17A.3 AN ACCUMULATED WINTER SEASON SEVERITY INDEX (AWSSI)

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1. INTRODUCTION

How bad was this winter? Was it the worst on record? What other winters had a similar severity? Questions such as these are commonly asked of meteorologists and climatologists, but to date, the current literature lacks a means to quantify the severity of a winter season to allow for objective comparison.

Previous research has provided a means to quantify the intensity of hurricanes (Saffir Simpson scale; Simpson 1974), tornadoes (Fujita and Enhanced Fujita scales; Fujita 1971, Edwards et al. 2013), droughts (Drought Monitor; Svoboda et al. 2002), and winter storms (Northeast Snowfall Impact Scale [NESIS], Kocin and Uccellini 2004). The use of scaling allows comparison of event characteristics, as well as impacts that are either explicitly included as an index factor or else compared against the background of the scales that are more meteorological or measurable in nature. No such scaling has been established for winter season severity. The Accumulated Winter Season Severity Index (AWSSI; pronounced to rhyme with *bossy*) is being created to fill that gap.

The intent of AWSSI is to use widely available daily meteorological parameters to quantify the severity of a winter season, cumulative from the onset of winter as defined in the study to the termination. AWSSI will be calculated with a temperature component and a precipitation/snowfall component, using methodology that allows an end-of-season total AWSSI to represent the severity of a season but also allows a daily running calculation through a winter to track its severity. While the temperature component will use maximum and minimum temperature data, the precipitation/snowfall component will be a little more complex. Snowfall and snow depth data are not available through the entire period of record at most stations, and even where available, the quality can be suspect. Precipitation data are generally more consistent through the period of record of most stations. Thus, the AWSSI will be created in two forms: one that uses snow data, and one that uses precipitation data, with snow information estimated based on precipitation amounts and temperatures, that has been calibrated to align with the snow-based calculation.

Once calculated, AWSSI can provide a wealth of information for investigating the historical context of a winter season, as well as site-to-site comparisons. Within the period of record of one station, quantities such as averages, percentiles, and extremes can be calculated to establish a baseline to which individual seasons can be compared. AWSSI can be compared among stations to assess the severity from one station to another. The station-based AWSSI also can be normalized by the mean at that station, allowing a comparison of normalized AWSSI to assess the relative severity at those stations.

AWSSI information can be used as a baseline to which innumerable impact-based data can be examined. The range of possibilities includes comparisons to car accidents or other transportation factors, home heating costs or other energy expenditures, number of school days or other affects on education, and number of mental or physical health treatments, just to name a few examples. Users of AWSSI information can pull apart the index into its temperature and snowfall/precipitation components, as well as examining the total AWSSI, in any number of ways that reach their goals of assessing the impacts of winter severity on their fields of interest.

2. DATA AND METHODOLOGY

Because one of the goals of the AWSSI is to be operationally useful, the AWSSI was created to use widely available meteorological data, with simple computations that can run in a spreadsheet environment that is available in National Weather Service (NWS) Weather Forecast Offices (WFOs).

2.1 Data

Daily temperature, precipitation, snowfall, and snow

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depth data were taken from the Applied Climate Information System (ACIS) database (Hubbard et al. 2004). Threaded data were used to extend the duration of records at historical sites, noting that the slight differences between widely available ACIS data and homogenized station data available from the National Climatic Data Center (NCDC) were likely to be too small to significantly affect the AWSSI threshold-based calculation. Using ACIS data gives NWS WFOs the ability to replicate the study and produce AWSSI results for any sites with daily data available in ACIS.

Sites included in the study to this point include Omaha, Nebraska (OMA), Des Moines, Iowa (DSM), Minneapolis/St. Paul, Minnesota (MSP), St. Louis, Missouri (STL), and Chicago-Midway, Illinois (MDW). Years with missing snow data were omitted from the AWSSI calculation, though the temperature contribution was allowed to accumulate through the season for investigation of temperature-only index contribution.

