Climatic Summary of Snowfall and Snow Depth in the Ohio Snowbelt at Chardon[1]

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ABSTRACT. **Snowfall records were examined for the period 1945-85 at Chardon, OH, the only station with a long climatic record in the snowbelt. Average seasonal snowfall was 269 cm (106 in) with a seasonal maximum of 410 cm (161 in). Seasonal snowfall was positively correlated with other sites in the lower Great Lakes snowbelts and along the western slope of the Appalachians from Tennessee to Quebec, but was not correlated with snowfall in the snowbelts of the upper Lakes. The time series of seasonal snowfall was not random but showed weak year-to-year persistence. The average number of days with 2.5 cm (1 in) of snowfall was 35. The average dates of the first and last 2.5 cm snowfalls of the winter were 10 November and 4 April. The largest two-day snowfall of the winter averaged 33 cm. The average number of days with 2.5 cm of snow cover was 82. Daily probability of snow cover reached the seasonal maximum of 86% in mid-January and early February. These results may be reasonably extrapolated throughout the Ohio snowbelt for applications in vegetation studies, animal ecology, hydrology, soil science, recreation, and transportation studies.**

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INTRODUCTION

The Great Lakes exert a significant influence on the regional climate (Changnon and Jones 1972, Eichenlaub 1979). One facet of that influence is frequent snowfall downwind of the Lakes. This "lake-effect snow" is made possible by excessive evaporation from the Lakes because of a large vapor pressure deficit between the relatively warm water and cold air. The lower layer of the moistened air mass becomes unstable by warming of the cold air from the lake below. This instability causes upward motion, resulting in clouds and precipitation, and is enhanced by frictional convergence as the air passes from the lake to the land. The snowfall is increased further in areas where terrain causes additional uplift and cooling as the moist, unstable air comes onshore. Regions where this lake-effect snow is common are called "snowbelts" (Muller 1966, Eichenlaub 1970, Kelly 1986).

Since the cold air flow associated with lake-effect snow comes primarily from the west or northwest, snowbelts are located southeast and east of each of the Great Lakes (Muller 1966, Eichenlaub 1970). The Lake Erie snowbelt extends from the eastern suburbs of Cleveland through extreme northeastern Ohio into northwestern Pennsylvania and western New York (Fig. 1). Seasonal snowfall in this region averages over 200 cm and reaches over 400 cm along the higher ridges of western New York (Pack 1972). In addition to the influence of Lake Erie, it is likely that moisture and heat from Lake Huron also contribute to the snowfall in Ohio's snowbelt. The distance across the low land separating Lake Huron and Lake Erie is 75 km, and average snowfall in that region of Ontario is only 100 to 140 cm (Brown et al. 1980). Without much orographic uplift, moisture gained by north or northwest winds from Lake Huron is not precipitated as snow in southwest Ontario, but instead is supplemented by moisture from Lake Erie and extracted by the hills of the Ohio snowbelt.

Lake-effect snow is an economic and ecological factor in the snowbelts. Recreational opportunities are provided for skiing and snowmobiling through a longer snow season than is available outside the snowbelt. Costs for snow removal on highways, commercial lots, and residential areas are higher as a result of the frequent snow. Transportation is occasionally delayed by

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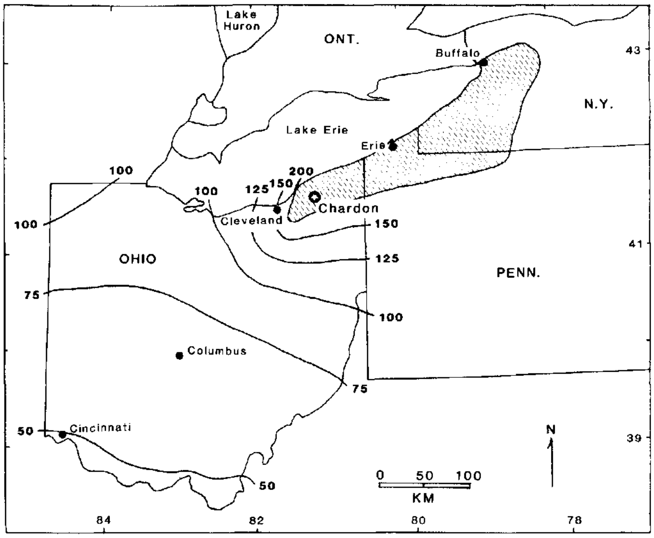

FIGURE 1. Mean annual snowfall (cm) in Ohio, the location of Chardon (41.6°N, 81.2°W), and the Lake Erie snowbelt. The snowbelt is approximately the area with over 200 cm mean annual snowfall.

lake-effect snow in the busy highway corridor south of Lake Erie. Snow cover affects the hydrological balance by insulating the ground from very cold air temperatures and by providing abundant moisture upon melting. Pollutants accumulate in a snow pack through wet and dry deposition and can provide highly polluted and acidic meltwater. Research in the Lake Michigan snowbelt showed that 52% of the ions, such as hydrogen, sulfate, and nitrate, contained in the snowpack were released with the first 17% of snowpack meltwater (Cadle et al. 1984). This concentration of pollutants in the earliest snow melt has been shown to cause a 400% to 600% increase in concentrations of sulfate and other ions in streams and may result in fatal physiological stress on fish (Johannessen and Henriksen 1978, Siegel 1981).

