Development of a Severe Winter Index: Buffalo, New York

Theodore McInerney
CBS4
231 18th Street
Rock Island, IL 61201
E-mail: tmcinerney@cbs4qc.com

Stephen Vermette
Department of Geography and Planning
Buffalo State College
Buffalo, NY 14222
E-mail: vermetsj@buffalostate.edu

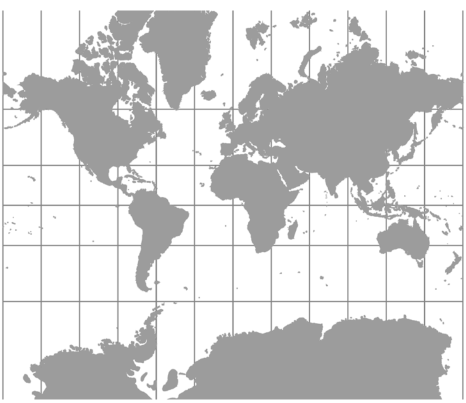
ABSTRACT

Climate indices provide a useful way to characterize climate. The objective of this study is to rank the past 37 winters (1970-1971 to 2006-2007) in Buffalo, New York using a 'Severe Winter Index' (SWI) that incorporates a number of winter-related elements. Five elements were chosen to reflect varying aspects of a winter season: snowfall amount, number of days with 12 inches or greater of snow on the ground, heating degree days (HDD), number of days with temperatures at or below 0°F, and percent cloudiness during daylight hours. Data were obtained from the Buffalo Forecast Office of the National Weather Service. The SWI normalized each element by calculating the percentile-ranking of each data point within the data set. Each element was given equal weighting. The 1983-1984 winter season was the most severe, followed by 1977-1978 and 1976-1977. The mildest was the 1990-1991 winter season. 'Severe' winter seasons tend to group in the dataset, occurring for no more than three consecutive years. The SWI exhibits a decreasing trend and greater variability in winter severity. While 'Severe' and 'Average' winters can be expected, there appears to be a growing tendency for 'Mild' winters.

Key Words: winter, Buffalo, New York, index, climate

INTRODUCTION

Buffalo, New York, and the surrounding area, have long been characterized as a region that experiences some of winter's worst ferocity. This characterization is reinforced by the lake effect snow bands that blow off of Lake Erie, and by the Blizzard of 1977, with its cold temperatures, high winds, and huge snow drifts (Bahr 1980, Rossi 1999). The Blizzard of 1977 was the first snowstorm to warrant a federal disaster area declaration. Like no other storm, that blizzard has entered the psyche of residents in the Buffalo area, whether or not they actually experienced it.



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All subsequent winters and winter storms are compared to 1976-1977 and that blizzard (*Buffalo News* 2002, New *York Times* 2002, *USA Today* 1997).

Winter severity can be measured by a number of factors other than severe blizzards, however, such as the number of days at or below 0°F temperatures and the number of cloudy days. The objective of this study is to create a Severe Winter Index (SWI) that incorporates a range of winter-related parameters into one easily interpreted value. Whether characterizing a fanciful climate based on a number of parameters, as with the Camelot Climate Index[1], or extremes and trends, as with the Climate Extreme Index (CEI) (Karl et al. 1996), climate indices provide a useful tool to combine numerous measures with the purpose of characterizing a climatic condition or to plot climatic trends.

The purpose of creating such an index extends beyond simply labeling winter severity. Future winter climate scenarios for the Great Lakes and Upstate New York suggest a changing winter climate of warming temperatures and increased precipitation (Kling et al. 2003), fewer heavy lake effect snow events, more frequent lake-effect rain events (Kunkel et al. 2002), decreased snowpack (Mortsch and Quinn 1996), and increased precipitation intensity and fewer cold waves (Easterling et al. 2000a). The SWI may be used to monitor overall winter trends in the context of a changing climate, and may be used as a tool to compare future winter conditions with those of the past.

