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**GREAT LAKES MONTHLY AND SEASONAL ACCUMULATIONS OF FREEZING
DEGREE-DAYS -- WINTERS 1898-2002**

Raymond A. Assel

NOAA, Great Lakes Environmental Research Laboratory, Ann Arbor, MI 48105

Great Lakes Environmental Research Laboratory
Ann Arbor, Michigan

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Donald Evans
Secretary

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Conrad C. Lautenbacher, Jr.
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Great Lakes Monthly and Seasonal Accumulations of Freezing Degree-Days Winters 1898-2002

Raymond A. Assel

ABSTRACT. This is the third in a series of reports on Great Lakes freezing degree-days (FDDs). The first and second reports included daily FDDs and seasonal maximum FDDs at individual stations for winters 1898-1977 and 1978-1983, respectively. This report updates the daily time series of FDDs for the winter seasons from 1984 through 2002. Results are presented within the context of a 105-winter record of monthly and seasonal FDDs at 18 stations around the shores of the Great Lake. Tabulations, graphics, statistics (average, standard deviation, maximum, minimum, ranked order), and winter severity classes are presented for 105-winter monthly and seasonal FDDs for beginning of month (BOM) dates at each station. A few examples of applications of these data are discussed briefly. Electronic files of the daily FDDs (1984-2002) and monthly and seasonal accumulation on BOM dates (1989-2002) supplement the FDD tabulations.

INTRODUCTION

Freezing degree-days (FDDs) are used to define winter severity and trends in winter severity (Assel 1980b), develop empirical models of ice thickness (Assel 1976, Hinkel 1983) and ice cover (Richards 1964, Rogers 1976, Shen and Yapa 1983, Assel 1990) and assess the severity of anomalous winters (Assel et al. 1996, Assel et al. 2000).

This is the third in a series of reports providing climatological information on freezing degree-days (FDDs). The first report (Assel 1980a) provided a detail daily summary of FDDs, and air temperatures at 25 stations along the perimeter of the Great Lakes for an 80-winter period, 1898-1977. That data set was subsequently updated to include six additional winters (Assel 1986). The period of the update 1978-1983 was remarkable in that it contained some of the most severe and some of the mildest winters over the 86-winters (1898-1983). These data are archived at the NOAA National Snow and Ice Data Center (NSIDC) in Boulder, Colorado and air temperature records used to derive these data are available over the Internet at: <http://nsidc.org/data/g00801.html>.

In this report we provide monthly accumulations and seasonal accumulations of FDDs on Beginning of Month Dates (BOM) for a 105-winter period, 1898-2002, and daily FDD accumulations for the period of the update (1984-2002) at 18 stations around the United States shores of the Great Lakes (Fig. 1). The objective is to expedite the access of these data for operational and research applications. Monthly and seasonal FDD accumulations on BOM dates were requested by the Navy/NOAA National Ice Center (NIC) for operational applications. These data are used along with a 30-winter (1973-2002) ice cover data set and climatology (Assel 2003), by the NIC and the Canadian Ice Service in making operational Great Lakes ice chart products. Basic data, methods used in the calculation of: daily, monthly, and seasonal accumulation of FDDs on BOM dates is presented and discussed. Statistics on seasonal accumulations on BOM FDD and Monthly FDD accumulations are presented and a FDD index is used to classify winter severity over the 105-winters at each of the 18 stations. A regional average of seasonal maximum FDD accumulations is used to examine trends in winter severity over the 105 winters.

DATA

Air temperature and daily freezing degree-day data for 12 of the 18 sites, (Table 1), were obtained from the National Weather Service Forecast Office in Cleveland, Ohio. Air temperature data for the other stations used in this report were obtained from the NOAA National Climate Data Center in Asheville, North Carolina. The data for this update (winters 1984 through 2002) contains some missing data. A missing data code (-999.) was used in the tabular summaries given below to indicate missing data.