The purpose of this paper is to present a climatic summary of snow at Chardon, in the Ohio portion of the snowbelt. Forty years of snowfall and snow cover data from the National Weather Service cooperative climate station at Chardon were analyzed. Chardon was chosen for this analysis because it is the only station in the Ohio snowbelt with a long period of record and few missing daily observations. Other locations in the Ohio snowbelt may have a higher average snowfall but recent records covered only a few years, and the snowfall measurements were sporadic. Daily, monthly, and seasonal snowfall data were examined along with characteristics of snow depth and snowmelt. Relationships with seasonal snowfall in other regions of eastern North America were explored.

Chardon is an important station because it is the first station in the snowbelt with sufficiently long records to show the magnitude of snowfall in the region. Early publications on Ohio's climate noted that the snowiest part of the state was the northeast, but average snowfall was underestimated in those early works because of a lack of data. Jennings (1903) described the snowfall patterns over Ohio in one paragraph without mentioning a snowbelt inland from the lake. He published a map showing that the average snowfall decreased steadily southwestward from about 150 cm in extreme northeast Ohio to 130 cm at Chardon's location in northern Geauga County. Smith (1912) published a map showing that snowfall exceeded 150 cm in northeast Ohio, but gave no indication of heavier snowfall.

In a voluminous climatological history of Ohio, Alexander (1923) gave a map of average snowfall showing over 130 cm in northeast Ohio. Alexander's snowfall map was published later in a state climate summary by Alexander and Patton (1934). Carlson (1939) summarized Ohio snow data collected up to 1937 and showed averages over 130 cm in northeast Ohio. Even as recently as 1975, an Ohio atlas by Collins (1975) showed that the snowiest region in Ohio was northern Ashtabula County with over 180 cm. The Chardon site was shown to have an average snowfall of 140-150 cm in this 1975 atlas.

The most detailed study of Ohio snowfall and the first published work to note the very high snowfall of northern Geauga County was published by Miller and Weaver in 1971. They analyzed snowfall over the period 1936-65 at 91 locations. Their study covered the first 20 years of the Chardon record when the average snowfall was 268 cm. The next snowiest station was Geneva, near the lake shore, with 183 cm. Miller and Weaver's (1971) map showed an average snowfall of over 250 cm in a band across northern Geauga County into west-central Ashtabula County. This map was later reproduced by Noble and Korsok (1975).

MATERIALS AND METHODS

Chardon is located in northern Geauga County about 20 km from Lake Erie (Fig. 1). Daily measurements of maximum and minimum temperatures, precipitation, snowfall, and snow depth were taken at 08:00 h EST at Chardon. Snowfall over the previous 24 hrs was measured by collecting snow in a standard 20 cm diameter gauge or by measuring new snow accumulated on bare ground or a snow board. Snow depth at 08:00 h was recorded after taking several measurements in the area to obtain a representative average. Snowfall measurements were recorded in tenths of inches and snow depth was recorded to the nearest inch (units are converted to metric in this paper). Snowfall and snow depth are among the most difficult climatological parameters to measure because of local variability and drifting, settling, and melting between observations.

There have been four observers at Chardon since the station began operation in February 1945. The elevation of the station has ranged from 344 m to 393 m. The station was located in a residential area of the village of Chardon and observations were made at 18:00 h until August 1972 when the station was moved 1 km to the sewage treatment plant and the observation time changed to 08:00 h. The changes in station location did not significantly affect snowfall measurements (Mike Wyatt pers. commun.).

The high elevation at Chardon, its proximity to Lake Erie, and its northern location give this station the coldest average annual temperature (8.8°C) of any station in Ohio (National Oceanic and Atmospheric Administration 1982). Chardon is also the wettest location in Ohio with 1149 mm average annual precipitation, 242 mm more than on the lake shore at Painesville where the station is 186 m lower in elevation (NOAA 1982). Precipitation generally increases as elevation increases and this feature is exaggerated in the highlands of northeast Ohio, where additional moisture is provided by Lake Erie.

The monthly and seasonal totals of snowfall at Chardon were examined for the period 1945-85. These were analyzed for the expected values, variability, and extremes. Statistical tests were performed on the monthly and annual snowfall totals to determine their frequency distribution. The Shapiro-Wilk test (Shapiro 1980) was used to test the hypothesis that the snow totals fit a normal, or Gaussian, frequency distribution. A logarithmic (base 10) data transformation was performed on the snowfall data for months that did not fit a normal distribution. Daily snowfall and snow depth

TABLE 1

Comparison of average (1945-85) snow statistics at Chardon with the three largest cities in Ohio.