METHODOLOGY

While the meteorological winter season is defined as the months of December through February, we chose to define the winter season as November through March. These months better reflect conditions in the Buffalo area, as defined by accumulated heating degree days (HDD) used by National Grid (a New York energy company).

We chose five winter-related elements to calculate the SWI: snowfall amount, number of days with twelve inches or more of snow on the ground, heating degree days (HDD), number of days with temperatures at or below 0°F, and percent cloudiness (during daylight hours) [2]. A number of potentially useful elements (e.g. wind chill and a count of individual lake-effect storms) were not used due to the lack of easily obtainable historical data.

While cold temperatures, snowfall amount, and number of days of substantial snow cover are obvious choices, HDD and percent cloudiness (during daylight hours) are less obvious ones. The heat-unit-approach, or HDD, is used as a substitute for daily temperatures as it is an additive value that best reflects differences between a warm versus cold winter. HDD is defined as the number of degrees that the daily mean temperature is below a threshold temperature of 65°F (temperature at which a furnace needs to be turned on). These differences are accumulated over a season and reported as HDDs. The greater the number of accumulated HDDs, the colder the winter season. The heat-unit-approach is used by utilities to calculate and predict electric energy and heating oil consumption (Quayle and Diaz, 1980). Percent cloudiness was chosen because of its impact on human health. Seasonal Affective Disorder (SAD), caused by a lack of sunshine, manifests itself through depression and general malaise (Lurie et al. 2006).

The SWI differs from the established Climate Extreme Index (CEI), since it focuses on the normal range of elements and is designed for a single location, whereas the CEI focuses solely on the severity of events and is used to calculate the percentage of the country influenced by extremes. The CEI also includes elements (e.g. severe drought) that do not pertain to winter severity, and excludes measures that do (e.g. snowfall). Modifications are possible to such indices, as seen in the case of the Canadian index (similar to the CEI) that includes elements important to high-latitude climates (Easterling et al. 2000b),

Our proposed SWI is modeled after the Water Quality Index (WQI) which was developed to compare river water quality from a site at different times and in various parts of the country. (Mitchell and Stapp 1996). The SWI is calculated from five weather-related elements, collected for 37 winter seasons from 1970-1971 to 2006-2007. We obtained data from the National Weather Service (NWS), reflecting official conditions as recorded by the Buffalo Forecast Office (located in Buffalo, NY). While the WQI normalizes each element using a rating curve and expert opinion, the SWI normalizes each element by calculating the percentile-ranking of each data point within the data set. Within each element, the highest score (99) represents the most severe occurrence (e.g. most snowfall). The percent-possible-sunshine data is inverted, such that a score of 99 represents the least amount of possible sunshine (greatest amount of clouds during daylight hours). The yearly score for each variable is given equal weighting (multiplied by 0.2) and totaled. For example, the 1984-1985 winter season SWI score is calculated as:

$$SWI = (66.6*0.2) + (91.6*0.2) + (44.4*0.2) + (41.6*0.2) + (86.1*0.2) = 66.1$$

where the first value in each parenthesis are percentiles calculated for each winter-related element (snowfall amount, number of days with twelve inches or more of snow on the ground, heating degree days (HDD), number of days with temperatures at or below 0°F, and percent of cloud cover during daylight hours. The resulting SWI score for each winter ranged from 0 to 99, with 0 being the least severe winter and 99 being the most severe. The SWI is reported as a single score, but the individual element scores are retained within the data set.

CLIMATE ELEMENTS: VALUES AND TRENDS

Snowfall

Data from each of the five parameters used in the SWI are presented below. The 37-year-average snowfall in Buffalo, NY is 97.3 inches (243.3 cm). The snowfall from 1976-1977 (including the Blizzard of 1977) shows the highest measured value of 199.4 inches (498.5 cm) (Fig. 1). While a linear trend over the 37-year period suggest no change in snowfall amounts, this fit is not significant ($p = 0.10$). A polynomial fit (significant at $p = 0.05$), shows a bimodal sinusoidal pattern with a decrease in snow amounts during the middle of the study period (mid-1980s to mid-1990s), with equal wave crest amplitudes at the beginning and end of that period.

