National Climatic Data Center

DATA DOCUMENTATION

FOR

DATA SET 9712D (DSI-9712D)

Air-Freezing Index Statistics for the United States

December 26, 2002

National Climatic Data Center
151 Patton Ave.
Asheville, NC 28801-5001 USA

:

Table of Contents

1. **Abstract**: A climatography of the **Air-freezing Index** (AFI) has been developed for 3,110 stations in the United States and is presented here as a digital data set. The AFI is a measure of the combined magnitude and duration of air temperatures above and below freezing during any given winter season. The AFI, the thermal properties of the soil, and the surface soil cover are the major parameters used to determine the ground freezing potential of a given climate.

Data Set Overview:

This data set consists of two statistics stored as separate records within this data-set file. The first statistic represents the computation of 29 seasonal AFI totals for each winter season that occurred during the 1951-1980 period. These winter season AFI totals were computed separately for each climate station. The second statistic represents an estimate of various return periods of the AFI for each station using the 29 seasonal totals for that station as input. The return periods included in this data set are 1.1-years, 1.25 years, 2-years, 2.5-years, 3.3-years, 5-years, 10-years, 20-years, 25-years, 50-years, and 100-years. A return period is defined as a measure of the average amount of time between which an event of a given magnitude will be equaled or exceeded (Gumbel, 1958). Thus, a 100-year return period of the AFI, as an example, would be equaled or exceeded once every 100 years on average.

Work by Steurer (1985, 1989) used serially complete daily maximum and minimum temperature data from 1951-1980 to generate the 29 seasonal totals of the AFI for 3,110 stations in the United States. A detailed description of the computation procedures used to generate the AFI is presented by Steurer and Crandell (1995) along with a graph that depicts a sinusoidal cumulative AFI curve for a typical mid-latitude station. See References.

Generally, the daily AFI is defined as the departure of the daily mean temperature above or below 32 degrees Fahrenheit. The daily AFI departures are then summed each day throughout the freezing season and plotted as a cumulative AFI total. A freezing season is defined as beginning on August 1 and ending on July 31 of the next year. Starting at zero, the daily AFI cumulative curve for a typical mid-latitude station would become positive and turn upward at the beginning of the freezing season when the daily average temperature was above freezing, then become negative and turn downward as daily average temperatures consistently dropped below 32 degrees Fahrenheit in the Winter, and then turn upward again in the Spring or Summer when daily mean temperature consistently was above freezing. The AFI for a winter season is defined as the difference between the highest and lowest inflection points on this cumulative time curve of daily AFI departures. However, for sites that do not exhibit a typical four-season climate such as in the Southern United States, there may not be a well-defined cumulative AFI time curve. Instead there may be several maxima and minima that correspond to cold outbreaks that occur throughout the winter months. Since each cold outbreak is essentially a separate event for these warmer climate stations, only the difference between the maximum and its corresponding minimum of the largest cold outbreak event is assigned the seasonal AFI total.

Data Applications

When the temperature remains below freezing for a period of time, ice lenses can form in the soil that result in frost heave and possible damage to overlying structures (Jones et al., 1982). Structural damages caused by frost action in soils are most notable in the pavement of highways and airfields, in

:

hydraulic structures such as dams and canals, and in residential and commercial buildings. An important application of the AFI is the estimation of the effect of freezing conditions upon the soil foundations of structures. In non-permafrost environments, a conventional method of controlling frost action in soils is to locate a structural foundation below the depth of frost penetration. The depth of frost penetration has empirically been determined by using the AFI in conjunction with the soil type and surface soil cover (Linell and Lobacz, 1980).

A frost-protected shallow foundation (FPSF) is another method used to protect structural foundations from frost heave (Farouki 1992; Morris 1988). FPSF incorporates the strategic placement of insulation to raise the frost depth around a building, thereby allowing foundations as shallow as 0.4 meters (16 inches), even in the most severe climates. The amount of insulation required to protect a foundation has been found to be a function of the AFI ("Frost" 1993). Cost savings to the buyer of new homes using FPSF have been estimated to range from 1 to 4 percent over the cost of conventional slab-on-grade construction or an annual savings of $300 million nationally. Additional long-term savings are expected from increased energy efficiency ("Frost" 1994).