City	Snowfall (cm)	Days with ≥2.5 cm snowfall	Days with ≥2.5 cm snow cover	First snowfall ≥2.5 cm	Deepest snow depth of winter
Chardon	269	35	82	10 November	43
Cleveland	137	17	53	21 November	24
Columbus	74	10	29	7 December	17
Cincinnati	58	7	22	12 December	15

were examined for the periods 1950-56 and 1964-85 (these data were unpublished in other years). The daily data were analyzed for the dates that snowfall or snow cover thresholds were met, the number of days over certain thresholds, probability distributions, and extreme events.

RESULTS AND DISCUSSION

MONTHLY AND SEASONAL TOTALS. The average snowfall at Chardon over the 40 winters 1945-46 to 1984-85 was 269 cm. Snowfall at Chardon has been compared with snowfall at the three largest cities in Ohio (Table 1). The snowiest winter was 1959-60 when 410 cm fell, the greatest seasonal snowfall ever recorded in Ohio (Fig. 2). The snowiest calendar year was 1960 with 461 cm. The lowest seasonal total was 114 cm in 1948-49. This was greater than the *average* snowfall in most of Ohio. Snow has been recorded in every month except June, July and August, although snow is rare in September and May. (A summary of monthly and seasonal snowfall is given in Table 2. Five-year smoothed averages of seasonal and monthly totals are shown in Fig. 3).

Snow flurries are not uncommon by mid-October at Chardon. These first snowflakes of the season usually fall with surface temperatures above freezing and melt quickly on the ground or pavement. The earliest measurable (>0.25 cm) snow recorded at Chardon, and the only snow recorded in September, was 1.3 cm on 20 September 1956. Snow fell in 11 of the 40 Octobers examined in this study, generally after the 20th of the month. Among the heavier October snowfalls were 30.5 cm on 31 October 1954 and 22.9 cm on 26 October 1962.

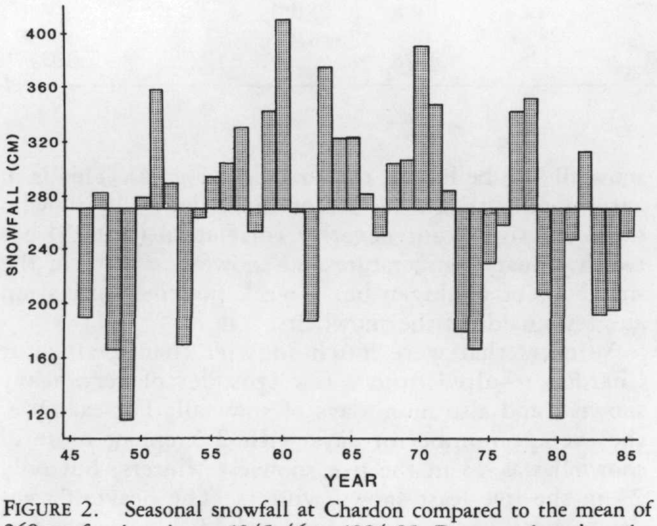

FIGURE 2. Seasonal snowfall at Chardon compared to the mean of 269 cm for the winters 1945-46 to 1984-85. Data are plotted on the year of the January for the winter (winter 1949-50 is plotted on 1950).

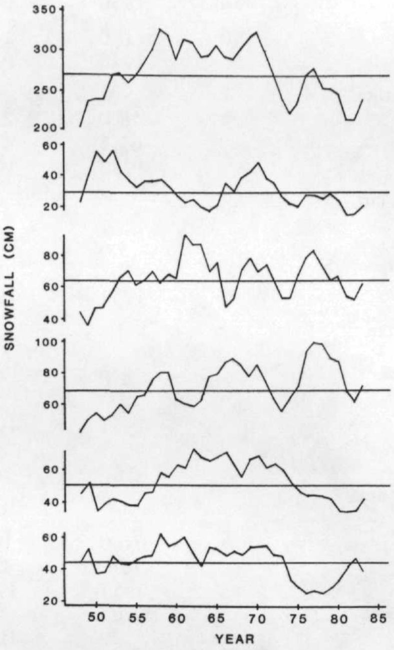

FIGURE 3. Smoothed plots of seasonal and monthly snowfall at Chardon. Smoothing is a five-year moving average with equal weight to each year and plotted on the central year.