Days with Snow Cover of 12 Inches or Greater

The mean number of days with a substantial snow cover (12 inches or greater) is 10. The periods from 1976-1979 and from 1983-1985 show the greatest number of days with a substantial snow cover, the highest number of days (67) occurring during the 1976-1977 season (Fig. 2). Nearly one-third of the years failed to accumulate a substantial snow cover. A polynomial fit (significant at $p = 0.05$) again exhibits a bimodal sinusoidal, but in this case the amplitude of the wave crest is greatest in the initial years of the study period, as influenced by the three heavy snowfalls of 1976-1977,1977-1978, and 1978-1979.

Heating Degree Days

During the study period, heating degree days (HDD) averaged 5087.4 degree days. The years 1976-1977, 1977-1978, and 1995-1996 stand out as experiencing the coldest overall winter seasons (Fig. 3). While there are dramatic year-to-year changes in HDD, two wave peaks are apparent in the polynomial fit shown (significant at $p = 0.05$). The sinusoidal pattern suggests a downward trend (or warming) over the study period.

Number of Days with Temperatures at or Below 0°F

The NWS routinely catalogs the number of days with temperatures at or below 0°F.

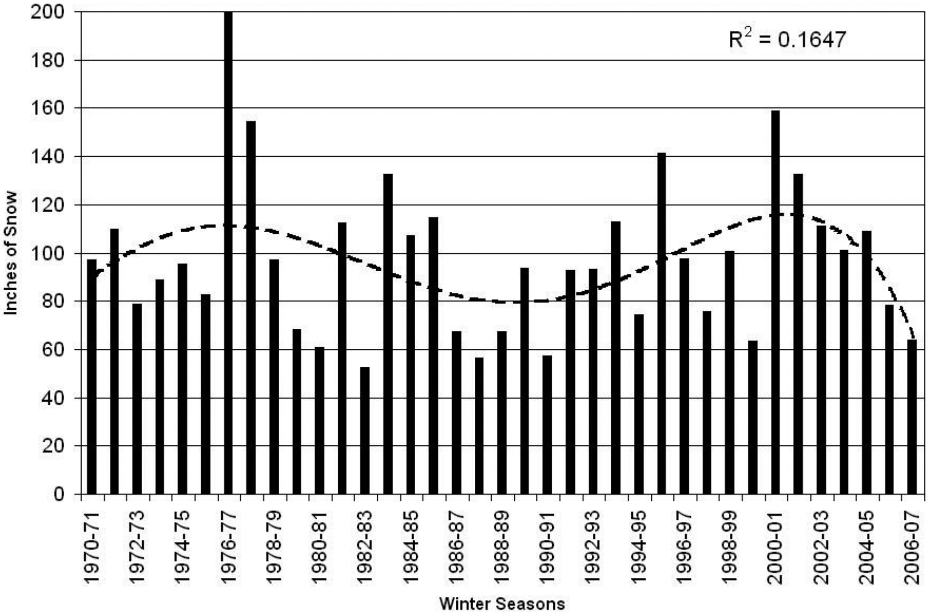

Figure 1. Winter snowfall totals.

