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EXTREME WINTER TEMPERATURES IN TENNESSEE

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INTRODUCTION

Extremely low temperatures affect everyone. In addition to the personal discomfort or injury resulting from severe cold, the economic losses are huge. During the recent cold winter of 1962-63, for example, news media were filled with stories of freeze damage. Among the damages noted were frozen water lines and pipes, road deterioration, and winter kill of small grains, pastures, fruit trees, strawberries, and shrubbery. Many schools were forced to close and some industries shut down. Transportation was interrupted and most outdoor work, including construction, was halted. The severity of winters and the damage caused by them cannot be attributed to a single weather element. The extreme lowest temperature is but one factor in determining the severity of a winter but it is an important one.

Knowledge of the risk of extremely low temperatures is important to long-range planners in agriculture, commerce, business, and industry. The more severe low temperatures are a critical factor in the growth and survival of plants, insects, and animals. Some types of outdoor work which may not be affected by a moderate freeze may be interrupted by a more severe one. Roads and other structures must be designed to withstand the rigors of low temperatures. Also, knowledge of the severity of cold weather is useful in determining the amount of protection from freeze needed in many instances. In order to meet both practical needs and natural curiosity, an analysis of the risks or probabilities of extreme annual low temperatures at various locations in Tennessee is discussed below.

TEMPERATURE DATA

Daily minimum temperatures recorded at Weather Bureau climatological stations in Tennessee have been used to determine series of annual extreme minimum temperatures. In an attempt to record representative air temperatures at these stations, the thermometers are installed in well ventilated shelters which shade them from incoming solar radiation during the day and protect them from direct loss of heat by outgoing radiation at night. The height of the thermometers is about 5 feet above the ground. On clear, calm nights, the usual situation during lowest temperatures, the minimum temperature near the ground will usually be a few degrees lower than at the thermometer level. This temperature inversion may extend upward above the instrument shelter a short distance before temperatures again start to decrease with increasing height.

Several factors cause sizeable minimum temperature differences over small distances. Among these are (1) type of vegetative cover, (2) urban areas, (3) mountains and valleys, and (4) type of weather situation. During calm, clear nights the minimum temperature over a meadow may be lower than over a similar area of bare ground. This difference in temperature is due mainly to cooling from the leaf surface of plants. The minimum temperature in rural areas is usually lower than in urban areas. On the average, temperature decreases with increase in altitude, about 3°F per thousand feet. However, on calm, clear nights air cooled near the ground by radiation may collect in valleys and cause lower temperatures there than on nearby slopes throughout the depth of radiation cooled air. At higher levels temperatures will again decrease with increase in elevation. On windy or cloudy nights near-average decrease of temperature with altitude prevails.

These differences in station location, which may create a rather complicated pattern of minimum temperatures at a given time, no doubt have some effect on the series of extreme annual temperatures in Tennessee. There is, however, an obvious general decrease of extreme minimum temperatures with increase of latitude and elevation. The absolute lowest temperature ever officially recorded in Tennessee was —32° at Mountain City in the northeast corner of the State, at an elevation of more than 2,400 feet, on December 30, 1917. The coldest temperature near the surface in Tennessee probably has occurred at some high elevation in the Unaka Mountains of the east and has gone unrecorded.

ANALYSIS OF DATA

Series of annual minimum temperatures [1] at 44 stations throughout Tennessee, with long records during the period 1921-62, were analyzed in order to determine probabilities of extremely low temperatures. The data for each station were fitted by the Fisher-Tippett Type I distribution, an extreme value distribution which has been widely used (Hershfield, 1961; Brown and Williams, 1962) in treating climatological data extremes.

The Fisher-Tippett Type I distribution, in its cumulative probability form, is expressed by the double exponential equation.

$$F(x) = \exp(-e^{-(x-A)/B})$$

where $F(x)$ is the probability that a selected x value will not be reached. The exponent $(x-A)/B$ is a standardized variable, i.e., it is a variable located at A and scaled in B.