The risk for heavy snow is high at Chardon during November and early December when the rest of Ohio has a low risk of heavy snow. Lake Erie water temperatures are mild (10-13°C) (Webb 1974) in November, so an unusually cold air flow from the northwest gains much moisture and heat from the lake surface. Average snowfall at Chardon is heaviest during December and January, when the difference between lake temperature and air temperature is great and air temperatures are often below freezing. Lake Erie begins freezing in the shallow western basin during December and reaches its greatest ice cover, an average of 90-100%, in late February (Assel et al. 1985). As the lake freezes, most lake-effect snow ends because the source of moisture and heat is reduced by the ice cover. Snowfall decreases somewhat in February and March, although averages are still greater than other regions in Ohio from the occasional lake-effect snow and generally heavier precipitation at Chardon's high elevation. Snow is rare after mid-April at Chardon. Measurable snowfall has been noted only twice during May, the greatest being 7.6 cm on 1 May 1963.

TABLE 2

Snow statistics for Chardon, Ohio (1945-85).

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Season
Snowfall									
Average (cm)	2.8	29.2	64.0	68.3	51.1	43.4	9.9	0.3	269.0
Median	0.0	25.1	54.4	68.6	47.2	38.1	4.6	0.0	279.7
Standard deviation	7.0	23.4	35.6	31.2	25.4	25.9	14.0	1.3	73.7
% of years with snow (≥0.25 cm)	27	98	100	100	100	100	72	5	100
Largest total	33.0	97.8	176.5	145.0	115.6	104.1	62.2	7.6	410.2
Year	1954	1950	1962	1978	1947	1960	1957	1963	1959-60
Smallest total	0.0	0.0	14.0	24.1	11.4	2.1	0.0	0.0	114.0
Year	*	1946	1947	1949	1948	1985	*	*	1948-49
Largest two-day total									
Average		18.0	22.6	22.3	20.0	19.6	5.3		33.3
Maximum		63.5	41.9	43.2	50.8	53.3	25.4		63.5
Year		1950	1977	1978	1971	1966	1982		1950
Days with ≥2.5 cm snowfall									
Average		3.6	7.9	9.7	7.0	5.6	1.2		35.0
Maximum		8	17	17	11	12	5		53
Year		1951	1969	1976	1972	1971	1956		1969-70
Days with ≥10 cm snowfall									
Average		1.0	2.4	2.1	1.5	1.1	0.1		8.2
Maximum		4	7	6	4	4	1		13
Year		1951	1981	1978	1964	1971			*
Snow Cover									
Days with ≥2.5 cm snow cover									
Average		6.0	19.1	24.5	20.4	11.7	1.0		82.7
Maximum		16	31	31	29	26	5		112
Year		1951	1974	*	1972	1984	1985		1977-78
Minimum		0	8	15	8	1	0		42
Year		*	1971	1953	1953	1985	*		1952-53
Days with ≥10 cm snow cover									
Average		2.4	10.6	17.7	15.3	5.6	0.1		51.7
Maximum		8	25	31	28	22	2		104
Year		1977	1974	*	*	1984	1982		1981-82
Minimum		0	0	1	2	0	0		12
Year		*	1965	1967	1952	*	*		1952-53
Days with ≥30 cm snow cover									
Average		0.3	1.5	4.2	4.1	0.8	0.0		10.9
Maximum		7	8	25	24	10	0		49
Year		1950	1974	1977	1978	1978	*		1977-78

*Indicates occurrence in more than one year

Annual and January snowfall totals fit a normal frequency distribution. Monthly snowfall totals for December, February, and March are positively skewed and fit a log-normal frequency distribution. This knowledge allows the probability of specific snowfall amounts to be calculated and provides data for mathematical models of future snowfall.

Snowfall at Chardon was compared to the historical state-wide monthly average temperature for Ohio given by Karl et al. (1983). Monthly snowfall totals at Chardon are negatively correlated with Ohio average monthly temperatures from November through March ($r = -0.42$ to -0.68). As a general rule, an outlook for a cold month in Ohio indicates heavy snow in the snowbelt, while an outlook for a mild month indicates snowfall will be lighter than average (Fig. 4). This is in agreement with the results of Eichenlaub (1970) who showed a significant negative correlation (−0.75) between January temperature and snowfall at sites in the snowbelts of Michigan but a weak positive correlation at sites outside of the snowbelts.

Winters that were much snowier than average at Chardon resulted from a few episodes of very heavy snowfall and also more days of snowfall. For example, the average number of days with 2.5 cm or more of snowfall was 43 in the five snowiest winters, but only 23 in the five least snowy winters. The heaviest two-day snowfall of the winter averaged 43.9 cm in the five snowiest winters, but only 26.7 cm in the five least snowy winters.