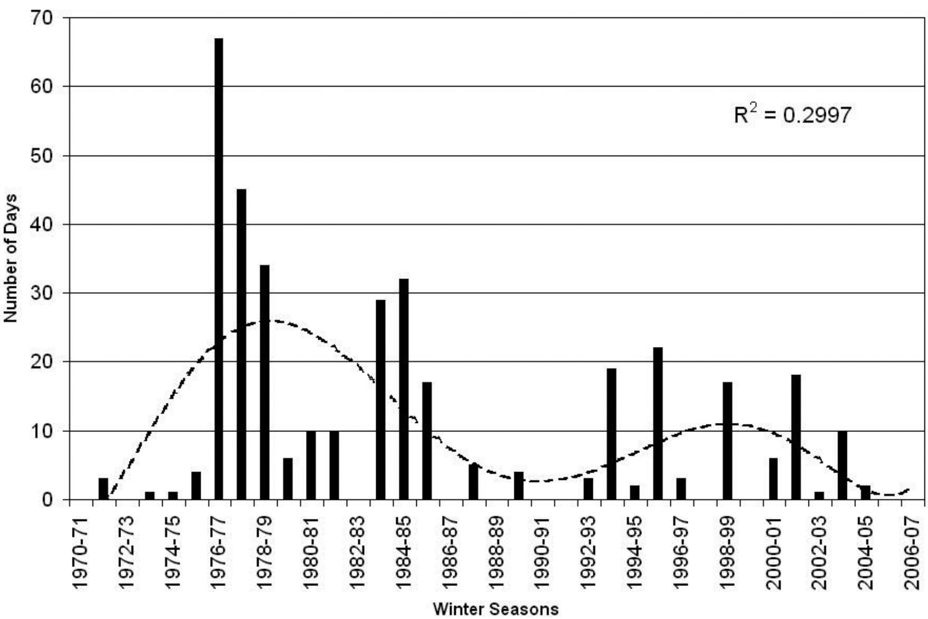

Figure 2. Number of days with snow cover 12 inches or greater.

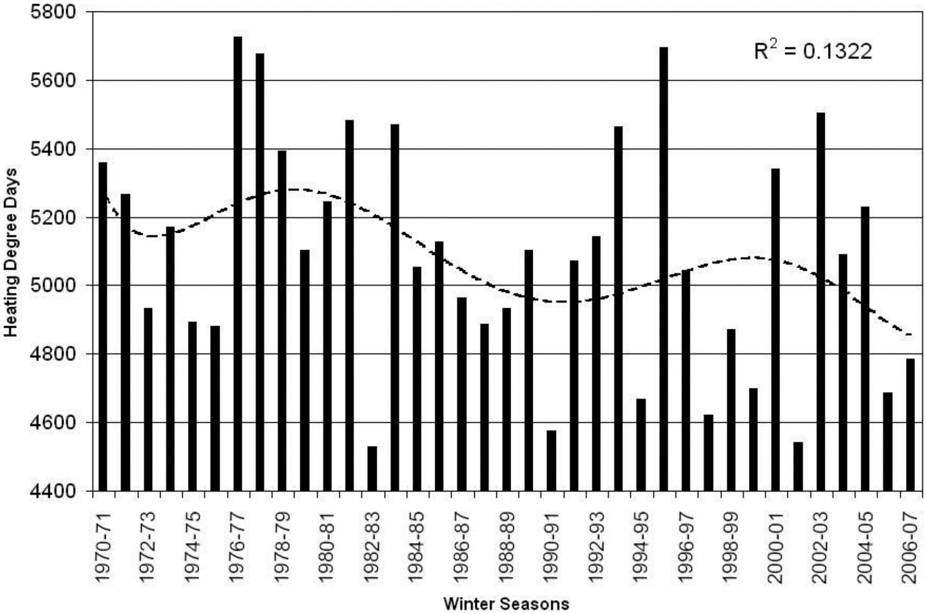

Figure 3. Seasonal heating degree days.