METHODS

Daily maximum and minimum air temperatures at the stations shown in Table 1 were used to calculate mean daily air temperature. The difference between the mean daily air temperature and the freezing point of fresh water (32°F) is used to define the number of “freezing degree-days” accumulated for that day. If the mean daily air temperature is above the freezing point then the FDDs are negative. If the mean daily air temperature is below the freezing point then FDDs for that date are positive. Freezing-degree days are summed (accumulated) for each day from October 1 to the following May 31. If the cumulative sum becomes negative on a given date, due to a series of days with above freezing air temperatures, the sum is set to zero and a new sum is started the following day. This is the same method used in previous reports (Assel 1980a, Assel 1986). Annual maximum FDDs are defined as the maximum value of the daily accumulations of FDDs over a given winter season at a site. The annual maximum FDDs are used as an index of the severity of the entire winter.

RESULTS

Seasonal FDDs at Beginning of Month Dates. The beginning of the month (BOM) accumulated FDDs is a measure of the winter severity up to that month. The BOM FDDs are given for the months of November, December, January, February, March, April, and May. The FDDs for November and December are for the previous year as indicated in Tables 2, e.g., winter 1897-1898 is November and December 1897 and January, February, March, April, and May 1898. Table 2 summarizes the BOM FDDs by station with a set of summary statistics [maximum, minimum, standard deviation, and average] at the end of each station. By comparing the long-term average BOM FDD with that of any year in the listing one can obtain a measure of the severity of the winter season up to that month relative to the mean value.

Monthly FDDs. Monthly FDDs for the months of November, December, January, February, March, and April are calculated by taking the difference between the accumulated FDDs from the last day of the previous month and the last day of the month in question. Monthly FDDs for October is the FDD accumulation on October 31. Monthly FDDs are not calculated for May because April FDDs are negative virtually every year. Results, summarized in Table 3 by station, follow the same convention as Table 2, i.e., for winter 1897-1898 October, November, and December refer to the year 1897 and January, February, March, and April, refer to the year 1898. Statistics are summarized at the bottom of each station’s listing.

DISCUSSION

BOM Winter Severity. The seasonal BOM FDDs given in Table 2 are ranked from highest to lowest for the 105 winters in Table 4. The years given in Table 4 refer to January of that winter season, thus to obtain the calendar year associated with the November and December listings you must subtract one from the year listed. This table is useful for climatic comparisons with future winters and or projections of impact of global warming on Great Lakes winter severity. A winter severity index (Table 5) defined in Assel (1986) for annual maximum FDD accumulations based on the cumulative frequency distribution (cdf) function is applied here to the seasonal BOM FDD accumulations (Table 4) to classify winter severity as Severe, Above Normal severity, Normal severity, Below Normal severity and Mild. The upper bound of winter severity index class limits in Table 5 for the Above Normal, Normal, Below Normal and Mild winter severity classes are summarized at the bottom of each station (Table 4.1 through Table 4.18). For example for Duluth, Minnesota for the month of February, if seasonal accumulation of FDD for February 1 (BOM February) are less than or equal to 815 FDD, that year’s FDD accumulation through February 1 is classified as Mild, if it is greater than 815 but less than or equal to 1143, it is classified as Below Normal, if it is greater than 1143 but less than or equal to 1705, it is classified as Normal, if it is greater than 1143 but less than or equal to 1928, it is classified as Above Normal, and if it is greater than 1928 it is classified as Severe.

The results given in Table 4 are summarized graphically in Figure 2 through Figure 19 (for the months of December through April). These figures show the cdf of the data, that is the percent of the 105 winter BOM FDDs (Table

4), above a given FDD threshold value. These figures make it easier to compare differences and similarities in the cfd of BOM FDD for a given station and among different stations.

Comparing all the BOM stations in Fig. 4, it can be seen that the cfd curves for December, January, February, and March have the greatest difference between them. These are the months that FDDs are accumulating most rapidly. The curves for March and April have much less difference between them because the seasonal accumulation of FDDs is approaching its annual maximum value these months. The difference in BOM FDDs at Duluth for 1994 (Fig. 20) illustrate this, differences between: December and January (478), January and February (1078), February and March (682), and March and April (81).

The cfd BOM curves for February, March, and April are grouped closely together for Chicago (Fig. 8), Toledo (Fig. 14), Cleveland (Fig. 15), and Erie (Fig. 16). These stations are all located along the southern boundary of the Great Lakes (Fig. 1), three of the four sites are located along the shores of Lake Erie. The seasonal maximum FDD usually occurs in February or in early March at these sites due to their extreme southern location. Thus, BOM FDDs are more similar for these months than they are for January and December. A graph of the cumulative FDDs for Toledo, Ohio for winter 1994 (Fig. 21) illustrates this point, BOM FDDs for: February (644), March (870), and April (691) are near the annual maximum and much greater than they are for December (9), and January (161).

Monthly Winter Severity. The monthly FDDs given for each station in Tables 3 are ranked from highest to lowest for the 105 winters in Table 6.1 through Table 6.18. The years given in Table 6 refer to January of that winter season, thus to obtain the calendar year associated with the October, November, and December listings you must subtract one from the year listed. Table 6 is summarized graphically in Figure 22 through Figure 39 for the months November through April. The upper bound of winter severity class limits in Table 6 are summarized at the bottom of each station's listing. Monthly FDDs with a rank between 1 and 5 are classified as severe winters, between 6 and 21 are classified as above-normal severity winters, between 22 and 84 are classified as normal severity winters, between 85 and 100 are classified as below-normal severity winters, and between 101 and 105 as mild winters. Thus it is possible to identify for each of these months the severity of that winter (classes of severity in Table 5) relative to the 105-winter period of record. For example winter 1984 for Duluth, Minnesota for the month of January has a rank of 43 (Table 6.1) so that January 1984 is classified as having normal winter severity. The 1984 monthly FDDs for March at Duluth has a rank of 13, so that March 1984 monthly FDD accumulation is classified as above normal winter severity at Duluth. Similar analysis can be made for any other station or month to place it in historical perspective.

November is the first month that significant FDD accumulate. The amount of monthly FDDs in November increases as one goes north and along western lakeshores relative to eastern lake-shores due to the moderating effects of the lakes. The monthly total FDDs in November is never negative because the previous month (October) always has fewer FDDs than November so that the minimum FDD accumulation for November is zero.

The months of January and February are usually the coldest months of the year and for this reason the cfd of monthly FDD accumulations for these months are similar in value at most sites and much larger than the December's FDDs. January cfd is the largest at 11 of the 18 sites (Duluth, Sault Ste. Marie, Houghton, Marquette, Green Bay, Milwaukee, Chicago, Port Huron, Detroit, Toledo, and Cleveland). Of the seven remaining sites the cfd for February monthly FDD accumulation is virtually the same as January's. Six of the seven sites are on windward (eastern or southern) lake shores (Traverse City, Muskegon, Buffalo, Erie, Rochester, and Oswego) so that air masses from the north and west are warmed by the open waters of the Great Lakes as they approach these sites, and all but one of these sites (Traverse City) are located south of 43.5 °N. The January and February monthly FDD accumulations at the seventh site, Alpena, may be moderated by easterly winds from the open waters areas of Lake Huron in January and February.

Another pattern is the similarity in the cfd of December and February FDDs for stations along the west side of Lakes Superior (Duluth), Michigan (Green Bay, Milwaukee, Chicago), and Erie (Toledo and to a lesser degree

Cleveland). The cause of the similarity in the December and February cfd at these sites is not known. A contributing factor may be that prevailing winter air masses approach the Great Lakes from the west and north and thus sites on the western end of Lake Superior and western shore of Lake Michigan are not moderated by passage over the waters of Great Lakes in winter. Thus, these sites may have colder air temperatures in December relative to other sites.

The transition in the cfd between monthly FDDs that are positive and monthly FDDs that are negative occurs primarily in March for stations south of approximately 45°N (Fig. 1). For Lake Superior and the northern end of Lakes Michigan monthly FDDs are negative in April because the mean date of the seasonal maximum FDD is in the last 10 days of March or in first week of April for those stations (Assel 1980b). Thus, March monthly FDDs are usually positive for those sites.

CONCLUDING REMARKS

The FDD data presented here along with the FDD data from the two previous two reports (Assel 1980a, Assel 1986) are meant to be resources for other applications. It is envisioned that these data will prove to be useful for a broad spectrum of research, educational, engineering, and operational applications including climate studies, winter lake ecosystem studies, winter navigation applications, ice cover modeling, and lake effect snowfall studies, to name a few. Analysis of trends in winter severity, trends of annual maximum ice extent, and models of BOM lake-averaged ice cover given below provide a few examples of potential applications.

Trends in Annual Winter Severity. The maximum FDD accumulation each winter at each site is an index of the severity of the entire winter. The average of the maximum FDDs for the FDD data provided by NWS Cleveland for 12 stations (see Figure 1) was calculated and used as a measure of the regional winter severity. A normalized value was calculated from these data by subtracting out the average and dividing by the standard deviation. A plot of the cumulative normalized value portrays the change in winter severity over the 105 winter base period relative to the long-term average (Figure 40). This figure updates a similar figure given in Assel (1980b). That earlier figure showed trends in regional winter severity from 1898 to 1977. The trends in Fig. 40 are virtually identical through 1977. There was a trend for less severe winters (maximum FDD values above the long-term mean) from the beginning of record (1898) to approximately 1920, a period near the long-term mean 1921-1929, a trend for less severe winters from 1930 to approximately 1958, a second trend to more severe winters from 1959 to the early 1980's, and a trend to less severe winters from the mid-to-late 1980s to 2002, that still may be continuing. These findings are reflected in the ranking given in Tables 4 and Tables 6.

Trends in Contemporary Annual Maximum Ice Cover. The trends in winter severity during the last 30-winters provides insight of the ice cover climatology over those winters. The period of the 30-winter ice cover climatology (1973-2002) contained both a trend for more severe winters during approximately the first decade (1973-1982) and a trend for less severe winters during the last two decades (1983-2002), relative to the 105-winter period of record. Ranking the regional average of annual maximum FDDs [rank shown in brackets] it was found that 40% of the winters between 1983 and 2002 were ranked in the lowest 20% (relatively mild winters) of the 105 winters (1998 [1], 2002 [3], 1987 [8], 1983 [9], 1992 [10], 2000 [11], 1995 [12], and 1999 [19]) while 40% of the winters between 1973 and 1982 ranked in the highest 20% (relatively severe winters) of the 105 winters (1977 [104], 1978 [101], 1979 [100], 1982 [95]). These findings are in agreement with Assel et al. (2003) who found that the mean of the annual maximum Great Lakes ice cover for the 6-winters 1977-1982 was greater than the 14-winters before them (1963-1976), and the 19-winters after them (1983-2001).

Ice Cover, Lake-effect snowfall and FDD on BOM dates. Lake-effect snowfall can be above average during the early winter (December, January) for winters with BOM FDD severity classifications of above average or severe. These winters may also develop above average early winter ice cover formation. Anomalously cold air masses, inferred by high FDD accumulations, moving over the much warmer open waters of the Great Lakes are moisture enriched and warmed by the surface waters through the process of evaporation. When the air reaches the windward shore of the lake it is cooled and the moisture is deposited as lake-effect snowfall. However, this can be a

self-limiting process because as the waters of the Great Lakes cool and the surface layer approaches the freezing point, ice formation can occur. An ice cover will reduce additional moisture flux to the atmosphere. A extreme example of this occurred in the early winter of 1989-1990 (i.e. December 1989–January 1990), which in Table 4 is given as 1990 (i.e. the winter of 1990 starts with the fall of 1989 (October, November, December). The BOM January 1990 FDDs are classified as severe in a majority of the 18 stations, implying that much below-average air temperatures occurred during December 1989. A study by Assel (1992) indicated that relative to a 20-winter (1960-1979) monthly average of regional lake-effect snowfall, December 1989 lake-effect snowfall and monthly ice cover were both above average.

In general BOM lake averaged ice cover correlates well with seasonal FDD accumulations on BOM Dates and or the preceding month's FDD accumulation (Table 7). Regression equations that include FDDs are currently being explored as one method to improve 30-days in advance forecasts of lake averaged ice cover (Assel, personal communication).

ELECTRONIC SUPPLEMENT

Tabulations for the daily FDD accumulations over each winter season and each station for the 19-winter period of this update (winters 1984–2002) are given as an electronic appendix (Appendix 1). The data in Table 2 and Table 3 are also given as an electronic appendix (Appendix 2). Record format and file structure are documented in each appendix. The data in the remaining tables can be generated from the data given in the two electron appendices. These data are also being provided to the National Snow and Ice Data Center for archiving. Their current Internet address is: <http://nsidc.org>.

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Appendix 1. Daily FDDs for Winters 1984 – 2002.

Daily FDD accumulations are summarized for each station given in Fig.1 as individual ASCII table files for each winter season for the period of this update, winters from 1984 to 2002. File names are listed below. The files structure and record format of the data for all files is as follows: the first three records are (1) the winter season, (2) the station name, and (3) a header for months. The next 31 records give the day of the month and the seasonal FDD accumulations up to that date. The Fortran algorithm for writing these data is given below. **ASCII files can be opened by clicking on the blue highlighted text below.**

```

-----
      DO ISTA =1,18
      WRITE(6,31) IYEAR1,IYEAR2,STANAM(ISTA)
      WRITE(6,33)
c write out data
      DO IOUT=1,29
        WRITE(6,30)IOUT,FD(IOUT),FD(IOUT+31),FD(IOUT+61),FD(IOUT+92),
        * FD(IOUT+123),FD(IOUT+152),FD(IOUT+183),FD(IOUT+213),IOUT
        ENDDO
        WRITE(6,300)IOUT,FD(30),FD(61),FD(91),FD(122),FD(182),
        * FD(213),FD(243),IOUT
        WRITE(6,301)IOUT+1,FD(31),FD(92),FD(123),FD(183),FD(244),IOUT+1
        ENDDO
30 FORMAT(1X,I3,1X,8(F5.0,1X),1X,I3)
31 FORMAT(11X,' FDD WINTER SEASON OF ',I4,'-',I4,'/',
        *20X,' AT ',A18)
33 FORMAT(5X,'OCT NOV DEC JAN FEB MAR APR MAY')
300 FORMAT(1X,I3,1X,4(F5.0,1X),6X,3(F5.0,1X),1X,I3)
301 FORMAT(1X,I3,1X,F5.0,1X,6X,2(F5.0,1X),6X,F5.0,7X,F5.0,2X,I3)
      END
-----

```

<u>File Name</u>	<u>Station Name</u>
alp8402.txt	Alpena, MI
buf8402.txt	Buffalo, NY
chi8402.txt	Chicago, IL
clv8402.txt	Cleveland, OH
dtw8402.txt	Detroit, MI
dul8402.txt	Duluth, MN
eri8402.txt	Erie, PA
grb8402.txt	Green Bay, WI
hou8402.txt	Houghton, MI
mil8402.txt	Milwaukee, WI
mqt8402.txt	Marquette, MI
msk8402.txt	Muskegon, MI
osw8402.txt	Oswego, NY
phr8402.txt	Port Huron, MI
roc8402.txt	Rochester, NY
ssm8402.txt	Sault Ste. Marie, MI
tol8402.txt	Toledo, OH
tvc8402.txt	Traverse City, MI

Appendix 2. Beginning of Month Seasonal FDD Accumulations and Monthly FDD Accumulations for winters 1898-2002.

Seasonal BOM FDD and monthly FDD data are available as ASCII files: App-sea.txt and App-mon.txt, respectively. The files structure and record format of the data in both files is as follows: there are 18 stations in the same order as given in Table 1. The first record is the station name and records 2-106 are data records, one for each winter from 1898 to 2002. The first data record is for winter 1898 and the last is for winter 2002. Each data record has seven fields. Details are given below. **ASCII files can be opened by clicking on the blue highlighted text below.**

[App-sea.txt \(BOM FDD\)](#)

Record 1 station name [format (a60)]
Record 2 Winter 1898 BOM FDD for Nov., Dec., Jan, Feb., Mar., Apr., May [format (7(1x,f6.0,))]
Record 3 Winter 1899 BOM FDD for Nov., Dec., Jan, Feb., Mar., Apr., May .
. . .
Record 106 Winter 2002 BOM FDD for Nov, Dec, Jan, Feb, Mar, Apr, May .

[App-mon.txt \(FDD\)](#)

Record 1 station name [format (a60)]
Record 2 Winter 1898 FDD for Oct, Nov, Dec, Jan, Feb, Mar, Apr [format (7(1x,f6.0))]
Record 3 Winter 1899 FDD for Oct, Nov., Dec, Jan, Feb, Mar, Apr
. . .
Record 106 Winter 2002 FDD for Oct, Nov, Dec, Jan, Feb., Mar, Apr .

Tables

Tables are available as text files or in PDF file format.
Click on the blue highlighted text below to download and view the files.

Table 1. Eighteen United States National Weather Service Stations Used for FDD Calculations
Arranged by lake.

[Table1.txt](#)

[Table1.pdf](#)

Table 2.1 through Table 2.18. Seasonal FDD Accumulations on BOM Dates at
Duluth, MN, Sault Ste. Marie, MI, Houghton, MI, Marquette, MI, Green Bay, WI, Milwaukee, WI,
Chicago, IL, Traverse City, MI, Muskegon, MI, Alpena, MI, Port Huron, MI, Detroit, MI, Toledo, OH,
Cleveland, OH, Erie, PA, Buffalo, NY, Rochester, NY, Oswego, NY.

[Table2.txt](#)

[Table2.pdf](#)

Table 3.1 through Table 3.18. Monthly FDD Accumulations at
Duluth, MN, Sault Ste. Marie, MI, Houghton, MI, Marquette, MI, Green Bay, WI, Milwaukee, WI,
Chicago, IL, Traverse City, MI, Muskegon, MI, Alpena, MI, Port Huron, MI, Detroit, MI, Toledo, OH,
Cleveland, OH, Erie, PA, Buffalo, NY, Rochester, NY, Oswego, NY.

[Table3.txt](#)

[Table3.pdf](#)

Table 4.1 through 4.18. Ranked Seasonal FDD Accumulations on BOM Dates
Duluth, MN, Sault Ste. Marie, MI, Houghton, MI, Marquette, MI, Green Bay, WI, Milwaukee, WI,
Chicago, IL, Traverse City, MI, Muskegon, MI, Alpena, MI, Port Huron, MI, Detroit, MI, Toledo, OH,
Cleveland, OH, Erie, PA, Buffalo, NY, Rochester, NY, Oswego, NY.

[Table4.txt](#)

[Table4.pdf](#)

Table 5. The winter severity index.

[Table5.txt](#)

[Table5.pdf](#)

Table 6.1 through 6.18. Ranked Monthly FDD Accumulations at
Duluth, MN, Sault Ste. Marie, MI, Houghton, MI, Marquette, MI, Green Bay, WI, Milwaukee, WI,
Chicago, IL, Traverse City, MI, Muskegon, MI, Alpena, MI, Port Huron, MI, Detroit, MI, Toledo, OH,
Cleveland, OH, Erie, PA, Buffalo, NY, Rochester, NY, Oswego, NY.

[Table6.txt](#)

[Table6.pdf](#)

Table 7. Regressions of FDD vs. Lake Averaged Ice Cover on BOM Dates.

[Table7.txt](#)

[Table7.pdf](#)

Figures

**Figures 1-40 are located in a separate PDF file.
Click on the blue highlighted link below to download and view the file.**

[tm-127figs.pdf](#)