CRARP 24-02 A SNOW COVER CLIMATOLOGY FOR SOUTH BEND, INDIANA (1949-50 THROUGH 1998-99)

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1. Introduction

Snowfall is a common occurrence during the winter in the Great Lakes region. Seasonal snowfall can be especially plentiful in locations in the lee of each of the individual Great Lakes. South Bend, Indiana is located approximately twenty miles southeast of southern Lake Michigan. Since Lake Michigan rarely freezes over completely during the winter, northwesterly winds can pick up abundant moisture from the lake surface and deposit it downwind as lake-effect snow. This is the main reason locations near the lee coasts of the lakes record so much larger yearly snowfall totals than locations just ten or twenty miles farther inland. The higher elevations that necessarily surround the lakes also contribute uplift that enhances lake-effect snowfall. This is noticeable at South Bend which, at an elevation of 710 feet, is approximately 130 feet higher than the surface of Lake Michigan. This effect can also be seen downwind of the other Great Lakes. Each lake has one (or more) snow belts that experience enhanced snowfall due to the influence of the lake surface on air masses passing over it (Eichenlaub 1979).

South Bend receives an average of 82 inches of snowfall each winter. Snowfall totals however can vary greatly from this average. In the fifty years of this study (covering the winter seasons 1949-50 through 1998-99) the highest total was recorded in 1977-78 when 172.0 inches of snow fell (86.1 inches of snow fell in just January alone). The least amount during this fifty-year period was in 1952-53 when only 36.2 inches of snowfall was reported.

This total however is close to the average of the seasonal snowfall totals reported during the 1920s through the 1940s, a period of relatively dry winter seasons across northern Indiana. This trend for the same period was also noticed by the authors in a snow cover climatology for Fort Wayne, Indiana. Figure 1 shows the average annual snowfall for South Bend for each decade of the twentieth century. It shows the relatively dry decades of the 1920s, 1930s, and 1940s and the relatively moist 1960s, 1970s, and 1980s.

This study of the winter climate in northern Indiana used snow cover for a couple of reasons. First, ice on the ground (and for the purposes of our study snow cover) is a parameter that is reported daily at most observation sites across the United States and is readily available. Second, snow cover can be used to compare the relative severity of winter seasons. This is because snow cover would be affected by both the total snowfall experienced and the duration of cold temperatures. Higher snowfall and/or colder temperatures should result in prolonged periods of snow cover. Conversely, less snowfall and/or relatively warmer winter temperatures should result in shorter durations of snow cover.

This snow cover climatology can serve the same purposes as the companion snow cover climatology for Fort Wayne, Indiana. (O'Hara and Pyle 2000). For example, a knowledge of both average and extreme winter conditions across the region can help new forecasters become familiar with the forecast area. This climatology should help accomplish that. In addition, knowledge of snow cover conditions from past winters can help meteorologists determine the relative severity of a current winter. This should help answer questions from the public or the media.

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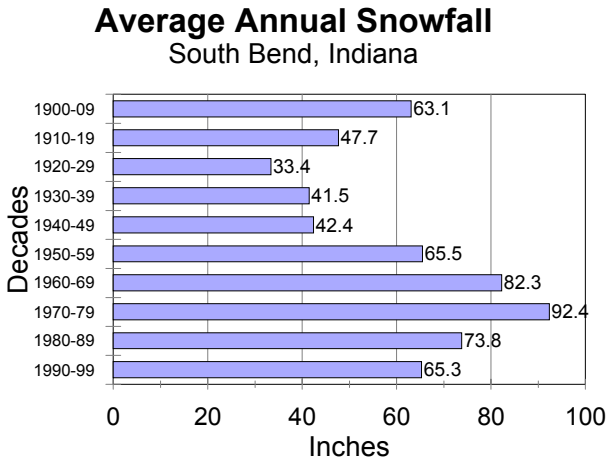

Figure 1. Average annual snowfall (in.) by decade for South Bend, Indiana

Finally, since subjects such as El Nino and global warming are so much in the news, this climatology can help meteorologists see whether conditions have actually changed very much during the last fifty years. It might be especially helpful to use both this snow cover climatology and the companion Fort Wayne climatology to review winters across northern Indiana. It would also be a good way to directly compare winter conditions at both South Bend and Fort Wayne. The larger snow cover amounts at South Bend, which are often a result of lake effect snow, are especially noticeable.

2. Methodology

The methodology used in this study was similar to the one used in compiling the companion snow cover climatology for Fort Wayne. The monthly Local Climatological Data (LCD) records for Michiana Regional Airport (SBN) were studied. The LCDs list the amount of frozen precipitation (snow, ice, ice pellets, hail, etc.) present on the ground at the same time each day. These readings are reported to the nearest inch. These amounts at South Bend were being reported daily at 1830 Central Standard Time (CST) when our fifty-year study period began with the snowfall season of 1949-50. Snow cover and ice on the ground continued to be reported daily at 1830 CST until the summer of 1952. In July, 1952 the observation time was changed to the morning at 0630 CST. In June, 1957 the observation time was changed to 0600 CST. Another change was made in May, 1969 when the LCDs list the observation time as 0600 Eastern Standard Time (EST). In February, 1970 the observation time was changed to its present time of 0700 EST.

3. Results

Figure 2 shows the total number of years that various snow cover amounts were reported for each day contained in the study. The graph shows a fairly typical bell shape. However, since the period of study is only fifty years, daily totals just days apart can vary considerably. For example, a trace or more of snow cover has been reported on February 13 in forty-five of the fifty seasons studied (90 percent) while a trace or more was reported on February 22 only thirty-one times. With a larger database these totals would start to converge and the resulting graph should approach a smooth bell-shaped curve.

