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AIR FORCE CAMBRIDGE RESEARCH LABORATORIES

L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS

Duration and Unusual Extremes of Cold

IRVING I. GRINGORTEN



THE AIR FORCE
CAMBRIDGE RESEARCH LABORATORIES
L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS

United States Air Force

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L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS

Duration and Unusual Extremes of Cold

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Abstract

Duration, in hours and days, of low temperature during which equipment must operate and long term durations of extreme cold which equipment should "withstand" without irreversible damage, are provided in the revision of MIL-STD-210A, Climatic Extremes for Military Equipment. A low temperature of -60°F was established (in guidance from the Joint Chief of Staff) at which equipment should still be operable. But still lower temperatures, persisting from one to several days, at which the equipment must be able to withstand on standby for periods of 2 to 25 years, had to be inferred by modelling, to supplement the evidence of several scant data sources in the remote frigid areas of the world. The operational 20 percent extreme cold, equalled or exceeded continuously for 12 hours in the cold heart of Siberia, is -60°F . The withstanding 10 percent extreme is lower than -80°F in 2 to 4 days' exposure for a planned life of 2 to 25 years.

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Duration and Unusual Extremes of Cold

I. INTRODUCTION

MIL-STD-210A, Climatic Extremes for Military Equipment, is being revised to include those extremes of cold temperatures at which military operations are considered possible and during which combat equipment should operate. Also, since such equipment should survive when unusual, even colder extremes are experienced, an additional set of values will be provided for "withstanding" without irreversible damage.

A temperature extreme for operation, -60°F , was established in guidance from the Joint Chiefs of Staff (JCS) (Memorandum for the Secretary of Defense, subject: Military Standard MIL-STD-210A, Climatic Extremes for Military Equipment, JCSM-502-69, 12 August 1969). In North America, this extreme occurs during only 1 percent of the time of the coldest month over small areas on the northern Alaskan-Canadian border and over the Canadian Arctic Archipelago. The interior of the Greenland ice cap fell below -60°F during 35 percent of the time in February during a 1930-1931 expedition. A record of -87°F was observed there in 1949. A considerable area of the cold heart of Siberia experiences -60°F over 1 percent of the time, and in two smaller centers, it falls to this level during 20 percent of January. In these centers, an extreme of -90°F , the officially recognized record low for the Northern Hemisphere, was obtained. These percentages of times of

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occurrence for temperatures of -40 to -70°F are mapped in a parallel study by Salmela and Sissenwine (1970). In its draft form, this study served as a basis for establishing the operational goal of -60°F .

The Joint Chiefs of Staff also provided "withstanding" guidance whereby equipment should recover from exposures that have only 10 percent probability of occurrence in the planned life of the equipment, suggested as 2, 5, 10, or 25 years. Such extremes would normally be expected to occur in these cold centers which have the highest probability of -60°F , the operational extreme. The values for "withstanding" should, therefore, be obtained from annual extremes for many decades and the statistical model (Gumbel, 1958; Gringorten, 1963b) for extreme values. Unfortunately, such annual extremes were not available for stations in the Siberian cold centers during background discussions leading to this guidance. Therefore, a 23-year set of annual extremes for Snag, Yukon Territory, (62°N , 140°W), was used for preliminary exploration of this problem. Though the coldest month for Snag only approaches a -20°F average compared to -53°F in Siberia, the likelihood of extremes at Snag is much greater than this average implies. Located in the eastern foothills of the Rocky Mountains, Snag is normally under the influence of continental air which radiates its heat to the clear skies and becomes extremely cold until it builds up such great density that it breaks down and moves out to the south and east. This is followed by warm air pouring over the mountains from the Gulf of Alaska, raising the monthly average. During one period of immersion in cold air, Snag attained an extreme of -81°F , the record for North America. (This is only 9°F warmer than for Siberia despite more than 30°F difference in January averages.) The 10 percent probable extremes for 2, 5, 10, and 25 years from the 27-year record are -78 , -83 , -87 , and -92°F , respectively (tentative values suggested by the JCS, in the guidance memorandum noted previously.) The last value exceeds the record values for Siberia and has a return period of about once in every 250 years.

2. PURPOSE

The ability of equipment to operate or withstand in cold extremes is very dependent on the duration of the specified extremes, the associated lesser extremes, and ventilation. The purpose of this report is to describe, realistically, these conditions (especially the duration) of extremes, and also, to examine the tentative "withstanding" values obtained from the Snag data, revising these in accordance with the 10 percent risk established by the JCS if better data than for Snag can be found.

3. DATA

The records of winter temperatures, that were requested through ETAC from NWRC, Asheville, N. C. in Oct. 1968 included the frequency distributions of all observed temperatures for 12 Siberian stations, as well as for five stations in North Dakota, three in Montana, two in the Northwest Territories of Canada, and three stations in Greenland. The latter were Thule, Umanak, and Nord, all coastal stations. The records of Eismitte, in the interior of Greenland, appear in the Meteorological Office tables (1958), but only for the period 1930 to 1931.

Snag hourly observations, for the period 1944 to 1966, were provided by ETAC on microfilm. The record for Verkhoyansk ($67^{\circ} 33'N$, $133^{\circ} 23'E$) available for January, included 2260 observations, taken several times each day during the period 1948 to 1963. An additional record for January at Oymyakon ($63^{\circ} 16'N$, $143^{\circ} 09'E$) consisted of 1891 observations in the same years. The times of observation were 0000, 0300, — or 2100 local time, but there was no consistent regularity throughout the 16-year period.

Recently, ETAC published the study, Cloud Data During Periods of Low Temperatures for Verkhoyansk and Oymyakon. For every hour of record during the period 1948 to 1963, there was a temperature reading. Minimum temperatures were also reported but again with no apparent regularity. The ETAC distributions will be designated as "Source A" in the following discussions.

The British Meteorological Office (1958) lists 6 statistics on temperature by month and year: daily average maximum and minimum, monthly and annual average maximum and minimum, and monthly and annual absolute maximum and minimum. The record for Verkhoyansk was for the periods 1884 to 1920 and 1926 to 1935. The record for Oymyakon covered only the period of 1930 to 1934, for which the British table gives only the absolute extreme. The British means and extremes will be designated as "Source B" in the text that follows.

4. REVISION OF ESTIMATES OF "WITHSTANDING" COLD EXTREMES

Since the preliminary estimates were made for SAES-JCS, there has been an opportunity to study Sources A and B for Verkhoyansk and Oymyakon. The most obvious and straightforward approach to the estimation of extremes would be to sample the data directly, which requires many years of annual extremes. Source A can provide only 15 annual extremes at each of the two Siberian stations, and these are suspect. Table 1 lists the minimum annual temperatures as they were found. In column (1), all the temperatures of the season, taken at times 0000, 0300, — or 2100 were surveyed for the minimum. Column (2) consists of all the so-called

Table 1. The Lowest Annual Temperature at Verkhoyansk ($67^{\circ} 33'N$, $133^{\circ} 23'E$) and Oymyakon ($63^{\circ} 16'N$, $143^{\circ} 09'E$) as Found in a Selected List of Temperatures Provided by ETAC, Using 1948 to 1963 Data. Columns (1) Show the Minimum of One or More Daily Temperature Observations During the Season. Columns (2) are Temperatures that were Recorded as "minimum".

Season	Station			
	Verkhoyansk		Oymyakon	
	(1)	(2)	(1)	(2)
1948 (January)		-78°F		-90°F
1948-1949	-76°F	-71°F	-74°F	-76°F
1949-1950	-69°F	-69°F	-72°F	-72°F
1950-1951	-67°F	-67°F	-78°F	-81°F
1951-1952	-71°F	-72°F	-76°F	-83°F
1952-1953	-74°F	-80°F	-72°F	-76°F
1953-1954	-74°F	---	-76°F	-78°F
1954-1955	-67°F	-74°F	-67°F	-72°F
1955-1956	-76°F	-67°F	-72°F	-76°F
1956-1957	-67°F	-78°F	-76°F	-80°F
1957-1958	-71°F	-72°F	-74°F	-78°F
1958-1959	-69°F	-67°F	-78°F	-80°F
1959-1960	-71°F	-74°F	-74°F	-74°F
1960-1961	-72°F	-74°F	-71°F	-72°F
1961-1962	-71°F	-71°F	-74°F	-74°F
1962-1963	-71°F	-69°F	-72°F	-76°F
Averages	-71.1	-72.2	-73.7	-77.4

minima. In the Verkhoyansk listing, it is not clear why the first minimum should be lower than the second minimum in four out of fifteen years. Also, knowing that there was a record low at Verkhoyansk of $-90^{\circ}F$, it is puzzling to find no temperature lower than $-80^{\circ}F$ from 1948 to 1963. However, the Oymyakon record does have a low of $-90^{\circ}F$ during January 1948. Also, at Oymyakon, the second minimum (Column 2) is at least as low as the first minimum (Column 1) in all years.

