a deviation during the first approximately 20 years, and lesser effects afterward. DATE FIRST, DATE LAST, and LENGTH were least sensitive to discontinuities. Season LENGTH (Figure 11) showed a gradual deviation from approximately 1935 to 1950, with minimal effects before and after.

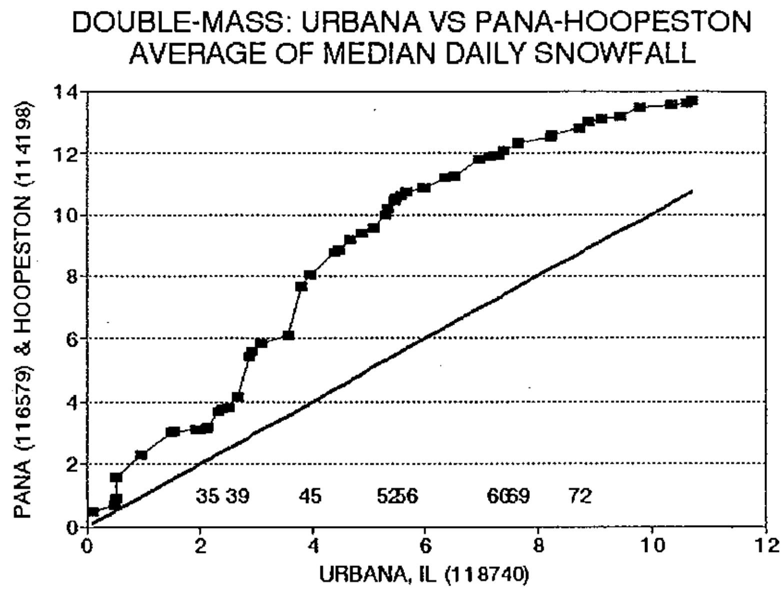

Figure 9. Same as in Figure 7a, except for annual (August-July) average median daily snowfall amount.

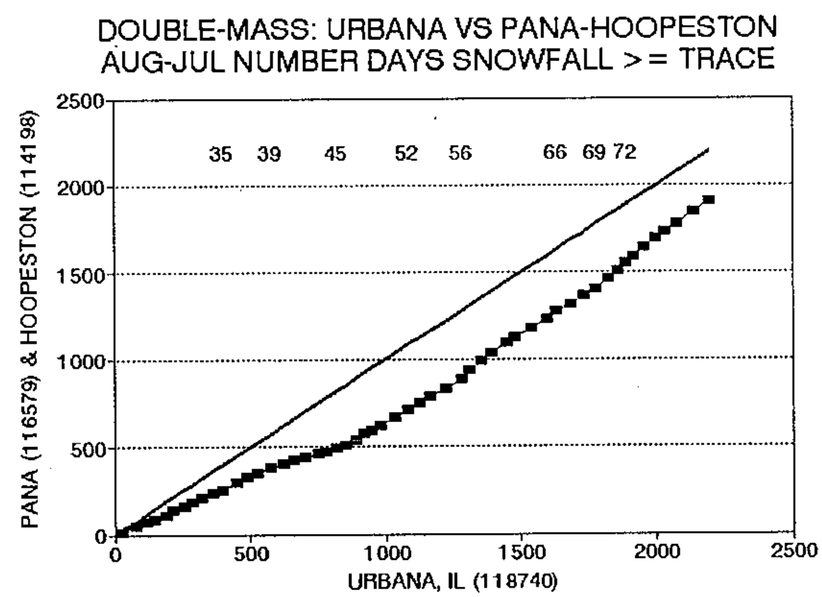

Figure 10. Same as in Figure 7a, except for annual (August-July) total number of days with snowfall.

Some of these deviations could be due to changes in observer-related measurement practices and exposure. Pana had six observers during 1925-1951, with the greatest station relocation being 0.8 km. (0.5 mi.). Hoopeston had the same observer during 1951-1979, however a station move of 1 km. (0.6 mi.) in February 1962 resulted in a change from a fairly open exposure with no trees to a limited exposure with trees and buildings in the vicinity.

Plots of the difference between Urbana's values and the corresponding values for the "control" station for 1924-25 to 1978-79 are shown in Figures 12-17. The ticks on the zero line in these graphs mark years with known inhomogeneities. Differences that are fairly consistent between ticks indicate periods for which it might be feasible to compute and apply adjustment factors to the data. Only two parameters have difference graphs which suggest adjustment factors may be possible: NUMDAYS (Figure 12) and snowfall season LENGTH (Figure 13). The snowfall amount parameters have difference graphs (Figures 14-17) which indicate that adjustment factors likely cannot be computed.