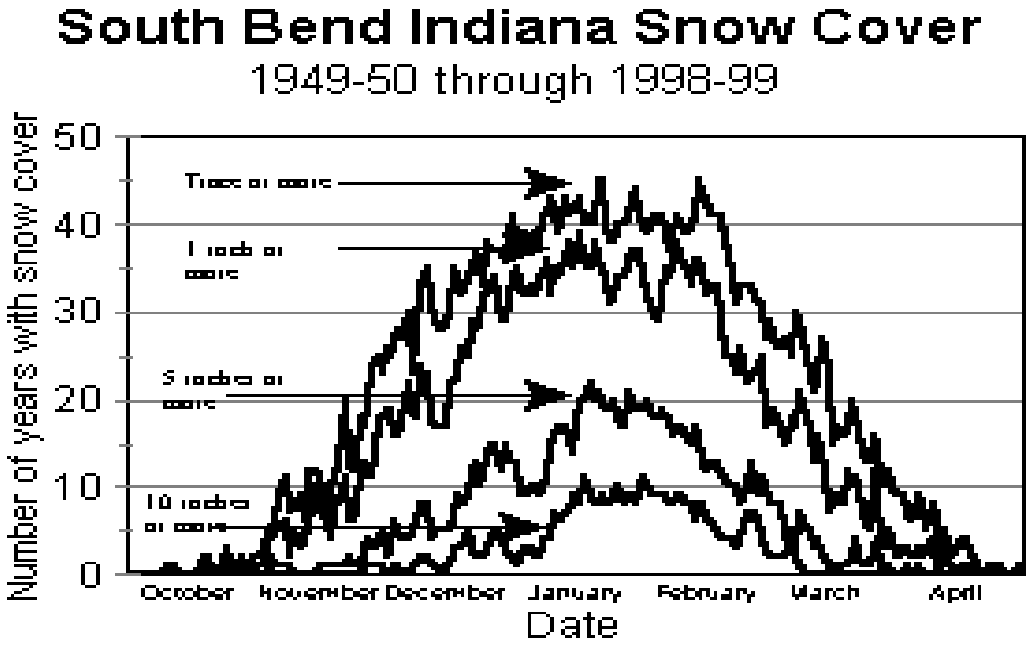

Figure 2. Frequency of years reporting indicated snow depths for each date of snow seasons from 1949-50 through 1998-99 for South Bend, Indiana

Throughout October and most of November the probability of at least a trace of snow cover being reported on any given day is small, only approaching 20 percent by mid-November. The probability then increases steadily, reaching 60 percent by mid-December. The probability of snow cover continues to increase through the winter season, reaching a maximum of 90 percent on January 20. It remains above 70 percent (thirty-five out of the fifty years studied) through early February until reaching a second maximum of 90 percent on February 13. The probability of snow cover then decreases sharply, dropping to below 60 percent on March 1 and to below 40 percent by mid-March. Table 1 lists the periods that at least a trace of snow cover was reported continuously during the fifty-year period of this study.

Table 1. Percentage of Years with at Least a Trace of Snow Cover Reported Continuously at South Bend

Percentage of years (%)	Inclusive Dates Various Percentages Were Reported Without Break
10	Nov. 3 through April 10
20	Nov. 18 through March 31
25	Nov. 24 through March 27
30	Nov. 25 through March 23
40	Nov. 27 through March 16
50	Dec. 8 through March 10
60	Dec. 16 through Feb. 28
70	Dec. 25 through Feb. 20
75	Dec. 30 through Feb. 5
80	Jan. 25 - 31

a. Dates of earliest and latest occurrences of various amounts of snow cover

Snow cover is common during the winter in the lake effect areas of the Great Lakes. In some winters snow cover can be almost continuous from mid-December through mid-March. Snow cover is occasionally reported as early as mid-autumn or as late as mid-spring. These are often the result of substantial snowstorms that move through the region and drop unseasonably large amounts of snow. Table 2 lists the dates of the earliest and latest occurrences of various amounts of snow cover (from a Trace or more to 40 inches or more) during the fifty years of this study. As can be seen from the data, the winters of 1977-78 and 1978-79 dominate the statistics for the largest amounts of snow cover of 10 inches and greater.

Table 2. Dates of Earliest and Latest Occurrence of Various Snow Cover Amounts at South Bend, Indiana

Snow cover	Date of earliest occurrence	Date of latest occurrence
At least a Trace	Oct. 10, 1964	April 30, 1963
At least 1 inch	Oct. 20, 1989 and Oct. 20, 1992	April 24, 1967
At least 5 inches	Oct. 20, 1989	April 17, 1961
At least 10 inches	Nov. 26, 1977	March 18, 1960
At least 15 inches	Nov. 26, 1977	March 6, 1978
At least 20 inches	Nov. 27, 1977	Feb. 20, 1979
At least 25 inches	Jan. 27, 1978	Feb. 8, 1978
At least 30 inches	Jan. 27, 1978	Feb. 6, 1978
At least 35 inches	Jan. 29, 1978	Feb. 1, 1978
At least 40 inches	Jan. 30, 1978	Jan. 30, 1978

The 1977-78 season had snow cover throughout most of the late-autumn and winter. Much of this snow

cover was deep (over 15 inches). A system that moved through the region in late-November, 1977 dumped 24.4 inches of snow over the four-day period of November 25-28 (14.6 inches fell on November 25th alone). Over ten inches of snow was on the ground from the 26th through the 30th. Twenty inches of snow cover was reported on November 27th, the earliest date 20 or more inches of snow cover was reported during the fifty years of this study.