Source B gives us only two pertinent values for Verkhoyansk: the 23-year average of annual minimum of $-80^{\circ}F$ and the 40-year extreme low of $-90^{\circ}F$.

The generally accepted assumption about annual extremes is that their distribution fits the Gumbel (1958) theoretical distribution. In Figure 1, the Extreme Probability Paper, this assumption seems reasonable with respect to the 16 Oymyakon values of Source A. Their mean is $-77.4^{\circ}F$, standard deviation $4.73^{\circ}F$.

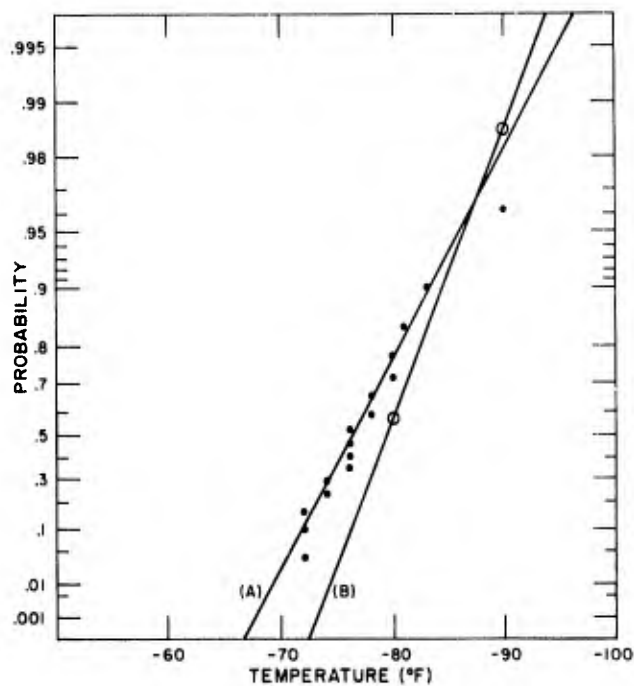


Figure 1. Annual Low Extreme Temperatures, Plotted on Extreme Probability Paper. Line (A) is the Best Fitting Straight Line to the Data of Source A for Ojmjakon (dotted) Based on 1948 to 1963 Extremes, the Latter Ordered and Plotted About This Line. Line (B) is Fitted to the Two Values of Source B for Verkhoyansk (circled) Based on 1884 to 1920 and 1926 to 1935 Data.

Source B's extreme value of -90°F is treated as the percentile (\hat{P}) of the extreme value distribution, given by the formula (Gringorten, 1963a)

$$\hat{P} = \frac{(i - 0.44)}{(n + 0.12)},$$

where $i = 40$ for the 40-year extreme, and

$n = 40$ for the 40-year sample.

Thus, \hat{P} is 0.986 for the highest of 40 years. The two statistics of Source B are plotted at ($P = 0.57, T = -80^{\circ}\text{F}$) and ($P = 0.986, T = -90^{\circ}\text{F}$), to give a best-fitting straight-line Gumbel distribution (Figure 1).

For the 10-percentiles, the two sources yield the following estimates, compared with the previous estimates for Snag:

Data Source	Planned Life (years)				
	1	2	5	10	25
Reduced variate	2.26	2.93	3.88	4.59	5.48
Snag	-73°F	-78°F	-83°F	-87°F	-92°F
Ojmjakon (Source A)	-83°F	-86°F	-89°F	-92°F	-96°F
Verkhoyansk (Source B)	-85°F	-86°F	-89°F	-91°F	-93°F

With regard to a choice as to which estimate to use for the withstanding extremes, the Snag temperatures are subject to wide variations which is why the 25-year 10 percent extreme is as low as -92°F . But this temperature was not even closely approximated by the record at Snag. Source A is under suspicion, largely because of the sporadic reports of the minimum temperatures. On the other hand, the British record's annual low average of -80°F is a 23-year average instead of the 16-year average of Source A, and the all-time extreme of -90°F is shown as the extreme of 40 years. The estimates from Source B are preferred. If accepted, the value of -89°F is estimated to have roughly a 50-year return period and -91°F a 100-year return period.

5. ESTIMATES OF COLD DURATION

The direct approach to estimate duration would require an abundance of hourly data when cold extremes are observed. The preliminary estimates that were made for SAES-JCS, a few years ago, were based on 23 years of hourly data at Snag, which were still too few for confidence. Source A on Verkhoyansk not only is suspect, but is not a complete 15-year record. However, Source A is valuable in demonstrating that the model of duration (Gringorten, 1968) is applicable to Verkhoyansk temperatures with the better, though fewer, statistics of Source B.

In the following four sections of this chapter (5.1 through 5.4), the model is tested and parameters are determined, using first the Snag data, then applied to the Verkhoyansk-Oymyakon statistics using Sources A and B. Lastly, the model is applied to the scant Eismitte, Greenland values in the British Meteorological Office tables (1958).

5.1 Snag, Yukon Territory

The January and February hourly observations at Snag provided the cumulative frequency distributions of Figure 2. The collection of m-hour maxima provided the curves of Figure 3 for January, and Figure 4 for February. By the method of Gringorten (1966), estimates were made of hour-to-hour correlation coefficients in a Markov process (Tables 2 and 3), which gave averages $\hat{\rho} = 0.980$ and 0.989 for February and January, respectively.

From Figure 3 directly, the two to 98-percentiles of m-hour maximum temperatures for $m = 1$ to 768 hours are shown in Table 4. These temperatures are far too high for world-wide extremes of cold. But the Snag exercise has been valuable in providing the hour-to-hour correlation, which is assumed to be $\rho = 0.989$, the January value, it being the coldest month.

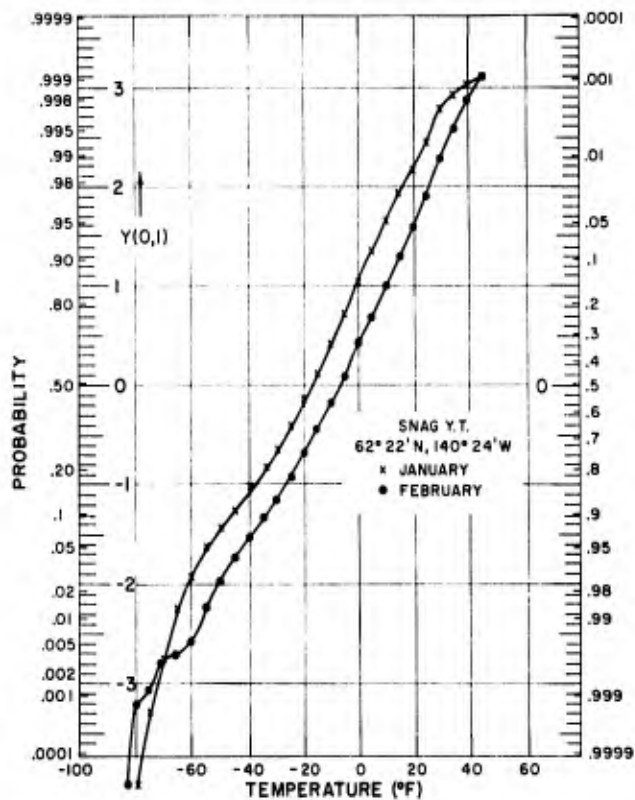


Figure 2. Snag Cumulative Frequency Distribution of Hourly Temperatures in January (crosses) and February (dots) Based on 1944 to 1966 Data

Table 2. Estimates of hour-to-hour Correlation, by Model (Gringorten, 1966), Using the Values of $y(0,1)$ Interpolated in Figure 2 Between Isoleths of the m -hour Maximum of Temperature at Snag, Based on Hourly Data for January, 1944 to 1966. Average $\hat{\rho} = 0.989$

Prob	$y(0,1)$										
	-2.0	-1.5	-1.0	-0.5	0.0	0.5	1.0	1.5	2.0	2.5	3.0
.02									.982	.982	.982
.10								.995	.993	.987	.975
.25							.990	.988	.993	.984	
.50						.989	.989	.990			
.75				.991	.993	.988	.990	.990			
.90			.996	.994	.992	.988	.990				
.98	.988	.982	.994	.994	.992	.987					