2.2 Calculations

AWSSI was designed as a point accumulation system, with points assigned based on reaching various thresholds. Table 1 lists the points assigned for maximum and minimum temperatures, as well as snowfall and snow depth. Point thresholds were created to give greater weight to extreme or rare occurrences, which would like have a higher impact, though the thresholds are admittedly somewhat arbitrary. For each calendar day, points are assigned based on the thresholds reached for maximum and minimum temperatures, snowfall, and snow depth. The points assigned in each category are summed for the calendar day into the categories of temperature, snowfall, and total AWSSI. For example, a day with a maximum temperature of 24 (2 points), a minimum temperature of 11 degrees (4 points), new snowfall of 2.5 inches (3 points), and snow depth of 5 inches (4 points) would have a temperature score of 6 points, a snowfall score of 7 points, and total AWSSI of 13 points for the day. The daily point totals are accumulated through the winter season, created a cumulative point total through the season. An example of one season's accumulation is shown in Figure 1, with the 2009-10 AWSSI for OMA.

AWSSI is triggered to start accumulating on the date when one of three criteria is met: (1) measurable snowfall occurs, (2) daily maximum temperature is lower than 32° F, or (3) on December 1. The winter season ends, and AWSSI accumulation stops, after the latest of four criteria occurs: (1) the last measurable snowfall occurs, (2) snow depth remains below 1 inch, (3) daily maximum temperature does not fall below 32 °F, and (4) on March 1. The date thresholds were set to capture a traditional meteorological winter season of December through February, while the meteorological criteria allow the accumulation to begin and end when wintry conditions occur, capturing the winter season for sites with longer seasons of winter weather impacts.

Because of the flexible start and stop dates to accumulation, AWSSI will be useful in cold and mild climates alike.

There are a number of limitations of AWSSI. The index does not account for wind in its calculation, which can cause impacts due to blowing and drifting snow as well as wind chills. Freezing rain also is not included, as total freezing rain accumulation climatologies are not available and freezing rain totals are included in the daily liquid precipitation totals. The impact of high-impact mixed precipitation, such as sleet accumulation, may be underestimated, as the accumulation of frozen precipitation would be grouped with snowfall in the daily climatological data.

3. RESULTS AND DISCUSSION

AWSSI was calculated from the winters of 1950-51 to 2011-12 at OMA, DSM, MSP, STL, and MDW (Figure 2). The time series of peak seasonal AWSSI allows investigation of year-to-year variability, as well as assessment of the severity of winters among the sites. For example, AWSSI at MSP is consistently higher than at STL, with the anticipated conclusion that winters are more severe at MSP than at STL. Four of the sites (OMA, DSM, MSP, and MDW) experienced relatively severe winters in 1961-62 and 1978-79, as visible in the relative peaks in AWSSI for those years. All five sites experienced relatively mild winters in 2005-06 and 2011-12.

Another means of analysis is to create a normalized AWSSI, with total annual AWSSI values normalized by the period-of-record average. Normalized AWSSI (Figure 3) allows investigation of the relative severity of a winter for a given point to its average severity. The winter of 1977-78 at STL stands out as a strong departure toward severity from the site mean, and 1978-79 stands out at the other four sites (OMA, DSM, MSP, and MDW) as exceptionally severe. The winter of 1961-62 appears severe at all sites. Similarly, 2000-06 and 2011-12 were distinctly mild at all sites. With normalized AWSSI data, the standardized anomaly of AWSSI also can be calculated for each seasonal total, to give a sense of the departure of each winter from the mean in terms of standard deviations (as in Hart and Grumm 2001).

Focusing on one site allows deeper analysis of the climatology of winter severity. Figure 4 shows the average AWSSI for OMA from 1950-51 to 2011-12, as well as the highest and lowest five AWSSI seasonal totals. The distributions through the winter season of AWSSI accumulation can be compared among years. The two highest AWSSI totals at OMA were in 1959-60 (1071) and 2009-10 (1058). While the final seasonal totals were close in number and were significant departures from the average of 614 (normalized AWSSI of 1.74 and 1.72 and standardized anomalies of 2.5 and 2.4, respectively), the distributions were distinctly different. AWSSI ramped up strongly from late

December through January in 2009-10, while the higher accumulations came later in the season in 1959-60, with the most significant increases from mid-January through early March. Among the mild winters, 1986-87 was on track to be tied for the second mildest winter until a bump in late March, which resulted from a 9.7 inch daily snowfall on 28 March and 0.8 inches on 29 March, followed by two days with snow depth of 11 inches before the snow depth quickly ablated by 3 April. The winter ended as the fourth mildest on record instead.

4. CONCLUSIONS AND FUTURE WORK

AWSSI is flexible enough to use to assess winter severity across the country, from mild to severe winter climates. The running total of AWSSI through a winter season allows investigation of the character of the winter, especially when looking at both the temperature and snowfall contributions and in comparison to the period-of-record average AWSSI. The seasonal totals, in turn, can be used to rank winter season severity at a site and compare severity site to site. By using normalized AWSSI and the standardized anomaly of AWSSI, the relative severity of a winter compared to average can be assessed both for placing a winter in context at one station and for comparing relative winter severity at multiple stations.

The snow-based AWSSI calculations are well underway and will be applied to several more stations across the United States. The precipitation-based AWSSI calculations are still under development. Some previous work (Fisk 2008) has investigated estimating snowfall based on surface temperature and precipitation amounts. The methodology developed by Fisk (2008) was applied to several sites, with mixed results. In particular, snow amounts during events with temperatures near freezing were overestimated, likely due to the presence of rain and mixed precipitation during those events. Arguably, some of the mixed precipitation events would have a high impact that is underestimated by snowfall measurement, due to icing in particular, and it may be that the overestimate of AWSSI relative to snow-based calculation actually provides a more realistic measure of severity than looking at only snowfall. The authors will continue to investigate methodologies to convert temperature and precipitation amounts to snow estimates. Additionally, the authors continue to investigate a means to estimate the snow depth based on estimated snow fall, compaction, and melting. Overall, it is not expected that the snowfall estimates will match observations perfectly, as erroneous snow observations also exist in the records (such as historical use of a 10-to-1 snow-to-liquid ratio, incorrect estimation due to blowing and drifting snow, and other human observer errors). The authors do intend, though, to create precipitation severity measurements that realistically reflect the contribution of snow to the AWSSI.

Once a precipitation-based AWSSI is created, it will be possible to investigate the severity of winter seasons prior to snowfall records. Historically severe winters such as 1880-81 (Mayes 2011) and 1887-88 could be compared to winters in the post-1950 years to determine a longer climatology of winter severity and to further investigate the range of winter severity that has occurred historically at a given site.

One potential application of the AWSSI records is to analyze winter severity in the context of teleconnection patterns such as the El Niño/Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO). The relative frequency of severe winters, including total AWSSI as well as temperature and snowfall accumulations, can be analyzed as a conditional climatology by ENSO phase or NAO strength. Comparisons could be made to the length of winter accumulation, as well as start and end dates individually.

The AWSSI totals provide beneficial information for a number of sector-based applications. Transportation officials could correlate AWSSI to traffic accidents or road cleaning expenses. Health officials may find relationships between AWSSI and mental health admissions or prescriptions or weather-related injuries and illnesses. Relationships may exist between AWSSI and energy expenses (ranging from homeowner to regional scales), vacation bookings from colder cities to warmer climates, recreation expenses, or homebuilding.

AWSSI may have predictive applications, as well. If a sector is aware of sensitivity to AWSSI exceeding a certain threshold for a given application, those in that sector could monitor the rate of AWSSI accumulation through the winter. When the threshold of importance is nearing, analysis could determine the frequency that the threshold is exceeded given the to-date accumulation, allowing assessment of the risk of hitting the critical threshold as determined in that application.

Much work lies ahead to refine and test AWSSI across more sites, with more applications, and with precipitation data replacing snowfall and snow depth data. Early indications are that the index will be able to separate mild winters from severe ones, allowing analysis of departure from average and impacts based on the total AWSSI.

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AWSSI Point Thresholds				
	Temperature (°F)		Snow (in)	
Points	**Max**	**Min**	**Fall**	**Depth**
1	25 to 32	25 to 32	0.1 to 0.9	1
2	20 to 24	20 to 24	1.0 to 1.9	2
3	15 to 19	15 to 19	2.0 to 2.9	3
4	10 to 14	10 to 14	3.0 to 3.9	4 to 5
5	5 to 9	5 to 9	-	6 to 8
6	0 to 4	0 to 4	4.0 to 4.9	9 to 11
7	-1 to -5	-1 to -5	5.0 to 5.9	12 to 14
8	-6 to -10	-6 to -10	-	15 to 17
9	-11 to -15	-11 to -15	6.0 to 6.9	18 to 23
10	-16 to -20	-16 to -20	7.0 to 7.9	24 to 35
11	-	-21 to -25	-	-
12	-	-	8.0 to 8.9	-
13	-	-	9.0 to 9.9	-
14	-	-	10.0 to 11.9	-
15	<-20	-26 to -35	-	36+
18	-	-	12.0 to 14.9	-
20	-	<-35	-	-
22	-	-	15.0 to 17.9	-
26	-	-	18.0 to 23.9	-
36	-	-	24.0 to 29.9	-
45	-		>=30.0	-

Table 1. Points accumulated in daily AWSSI totals, based on thresholds of daily temperature, snowfall, and snow depth data. More rare/extreme events would accumulate higher points for the day. Daily points are added to a running winter season total to produce a cumulative AWSSI.

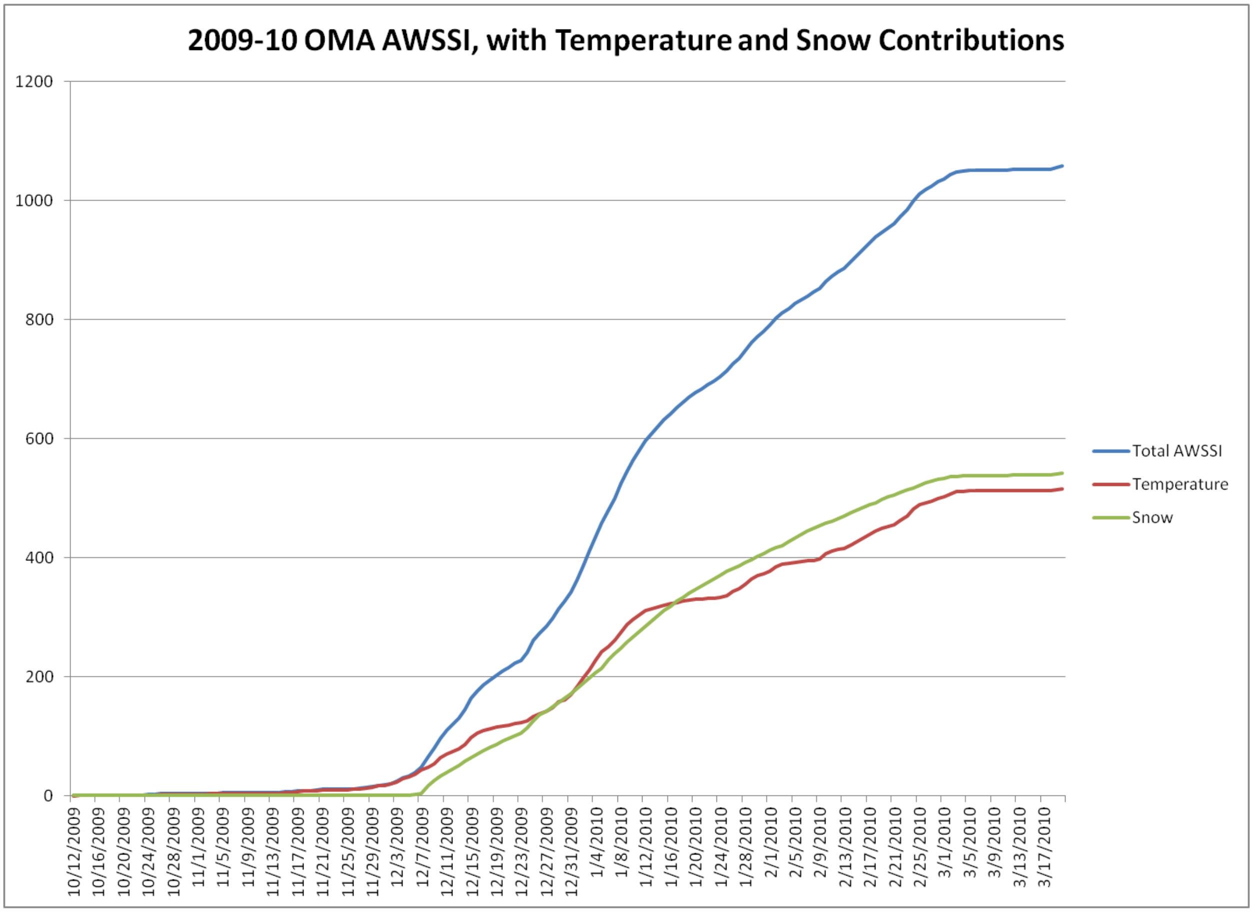

Figure 1. Running total of daily AWSSI contributions through the winter of 2009-10 at OMA. The temperature and snow contributions are shown separate from the total AWSSI accumulation.

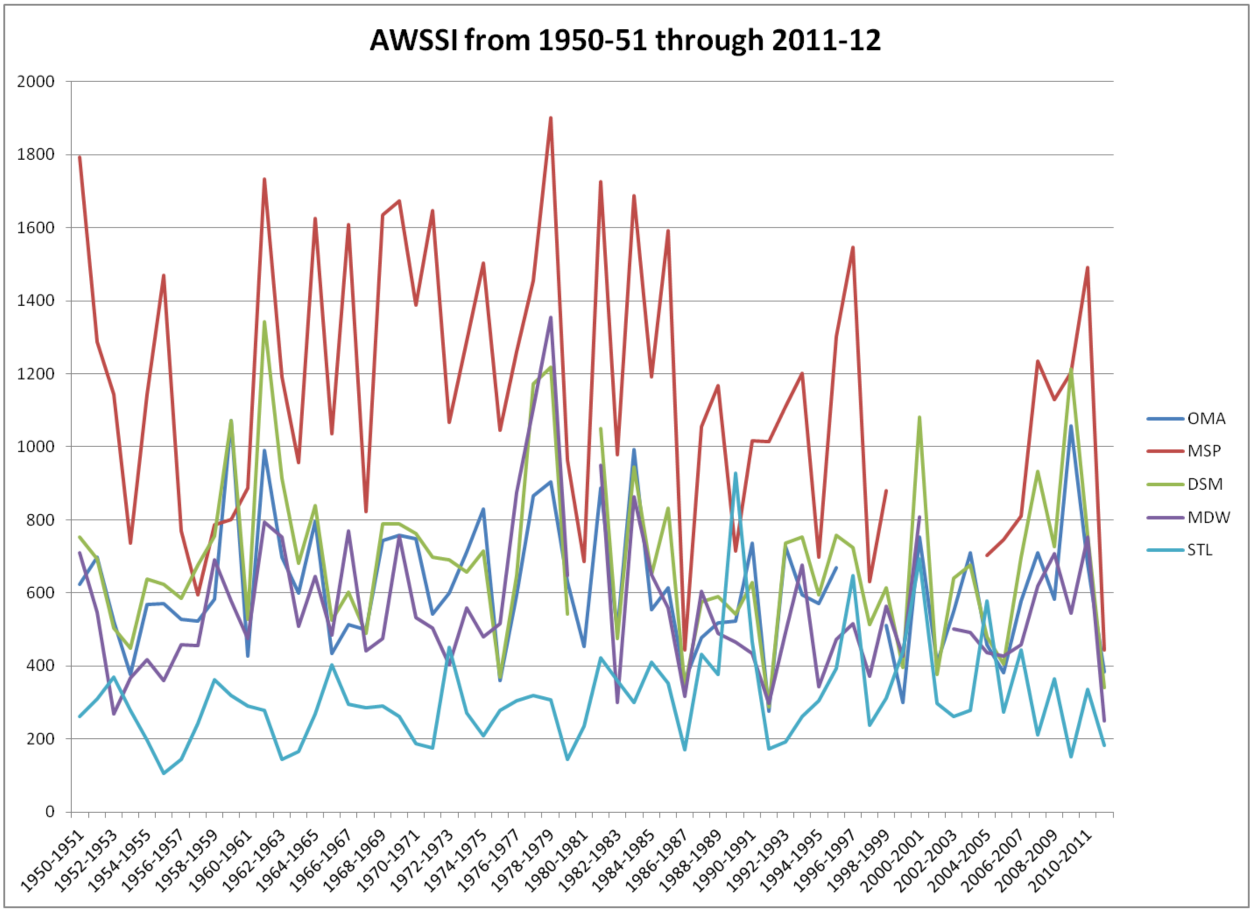

Figure 2. Seasonal total AWSSI for Omaha (OMA), Minneapolis/St. Paul (MSP), Des Moines (DSM), Chicago/Midway (MDW), and St. Louis (STL) from the winter of 1950-51 through 2011-12.

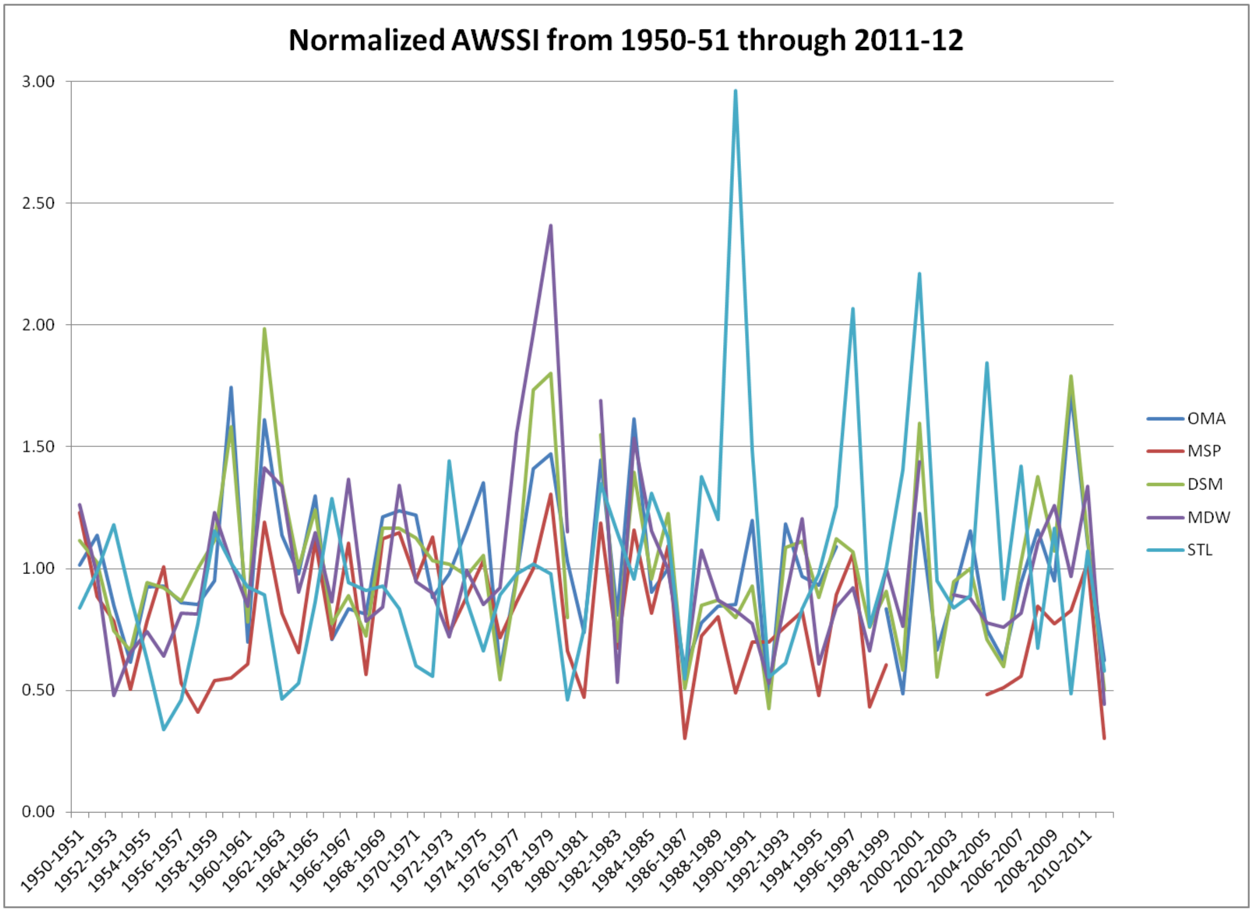

Figure 3. Seasonal total AWSSI, normalized by the mean AWSSI for each site, at Omaha (OMA), Minneapolis/St. Paul (MSP), Des Moines (DSM), Chicago/Midway (MDW), and St. Louis (STL) from the winter of 1950-51 through 2011-12.