Snow fell throughout January, 1978. Over five inches of snow fell on each of seven days during the month. The largest daily amount (15.6 inches) fell on January 26th. This is the largest daily snowfall total during the last fifty years. After three more days of snow (including 8.2 inches on January 29th), the depth of snow cover reached 41 inches on the morning of January 30th. Snow cover remained above 10 inches through March 10th. February's snow cover never dropped below 15 inches. February had near-normal snowfall but was one of the coldest Februaries on record. With an average temperature of 14.8 °F, February, 1978 was the coldest since 1904.

b. Average seasonal snow cover per 5-year and 10-year periods

As mentioned above, seasonal snowfall totals have varied throughout the years at South Bend. The 1920s, 1930s, and 1940s tended to have less snowfall than other recent decades. The 1960s and 1970s, on the other hand, had averaged more snowfall than any other decades this century.

Tables 3 and 4 below list the average number of days per snowfall season that various amounts of snow cover have been reported. Table 3 divides the decades into five-year periods. Table 4 lists the data per decade.

The late-1950s through the early-1980s stand out as being relatively snowy. The early-1960s and late-1970s both averaged over 100 days per year of snow cover of at least a Trace. They also averaged more than eighty days per year of an inch or more snow cover. The late-1970s, in addition, averaged just over fifty days per year of snow cover of at least 5 inches.

In contrast, the late-1950s and early-1970s averaged over three months per year of at least a Trace of snow cover. The seasonal snow cover, however, tended not to be very deep. Both five-year periods averaged less than a month per year of snow cover of 5 inches or more.

Table 3. Average Number of Days Various Snow Cover Amounts Were Reported During A Season

5-year period	Trace or more	1 inch or more	5 inches or more
1949-50 through 1953-54	80.4	47.8	13 .4
1954-55 " 1958-59	92.6	72.4	26.4
1959-60 " 1963-64	102.2	84.0	36.0
1964-65 " 1968-69	99.2	73.8	30.4
1969-70 " 1973-74	97.2	73.4	22 .0
1974-75 " 1978-79	108.0	90.0	50.8
1979-80 " 1983-84	87.4	64.8	36.2
1984-85 " 1988-89	81.6	52.2	17.4
1989-90 " 1993-94	77.2	54.2	16.8
1994-95 " 1998-99	66.2	50.2	12.4

The relatively heavy snowfall experienced during the 1960s and 1970s resulted in long periods of snow cover. As can be seen in Table 4, both decades averaged over 100 days per year of snow cover of at least a Trace. They also averaged over seventy days annually of at least an inch of snow on the ground, and over a month per year of at least 5 inches. The 1950s, by contrast, reported very little deep snow cover. These ten years averaged almost three months annually of at least a Trace of snow cover, but less than twenty days each year of snow cover of at least 5 inches.

Table 4. Average Number of Days Various Snow Cover Amounts Were Reported During A Season

10-year period	Trace or more	1 inch or more	5 inches or more
1949-50 through 1958-59	86.5	60.1	19.9
1959-60 " 1968-69	100.7	78.9	33.2
1969-70 " 1978-79	102.6	81.7	36.4
1979-80 " 1988-89	84.5	58.5	26.8
1989-90 " 1998-99	71.7	52.2	14.6

c. Yearly comparison of snow cover

Like seasonal snowfall totals, seasonal snow cover amounts show a large year-to-year variability. And, as might be expected, winters that experience large snowfall totals also register long periods of deep snow cover. South Bend experiences a relatively large number of days each winter with snow cover. In a more continental-type of climate a snowstorm would deposit snow and, with the return of high pressure and decreasing cloudiness, the snow cover could completely melt within a matter of days.

However, lake effect snow can help to prolong periods of snow cover. A synoptic-scale system can pass through the region, leaving more than a foot of snow on the ground. As the surface low pressure area moves to the north or northeast the northwesterly winds west of the low can deposit lake effect snow over the region for up to a week.

Many years during the late-1950s and early-1960s, and again during the late-1970s to early-1980s, recorded over 100 days with at least a Trace of snow cover. The snowy winters of the late-1970s and early-1980s are especially prominent. The 1969-70 winter season was the eleventh snowiest this century at South Bend. It also reported the third highest number of days with snow cover of at least a Trace (117 days).

Figure 3 shows the snowfall seasons at South Bend (during the last fifty years) which recorded at least 100 days with snow cover of a Trace or greater. Figure 4 lists the winter seasons during this period which recorded the fewest number of days with snow cover of at least a Trace. Figures 5, 6, and 7 list the years with the most days reporting at least one inch, five inches, and ten inches, respectively, of snow cover.

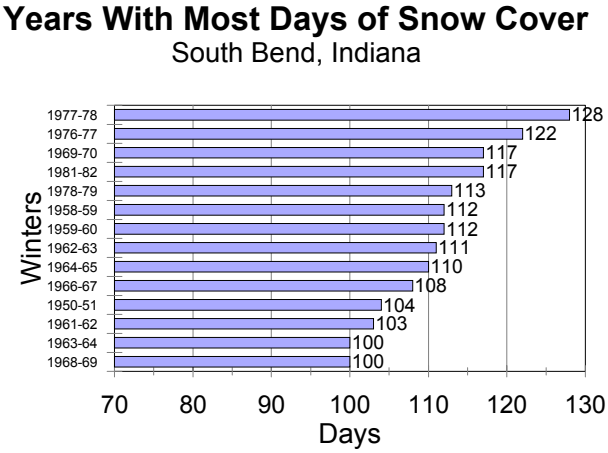

Figure 3. Winters with most days of snow cover observed at South Bend, Indiana. Number of days having snow cover is given to the right of the bar for each winter.

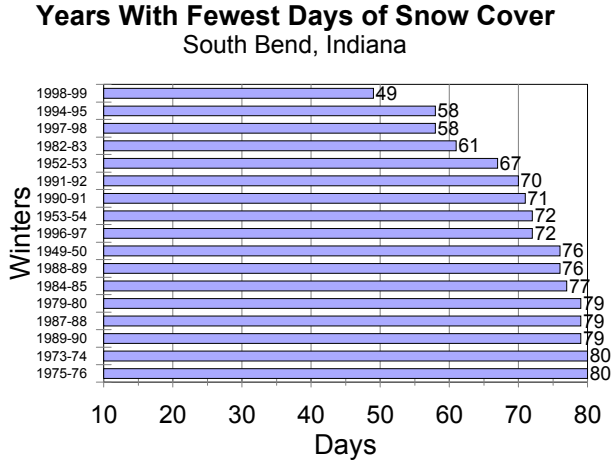

Figure 4. Same as Figure 3,
but for winters with fewest days of snow cover observed at South Bend, Indiana.

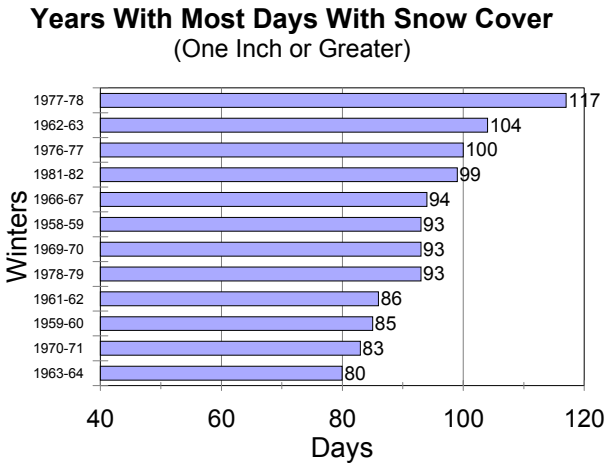

Figure 5. Winters with most
days having a snow depth of one inch or greater at South Bend, Indiana. Number of days with at least one inch snow depth observed is given to right of bar for each winter.

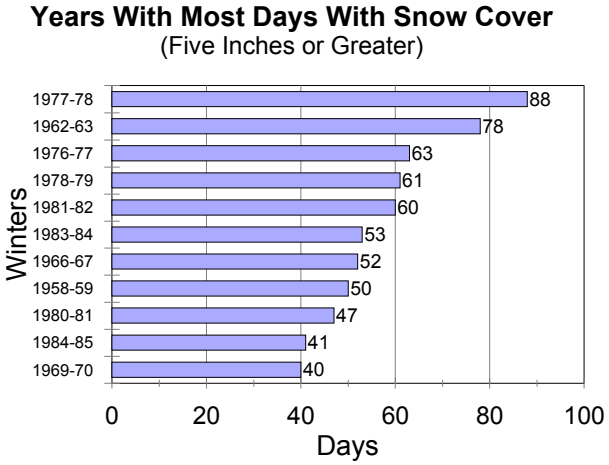

Figure 6. Same as Figure 5,
but for winters with the most days of five inches or greater snow depth.

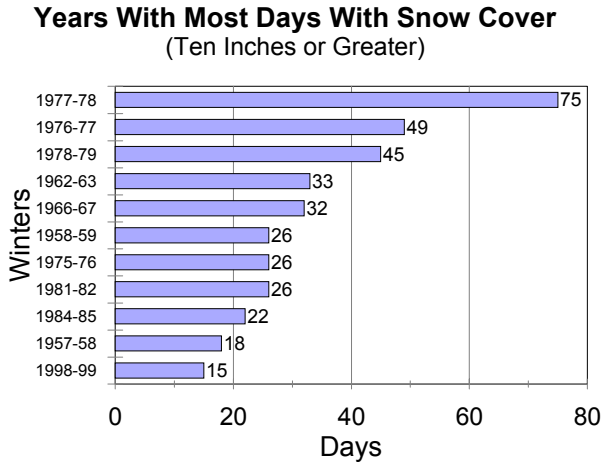

Figure 7. Same as Figure 5,
but for winters with the most days of ten inches or greater snow depth.

d. Periods of continuous snow cover

It should not be a surprise that heavy snowfall and deep snow cover in the southern Great Lakes region is not just a recent phenomenon. Ludlum (1968) reports that some winters during the nineteenth century in the Great Lakes and upper Mississippi valley regions became legendary. A famous winter he describes was the "Winter of the Deep Snow in Illinois" (1830-31). An incredible snowstorm during the last week of December dumped approximately thirty inches of snow on the sparsely populated region from western Missouri to northern and central Illinois. By early-January 1831, after a second snowstorm moved through the region, snow cover was reported to be "four feet" deep at Peoria, Illinois.

Ludlum says that the winter of 1842-43 was remarkable for its snow cover and especially for its cold temperatures. One contemporary account said that by mid-January winter conditions were similar to those of 1830-31. Snow started to accumulate by mid-November and many areas remained snow covered for most of the winter. Much of the Mississippi River north of St. Louis was frozen over by early- December. Parts of the upper Ohio were closed to river traffic as early as late-November. Snow cover was still two feet deep in northern Indiana and southern Michigan in late-March. The Mississippi River at Muscatine, Iowa was frozen over for a record four months.

The winter of 1856-57 was also known for its severity across the Great Lakes region. Ludlum says that it was called the "severest winter ever known" by the weather observer at Fort Ripley in north- central Minnesota. January, 1857 remains one of the coldest months on record in the northern Midwest. Snow cover was 20 inches deep at Madison, Wisconsin by late-January. Harbor ice at Chicago was 30 inches thick by the end of January.

The combination of both synoptic-scale and lake effect snow events occurring throughout the winter can cause the intense conditions described above. At South Bend seasonal snowfall totals are typically high, often reaching seventy inches or greater. And with high snowfall totals, the probability of long periods of snow cover increases substantially. Even with these high snowfall totals some seasons in our fifty-year study stand out from the rest. Winters during the late-1950s to early-1960s, and again during the late-1970s to early-1980s, experienced large snowfall totals with correspondingly long periods of snow cover. Table 5 is a list of some periods during which snow cover lasted for over two months at South Bend.

Table 5. Some Notable Periods of Continuous Snow Cover
of at Least a Trace at South Bend, Indiana

Inclusive Dates	Length of time (days)	Comments
Nov. 23, 1950 - Feb. 18, 1951	88	On Jan. 19th no snow cover was reported
Dec. 31, 1957 - March 6, 1958	66	Deep snow cover; 15 to 23 inches
Dec. 6, 1958 - March 11, 1959	96	Deep snow cover; 15 to 25 inches
Jan. 18, 1960 - March 29, 1960	72	On Feb. 5th no snow cover was reported
Dec. 19, 1961 - March 18, 1962	90	On Jan. 6th no snow cover was reported
Dec. 5, 1962 - March 16, 1963	102	Fairly deep snow cover; 10 to 16 inches
Dec. 3, 1969 - March 1, 1970	89	
Nov. 28, 1976 - Feb. 25, 1977	90	Deep snow cover; 15 to 27 inches
Nov. 25, 1977 - March 31, 1978	127	Dec. 18-20 no snow cover was reported Record deep snow; 41" on Jan. 30, 1978
Dec. 25, 1978 - March 13, 1979	79	Deep snow cover; 15 to 23 inches
Dec. 8, 1981 - March 17, 1982	100	Fairly deep snow cover; 10 to 17 inches

Table 6 lists the longest periods of time that various amounts of snow cover have been reported on consecutive days. The inclusive dates are also listed.

Table 6. Longest Periods of Snow Cover of Various Amounts
at South Bend, Indiana

Amount	Days	Inclusive dates
Trace or more	102	Dec. 5, 1962 - March 16, 1963
	101	Dec. 21, 1977 - March 31, 1978
	100	Dec. 8, 1981 - March 17, 1982
	96	Dec. 6, 1958 - March 11, 1959
	90	Nov. 28, 1976 - Feb. 25, 1977
	89	Dec. 3, 1969 - March 1, 1970
	79	Dec. 25, 1978 - March 13, 1979
	71	Jan. 7, 1962 - March 18, 1962
	66	Dec. 31, 1957 - March 6, 1958
	64	Dec. 24, 1970 - Feb. 25, 1971
1 inch or more	97	Dec, 6, 1962 - March 12, 1963
	91	Dec. 21, 1977 - March 21, 1978
	85	Dec. 17, 1981 - March 11, 1982
	73	Dec. 25, 1978 - March 7, 1979
	65	Dec. 21, 1976 - Feb. 23, 1977
	64	Dec. 31, 1957 - March 4, 1958
	64	Dec. 20, 1969 - Feb. 21, 1970
	63	Jan. 7, 1962 - March 10, 1962
	61	Dec. 19, 1980 - Feb. 17, 1981
(Table 6. Continued)	58	Dec. 17, 1983 - Feb. 12, 1984

5 inches or more	65	Jan. 9, 1978 - March 14, 1978
	59	Jan. 4, 1979 - March 3, 1979
	54	Dec. 21, 1976 - Feb. 12, 1977
	51	Dec. 22, 1983 - Feb. 10, 1984
	43	Jan. 27, 1967 - March 10, 1967
	40	Jan. 9, 1982 - Feb. 17, 1982
	39	Jan. 15, 1985 - Feb. 22, 1985
	37	Jan. 17, 1959 - Feb. 22, 1959
	34	Jan. 8, 1976 - Feb. 10, 1976
	31	Feb. 26, 1960 - March 27, 1960
10 inches or more	61	Jan. 9, 1978 - Feb. 10, 1978
	47	Dec. 27, 1976 - Feb. 11, 1977
	45	Jan. 14, 1979 - Feb. 27, 1979
	26	Jan. 17, 1959 - Feb. 11, 1959
	21	Jan. 27, 1967 - Feb. 16, 1967
	15	Feb. 10, 1958 - Feb. 24, 1958
	15	Jan. 14, 1976 - Feb. 9, 1976
	15	Jan. 3, 1999 - Jan. 17, 1999
	14	Feb. 8, 1985 - Feb. 21, 1985
	12	Dec. 9, 1962 - Dec. 20, 1962
15 inches or more	41	Jan. 14, 1979 - Feb. 23, 1979
	34	Jan. 26, 1978 - Feb. 28, 1978
	17	Jan 8, 1976 - Jan. 24, 1977
	14	Jan. 17, 1959 - Jan. 30, 1959
	14	Jan. 27, 1977 - Feb. 9, 1977
	13	Feb. 2, 1967 - Feb. 14, 1967
	10	Jan. 6, 1999 - Jan. 15, 1999
20 inches or more	17	Jan. 26, 1978 - Feb. 11, 1978
	9	Feb. 12, 1979 - Feb. 20, 1979
	5	Jan. 10, 1977 - Jan. 14, 1977
	5	Jan. 24, 1979 - Jan. 28, 1979
	4	Feb. 17, 1958 - Feb. 20, 1958
	4	Dec. 12, 1962 - Dec. 15, 1962
	4	Feb. 1, 1979 - Feb. 4, 1979
25 inches or more	13	Jan. 27, 1978 - Feb. 8, 1978
	1	Jan. 22, 1959
30 inches or more	11	Jan. 27, 1978 - Feb. 6, 1978
35 inches or more	4	Jan. 29, 1978 - Feb. 1, 1978
40 inches or more	1	Jan. 30, 1978 (41 inches)

e. Winters with most and least snow cover

In a snow cover climatology for Fort Wayne a Snow Cover Inch-Day Index (SCIDI) was developed to

compare the relative severity of winters. (O'Hara and Pyle 2000). The index assigns increasingly larger weights to successively larger snow cover depths. For example, during a snowfall season, each day that had a snow cover depth of an inch would be assigned a value of one. Each day which had two inches of snow cover would have a value of two. Each day with a reported snow cover of five inches would be given a value of five, etc. Each day with a trace of snow cover is given a weight of 0.5. The SCIDI is calculated by the following equation:

$$SCIDI = \sum D\,n \qquad (1)$$

where D = Daily snow cover (inches) and n = number of days.

In calculating the SCIDI for the 1980-81 winter season, for example, the total number of days with a trace of snow cover (fourteen days) was multiplied by 0.5, giving 7. The number of days with an inch of snow cover (seven) was multiplied by one, giving 7. The total number of days with five inches of snow cover (six) was multiplied by a factor of five, giving a total of 30. The number of days with 10 inches of snow cover reported (four) was multiplied by ten, resulting in 40. The largest snow cover reported during the season was 13 inches. It occurred twice so 13 was multiplied by 2, giving a total of 26. The SCIDI calculations for each of the various snow cover amounts during the season (trace, 1 inch, 2, 3, 4, 5, 6, etc.) add up to the total SCIDI of 428. The total calculation for the 1980-81 season is below. .

South Bend, Indiana snow cover
(1980-81 season)

	Trace	1"	2"	3"	4"	5"	6"	7"	8"	9"	10"	11"	12"	13"
Days of snow cover	14	7	4	8	3	6	7	14	4	5	4	3	2	2
SCIDI (=428)	7	7	8	24	12	30	42	98	32	45	40	33	24	26

In using the SCIDI, the winter of 1977-78 definitely stands out as the winter with the most snow cover during the last fifty years. The SCIDI of 1569.5 is the only one during this period that was greater than fifteen hundred. The 1977-78 index is so much higher than the next highest (1008 in 1978-79) because of the very deep snow cover that lasted from mid-January to mid-March 1978. During this two-month period the snow depth was greater than 25 inches on thirteen days and, of those days, the depth was greater than 30 inches on eleven of them.

Table 7 lists the 25 winters with the most snow cover at South Bend during the period of our study (1949-50 through 1998-99). The anomalously cold and snowy winters of both the late-1950s to early-1960s and the late-1970s to early-1980s stand out. Table 8 lists the 25 winters with the least snow cover during this fifty-year period.

Table 7. Most Snow Cover in South Bend
(1949-50 through 1998-99)

	SCIDI	Trace or more	1 inch or more	5 inches or more	10 inches or more	15 inches or more	20 inches or more
1. 1977-78	1569.5	128	117	88	75	54	23
2. 1978-79	1008	113	93	61	45	41	19
3. 1976-77	1004	122	100	63	49	37	9
4. 1962-63	863.5	111	104	78	33	15	4
5. 1966-67	755	108	94	52	32	25	1
6. 1958-59	661.5	112	93	50	26	14	1
7. 1981-82	639	117	99	60	26	4	0
8. 1984-85	489.5	77	54	41	22	9	4
9. 1957-58	478.5	94	77	39	18	7	4
10. 1983-84	473.5	97	74	53	12	0	0
11. 1975-76	469	80	68	35	26	6	0
12. 1969-70	438	117	93	40	9	0	0
13. 1980-81	428	83	69	47	11	0	0
14. 1959-60	401.5	112	85	38	6	1	1
15. 1967-68	341.5	92	73	34	2	0	0
16. 1968-69	338	100	68	20	12	3	0
17. 1998-99	337	49	45	25	15	12	0
18. 1964-65	332	110	78	29	3	0	0
19. 1970-71	316.5	98	83	25	5	0	0
20. 1951-52	315.5	83	54	21	10	3	0
21. 1961-62	309.5	103	86	26	0	0	0
22. 1963-64	294	100	80	16	4	0	0
23. 1985-86	290	95	75	18	5	0	0
24. 1950-51	270	104	64	24	1	0	0
25. 1993-94	261	81	65	19	5	0	0

Table 8. Least Snow Cover in South Bend
(1949-50 through 1998-99)

	Trace	1 inch	5 inches	10 inches	15 inches	20 inches

	SCIDI	or more	or more	or more	or more	or more	or more
1. 1952-53	78.5	67	28	0	0	0	0
2. 1988-89	97	76	42	2	0	0	0
3. 1982-83	110.5	61	28	8	0	0	0
4. 1997-98	142.5	58	43	11	0	0	0
5. 1995-96	145.5	94	69	3	0	0	0
6. 1953-54	155.5	72	51	8	0	0	0
7. 1990-91	161	71	49	10	3	1	0
8. 1955-56	162.5	91	62	5	0	0	0
9. 1949-50	164	76	42	14	1	0	0
1987-88	164	79	53	7	0	0	0
1994-95	164	58	40	11	2	0	0
12. 1991-92	164.5	70	45	15	0	0	0
13. 1972-73	176	94	60	10	2	0	0
14. 1996-97	180	72	54	12	4	0	0
15. 1974-75	181.5	97	72	7	0	0	0
16. 1979-80	187.5	79	54	13	0	0	0
17. 1986-87	200	81	37	19	3	0	0
18. 1973-74	229.5	80	53	19	4	0	0
19. 1956-57	232.5	85	68	21	0	0	0
20. 1992-93	237.5	85	60	17	6	3	0
21. 1960-61	242	85	65	22	2	0	0
22. 1954-55	242.5	81	62	17	4	0	0
23. 1989-90	244.5	79	52	23	3	0	0
24. 1965-66	256	86	56	17	6	0	0
25. 1971-72	260.5	97	78	16	2	0	0

f. Average SCIDI totals during a season

Snowfall in northern Indiana is fairly generous and the season extends from mid-autumn through early-spring. Lake effect snow events often begin by late-November and can occur throughout the winter since Lake Michigan rarely freezes over completely. These lake effect snow events can dump two feet of snow over a period of a couple of days. During an active winter season snow cover can accumulate rapidly.

In studying the climate of this region it is interesting to see how snow cover has accumulated throughout various winters. Some winters accumulate large snow covers early in the season as a result of lake effect snowstorms, synoptic snow events, or both. During other winters it isn't until January that deep snow cover begins to pile up.

It is valuable to meteorologists to be able to compare the current snow cover reported at some point during a winter with snow cover that has been experienced during previous winters. The two tables below show the average SCIDI total that has been calculated on the 15th day of each month and the last day of each month for different periods of time. Table 9 shows the SCIDI totals that have accumulated on these two dates at South Bend during the decades of this study from the 1950s through the 1990s. Table 10 shows the average SCIDI totals for these two dates of each month for different periods of time from the last fifty years (1950s through 1990s) to the last ten years (1990s). (October has not been included in the tables due to the relative rarity of snowfall during this month.) From this data one can calculate the current SCIDI on the 15th or the last day of a month during a winter season and compare it to the average SCIDI for those dates during previous decades.

Table 9. Average SCIDI Accumulations at South Bend On Certain Dates
(By Decade)

	Nov. 15	Nov. 30	Dec. 15	Dec. 31	Jan. 15	Jan. 31	Feb. 15	Feb. 28	Mar. 15	Mar. 31	Apr. 15	Apr. 30
1950s	5.6	19.6	42.6	91.9	119.4	174.1	225.4	262.4	269.7	274.6	276.0	276.5
1960s	4.9	12.5	46.7	97.3	147.6	221.9	290.1	346.5	391.8	410.7	411.9	413.5
1970s	5.2	23.9	56.2	105.0	196.6	337.4	469.6	523.7	550.8	561.1	565.4	565.5
1980s	1.1	4.8	18.8	61.7	110.2	185.5	262.1	289.0	299.7	305.5	308.0	308.1
1990s	3.7	10.1	23.4	50.0	95.0	135.4	153.6	180.6	200.2	202.9	203.8	204.0

As can be seen from Table 9, the 1960s and 1970s generally averaged more snow cover at South Bend than other decades during the period of our study. Each of these two decades averaged annual SCIDI totals of over 400. In fact, the 1970s was the only decade that had an average SCIDI that reached at least 100 by the end of December and at least 500 by the end of February. The 1990s averaged less snow cover than other decades, with an average yearly SCIDI total of just over 200.

Table 10 shows average SCIDI accumulations for various periods of time. The relatively snowy 1960s and 1970s can be inferred from this data. For the last fifty-, forty-, and thirty-year periods SCIDI totals averaged over 300 by April 30th. During the last ten and twenty-year periods total yearly SCIDIs averaged less than 300. During the 1990s average SCIDIs remained below 200 into early-March. When the decades of the 1950s, 1960s, and 1970s are added to the data average SCIDIs reach 200 by the end of January.

Table 10. Average SCIDI Accumulations at South Bend On Certain Dates
(By Decade)

	Nov. 15	Nov. 30	Dec. 15	Dec. 31	Jan. 15	Jan. 31	Feb. 15	Feb. 28	Mar. 15	Mar. 31	Apr. 15	Apr. 30
1950s - 1990s	4.1	14.2	37.5	81.2	133.8	210.9	280.2	320.4	342.4	351.0	353.0	353.5

1960s - 1990s	3.7	12.8	36.3	78.5	137.4	220.1	293.9	335.0	360.6	370.1	372.3	372.8
1970s - 1990s	3.3	12.9	32.8	72.2	133.9	219.4	295.1	331.1	350.2	356.5	359.1	359.2
1980s - 1990s	2.4	7.5	21.1	55.9	102.6	160.5	207.9	234.8	250.0	254.2	255.9	256.1
1990s	3.7	10.1	23.4	50.0	95.0	135.4	153.6	180.6	200.2	202.9	203.8	204.0

Table 11 shows the dates that various SCIDI totals were reached during winters that had some of the largest snow cover totals at South Bend. As can be seen in the data, the winter of 1962-63 reported a SCIDI of over 800 by early-March. Almost half of this total was accumulated by mid-January. A few of the winters of the late-1970s were some of the snowiest of the last fifty years. The snowiest season as South Bend was the winter of 1977-78 when 172.0 inches of snow fell. An incredible three-day snowstorm during the last week of November dumped 24.3 inches of snow (14.6 inches fell on the first day of the storm alone). Mainly as a result of this storm the SCIDI reached 100 by early-December. Almost twenty more inches of snow fell during the first two weeks of December, pushing the SCIDI to over 200 by mid December. Numerous snowstorms continuing through mid-February raised the SCIDI total to almost 1400 by the end of February. With snow cover persisting through most of March the SCIDI reached almost 1600 by March 31st.