The two parameters A and B were estimated from the data by using Lieblein's procedure as described by

[1] The choice of calendar minima introduces a small sampling error if the results are to be applied to winter season minima, because a cold spell lasting over New Year's Day could produce the lowest minimum for 2 consecutive calendar years—in December for the first, in January for the second. This error is not believed to be large enough to be of importance for most purposes.

Thom (1960) and Vestal (1961). The line of best fit was determined by evaluating the reduced variate $(x-A)/B$ for two values of x fairly far apart. The results were then plotted on extreme probability paper which gives a straight line fit to the probability distribution.

A fitted annual minimum temperature series for Lewisburg, Tennessee, is shown in Fig. 1. From this graph, probabilities or recurrence intervals, commonly called return periods, for various annual temperature extremes can be obtained. Alternatively, the annual extreme minimum temperature to be expected at any selected probability level (or the return period associated with a selected temperature) can be read easily from the graph. One can, of course, make a probability determination directly from the distribution function, but the use of extreme probability paper greatly simplifies the process.

How well the sample of data fits the probability distribution is also illustrated in Fig. 1 for Lewisburg. The plotting formula used in this example was

$$P_i = (i - 0.44)/(n + 0.12),$$

where n is the number of observations, i is the order of the observation from the smallest, and P_i is the estimate of the cumulative frequency of the i *th* term. This equation was developed by Gringorten (1963) for plotting the i *th* of n ordered observations, if the n observations are plotted to facilitate their inspection.

The series of annual extreme minimum temperatures were tested for homogeneity by use of the well known run test before fitting the extreme value distribution curve. This was necessary because of numerous location changes of climatological stations which might cause part of the record to be incompatible with other parts. Results of these tests using 0.10 significance limits failed to show heterogeneity in any of the series except at one station. The station history showed that this station had not been moved during the periods of record used.

Station locations at Nashville made it possible to apply the more powerful Student's t test (Bowker and Lieberman, 1959) to the series of monthly and annual mean temperatures in order to test for homogeneity. This test was applied first to City Office and Airport data for the period January 1941 to August 1948 during which time both stations were in operation. Since