Description of the AFI Return Period Estimates

Various statistics can be used to represent the AFI. The ones more commonly used in the United States are the mean, the design value (Jones et al., 1982), and the 100-year return period (Steurer, 1989). The mean is a measure of average conditions and is simply the average of the seasonal AFI totals for ten or more winter seasons. Jones et al. (1982) indicate that the mean index is used primarily in the construction phase of temporary structures. For more permanent structures, the design AFI can be used. Here, the seasonal totals for the three coldest winters in a 30-year period are averaged. To provide an index that reflects conditions during the coldest winter seasons, work by Steurer (1989) resulted in the development of an estimate of the 100-year return period of the AFI using the Weibull probability distribution.

A total of 29 seasonal totals of the AFI was computed at each climate station and used to compute an estimate of the 100-year return period for that station. These statistics were produced for 3,110 stations in the United States based upon the period 1951-1980. A return period is defined as a measure of the average amount of time between which an event of a given magnitude will be equaled or exceeded (Gumbel, 1958). A return period is described by the equation 1/p where p is the probability of the event occurring over a specified period of time. Using this equation, a 2-year return period of the AFI would occur on average in 50% of the years (1/.5), while a 100-year return period would occur on average in only 1% of the years (1/.01). A common misuse of return periods is to expect, as an example, the 100-year return period to occur exactly every 100 years. It is quite possible to equal or exceed the 100-year return period of the AFI in two successive years or not reach it in more than 500 years. But when the average is considered, the length of time between events will be 100 years for a valid 100-year return period estimate (Linsley et al., 1949).

Different methods have been used to obtain an estimate of the AFI for other locations around the world. Different AFI computation procedures have been performed for locations in Norway (Heiersted, 1976) and Finland (Anderson, personal communication, 1993). Work by Steurer and Crandell (1995) investigated the differences among the USA method, which used return periods, and Norway, and Finland methods. They found that the USA method was more representative of the freezing effect for all U.S. climate regimes. This was in terms of calculating an unbiased AFI that considered all freezing and thawing events during the winter regardless of their duration or time of occurrence. As a result of this work, U.S. building codes as regulated by the 1995 Edition of the Council of Building Officials (CABO) One and Two-Family Dwelling Code were changed to accept FPSF as a mechanism to offset increased construction costs and provide more energy-efficient housing (Crandell, personal communication, 1994).

However, Steurer and Crandell (1995) pointed out that there were potential shortcomings in fitting one probability distribution to every possible climate regime, especially when the sample size was relatively small (Kite, 1977). To address the problem of a small sample size, a longer-term data set was used in another study performed by Steurer (1996) that contained temperature data for 1901-1987. This 138-station network of U.S. observing sites is considered by some climate researchers to be a high quality and long-term temperature data sets in terms of temporal homogeneity and spatial coverage (Hughes et al, 1992). A total of 25 of the 138 available stations were selected for this study. The stations that were chosen had few missing data and also maintained the same observation time throughout the 1901-1987 period. This resulted in a sample size of 86 winter seasons or data points for each station. This latter work revealed that the Weibull probability distribution was still determined as the best choice for use in estimating the 100-year return period of the AFI for all U.S. climate regimes.

2. **Element Names and Definitions**:

The data are archived in a fixed length ASCII format. The total data volume is about 1 megabyte. The data are sorted by station using the station number as the primary key followed by statistic identifier number.

Each record is of fixed length and composed of 156 characters. The record format is:

Element Name	**Width**	**Position**
Station Number	6	001-006
Statistic Identifier	2	007-008

If Statistic Identifier in positions 007-008 = 01 then the following record layout is used:

1951-1952	Winter Season AFI	5	009-013
1952-1953	"	5	014-018
1953-1954	"	5	019-023
1954-1955	"	5	024-028
1955-1956	"	5	029-033
1956-1957	"	5	034-038
1957-1958	"	5	039-043
1958-1959	"	5	044-048
1959-1960	"	5	049-053
1960-1961	"	5	054-058
1961-1962	"	5	059-063
1962-1963	"	5	064-068
1963-1964	"	5	069-073
1964-1965	"	5	074-078

:
:

1965-1966	"	5	079-083
1966-1967	"	5	084-088
1967-1968	"	5	089-093
1968-1969	"	5	094-098
1969-1970	"	5	099-103
1970-1971	"	5	104-108
1971-1972	"	5	109-113
1972-1973	"	5	114-118
1973-1974	"	5	119-123
1974-1975	"	5	124-128
1975-1976	"	5	129-133
1976-1977	"	5	134-138
1977-1978	"	5	139-143
1978-1979	"	5	144-148
1979-1980	"	5	149-153
Not used		3	154-156

If Statistic Identifier in positions 007-008 = 02 then the following record layout is used:

Station Name	30	010-039
Latitude	5	041-045
Longitude	6	047-052
Elevation	4	054-057
Annual Mean Temperature	6	059-064
AFI 1.1-year return period	8	066-073
AFI 1.25-year return period	8	074-081
AFI 2-year return period	8	082-089
AFI 2.5-year return period	8	090-097
AFI 3.3-year return period	8	098-105
AFI 5-year return period	8	106-113
AFI 10-year return period	8	114-121
AFI 20-year return period	8	122-129
AFI 25-year return period	8	130-137
AFI 50-year return period	8	138-145
AFI 100-year return period	8	146-153
Not used	3	154-156

Station Number is an integer variable that refers to the Cooperative station number for this station. Range of values is 010252-666073

Statistic Identifier is an integer variable that defines the type of record that follows. Range of values is 01 and 02.

If **Statistic Identifier** = 01 then the following element names are used:

1951-1952 Winter Season AFI is an integer variable that defines the Air-Freezing Index that was compute for the 1951-1952 winter season. Range of values is 0 through 99999. Units are whole degrees Fahrenheit-Days. **1952-1953 Winter Season AFI** through **1979-1980 Winter Season AFI** are described above under **1951-1952 Winter Season AFI**

If **Statistic Identifier** = 02 then the following element names are used:

Station Name is a 30-character alphanumeric variable that defines the station name assigned as part of the Cooperative Observer Network

:

Latitude is a 5-character alphanumeric variable that defines the latitude of the station. The format is N9988 where N indicates North latitude, 99 indicates degrees and 88 indicates minutes. All stations are North Latitude in this data set.

Longitude is a 6-character alphanumeric variable that defines the longitude of the station. The format is W99988 where W indicates West longitude, 999 indicates degrees, and 88 indicates minutes. All stations are West Longitude in this data set.

Elevation is a 4-character integer variable that defines the elevation of the station in whole feet. The range of values is -194 to 9332 feet

Annual Mean Temperature is a real variable which represents the 1951-1980 normal of the annual mean temperature. Units are tenths of a degree Fahrenheit. Range of values is 9.0 to 76.7 degrees Fahrenheit.

AFI 1.1-year return period is an integer variable that defines the Air Freezing Index (AFI) at the1.1-year return period. A return period is described by the equation 1/p where p is the probability of the event occurring over a specified period of time. Using this equation, a 1.1-year return period of the AFI would occur on average in 90% of the years (1/.9). The range of values is -9999, -8888, and 0 through 99999. Units are whole degree Fahrenheit-Days. A value of -9999 indicates that the probability of occurrence of this return period is less than the return period probability, or in other words, the average daily temperature did not fall below 32 degrees Fahrenheit in every winter season during the 1951-1980 period. A value of -8888 indicates no freezing index values were recorded at base 32 degrees Fahrenheit during the 1951-1980 period or, in other words, the average daily temperature never fell below 32 degrees Fahrenheit during the entire1951-1980 period. Refer to Topic 22 below for the further descriptions of the Air-Freezing Index and return periods.

AFI 1.25-year return period is described above under the **AFI 1.1-year return period.** A 1.25-year return period would occur on average in 80% of the years (1/.8)

AFI 2-year return period is described above under the **AFI 1.1-year return period.** A 2-year return period would occur on average in 50% of the years (1/.5)

AFI 2.5-year return period is described above under the **AFI 1.1-year return period.** A 2.5-year return period would occur on average in 40% of the years (1/.4)

AFI 3.3-year return period is described above under the **AFI 1.1-year return period.** A 3.3-year return period would occur on average in 30% of the years (1/.3)

AFI 5-year return period is described above under the **AFI 1.1-year return period.** A 5-year return period would occur on average in 20% of the years (1/.2)

AFI 10-year return period is described above under the **AFI 1.1-year**

return period. A 10-year return period would occur on average in 10% of the years (1/.1)

AFI 20-year return period is described above under the **AFI 1.1-year return period.** A 20-year return period would occur on average in 5% of the years (1/.05)

AFI 25-year return period is described above under the **AFI 1.1-year return period.** A 25-year return period would occur on average in 4% of the years (1/.04)

AFI 50-year return period is described above under the **AFI 1.1-year return period.** A 50-year return period would occur on average in 2% of the years (1/.02)

AFI 100-year return period is described above under the **AFI 1.1-year return period.** A 100-year return period would occur on average in 1% of the years (1/.01)

3. Start Date: This data set represents a group of summary statistics. The beginning period of record used in generating these statistics was 19510101.