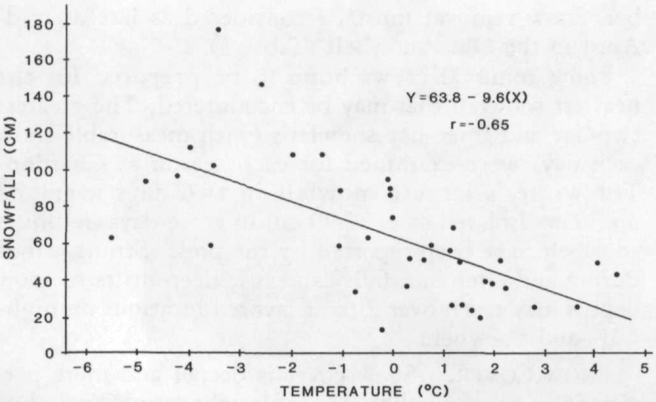

FIGURE 4. Plot of Ohio average December temperature (NOAA, 1982) and Chardon December snowfall. A least-squares regression line is fit to the data and the equation and correlation are given.

The magnitude of the lake-effect on snowfall at Chardon is not easy to determine, but some estimates can be made. We can ask how much snow would fall on Chardon if Lake Erie did not exist. Average snowfall in northwest Ohio is 80 to 100 cm (Fig. 1). Terrain is flat in northwest Ohio, elevations range from 180 to 280 m, and negligible amounts of lake-effect snow are received. Chardon would be snowier than northwest Ohio, even if Lake Erie did not exist. This results from the higher elevation at Chardon and its proximity to Atlantic coastal storms, which occasionally give precipitation as far inland as eastern Ohio. Locations in east-central Ohio, away from the lake-effect but at a relatively high elevation, average 90 to 120 cm of snow annually. It is likely that Chardon's average snowfall is doubled by Lake Erie, and Ohio's snowbelt would receive about 130 cm of snowfall without Lake Erie. This is supported by conclusions of Changnon and Jones (1972) and Kelly (1986) for the contribution of the lake-effect to seasonal snowfall elsewhere in the Great Lakes snowbelts.

REGIONAL COMPARISONS. Chardon's seasonal snowfall totals were compared to snowfall at other sites in eastern North America. The large-scale weather patterns that produce variety in Chardon's snowfall totals might be expected to produce similar variety in other snowbelt regions of the Great Lakes. Correlation of seasonal snowfall at Chardon and the other snowbelt regions of the southern Great Lakes and Georgian Bay was positive and significantly different from zero (Fig. 5). Correlation with Chardon snowfall was greatest (>0.50) in the snowbelts of Lake Erie, Lake Ontario, and southern Lake Michigan. Seasonal snowfall at Chardon was not correlated with snowfall in northern Michigan snowbelts. Chardon snowfall was also not correlated with areas to the west in central Michigan or Wisconsin. Significant correlation extended northeast through most of New York and Pennsylvania to Maine and Quebec and southward along the western Appalachians and into the Tennessee Valley.

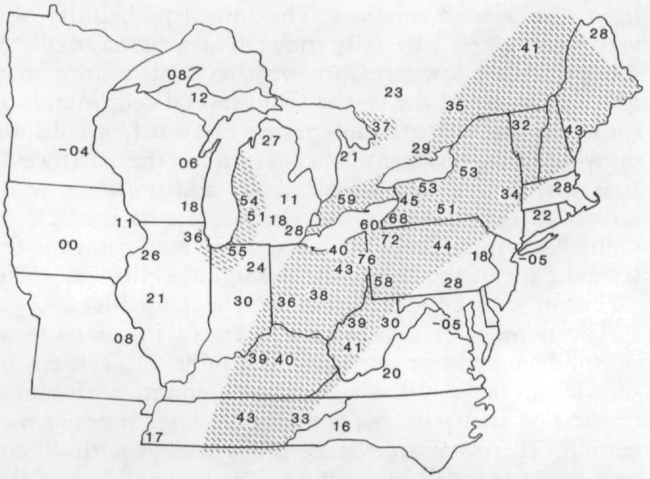

FIGURE 5. Regional correlations (× 100) of seasonal snowfall with Chardon snowfall. Shading indicates regions where correlation with Chardon snowfall is significantly different from zero ($p < 0.05$).

The presence of correlation with sites to the east and south but absence of correlation to the west might be explained by characteristics of storms that produce snow in the Ohio snowbelt. A storm track that produces snow in the upper Mississippi Valley and western Great Lakes states is likely to bring warm air and rain to Ohio, though snow may fall after the passage of the cold front. Conversely, a storm track that brings snow to the region south and east of Ohio creates a substantial flow of cold air from the northwest into Ohio. This situation is favorable for a general snowfall from the storm system and the development of lake-effect snow across the southern Great Lakes region.