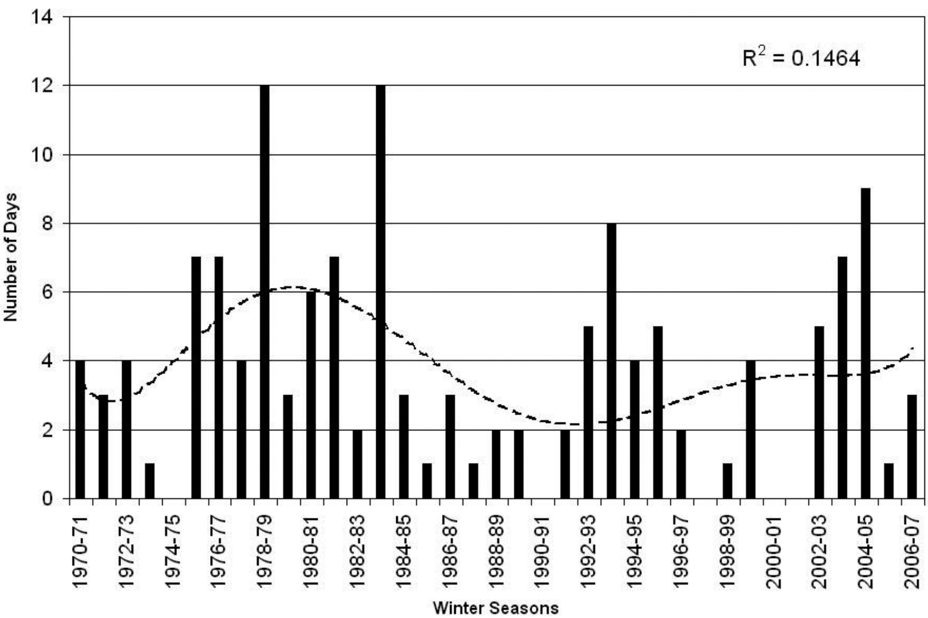

Figure 4. Number of days with temperatures at or below 0°F.

These values are indicative of extremely cold winter conditions, which have the greatest impact on human health (e.g. frostbite and heart attacks) and which greatly affects operation of machinery. The years 1978-1979 and 1983-1984 stand out as experiencing the greatest number of days with extreme cold temperatures (Fig. 4). The 37-year average for the number of days with temperatures at or below 0°F is 3.8. The polynomial fit (significant at p = 0.05) shows a well-defined wave peak in the late 1970s and early 1980s, but less defined undulations in later years.

Percent Cloudiness

The 37-year average for percent cloudiness (during daylight hours) averages 68% over the winter season, only 32% of possible sunshine. The winter season with the greatest percent of cloudiness was 1985-1986 (78%), while 1987-1988 experienced the least amount of cloudiness (55%) (Fig. 5). While there is limited year-to-year variability, the polynomial fit shows a slight decrease in cloudiness through the late 1980s to late 1990s.

SEVERE WINTER INDEX (SWI)

The SWI values graphed for Buffalo, NY (Fig. 6) highlight 1983-1984 as the most severe winter season in the 37-year study period, with the year 1977-1978 ranking second, just above the blizzard year of 1976-1977. The least-severe winter occurred in 1990-91. Based on SWI scores, each winter season can be grouped into three severity categories (based on natural breaks) with 13 seasons grouped into a 'Severe' category (SWI ≥ 60), 14 seasons into an 'Average' category (SWI 31 to 59), and 10 seasons into a 'Mild' category (SWI ≤ 30). It is interesting to note that the severe winters tend to be grouped, but this grouping does not extend for more than three consecutive years. Another apparent trend is that the first 16 winter seasons of the study period (prior to 1986-1987), with the exception of one season, are categorized as either 'Average' or 'Severe'. And nine of the ten 'Mild' winters have occurred since 1986-1987, with the mildest occurring in 1990-1991. The last two winters of this study (2005-2006 and 2006-2007) are also categorized as 'Mild'. The most severe and least severe winters, with their respective SWI scores, are presented in Table 1.

A weak polynomial fit of the SWI scores (significant at p = 0.05) shows a bimodal sinusoidal fit to the data, where scores from the mid-1970s to mid-1980s and early 2000's occur at the wave crests, although the second crest is of a lower amplitude than the first. The early 1970s and late 1980s to early 1990s occur at the wave troughs. The polynomial fit suggests that we are entering a period of mild to average winters.

As noted in the methodology, the individual weather parameter scores can be graphically depicted along with the overall

Table 1. Most and Least Severe Winters

Most Severe		Least Severe	
Year	SWI Score	SWI Score	Year
1983-1984	91	6	1990-1991
1977-1978 & 1976-1977	83	17	1982-1983 & 1988-1989
1981-1982 & 1995-1996	76	21	1987-1988
1978-1979	71	22	1986-1987 & 1997-1998
1993-1994 & 2002-2003	68	23	1999-2000

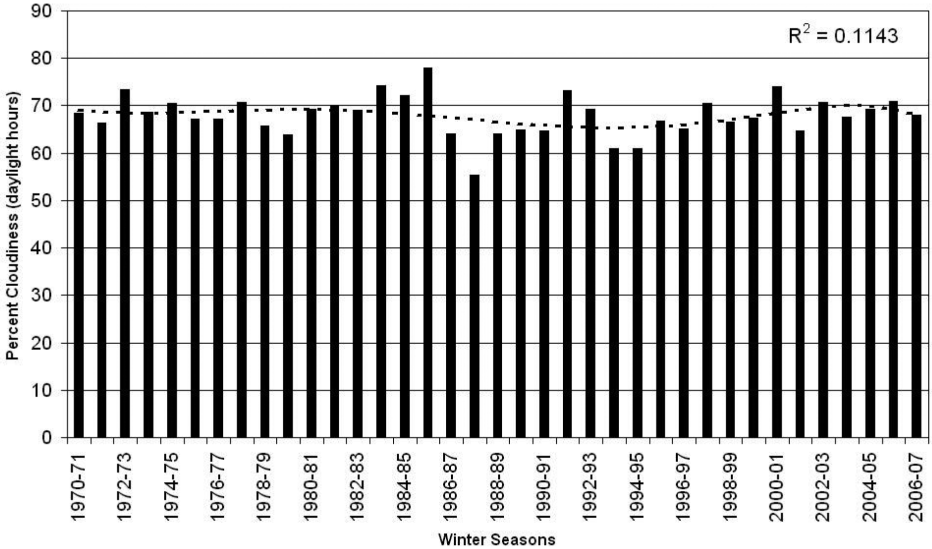

Figure 5. Percent cloudiness.

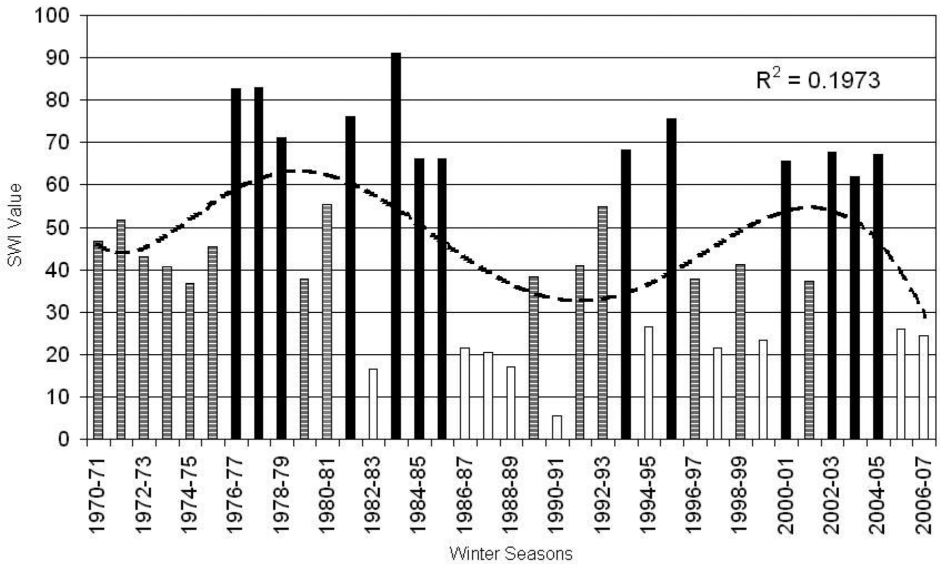

Figure 6. Severe Winter Index (SWI) scores (severe winters shown as black bars, average winters shown as stippled grey bars, and mild winters shown as white bars).