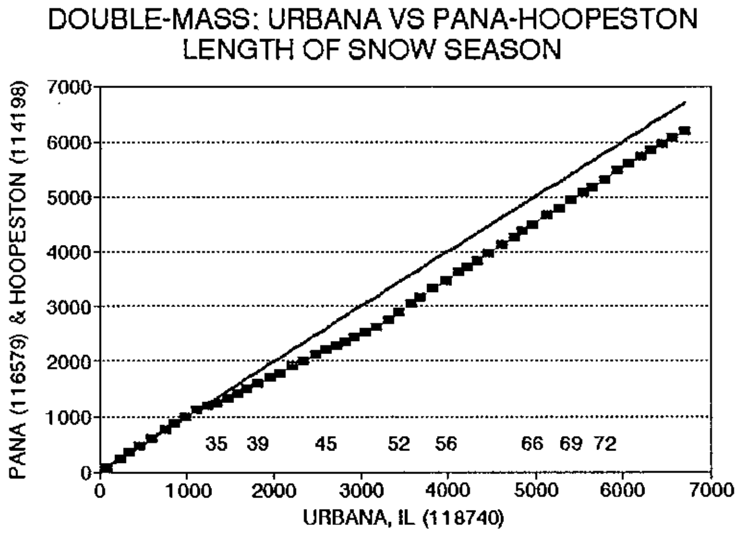

Figure 11. Same as in Figure 7a, except for length of snow season.

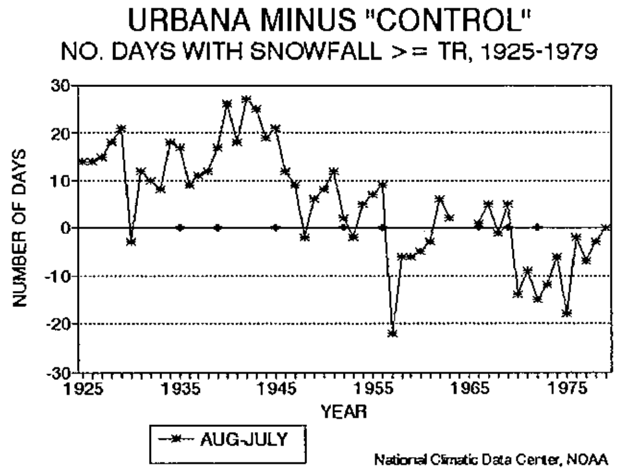

Figure 12. Annual (August-July) number of days with snowfall at Urbana minus same parameter at "control" station, 1925-1979.

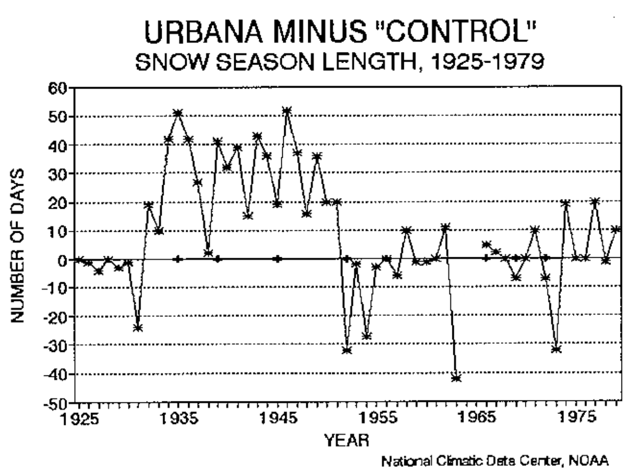

Figure 13. Same as in Figure 12, except for snow season length.

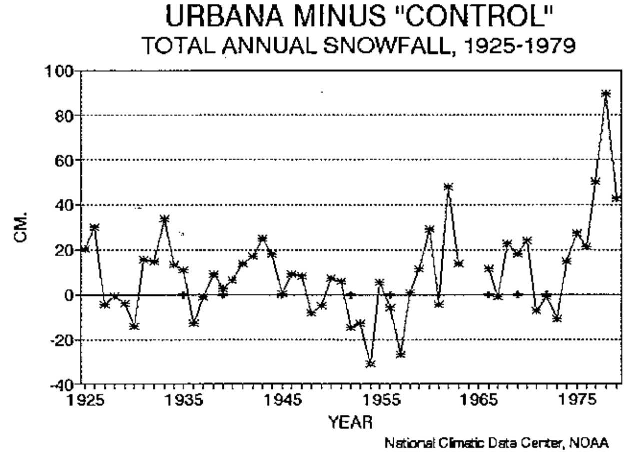

Figure 14. Same as in Figure 12, except for total annual (August-July) snowfall.

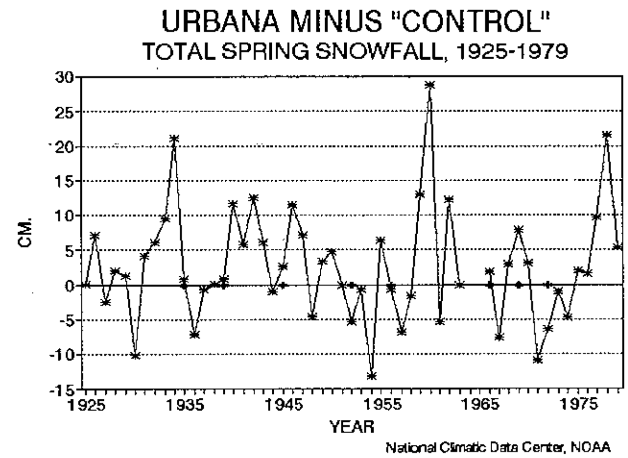

Figure 15. Same as in Figure 12, except for total spring (March-May) snowfall.

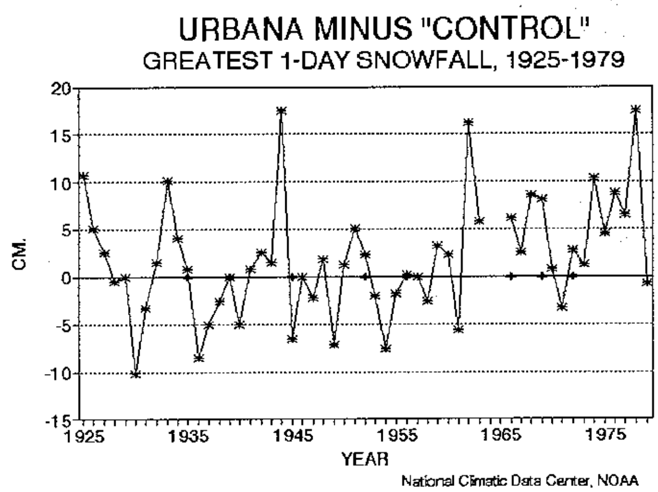

Figure 16. Same as in Figure 12, except for annual (August-July) greatest one-day snowfall amount.

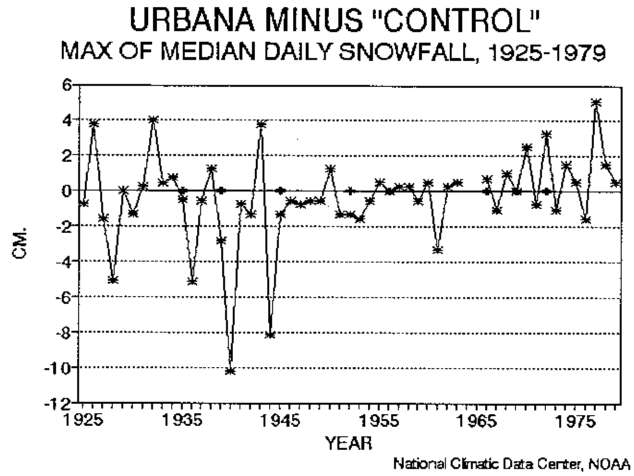

Figure 17. Same as in Figure 12, except for annual (August-July) maximum of median daily snowfall amount.

CONCLUSIONS

Climatic parameters based on daily snowfall were used effectively to illustrate 20th Century variations in the snow climatology at Urbana, Illinois. Broadly speaking, the century began on a snowy note, with heavier daily and seasonal total snowfalls, although the snow season tended to be shorter. During roughly the 1920's to 1940's, snowfall amounts were down but the length of the snow season increased. The 1950's to 1970's saw an increase in snowfall amounts and number of snowy days, with some of the longest snow seasons occurring at this time. The 1980's and 1990's were characterized by decreased snowfall amounts, fewer snowy days, and an increase in variability (extremes) of snow season length.

Total seasonal snowfall amount and number of days with snowfall at Urbana are significantly related to continental snow cover extent. This could be due to synoptic and geographic considerations.

Inhomogeneities have a noticeable effect on the data. Of the parameters tested, snowfall amount was most sensitive, number of days with snow was less sensitive, and snow season length was least affected. Changes in observation time appeared to be the most important factor, along with exposure changes. Station relocations did not appear to have as large an effect. It may be possible to compute adjustment factors for station data based on neighbor data for some snowfall parameters (number of days with snowfall and snow season length), but this is unlikely for other parameters (daily and total monthly snowfall amount).

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