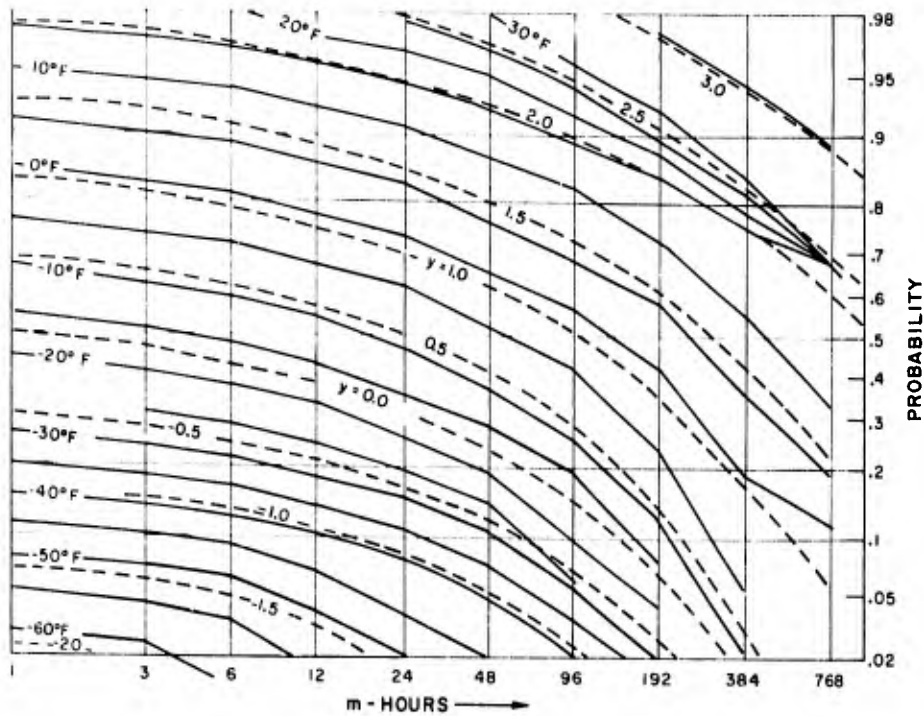


Figure 3. Snag January Distribution of m-hour Maximum Temperature. Solid Lines are Drawn to Actual Data; Broken Lines are Interpolated Isopleths Labelled in Terms of the Normalized Variate $y(0,1)$

Table 3. Same as Table 2, But Using Data for February 1944 to 1966. Average $\hat{\rho} = 0.980$

	y(0,1)										
Prob	-2.0	-1.5	-1.0	-0.5	0.0	0.5	1.0	1.5	2.0	2.5	3.0
.02										.975	.961
.10								.984	.980	.980	
.25							.987	.985	.992		
.50						.979	.984	.993			
.75				.985	.972	.983	.991				
.90			.978	.978	.982	.988					
.98		.958	.953	.972	.984	.992					

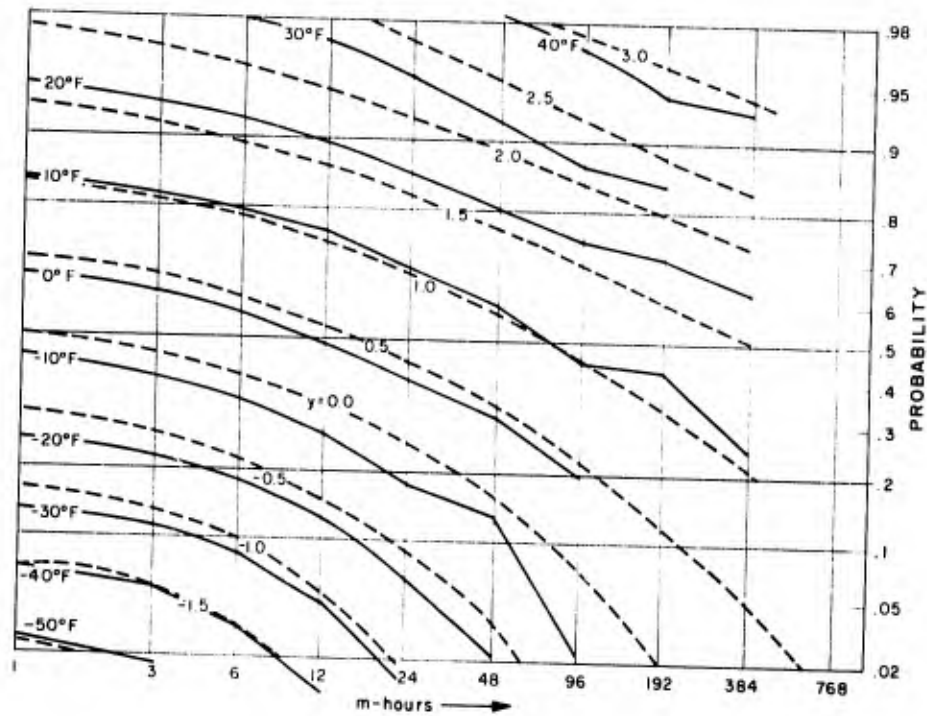


Figure 4. Snag February Distribution of m-hour Maximum Temperature. Broken Lines are Interpolated Isopleths Labelled in Terms of Normalized Variate $y(0,1)$

Table 4. Snag January m-hour Maximum Temperature Probability Estimates, Directly From 1944 to 1966 Sample

m	Probability						
	.02	.10	.25	.50	.75	.90	.98
1	-66°F	-47°F	-31°F	-17°F	-6°F	4°F	16°F
3	-62	-45	-29	-16	-4	5	18
6	-58	-44	-27	-14	-3	6	20
12	-53	-40	-25	-12	-1	8	24
24	-50	-36	-20	-9	1	9	26
48	-45	-30	-17	-6	4	12	30
96	-40	-20	-10	-2	7	17	33
192	-30	-12	-4	3	11	26	36
384	-10	-3	2	9	23	32	37
768	-2	0	7	12	31	36	38

Table 5 shows the lowest m-hour maximum in each January at Snag for which there are sufficient data. These values, when ordered, provided the plot of Figure 5 to estimate the probability distribution of the lowest m-hour maxima in the month of January.

Table 5. Snag January Lowest m-hour Maximum Temperature (degrees F) in Each January (actual data)

year	m									
	1	3	6	12	24	48	96	192	384	768
1944	-47	-44	-44							
1945	-38	-36	-35	-33	-24	-10				
1946	-33	-33	-30	-25	-18	-10	-7	-4	9	9
1947	-80	-76	-73	-62	-46	-42				
1948	-38	-35	-34	-28	-22	-17	-9			
1949	-52	-50	-43	-40	-30	-17				
1950	-68	-64	-57	-39	-22	-15				
1951	-60	-60	-58	-48	-40	-12	-6			
1952	-77	-74	-73	-57	-52	-47	-44	-4	10	
1953	-62	-61	-59	-59	-52	-45	-38	-24	-4	-1
1954	-61	-59	-55	-52	-42	-34	-16	-4	11	14
1955	-62	-49	-40	-38	-24	-16	-5	3	6	11
1956	-60	-56	-54	-48	-40	-34	-25	-21	3	10
1957	-60	-50	-50	-47	-38	-31	-9	-5	29	35
1958	-50	-34	-33	-26	-19	-14	-7	-6	4	32
1959	-64	-64	-63	-60	-53	-31	-30	-14	-9	5
1960	-51	-51	-51	-45	-35	-25	-15	-3	8	15
1961	-46	-41	-39	-30	-25	-24	-9	-5	0	11
1962	-70	-70	-68	-61	-45	-43	-13	-2	18	46
1963	-62	-58	-57	-55	-42	-32	-16	-8	22	33
1964	-59	-59	-56	-50	-40	-38	-30	3	4	
1965	-70	-69	-68	-67	-59	-50	-48	-36	1	13
1966	-66	-65	-63	-62	-53	-50	-40	-15	-14	-4