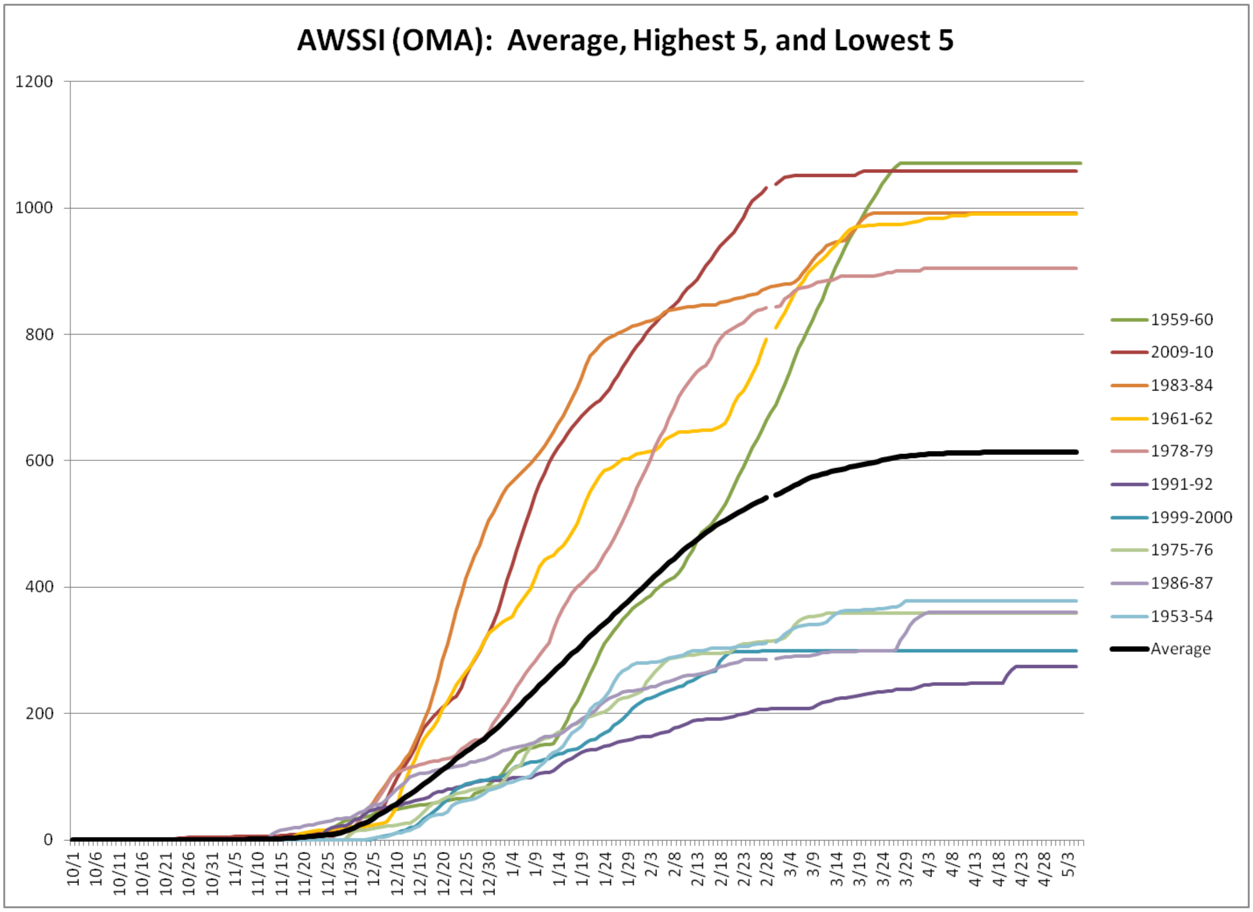

Figure 4. Average AWSSI at OMA for the 1950-51 through 2011-12 period of record, with the five highest and five lowest AWSSI totals on record.