By contrast, even though the next winter (1978-79) was the sixth snowiest of the last fifty years, heavy snowfall did not occur until January. It took until January 8th for the SCIDI to reach 100. However, during January and February snow cover accumulated rapidly. Snow fell almost every day during January and almost every other day during the first two weeks of February. Over fifteen inches of snow was on the ground from mid-January through the last week of February. The SCIDI reached 1000 by the first week of March.

Table 11. Dates Various SCIDI Totals Were Reached at South Bend

	SCIDI Totals							
Winter	100	200	400	600	800	1000	1200	1400
1958-59	12/21	01/19	01/30	02/18				
1962-63	12/13	12/18	01/17	02/04	03/02			
1966-67	01/05	01/30	02/11	02/27				

1976-77	12/21	12/30	01/11	01/21	02/02	03/22		
1977-78	12/02	12/13	01/14	01/27	02/02	02/08	02/18	03/02
1978-79	01/08	01/17	01/28	02/07	02/17	03/06		
1981-82	12/27	01/15	02/05	03/06				

g. Probability of a white Christmas

During early-winter the public is often interested in whether a white Christmas will occur. The probability in South Bend is high due to its proximity to Lake Michigan. By mid-December the lake effect snow process is often well-established. This can lead to a fairly significant snow cover accumulating through late-fall into early-winter. In looking at the data for the fifty winters in our study, a white Christmas occurred in thirty-eight of them (a probability of 76 percent). Table 12 is a list of the white Christmases which have occurred at South Bend from 1949 through 1998.

Table 12. White Christmases at South Bend, Indiana
(snow cover amounts in inches)

Year	Snow Cover	Year	Snow Cover	Year	Snow Cover
1950	6	1965	2	1980	6
1951	16	1966	Trace	1981	8
1952	Trace	1967	Trace	1983	14
1953	2	1968	10	1984	1
1954	2	1969	6	1985	9
1956	1	1970	Trace	1989	7
1958	4	1972	2	1990	7
1959	Trace	1973	4	1992	1
1960	5	1974	3	1993	1
1961	3	1975	1	1995	1
1962	8	1976	8	1996	4
1963	7	1977	1	1998	1
1964	Trace	1978	2		

h. Correlation of snow cover to snowfall and temperature

The relative severity of winters can be compared in many ways. One common way is to compare snowfall totals that are received each winter. Another way would be to study temperature data (specifically, temperature departures from normal). Snowfall and cold temperatures certainly would contribute to whether a winter is considered severe or not. The public or the media may feel that a winter had been severe, but a comparison of snowfall and temperature data would be an objective way to determine this.

Snow cover is another way to see how winters have compared and can be an index of how severe winters have been. To rank winter snow cover the Snow Cover Inch-Day Index (SCIDI) was used. To see whether there is a

direct correlation among snowfall, temperature, and snow cover the authors compared these parameters for the thirty winters (December through February) from 1960-61 through 1989-90. These thirty winters were chosen so that temperature departure from normal could be calculated. The latest normals are for this thirty-year period.

A very good correlation was found between snowfall and snow cover. In fact, nine of the ten snowiest winters (Dec.-Feb.) were also among the top ten winters with the most snow cover. There seemed to be a fairly strong correlation between temperature departure and snow cover data but this relationship was not as strong as that for snowfall and snow cover. Six of the coldest winters (Dec.-Feb.) were among the ten winters with the most snow cover. This is similar to the results found in the authors' study of snow cover at Fort Wayne. And this has also been correlated in other studies. Leathers and Robinson (1993) found that, over North America during the winter months (Dec.-Feb.), large (small) snow cover extent was associated with below- (above-) normal temperatures. They found the strongest correlation, however, in the central U.S. over the Great Plains and Mississippi valley.

Table 13 lists the top ten winters for each of the parameters studied. Snowfall is ranked from the snowiest winter to the tenth snowiest. Average Temperature Departure is ranked from the coldest winter (largest negative departure from normal) to the tenth coldest. Snow Cover is ranked from the winter with the most snow cover (largest SCIDI) to the winter with the tenth largest SCIDI.

Table 13. Comparison of Indices for South Bend (Dec. through Feb.)
(1960-61 through 1989-90)

	Snowfall	Average Temp. Departure	Snow Cover
1.	1977-78	1962-63	1977-78
2.	1981-82	1977-78	1978-79
3.	1976-77	1976-77	1976-77
4.	1978-79	1978-79	1962-63
5.	1984-85	1981-82	1966-67
6.	1966-67	1961-62	1981-82
7.	1962-63	1969-70	1984-85
8.	1985-86	1985-86	1983-84
9.	1980-81	1983-84	1975-76
10.	1983-84	1967-68	1980-81

4. Conclusions

Snow cover is a common occurrence at South Bend during the winter season. And during relatively cold and snowy winters snow can remain on the ground for months at a time. In this study the authors tried to determine how often snow cover could be expected during a typical winter and how variable the annual amount was over a period of years. The fifty years in this study showed that annual snow cover was quite variable and that a season with snow cover does not necessarily mean that the next year will be equally snow covered.

During the fifty-year period of this study a trace or more of snow cover was reported an average of 89.2 days per year at South Bend. An inch or more of snow cover was reported an average of 66.3 days. At least five inches

was reported on 26.2 days, and snow cover of ten inches or more was reported an average of 9.9 days per year.

Some of the coldest and snowiest winters dominated the statistics for South Bend. These winters not only recorded the greatest durations of snow cover, but they also had a disproportionate number of days during which deep snow cover (10 inches or greater) was reported. The prevalence of snow cover during a typical winter in South Bend definitely contributes to its reputation as a snowy locale.

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