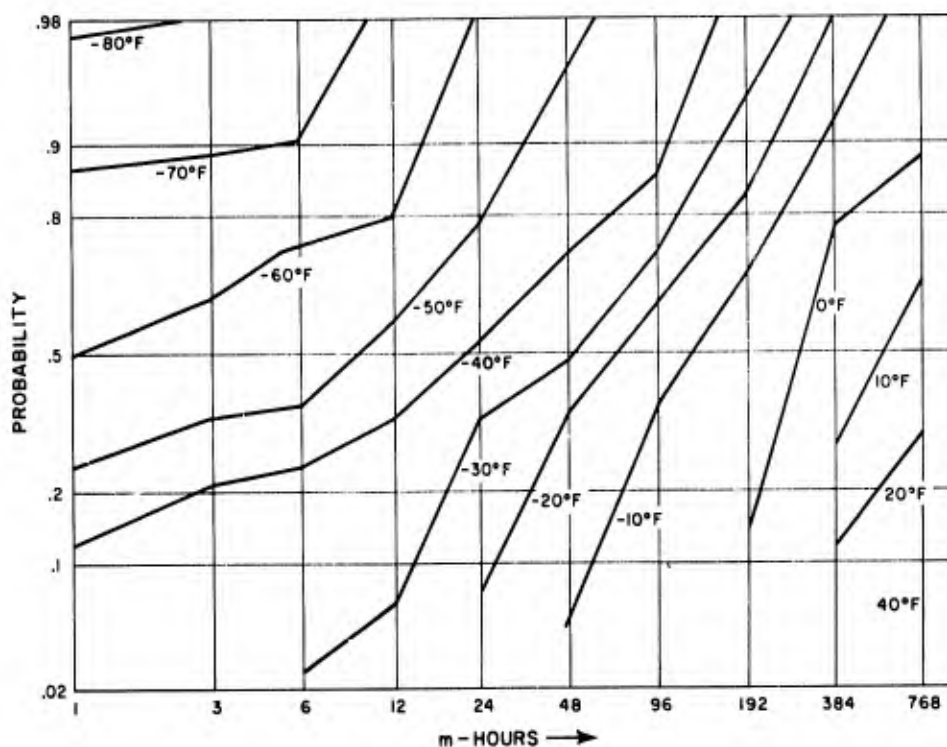


Figure 5. Snag January Frequency Distribution of Lowest m-hour Maximum in 32 Days (1 January to 1 February, incl.) Estimated From 1944 to 1966 Data

5.2 Verkhoyansk and Oymyakon - ETAC Data, Source A

The data, as first requested, were provided as a cumulative frequency distribution of observations in January, the coldest month. There were (supposedly) four observations per day during 1948 to 1958, and eight observations per day during 1959 to 1963. Since some observations were missing, there remained a total of 2260 values of January temperatures at Verkhoyansk, and 1891 at Oymyakon. The average January temperatures for this period of record are -52.3°F at Verkhoyansk, and -50.9°F at Oymyakon. Their cumulative frequencies are both plotted in Figure 6.

5.2.1 DURATION OF OPERATIONAL EXTREMES

At the 20-percent level, the temperatures at the Siberian stations are, by far, the coldest in the inhabited world. As previously stated, -60°F has been established as the goal for actual operations and has this probability in the coldest part of Siberia during the coldest month. The model (Gringorten, 1968) was applied to give the probability of temperature (T) remaining continuously below T for duration of m hours, assuming a Markov process, without diurnal cycle of temperature, and

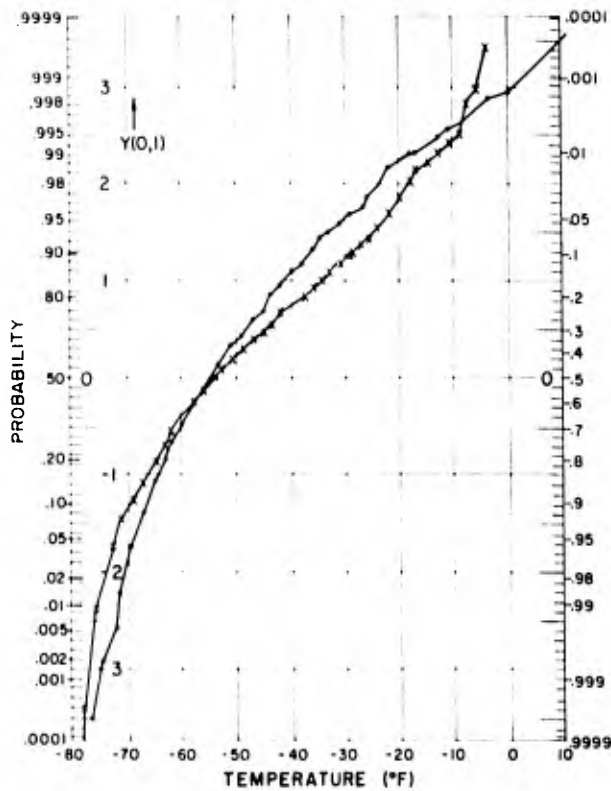


Figure 6. Verkhoyansk (dots) and Oymyakon (crosses) January Frequency Distributions of Temperature Based on 1948 to 1963 Data, Obtained From ETAC

hour-to-hour correlation was assumed to be the same as for January in Snag ($\rho = 0.989$). The model yields the isolines of Figure 7. From Figure 6, at Oymyakon, the value of $y = -3.5$ corresponds to -78°F , the value of $y = -3.0$ corresponds to -77°F , and so on. If, up to the 50-percentile, the isolines in Figure 7 are labelled with the Oymyakon values, but with the Verkhoyansk values for the higher percentiles, then at the 20 percent level, Figure 7 yields:

Temp.	Duration (hrs.)									
	1	3	6	12	24	48	96	192	384	768
$^{\circ}\text{F}$	-63	-63	-62	-61	-58	-54	-51	-46	-40	-32
$^{\circ}\text{C}$	-53	-53	-52	-52	-50	-48	-46	-43	-40	-36

In Figure 8 the solid lines are drawn from direct estimates of the distribution of m -hour maximum of Source A. To obtain the latter figures, the record, faulty though it was, had to be carefully scrutinized for intervals between recorded temperatures of 3 hours, 6 hours, 12 hours, and so on, and the maximum temperatures sorted. A comparison of the value noted along the 80 percent ordinant line

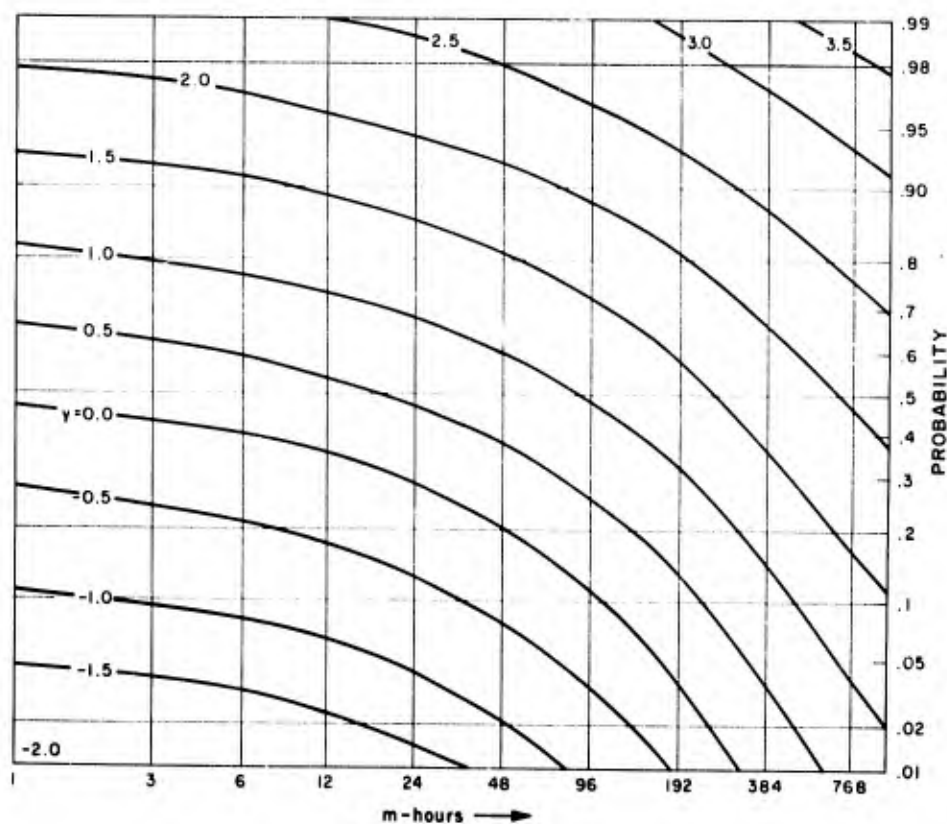


Figure 7. Probability Distribution of the m -hour Maximum of the Normalized Continuous Variate $y(0,1)$, Estimated by Model with Correlation Coefficient Equal to 0.989

(20 percent cold extreme) in Figure 8 to the values provided above indicates that the model with hour-to-hour correlation assumed as 0.989 works well for Verkhoyansk.