SEASONAL PERSISTENCE. The ability to predict snowfall totals several months in advance would be valuable to many industries and government agencies. The time series of seasonal snow totals at Chardon has considerable year-to-year variability. Miller and Weaver (1971) noted that snowy winters often follow, or are followed by, winters with little snowfall in Ohio. This observation is not true for Chardon, as shown by two statistical analyses. During the eight snowiest winters at Chardon, the average snowfall of the preceding winter was 295 cm and the average of the following winter was 310 cm, both above the 40-year average of 269 cm. For the eight winters of lowest snowfall, the average snowfall for the preceding winter was 240 cm and the average for the following winter was 245 cm, both below the 40-year average. This leads to the conclusion that winters with unusually high or low snowfall tend to occur with winters of similar departures from average. This is of limited use in seasonal forecasting of actual snowfall amounts, however, since there were exceptions (Fig. 3).

Correlation was also used to check for relationships between snowfall of adjacent winters. Autocorrelation (Chatfield 1980) between adjacent winters at Chardon is 0.323, which is significantly different from zero ($p = 0.04$). This verifies that the time series of seasonal snowfall totals is not random but has year-to-year (lag 1) positive correlation (Fig. 3). The correlation is weak and offers little predictive value, however, from one winter to the next. Of the 21 winters with above-average snowfall at Chardon, 13 (62%) were followed by winters with above-average snowfall. Of the 18 winters with below average snowfall, 10 (56%) were followed by winters with below-average snowfall.

DAILY SNOWFALL. A characteristic of snowfall in the snowbelts is that it occurs frequently, but usually in light to moderate amounts. The annual probability of a very heavy (>30 cm) daily snowfall at a site is small. A synoptic-scale low pressure weather disturbance may give Chardon and the rest of Ohio several centimeters of snow. As the disturbance passes eastward, a cold air mass typically flows into the state from the northwest. It is within this cold air mass that additional snowfall arrives in the snowbelt. As weather across the rest of Ohio clears in the cold air mass, snow may continue for several days in the snowbelt giving an additional 15 to 30 cm of snow in sporadic showers and squalls.

The number of days with 2.5 cm (1 in) or more of snowfall in a winter averaged 35 (Table 2). Ten cm of snowfall in one day is a significant amount, with major impacts on transportation and snow-related outdoor recreation. There was an average of eight days with 10 cm or more of snowfall in a winter. The average date of the first 2.5 cm snowfall was 10 November (Table 3). The date of the first 2.5 cm of snowfall was not correlated with total snowfall in that winter. The average date of the first 10 cm snowfall in two consecutive days, with measurable snow on both days, was 25 November. The date of the first 10 cm snowfall in two days was negatively correlated (R = −0.61) with snowfall in the upcoming winter. An early occurrence of the first 10 cm snowfall indicated snowfall in the upcoming winter was likely to be above the average. Seasonal snowfall was predicted to decrease by 20 cm for each delay of one week in the first 10 cm snowfall. This is an indication of the importance of early season snowfalls as contributions to the total winter snowfall at Chardon.

The dates of the first and last 2.5 cm of snow in one day and the dates of the first and last 10 cm in two consecutive days were from normal frequency distributions so the mean and variance completely describe the distributions. The dates when the probabilities of these snowfall amounts reach certain thresholds were determined (Table 3). Based on these probabilities of the first significant snowfalls, the snow season at Chardon begins by the last week of October for industries, such as snow removal and retail sales of winter goods, which must be prepared for the first snowfall. For industries which depend on a substantial snowfall, such as winter sports, the reliable snow season begins by mid-December. Snow removal must be considered as late as mid-April in the Ohio snowbelt (Table 3).

TABLE 3

Date when the probability of the first autumn and last spring snowfall reaches selected probability levels. The 50% probability dates represent the average dates of occurrence. Extremes represent the earliest and latest occurrences.

Prob.	First Autumn Snowfall		Last Spring Snowfall	
	2.5 cm in one day	10 cm in two days	2.5 cm in one day	10 cm in two days
Extreme	20 Oct	31 Oct	1 May	18 Apr
10%	27 Oct	6 Nov	19 Apr	9 Apr
25%	2 Nov	15 Nov	12 Apr	31 Mar
50%	10 Nov	25 Nov	4 Apr	22 Mar
75%	18 Nov	5 Dec	28 Mar	13 Mar
90%	25 Nov	14 Dec	21 Mar	4 Mar
Extreme	30 Nov	31 Dec	17 Mar	16 Feb

Snow removal crews hope to be prepared for the heaviest snowfall that may be encountered. The greatest two-day and three-day snowfalls (with measurable snow each day) were examined for each season at Chardon. The winter's largest snowfall in two days averaged 33.3 cm. Isolated cases of 90 cm in three days in Ohio's snowbelt have been reported by the press. Strong winds during and after snowfalls can cause deep drifts so snow depths may reach over 2 m at favored locations on highways and elsewhere.

SNOW COVER. Snow cover is deeper and more persistent in the snowbelt than elsewhere in Ohio, but rarely persists throughout the winter without periods of melt and bare ground. The snow depth and number of days with snow cover can vary widely within a small region depending on wind drifting, shelter from vegetation, and differential melting rates (Adams 1976). These data presented for Chardon represent small clearings with some shelter from trees nearby. Snow depths and persistence of snow cover will be less in open fields and greater in forests than reported here.