SWI score. Figure 7 shows the SWI scores delineated by each of the five weather-related parameters (the highest value for each parameter is 20, since the original scores were weighted by a 0.2 multiplication – e.g. 100 * 0.2 = 20). In terms of the SWI, the severe winter of 1983-84 surpassed that of 1976-77 (Blizzard of 1977) because it experienced a greater amount of cloudiness during daylight hours. That year also scored high for the other weather-related parameters. The winter season of 1976-77 scored highest for HDD, winter snowfall, and number of days with a snow cover of 12 inches or greater. The 1990-91 season was the mildest winter of the 36-year study, as it scored low for all five weather-related parameters, especially the number of days with temperatures below 0°F and the number of days with a snow cover of 12 inches or greater.

CONCLUSION

The SWI, as developed for Buffalo, NY, ranks the winter season of 1983-1984 as the most severe winter of the past 37 years. The winter season associated with the Blizzard of 1977 (1976-1977) is ranked third, just behind the year (1977-1978). 'Severe' seasons tend to group in the dataset, occurring for no more than three consecutive years. However, over the ten-year period from 1976-1977 to 1985-1986, seven of the winter seasons were categorized as 'Severe'. Another apparent trend is that the first 16 winter seasons of the study period (prior to 1986-1987), with the exception of one season, are categorized as either 'Average' or 'Severe'. And nine of the ten 'Mild' winters occurred since 1986-1987, with the mildest occurring in 1990-1991. Over the 37-year record (1970-1971 to 2006-2007), the SWI exhibits a decreasing trend and greater variability in winter severity. While 'Severe' and 'Average' winters can be expected, there appears to be a growing tendency for 'Mild' winters.

The SWI provides a tool to rank and compare the severity of past winters. Used as a pseudo-climate 'normal' (normals are traditionally 30 years), the SWI presented

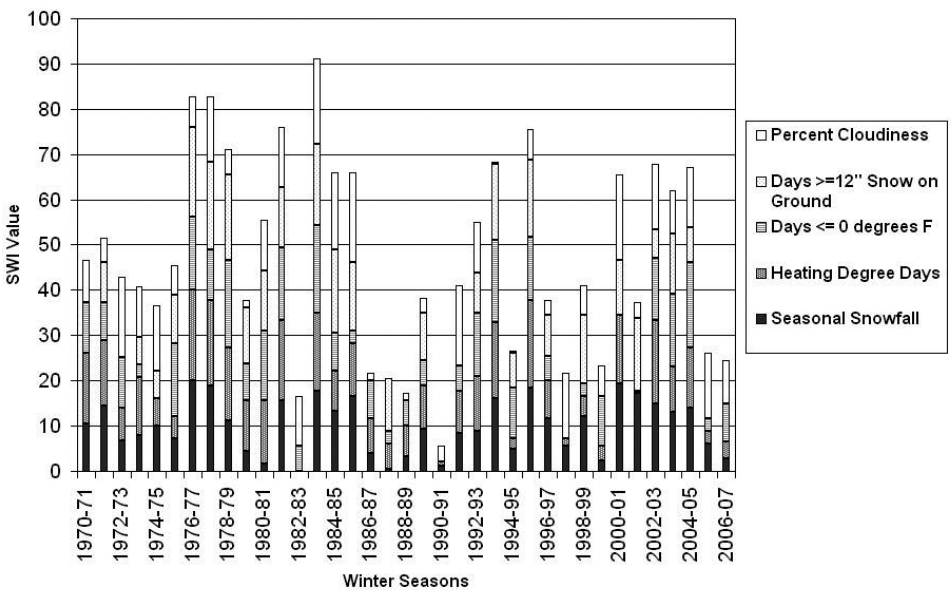

Figure 7. Severe Winter Index (SWI) delineated by contributing elements.

here could be used to compare the severity of future Buffalo, New York winters with that of past winters, and to evaluate changing winter severity. It is also possible to re-calculate the SWI incorporating future data (a larger data set). Use of the SWI is not limited in application to, or in comparison with, Buffalo, New York, but may be calculated for any region using suitable winter parameters and weighting factors for that region.

NOTES

1 A discussion of this index is available at [http://ggweather.com/Camelot.htm].

2 The temperature thresholds as reported by the National Weather Service and National Grid are reported on the Fahrenheit scale. The imperial scale was maintained for snow amounts to maintain consistency.

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