5.2.2 DURATION OF WITHSTANDING EXTREMES

It has been shown above that the model works well for m -hour maximum. To examine its applicability to the lowest m -hour maximum in the month, Figure 9 is provided. It can be compared with the empirical data for Snag in Figure 5, by holding one figure over the other. Although this is subjective, it is readily seen that the curves cross each other considerably. It must be concluded that the duration model, applied to the lowest m -hour maximum temperatures in one month at Snag, yields poor results. Would it also do likewise in the Siberian cold center?

The admittedly suspect record of Source A was again searched for an estimate of the distribution of the lowest m -hour maximum in 32 days at Verkhoyansk. The result shown in Figure 10, when compared with the model of Figure 9, again subjectively, indicates that the patterns are much closer than with the Snag data.

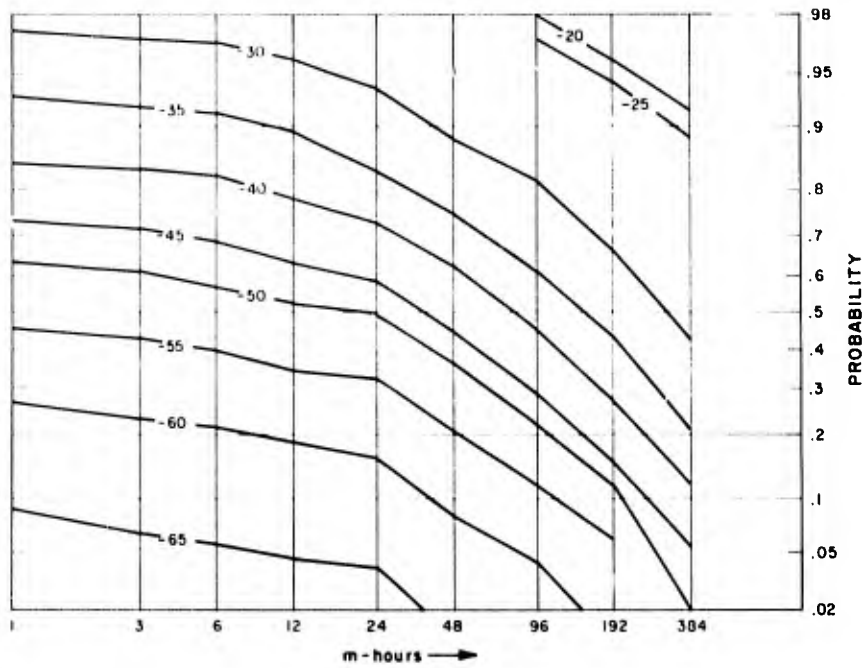


Figure 8. Verkhoyansk January Cumulative Frequency Distribution of m-hour Maximum Obtained Directly From a Partial Record of 1948 to 1963 Data (see text)

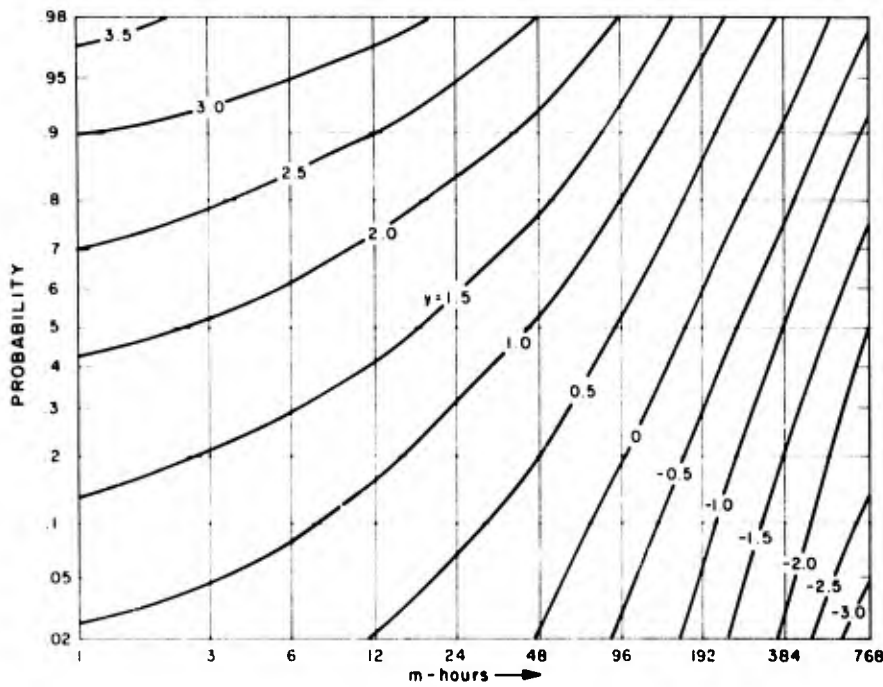


Figure 9. Model Cumulative Probability of Highest m-hour Minimum of the Normalized Variate $y(0,1)$ in 32 Days with hour-to-hour Correlation 0.989; or the Lowest m-hour Maximum in 32 Days of $-y(0,1)$

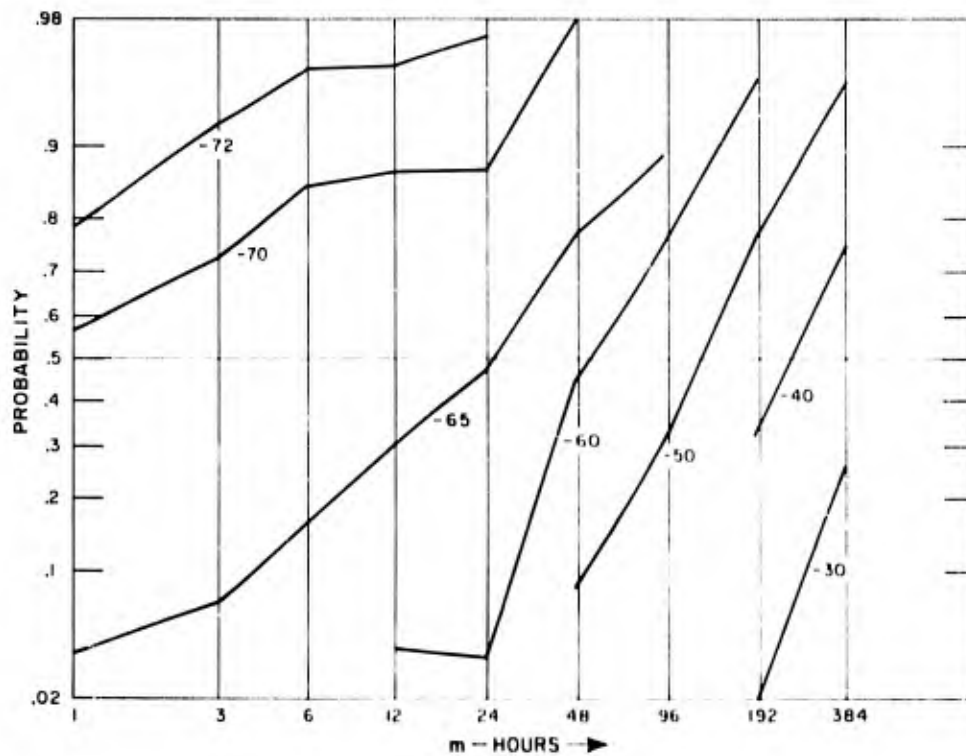


Figure 10. Verkhoyansk January Temperatures Processed to Show Frequency Distribution of the Lowest m -hour Maximum in 32 Days. The Data are the Selected Values of 1948 to 1963, Used in a Cloud Study (ETAC)

After some consideration of the problem, it is believed that Snag's weather regime is generally much warmer than Verkhoyansk's or Ojmjakon's, but is subject to a bimodal peak at very low temperatures that makes the usual Markov process much more difficult to apply satisfactorily. On the other hand, the model should still yield useful results for the Siberian cold center where the temperatures appear to be much more persistently cold in winter and with a much smaller standard deviation. It is decided, therefore, to continue to use the model, using Figure 9 for determining the distribution of the lowest m -hour maxima, in January, both with Source A data and Source B data (below).

Taking $m=1, 12, 24, 48, 96, 192, 384,$ and 768 , Source A yields curves of Figure 11. The latter are drawn on extreme probability paper, so that each temperature is shown in a one-to-one correspondence with η whose distribution is a double exponential: $P(\eta) = e^{-e^{-\eta}}$ (Gringorten, 1963b). As described in the reference, values of η can be found to correspond to a given risk and planned life (Table 6). Each value of η on the 10 percent line in Table 6 corresponds to a value of temperature on each curve of Figure 11, to yield the estimates, the 10-percentiles of

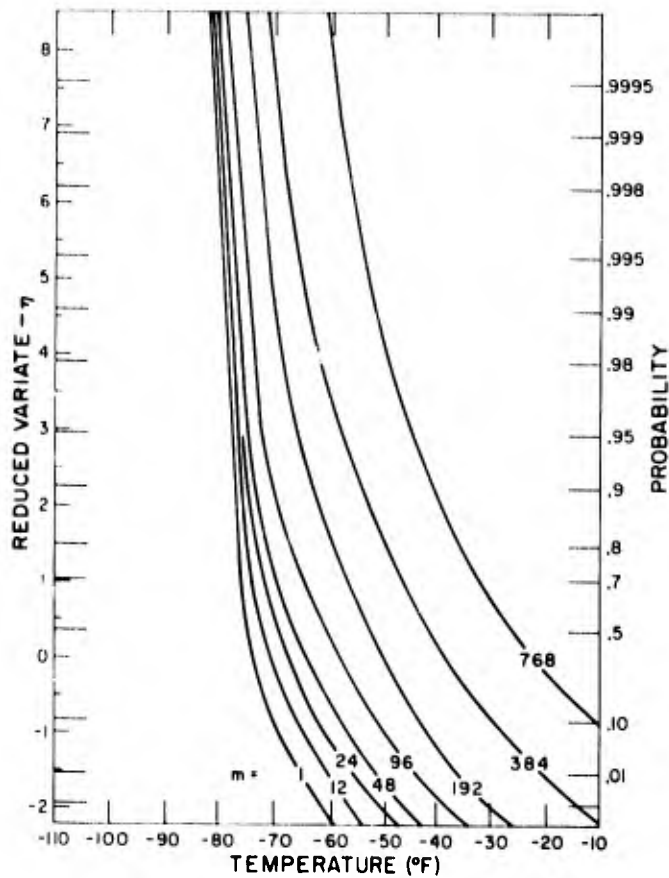


Figure 11. Verkhoyansk-Oymyakon January Probability Distribution of the Lowest m -hour Maximum in 32 Days (1 January to 1 February, incl.). Estimates, by Model, are Made for hour-to-hour Correlation of 0.989 and Based on 2260 Values of January Temperatures Supplied by ETAC, 1944 to 1966

extremes in Table 7. To obtain these estimates, however, the curves of Figure 11 had to be extrapolated above the 98-percent ranges of the curves.

Table 6. Value of the Reduced Variate, η , Whose Probability P is Given by $P = \exp(-\exp(-\eta))$ for the Combination of Risk and Planned Life.

Risk	Planned Life				
	1 year	2 years	5 years	10 years	25 years
1%	4.60	5.30	6.23	6.92	7.82
10%	2.26	2.93	3.88	4.59	5.48
25%	1.25	1.94	2.90	3.58	4.48
50%	0.36	1.04	2.00	2.69	3.60

Table 7. Verkhoyansk-Oymyakon 10-percent Probable Lowest m-hour Maximum Temperature in 32 Days (1 January to 1 February, Incl.) Estimates, by Model, Based on 1948 to 1963 Data Provided in Source A

m (hours)	Planned Life				
	1 year	2 years	5 years	10 years	25 years
1	-77°F	-78°F	-78°F	-79°F	-80°F
12	-76	-77	-77	-78	-79
24	-75	-76	-76	-77	-78
48	-74	-75	-76	-76	-77
96	-71	-73	-74	-75	-75
192	-67	-70	-72	-74	-75
384	-60	-64	-70	-72	-74
768	-50	-54	-59	-62	-65

5.3 Verkhoyansk and Oymyakon - British Data, Source B

The British Meteorological Office (1958) has published two to six statistics for each month for hundreds of stations. For Oymyakon, these statistics are based on observations in the period 1930 to 1934, and for Verkhoyansk 1884 to 1935. From such data, for the coldest month, January, it is possible to restore the cumulative frequency distribution of temperatures using the Markov-type model (Gringorten, 1968) as follows:

As above, the hour-to-hour correlation is assumed to be $\hat{\rho} = 0.989$, making the isopleths of Figure 7 apply to this problem. An n-year extreme is assumed to estimate cumulative probability which, by the Blom formula, is

$$\hat{P} = (n - 3/8)/(n + 1/4) \text{ for the maximum, and}$$

$$\hat{P} = (1 - 3/8)/(n + 1/4) \text{ for the minimum.}$$

The average is assumed to be the median value, $\hat{P} = 0.5$. All estimates are based on January figures.

For Oymyakon the absolute maximum, T, in 4 years is -9°F . For n equal to 4, we estimate \hat{P} at 0.853. From Figure 7, the value of $y(0, 1)$ for the 744-hour maximum, at P equal to 0.853, is 2.70 and is plotted at point (T = -9, y = 2.70) in Figure 12.

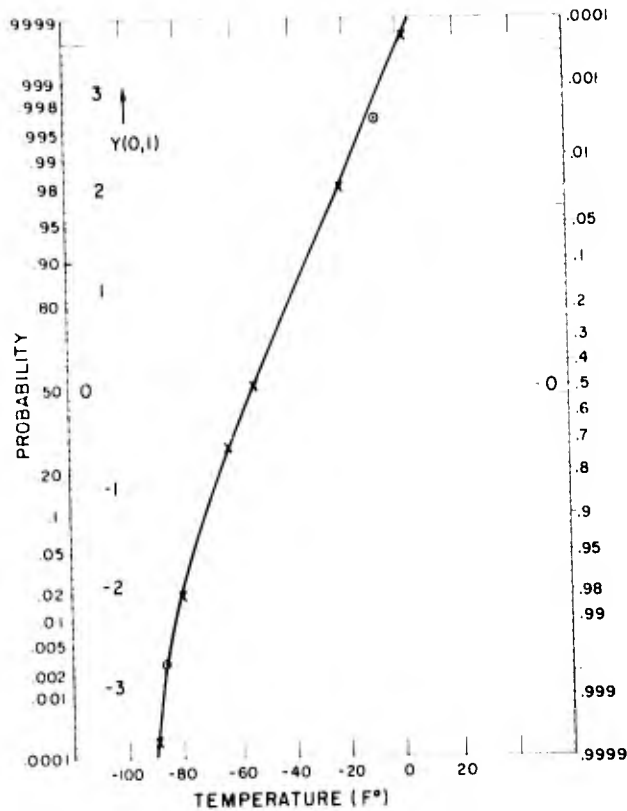


Figure 12. Verkhoyansk (crosses) and Oymyakon (circles) January Temperature Statistics Taken From British Meteorological Office (1958) and Plotted at Cumulative Frequencies Estimated by Model ($\rho = 0.989$). Solid Line is Best Fitting Distribution of January Temperatures

The absolute minimum of T in 5 years is -86°F . Estimating P at 0.119, Figure 7 (reversed for estimating minimum) gives, at 744-hour duration, y equal to -2.78 , which is plotted at point $(T = -86, y = -2.78)$ in Figure 12.

For Verkhoyansk, the average 1300 LST temperature is -54°F . If the assumption that the winter months at high latitudes have no significant diurnal cycle, this value, at a single hour like 1300, comes close to being an average for the day. When assumed to be the 50-percentile, it is plotted at $(T = -54, y = 0)$ in Figure 12.

The average daily minimum is -63°F . Assuming this to be for probability 0.5, Figure 7 gives, for the 24-hour minimum of y , -0.57 and is plotted at $(T = -63, y = -0.57)$ in Figure 12.

The average highest in each month is given as -22°F . Assuming this to be the 50-percentile of the 744-hour maximum, Figure 7 gives the corresponding y -value at 2.05, which gives the plotted point $(T = -22, y = 2.05)$ in Figure 12.

The average lowest in each month is -80°F . Assuming this to be the 50-percentile of the 744-hour minimum, Figure 8 gives the corresponding y as -2.05 , which leads to point $(T = -80, y = -2.05)$ in Figure 12.

The absolute maximum in 48 years is given as 2°F , for which the probability estimate is 0.9870. Figure 7 gives the 98.7-percentile of y , 744-hour maximum, as 3.60, which is plotted as $(T = 2, y = 3.60)$ in Figure 12.

The absolute minimum in 40 years is -89°F . Hence, estimating P at 0.016, Figure 7 gives y as -3.53 , which is plotted at $(T = -89, y = -3.53)$ in Figure 12.

Thus, the British Meteorological Office (1958) provided for the estimated location of six points on the cumulative probability curve of January temperatures at Verkhoyansk (Figure 12). The two points for Oymyakon lend encouraging support to the drawing of the smooth curve. Comparison of Figure 12 with Figure 6 suggests that the observed temperature distribution of the 1884 to 1935 period was the same as the observed temperatures of the 1948 to 1963 period for 70 percent of the time. But the most extreme temperatures were 10 to 14°F lower in the earlier years. This difference is real, since the 1948 to 1963 record never showed any temperature less than -78°F at either Siberian station (Columns(1) Table 1), whereas Siberia had become notorious for temperatures reaching the -90°s (Column (2) for Oymyakon, Table 1). Source A gave -80°F as the average minimum for January.

5.3.1 DURATION OF OPERATIONAL EXTREMES

At the 20-percent level, the model provides from the British data (Source B) estimates as follows:

Duration (Lows)	Hours									
	1	3	6	12	24	48	96	192	384	768
$^{\circ}\text{F}$	-64	-63	-62	-61	-58	-54	-50	-43	-36	-29
$^{\circ}\text{C}$	-53	-53	-52	-52	-50	-48	-46	-42	-39	-34

5.3.2 DURATION OF WITHSTANDING EXTREMES

As above, it is necessary to estimate the distribution of the lowest m -hour maximum in the month. P is assumed to be 0.989, allowing Figure 9 to be used as a basis for estimates. Labelling the isopleths of Figure 9 with the aid of Figure 12, the distribution of the lowest m -hour maximum in 32 days (Figure 13) is drawn on extreme probability paper. Again, the most extreme temperatures must be extrapolated.

The values for the 10 percent risk of lowest m -hour maximum in Table 6 are used to provide the values shown in Table 8. At this point, an observation must be made of the first line of Table 8 for the 10-percentile of the lowest 1-hour temperatures in January to compare with the 10-percentile estimates of the lowest annual temperatures as given in Chapter 4. For the 1-, 2-, or 5-year planned life, the estimates in Table 8 are 1 to 3 Fahrenheit degrees too extreme, but for the 10- and 25-year planned life the estimates are in remarkably good agreement, since the

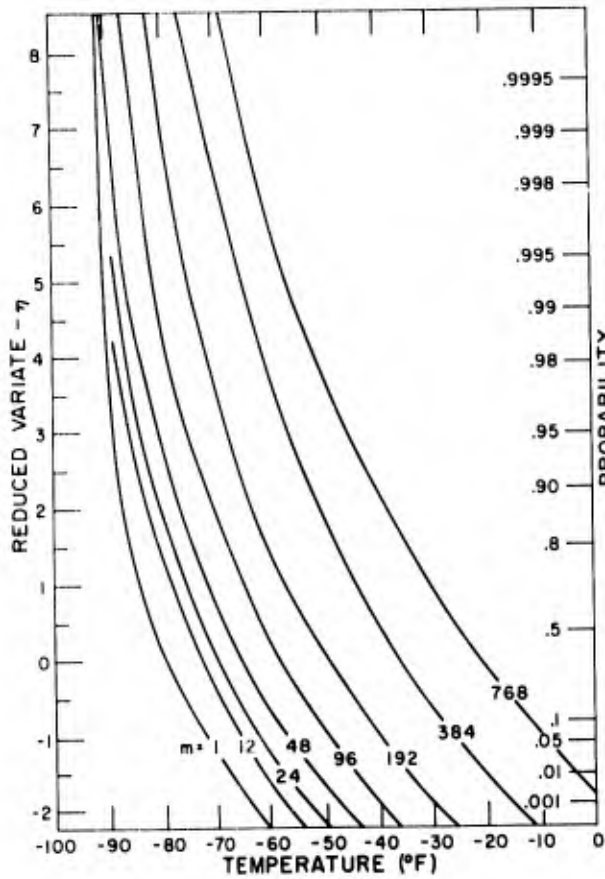


Figure 13. Verkhoyansk January Probability Distribution of the Lowest m-hour Maximum Based on British Data of 1886 to 1934 as Restored by Model in Figure 12

Table 8. Verkhoyansk 10-percent Probable Lowest m-hour Maximum Temperature in 32 Days, Estimates by Model, Based on January Statistics of Source B (British)

Duration (hours)	Planned Life				
	1 year	2 years	5 years	10 years	25 years
1-hour	-87°F	-89°F	-90°F	-90°F	-91°F
12-hour	-84	-86	-88	-89	-90
24-hour	-82	-84	-87	-88	-89
2-day	-78	-81	-84	-83	-87
4-day	-72	-75	-79	-81	-82
8-day	-63	-67	-71	-73	-76
16-day	-53	-56	-60	-63	-67
32-day	-39	-43	-49	-53	-57

lowest January temperature, in probability, should be a few degrees warmer than the lowest annual temperature.

In a choice, below, Table 8 will be used without the 1-hour line.

5.4 Eismitte, Greenland

In the same British Meteorological Office (1958) publication from which the above-mentioned Siberian statistics (Source B) were obtained, there appear four statistical values of temperatures for each month at Eismitte, in the heart of Greenland, as recorded during a single year, 1930 to 1931. The average daily maximum and minimum in each month, again, should serve as estimates of median values of 24-hour maximum and minimum, corresponding to values of y of 0.58 and -0.58, respectively (Figure 14), and the highest and lowest temperature recorded for the month should serve as estimates of the medians of the 744-hour maximum and minimum, corresponding to values of y of 2.05 and -2.05, respectively (Figures 7 and 14). Thus, there are four points to fit with a curve of probability distribution of temperature for February, as drawn in Figure 14. The curve, as might be expected, suggests even lower extremes in central Greenland than in Siberia, although there is a greater variance, allowing for warmer days. The average is the same, at -53°F .

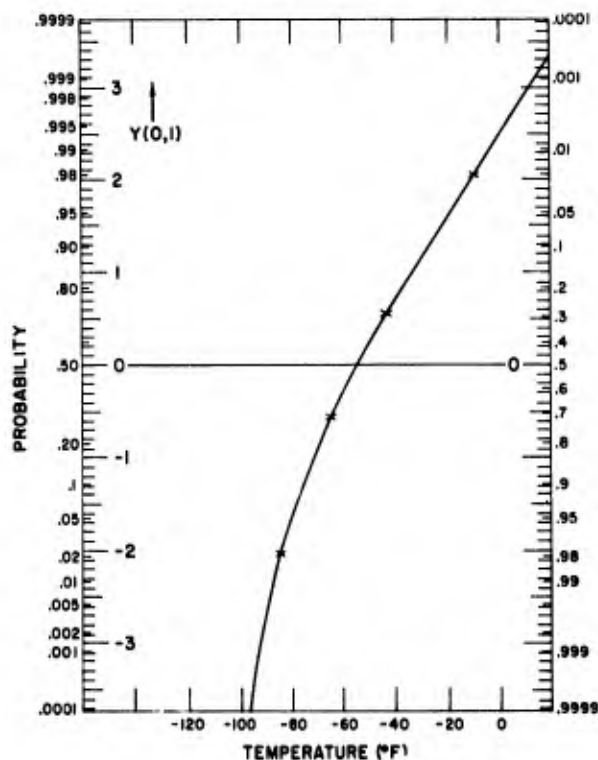


Figure 14. Eismitte, Greenland February Temperature Distribution Restored by Model From British Meteorological Office (1958) Data of 1931

The operational figures will not be affected by the above estimates for Central Greenland. But, for "withstanding", Figure 9 yields the distribution of lowest m-hour maximum in the coldest month, February in this case (Figure 15), and shows still lower extremes, even with conservative extrapolation. The estimates of the 10-percentiles of the lowest m-hour maximum in the month are shown in Table 9. These values are 6 to 9 degrees colder than Verkhoyansk for persistence of only a couple of hours, but for persistence of cold over 8 days, they are 1 or 2 degrees warmer. Since this result is based on only a 1-year data sample, it can be presented only as a matter of interest. Extremes for return periods of many years must be based upon the more reliable supporting data for Siberia.

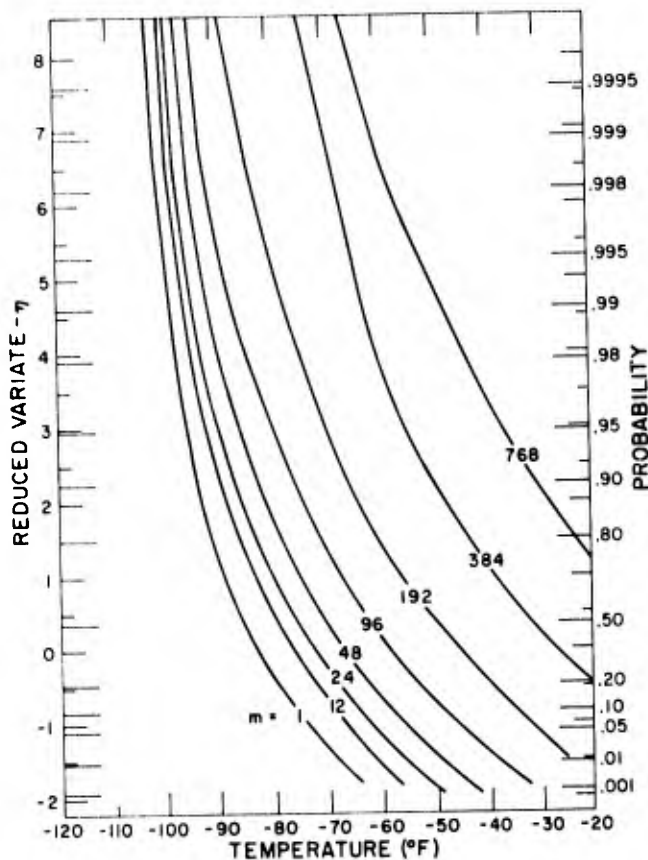


Figure 15. Eismitte, Greenland February Probability Distribution of Lowest m-hour Maximum Temperatures in 32 Days (1 January to 1 February, incl.). Estimates, by Model, are Based on Restored Distribution (Figure 14)

6. RECOMMENDATIONS

(a) The actual extremes for "withstanding" with a 10 percent risk in 2, 5, 10, and 25 years should be based upon the data for Siberia rather than Snag. From Table 1 in Section 4, values of -86, -89, -92, and -95°F are suggested.

Table 9. Eismitte, Greenland 10-percent Probable Lowest m-hour Maximum Temperature in 32 Days, Estimates by Model, Based on 1930 to 1931 Data of British Meteorological Office (1958)

Duration (hours)	Planned Life				
	1	2	5	10	25
1-hour	-93°F	-95°F	-97°F	-99°F	-100°F
12-hour	-89°F	-91°F	-94°F	-95°F	-97°F
24-hour	-87°F	-89°F	-92°F	-94°F	-95°F
2-day	-83°F	-85°F	-89°F	-91°F	-93°F
4-day	-76°F	-79°F	-84°F	-86°F	-89°F
8-day	-65°F	-69°F	-74°F	-76°F	-79°F
16-day	-50°F	-55°F	-60°F	-62°F	-65°F
32-day	-30°F	-36°F	-43°F	-47°F	-54°F

(b) The probability of persisting cold extremes for operations should be patterned after the values shown in Section 5.3.1. Since -60°F has been established as the actual goal, the model (Figure 7) is applied with -60°F as the key value on the Verkhoyansk distribution (Figure 12). It is, in fact, the 20 percent coldest month extreme on the periphery of the cold center. The model yields the following durations:

	Duration (hours)									
	1	3	6	12	24	48	96	192	384	768
°F	-60	-58	-57	-55	-53	-49	-45	-38	-31	-25
°C	-51	-50	-49	-48	-47	-45	-43	-39	-35	-32

(c) The probability of persisting cold extremes for "withstanding" should be obtained by supplementing the figures in recommendation (a) with the patterns in Table 8. The temperature estimates in Table 8 include no temperature that has not been experienced in Verkhoyansk and Oymyakon except for the -91°F with a 250-year return period. But, while these estimates are made for the single month of January, as opposed to the estimates for the whole winter season, the evidence described in Section 5.3.2 suggests that, by way of adjustment, Table 8 figures

should be accepted as annual extremes. Temperature ($^{\circ}\text{F}$) inputs for various durations up to a month (a 32-day month because of the model) with little additional smoothing are decided as follows:

Duration	Planned Life			
	2	5	10	25
1-hour	-86	-89	-92	-95
12-hour	-85	-88	-89	-90
24-hour	-84	-87	-88	-89
2-day	-81	-84	-85	-87
4-day	-75	-79	-81	-82
8-day	-67	-71	-73	-76
16-day	-56	-60	-63	-67
32-day	-43	-49	-53	-57

7. ASSOCIATED PHENOMENA

The coldest nights are assumed to be caused by radiational cooling, and therefore, are associated with winds calm. The relative humidity is assumed to be 50 percent. Radiation is assumed to be black-body radiation.

8. CONCLUDING NOTES

The durations presented herein do not necessarily occur as a single family of events. To clarify, recommendation (b) suggests that equipment should be able to operate after temperatures get as cold as -58°F for 3 hours and as cold as -49°F for 2 days. There is a 20 percent probability of each of these events independent of the other. Temperatures will fall below those values during the durations stated, but the model used does not imply that when it falls below -48°F for 48 hours it will be below -52°F for 24 hours, -54°F for 12 hours, and -56°F for 6 hours with the same probability. However, some such approximation would be useful in simulating durations of cold extremes when testing equipment. An early treatment (AFCRL, 1965) provided the average duration of temperature within 2, 4, 6, --- $^{\circ}\text{F}$ of the minimum when temperatures at 65°N to 90°N were below -55°F as follows:

$^{\circ}\text{F}$ above minimum	2	4	6	8	10	15
Duration (hours)	11	20	24	31	37	52

Comparison with recommendation (b) reveals that using the value for 24 hours or less as part of a single test will not be far from typical, but, for longer periods, temperatures as cold as the values in the recommendation would be somewhat overly conservative.

References

- Air Force Cambridge Research Laboratories (OAR) (1965) Handbook of Geophysics and Space Environments, pp. 3-11.
- ETAC-USAF, Data Processing Division, Special studies prepared at Federal Building, Asheville, N. C.
- Gringorten, I. I. (1963a) A Simplified Method of Estimating Extreme Values from Data Samples. J. of Appl. Meteorol., 2: 82-89.
- Gringorten, I. I. (1963b) A Plotting Rule for Extreme Probability Paper, J. Geoph. Res., 68: 813-814.
- Gringorten, I. I. (1966) A Stochastic Model of the Frequency and Duration of Weather Events, J. Appl. Meteorol., 5: 606-624.
- Gringorten, I. I. (1968) Estimates of Duration of a Continuous Variable by Markov Process, Proceedings of the First Statistical Meteorological Conference, 27-29 May 1968, Hartford, Conn., Amer. Meteorol. Soc., Boston, Mass., pp 52-60.
- Gumbel, E. J. (1958) Statistics of Extremes. Columbia University Press, New York.
- British Meteorological Office (1958) Tables of Temperature, Relative Humidity and Precipitation for the World, Parts I-VI.
- Salmela, H. A., and Sissenwine, N. (1970) Estimated Frequency of Cold Temperature Over the Northern Hemisphere, AFCRL, (to be published).

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13. ABSTRACT Duration, in hours and days, of low temperature during which equipment must operate and long term durations of extreme cold which equipment should "withstand" without irreversible damage, are provided in the revision of MIL-STD-210A, <u>Climatic Extremes for Military Equipment</u> . A low temperature of -60°F was established (in guidance from the Joint Chief of Staff) at which equipment should still be operable. But still lower temperatures, persisting from one to several days, at which the equipment must be able to withstand on standby for periods of 2 to 25 years, had to be inferred by modelling, to supplement the evidence of several scant data sources in the remote frigid areas of the world. The operational 20 percent extreme cold, equalled or exceeded continuously for 12 hours in the cold heart of Siberia, is -60°F. The withstanding 10 percent extreme is lower than -80°F in 2 to 4 days' exposure for a planned life of 2 to 25 years.		

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