The average annual number of days with 2.5 cm of snow cover was 82. Winters with over 100 days of snow cover occurred in 1969-70, 1976-77, 1977-78, 1981-82, and 1983-84. The longest winter period with 2.5 cm or more of continuous snow cover averaged 40 days. These data on the number of days with 2.5 cm of snow cover and the longest winter period with a 2.5 cm snow cover fit normal frequency distributions. The number of days with over 2.5 cm of snow cover for the winter was positively correlated (r = 0.52) with snowfall during the winter. This correlation implies an additional day of snow cover for each 7.6 cm of additional seasonal snowfall.

Ten cm of snow cover is needed for winter sports such as cross-country skiing and snowmobiles. This amount of snow cover also provides the soil and surface flora and fauna with significant insulation from the cold air above. The number of days with 10 cm or more of snow cover in a winter averaged 52, and the longest winter period with 10 cm or more of continuous snow cover averaged 30 days. The winter's longest period with over 2.5 cm and over 10 cm of continuous snow cover both had average middle dates of 21-22 January. Thus, the most likely time for an extended period of snow cover was early January to mid-February. The average number of days with 30 cm of snow cover was 11, and this depth occurred in 38 of 40 winters.

The greatest snow depths recorded at Chardon include 86 cm on 12 December 1962, 79 cm on 7 February 1977, 76 cm on 5 March 1960, and 66 cm on 28 January 1977. The deepest winter snow cover averaged 43.4 cm. The deepest winter snow cover has occurred as early as 31 October (1955) and as late as 4 March (1984) with a median date of 18 January.

The daily probability of a snow cover greater than 2.5 cm was less than 10% through the first week of November but increased rapidly during late November (Fig. 6.). The probability of snow cover exceeded 50% by the third week of December and peaked at 75% to 85% from 5 January to 15 February. Probabilities of

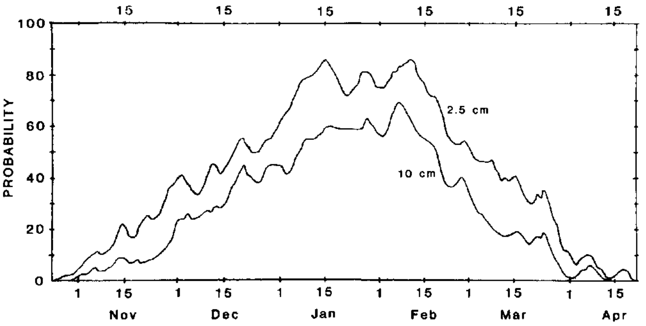

FIGURE 6. Smoothed daily probability of snow cover greater than 2.5 cm and greater than 10 cm. Smoothing is a five-day moving average plotted on the central day.

snow cover dropped to 40% by mid-March and then fell quickly to 10% at the end of March. Snow cover was rare at Chardon after 20 April. The probability of snow cover over 10 cm was less than 10% until late November. There was greater than 50% daily probability of 10 cm of snow cover from 10 January through 15 February with a peak of 70% probability during the first week of February.

SNOW DENSITY AND SNOWMELT. Snowmelt provides moisture to the soil and streams and may cause flooding if it occurs rapidly or along with rainfall. A decrease of snow depth is not a good indicator of the release of water through melt, since the snow depth may decrease with removal by wind, settling of the snowpack, or partial melting and refreezing within the snowpack. The change in daily water content of the snow cover is a direct measure of the water released to the environment, but snow cover water content is not measured at Chardon. This parameter is measured only at the National Weather Service (NWS) offices, so information on snowmelt at Chardon must be interpolated from a nearby NWS office. The closest NWS offices to Chardon were Cleveland and Youngstown, Ohio, both about 55 km away. However, the snow characteristics of the Erie, PA, NWS office, 70 km from Chardon, best represented the snowmelt at Chardon since Erie is located in the snowbelt and the average snowfall is 208 cm.

Edgell (1988) summarized the snow cover and snowmelt climatology of the NWS offices in Ohio and adjacent states, including Erie, PA. Some estimates can be made about snow density and snowmelt at Chardon by assuming that these follow the same patterns as at Erie (Edgell 1988). This is a reasonable assumption since the two sites are only 70 km apart and at similar positions within the Lake Erie snowbelt. On days when there was at least 5 cm of snow cover at Chardon, the median daily water equivalent of snow cover during January and February was 15 to 18 mm. The median annual maximum water equivalent of snow cover was estimated to be 38 mm at Chardon and the record for the greatest amount over the 40 year record was near 150 mm. The median density of snow cover at Chardon was estimated to be 0.10 g/cm^3 during November, less than 0.10 g/cm^3 from early December to early February, 0.10 g/cm^3 again from mid-February through early March, and greater than 0.10 g/cm^3 after early March. These expected density values reflect the seasonal temperature regimes, with colder temperatures during midwinter giving a less-dense snow cover. While very dense (>0.20 g/cm^3) snow covers were most common late in the snow season, they may develop at any time of the year from a combination of a long-lived deep snow cover, partial melting and refreezing of the snow cover, or the input of sleet or rain onto the snow. Snow density values over 0.30 g/cm^3 were rare.

Snowmelt is a sporadic winter event in this climate and may occur anytime that there is snow on the ground. The daily empirical probability of a melt of 5 mm of water from snow reached 10% during early December, dropped below 5% during the colder weather of January, and increased to over 10% again during 1-20 February. About 55% of the snowmelt events of 5 mm or greater in one day were accompanied by rainfall. The median annual maximum daily snowmelt was about 23 mm of water and the maximum daily melt in the 40-year record was estimated to be 50 mm. This amount of water input to the environment may lead to local flooding, especially if it occurs over frozen ground or is accompanied by rainfall.

CONCLUSIONS

This was the first detailed climatic summary of snowfall and snow cover for a site in the Ohio snowbelt. The average seasonal snowfall of 269 cm is approximately 20% of the annual precipitation at Chardon. This snowfall is among the heaviest to be found so far south in eastern North America. The average snowfall, number of days of snowfall, length of the snow season, and snow depths are all much greater at Chardon than elsewhere in Ohio. These summary statistics provide guidance for others working in the natural sciences, transportation, or winter recreation in the Ohio snowbelt.

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BOOK REVIEW

Genetic Improvements of Agriculturally Important Crops — Progress and Issues. Current Communications in Molecular Biology. Edited by R. T. Fraley, N. M. Frey, and J. Schell. 1988. Cold Spring Harbor Laboratory. 116 pp. $25.00 paper.

This book consists of a collection of short (3-5 page) summaries of participants' research/perspectives presented at a recent conference focused on advances in the general area of plant molecular biology and biotechnology. The participants included researchers from academia and industry, as well as government officials from the USDA, EPA and FDA. The goal of this meeting was "to assess the scientific and technical progress and to ponder the impact of this progress on agriculture."

There are papers discussing *Agrobacterium* mediated gene transfer technology, naked DNA injection and microprojectile bombardment to introduce foreign genes into plants, and a review describing various reporter genes commonly being used to study specific gene expression. Most of the authors were optimistic that technology will eventually allow for the stable transformation and regeneration of some of the more agronomically important crops including corn.

Several brief summaries were devoted to recent advances made in the areas of pest and herbicide resistance. Transgenic plants expressing viral capsid protein were shown to contain 70-95% fewer infection sites as compared to controls in field trials. The introduction of truncated *Bacillus thuringiensis* toxin genes (bt2) into plants has also been shown to display significant insecticidal activity. The construction of herbicide resistant cultivars of commercially important crops is obviously a major goal of industrial laboratories. Progress in this area is well represented in this volume. Currently, the two main approaches are to identify and isolate endogenous mutant plant genes coding for target enzymes resistant to a given herbicide or to identify and isolate enzymes from microbial origin which function to detoxify, by chemical modification, a particular herbicide and introduce genes coding for these enzymes into plants. Both approaches are showing promising results in field trials.

Papers include the use of transient gene expression experiments using protoplasts to dissect important regulatory elements within plant genes and the use of antisense gene constructions as a mechanism to assess the phenotypic response of inappropriate expression of selected genes. Efforts are also being made to manipulate, via biotechnological methods, the amino acid and lipid composition of seeds used for nutritional or industrial applications.

We are currently at a stage in the technology of developing genetically engineered plants where we are exclusively dealing with traits that can be modified by the introduction of a single foreign gene. This is mainly due to our lack of a thorough biochemical understanding of the vast majority of physiological processes in plants. As our knowledge grows we will be in a better position to tackle more genetically complex traits of agronomic importance such as standibility yield, maturity and stress tolerances. The book contains a report on the use of restriction fragment length polymorphism (RFLP) as a tool to dissect some of these genetically complex traits.

The latter portion of the book deals with issues concerning the lengthy process involved in product development and regulatory obstacles which might delay the commercialization of genetically engineered plants in the future. The current view held by federal agencies is that each new product will be judged on its properties, not on the process by which it was derived. There seems to be a concensus that regulatory requirements be established by cooperation between the various federal agencies involved to allow for the preservation of the food supply and the competitive position of the United States in agriculture. There is concern that a long-term vision for agricultural research and development is non-existent and therefore should be addressed immediately.

I enjoyed reading this book because it did a good job of describing current scientific progress, problems confronting agriculture in this country, and the role of plant biotechnology in agriculture. I highly recommend the reading of the volume to members of the plant science community as a means of keeping abreast of this rapidly evolving discipline.

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