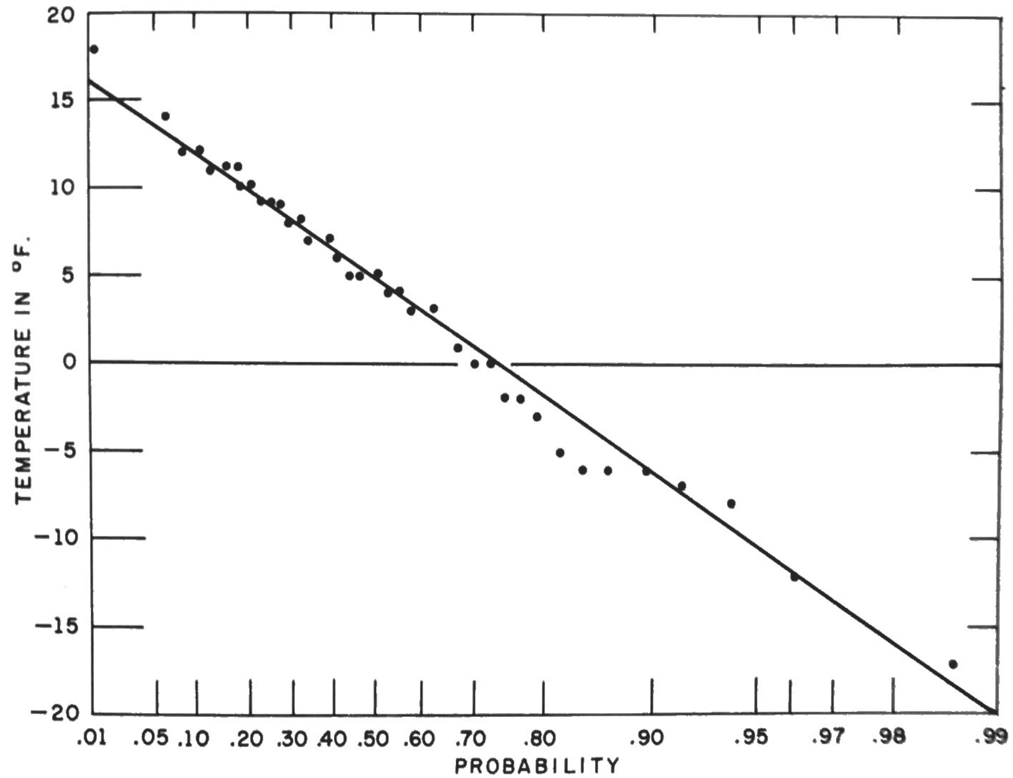

Fig. 1. Lewisburg (1921-62) annual extreme minimum temperatures fitted by the Fisher-Tippett Type 1 distribution.

the location of instruments at the airport was changed in August 1948 the airport record before this date was tested against the record after this date. Results of these tests using 0.10 significance limits showed that airport and city office data were inhomogeneous as expected and that temperatures at the two airport locations were homogeneous. Therefore, only airport data were used in the analysis of annual minimum temperatures at Nashville and Memphis. Most station relocations do not involve areas that are as different as city versus airport locations. Because of this fact and also since heterogeneities were not shown by the run tests, all other station data series used were assumed homogeneous.

Table 1

Annual minimum temperatures for selected recurrence intervals (return periods) and probabilities of occurrence in any one year.

Station	Years Record	Return Periods and Probabilities 1½ yr. 0.67	2 yr. 0.50	5 yr. 0.20	10 yr. 0.10	25 yr. 0.04	50 yr. 0.02	100 yr. 0.01
Ashwood	42	8	5	−2	−7	−11	−17	−21
Bolivar	36	9	6	−1	−5	−11	−15	−19
Bristol	15	6	4	−2	−6	−10	−15	−18
Brownsville	42	12	9	2	−3	−9	−13	−17
Carthage	42	9	6	−1	−5	−11	−16	−20
Chattanooga	42	14	11	5	1	−4	−8	−12
Clarksville	42	9	6	−1	−6	−12	−16	−20
Coldwater	42	9	6	0	−4	−10	−14	−18
Cookeville	24	6	3	−5	−10	−16	−21	−26
Copperhill	42	9	7	1	−3	−8	−12	−16
Covington	42	12	9	2	−3	−9	−13	−17
Crossville	42	1	−2	−8	−13	−18	−22	−26
Decatur	25	10	6	−1	−7	−13	−18	−23
Dickson	42	7	4	−3	−7	−13	−17	−21
Dover	42	6	3	−5	−9	−15	−20	−24
Franklin	42	7	4	−2	−6	−12	−16	−20
Gatlinburg	30	4	2	−5	−9	−14	−18	−22
Greeneville	30	5	2	−4	−8	−14	−18	−22
Jackson	42	10	7	−1	−6	−12	−17	−21
Johnsonville	20	8	5	−2	−7	−13	−17	−21
Knoxville	42	12	9	3	−1	−6	−10	−14
Lewisburg	42	8	5	−2	−6	−12	−16	−20
Loudon	40	11	8	2	−2	−6	−11	−15
Lynnville	32	8	5	−2	−6	−12	−16	−20
McMinnville	42	9	6	0	−5	−11	−15	−19
Memphis	20	14	11	5	1	−4	−8	−11
Milan	42	9	6	−2	−7	−13	−17	−22
Murfreesboro	25	9	6	−1	−6	−12	−16	−20
Monteagle	24	6	3	−4	−8	−13	−17	−21
Moscow	42	11	8	1	−3	−9	−13	−17
Nashville	20	8	6	1	−3	−7	−11	−14
Newbern	36	10	7	0	−5	−10	−14	−19
Newport	42	10	7	1	−4	−9	−13	−17
Norris	28	8	6	−1	−5	−10	−14	−18
Palmetto	42	9	6	−2	−7	−13	−17	−22
Paris	24	9	5	−3	−8	−15	−20	−25
Perryville	24	10	7	−1	−6	−13	−18	−22
Rogersville	42	8	5	0	−4	−9	−12	−15
Rugby	28	1	−2	−9	−14	−21	−25	−30
Samburg	20	8	6	−1	−5	−11	−15	−19
Savannah	42	11	8	1	−4	−10	−14	−18
Tullahoma	42	8	5	−2	−6	−12	−16	−20
Union City	42	8	5	−2	−7	−13	−17	−22
Waynesboro	42	5	2	−4	−9	−14	−18	−22

Results

Annual minimum temperatures to be expected on the average for various return periods are shown in Table 1. Below each return period is the probability with which it is associated, i.e., the probability that the temperatures listed below will occur in any one year. For example, a 5-year return period is associated with the 0.20 probability that the event will occur (or 0.80 probability that it will not) in 1 year. If intermediate return periods not shown are needed, they can be obtained by plotting any two points given in the table on extreme probability paper of the type shown in Fig. 1 and drawing a straight line through them.

The results of this analysis do not tell how low the temperature will go in any given year. They do, however, give approximate minima to be expected within longer periods of time on the average. Frequently in long-range planning, the temperature variable of interest is the extreme lowest to be expected over a period of time. If a designed structure or planned enterprise, for example, can withstand the lowest temperature during its existence it is assumed that it can withstand all other values not so low.

The minimum temperatures of Table 1 are the best estimates of the lowest temperatures to be expected for the given periods of time or return periods on the average. The value for a given return period, say 5 years for example, will not occur in every 5-year period, of course, but may occur more than once in others. Actually, the probability that any given temperature within the table will occur within a single return period is 0.63. If it is the probability that the given temperature will not be reached that is of interest then this risk is 0.37. The latter probability can be increased and the former reduced by selecting a temperature lower than that given in the table. Methods for selecting a temperature for any probability of occurrence within a return period can be found in the literature cited.

Conclusions

Examinations of the distribution of annual minimum temperatures over Tennessee reveals some interesting facts. The three major causes of differences in extreme annual minimum temperatures over the State on the average seem to be altitude, geographical location, and the urban influence. Coldest temperatures in the State on the average were in the northern Cumberland Plateau area for the stations analyzed but inspection of data for Mountain City, Johnson County, and nearby Silver Lake, 1898 to 1921 inclusive, show still colder annual minimum temperatures. Annual extreme low temperatures are not as cold in the Great Valley of East Tennessee as in other low-lying areas of the State. As expected, annual minimum temperatures decrease with increasing latitude. Annual minimum temperatures near the major population centers of the State are much higher than in rural areas.

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NEWS OF TENNESSEE SCIENCE

(Continued from page 17)

Under a program established last year at Tennessee Polytechnic Institute eight faculty members are engaged in college-assisted research, according to Dr. Richard Fraser, chairman of the Faculty Research Committee. The faculty members and their projects are: Dr. Oriole Wisner, "Comparison of National Teacher Examination Scores Earned by Comparable Groups of Education and Non-Education Majors at Tennessee Tech, Winter Quarter, 1964"; Dr. Richard C. Lukas, "A Study of the Air Force Aspects of American Aid to the U.S.S.R. during World War II"; H. B. Kerr, "German to English Language Translation by the Digital Computer"; John L. Dixon, "Digital Computer Control of a Thermal Process"; Hasan A. Hejazi, "The Vibratory Penetration of Soils"; Kahtan N. Jabbour, "Effect of Shear Deformation on Bending of Perforated Plates"; R. E. Frounfelker, "An Investigation of the Surface Energies of Ionic Crystals"; and Ralph W. Dimmick, "Mammals of the Upper Cumberland Region."

NSF summer institutes for college teachers are scheduled at Fisk University (physics), and ORINS (radiation biology, physics, and isotope technology). Vanderbilt University will conduct conferences on histochemistry, and linear algebra and topology.

Dr. John H. Barrett has been named head of the Department of Mathematics in the University of Tennessee's College of Liberal Arts at Knoxville.