4. Stop Date: The ending period of record used in generating these statistics was 19801231.

5. Coverage: **C**ontinental United States, Alaska, Hawaii, and Puerto Rico.

a. Southernmost Latitude: 18 Degrees 03 Minutes N.
b. Northernmost Latitude: 71 Degrees 18 Minutes N.
c. Westernmost Longitude: 176 Degrees 39 Minutes W.
d. Easternmost Longitude: 65 Degrees 39 Minutes W.

6. How to Order Data:

Ask NCDC's Climate Services about the cost of obtaining this data set.
Phone: 828-271-4800
FAX: 828-271-4876
E-mail: **NCDC.Orders@noaa.gov**

7. Archiving Data Center:

National Climatic Data Center
Federal Building
151 Patton Avenue
Asheville, NC 28801-5001
Phone: (828) 271-4800.

8. Technical Contact:

National Climatic Data Center
Federal Building
151 Patton Avenue
Asheville, NC 28801-5001
Phone: (828) 271-4800.

:
:

9. **Known Uncorrected Problems**: There are no known uncorrected problems in this data set.

10. **Quality Statement**: Extensive validation and interpolation procedures were performed on the daily maximum and minimum temperatures used to derive the Air Freezing Indexes at each station. The resulting indexes where visually checked based upon a map analysis.

11. **Essential Companion Datasets**: There are no additional data sets required in order to use this data set.

12. **References**:

Farouki, O. (1992). *European foundation designs for seasonally frozen ground*. Monograph 92-1, U.S. Army Corps of Engrs., Cold Regions Res. & Engrg. Lab., Hanover, N.H.

Frost protected shallow foundations in Residential Construction, 1993. Phase I Report Prepared for the U.S. Department of Housing and Urban Development, NAHB Res. Ctr., Upper Marlboro, Md.

Frost protected shallow foundations in Residential Construction, 1994. Phase II Final Report Prepared for the U.S. Department of Housing and Urban Development, NAHB Res. Ctr., Upper Marlboro, Md.

Gumbel, E.J. (1958). *Statistics of Extremes*. Columbia University Press, New York, New York, 375 pp.

Heiersted, R.S. (1976). *Frost I Jord (Frost Action in Ground)*. Committee on Frost Action in Soils, Royal Norwegian Council for Scientific and Industrial Res., Nr. 17, Oslo, Norway (in Norwegian).

Hughes, P.Y., E.H. Mason, T.R. Karl, and W.A. Brower (1992). *United States Historical Climatology Network daily temperature and precipitation data*. ORNL/CDIAC, NDP-042. Carbon Dioxide Information Analysis Ctr., Oak Ridge Nat. Lab., Oak Ridge, TN. 140 pp.

Jones, C.W., D.G. Miedema, and J.S. Watkins (1982). *Frost action in soil foundations and control of surface structure heaving*. Report No. REC-ERC-82-17, Bureau of Reclamation, Denver, Colo., 69 pp.

Kite, G.W. (1977). *Frequency and risk analysis in hydrology*. Water Resources Publications, Fort Collins, Colo., 224pp.

Linnel, K.A. and E.F. Lobacz (1980). *Design and construction of foundations in areas of deep seasonal frost and permafrost*. Special Report 80-34, U.S. Army Corps of Engrs., Cold Regions Res. & Engrg. Lab., Hanover, N.H.

Linsley, R.K., M. Kohler, and J.L.H. Paulus (1949). *Applied Hydrology*. McGraw-Hill Book Co., New York, New York, 689 pp.
Morris, R.A. (1988). *Frost-protected shallow foundations: Current state-of-the-art and potential application in the U.S.* Report prepared for the Society of the Plastics Industry, NAHB Res. Ctr., Upper Marlboro, Md.

Steurer, P.M. (1985): *Creation of a serially complete database of high quality daily maximum and minimum temperatures*. Nat. Oc. and Atmospheric

:

Admin., Nat. Climatic Data Ctr., Asheville, N.C.

Steurer, P.M. (1989). *Methods used to create an estimate of the 100-year return period of the air-freezing index.* Frost-protected shallow foundation development program-Phase II final report, Appendix A. Prepared for the Society of the Plastics Industry, NAHB Res. Ctr., Upper Marlboro, Md.

Steurer, P.M. and J.H. Crandell (1995). *Comparison of methods used to create an estimate of the air-freezing index.* J. Cold Reg. Engrg., 9(2), 64-74.

Steurer, P.M. (1996). *Probability distributions used in the 100-year return period of the air-freezing index.* J. Cold Reg. Engrg., 10(1), 25-35.

:
: