STATISTICAL INVESTIGATION OF ANOMALIES

IN THE TEMPERATURE RECORD OF BOSTON, MASSACHUSETTS

by

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ABSTRACT

Normal maximum and minimum temperatures are computed for each date of the winter season from the 92-year Boston temperature record. Trend is removed from the normal and individual yearly values and standard deviations and errors are computed. Statistical significance levels are calculated and a count of significant values is made. The probability of obtaining these by chance is computed and found to be quite high. Average maximum and minimum values are computed for each date for each phase of the double sunspot cycle in addition to a major-half phase and minor-half phase. A procedure similar to that mentioned earlier is followed and four phases out of 20 are found to have 1% significance counts with a high degree of confidence. The standard deviations of both maximum and minimum temperatures for the eight phases exhibit cycles that are parallel to the double sunspot cycle. The result of applying a statistical "F" test indicates that the maximum and minimum cycles are real. An apparent division of the winter season is examined in which anomalous values tend to occur in the early part of the winter during the minor-half phases and in the latter part of the winter during the major-half phases.

Thesis Supervisor: Hurd C. Willet
Title: Professor of Meteorology

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SECTION I

INTRODUCTION

A. HISTORICAL BACKGROUND

An investigation of the folklore of the world will reveal many references to the annual recurrence of weather phenomena characterized by periods of unseasonable warmth or cold. Names such as — "January Thaw", "January Frost", Ice Saints", "Indian Summer", "Old Wives' Summer" and "Christmas Thaw", to mention only a few, are common terms throughout the world, although some may apply only to certain geographic areas. Most amateur forecasters and meteorologists will stand fast and unambiguously maintain that these "singularities" are real and will undoubtedly recur in the future; while among professional meteorologists, the subject has always and is presently quite controversial.

At this point, it is necessary to define the terms, "singularity" and "anomaly", and to adopt these meanings throughout this text, although it may be necessary to supersede the definition when a direct quote is used. The term "anomaly" will be used to denote a value which appears to be a peak or trough in the parameter's time profile, while the term "singularity" will be used to denote an "anomaly" which can be shown to be statistically significant.

A review of the literature shows that the concept of temperature singularities dates as far back as 1860 when Forbes (1860) discussed

"Periodic Anomalies" in the 40 year temperature record of Edinburgh. Talman (1919) published a comprehensive bibliography of work done on this subject up to that date. In the past half century, the majority of contributions have come from the European scene (Bayer, 1956; Blagoev and Lalovski, 1958; Brooks and Mirrlees, 1930; Kramer, Post, and Scharringer, 1952; Lamb, 1950; McIntosh, 1953; Péczely, 1958; Reynolds, 1955; and Shinya, 1958). In general, results have been quite controversial with some agreement among authors and considerable disagreement.

The work in America has been chiefly confined to investigations of the "January Thaw". Since the origin of this "Thaw" is folklore, there is no precise, universal definition of this phenomenon. In New England, the "January Thaw" is thought to be a warm spell occurring approximately on 21-22 January. There is another warm period during the first week of January that has also been given this name in other parts of the country.

In 1919, Marvin, who was then chief of the United States Weather Bureau, made an examination of the annual temperature record of several North American cities. He concluded that: "Each striking feature on a long record is therefore no evidence of the persistent recurrence of peculiar irregularities, but is simply a residual scar or imprint of some unusual event or a few which have fortuitously combined at about the time in question. Time will inevitably efface these, ..."

There is no doubt that these stern and quite conclusive results seemed to close the case of "singularities" and hindered any further undertakings on this subject. Although research was hindered, it was not entirely stopped by Marvin's conclusions.

In contrast, Slocum (1941) investigated the temperature records in Washington, D. C., and a few other selected stations, and concluded that there was a definite "warm anomaly" during the period 20-23 January followed by a colder than normal period about 5 February.

In Marvin's (1919) paper, he stipulates that for a singularity to exist, it must be supported by physical reasoning. Further research along these lines was performed by Wahl (1952) who studied the temperature record of Boston, Massachusetts and other selected stations in addition to records of other parameters such as gradient wind direction, pressure gradient, thundershower occurrence, and snow depth. He attempted to relate the January Thaw to a general circulation index-cycle pattern.

When he compared the normal sea-level pressure chart for 20 January with that of 27 January, he found a striking contrast. On 20 January, the Bermuda High is stronger and further North than normal. In addition, the normal trough along the east coast of the United States is displaced far out to sea and another trough is located in the Midwest creating a strong southwesterly flow in the eastern United States. By the 27th, the pattern has completely changed. The trough that was in the Midwest is now off the East Coast and a large anticyclone dominates most of the United States. Thus Wahl concludes that a low zonal index-cycle pattern favors the anomalous warmth in January.

Another investigation seeking a link between a January Thaw and the general circulation was performed by Duquet (1963). Using 700 mb and mean weekly surface temperature data of many stations, he concludes: "The course of the winter ... involves two stages in the northeastern United States. The stages are separated by a 'warm spell' which occurs in early January. The geographical extent of the warm spell indicates that Gulf Coast cyclones tracking along the Appalachians are the vehicle by which warm air is transported into the region. Secular changes in the amplitude of the warm spell ... are related to simultaneous changes in the planetary circulation and are not independent fluctuations." Duquet also notes that at the time of the thaw the potential energy in the atmosphere over North America is at a maximum due to the fact that over the northwestern part of North America, the temperature is at a minimum.

This would lead one to expect to find the thaw at stations in the West at a different time than its occurrence in the East. This is confirmed by Wahl, who found a rise in temperature at Columbia, Missouri, between 17 and 21 January. Kangresses (1957) also found a possible singularity in the minimum temperature at Phoenix, Arizona. Rebman (1954) and Schick (1944) found similar results in other western stations. In each of these two cases, either normal or below normal temperatures occurred during 21-22 January.

In another investigation, Lautzenheiser (1957) tabulated dates of thaw periods during January in Boston in order to find a preferential period of occurrence. He concludes that: "This failed to show any particular date as being much favored over another, ... it is a curious fact that the period January 21-23 ... actually had fewer thaws than any other three day period." He attributes the fact that more thaws occur during the earlier part of January than the latter to the annual march of temperature. He further concludes that: "one cannot pick out a preferred date for a 'January Thaw' other than it should occur in January. They do not occur every year ... (but) on the other hand, over 50% of the January's had two or more thaws."

As can be seen by the brief discussions above of previous work on this subject that conclusions are inconsistent or contradictory. In addition, due to the lack of universal definition of the January Thaw, different time periods have been used for the occurrence of the thaw in many of the investigations.

B. OBJECT

The primary object of this study is to examine the winter-season temperature records of Boston, Massachusetts, and to investigate the existence of the January Thaw. By comparison with other singularities in the temperature record, the actual significance will be determined. It is necessary to emphasize the use of the term significance rather than reality. It is almost impossible, when dealing with data such as this, to prove that a singularity is real and exists, but it is possible to show that the probability of the chance occurrence of these anomalous points in the temperature record is very small.

It is not intended that a physical cause-and-effect relationship should be formed between the "Thaw" and some other parameter, but rather to determine when and how significant are any singularities during winter. It is also intended that a comparison between the "January Thaw" with other anomalies be made and a determination of its relationship to other time periods. The possible relationship between the eight phases of the double sunspot cycle and occurrence of anomalies will also be investigated.

SECTION II

INVESTIGATION OF NORMAL DATA

The official Weather Bureau temperature record for Boston, Massachusetts dates back to 1872. Although this consists of data taken at different locations, the errors introduced by different locations may be considered negligible because in this study only deviationsfrom the normals are used. Although most previous studies examined either the mean temperature record of a station or the maximum temperature, it was decided to investigate both the maximum and minimum temperature records and treat each as an independent entity. The data consist of the 92-yearly values for each date of the winter season, defined as 1 December to 28 February. Since 29 February occurs only approximately every four years and would therefore comprise a small sample, it was omitted from this study.

A 92-year arithmetic mean was computed for both maximum and minimum temperatures for each date. Let us call this the daily "normal", and denote it by $\overline{X}_i$,

$$\overline{X}_i = \sum_{n=1}^{92} \frac{x_n}{92} \qquad (i = 1, 2, 3, \ldots 90) \qquad (1)$$

Since maximum and minimum temperatures are treated separately, the notion may be applied to either.

Since the data contain a trend due to the annual march of temperature, it was decided that all computations would be done on data that are trend-free, i.e., actual data values minus the smoothed daily normal which represents the trend. If the trend were not removed and deviations, Δ_i, were computed from the grand normal, $\bar{\bar{X}}$,

$$\bar{\bar{X}} = \sum_{i=1}^{90} \frac{\bar{X}_i}{90} \tag{2}$$

$$\Delta_i = \bar{X}_i - \bar{\bar{X}} \tag{3}$$

unrealistic results would be obtained and would undoubtedly lead to incorrect conclusions concerning singularities and their significance. If a trend curve were used instead of the grand normal, the seasonal influence would be removed and all deviations would be relative to a straight-line mean.

Figures 1 through 3 illustrate this point. As can be seen in Figure 1, all deviations computed from point A to point C will have positive values while those computed from C to D will be negative. Figure 2 illustrates a hypothetical "normal" value curve and an associated trend curve. Figure 3 shows the result of taking deviations with respect to the trend. The mean $\bar{X}_i - \bar{\bar{X}}$ in this figure equals zero. As is quite evident, there are positive and negative values present throughout the entire time period.

The actual method used to determine the seasonal trend was arbitrary. Some authors (Duquet, 1963; McIntosh, 1953; and others)

1.

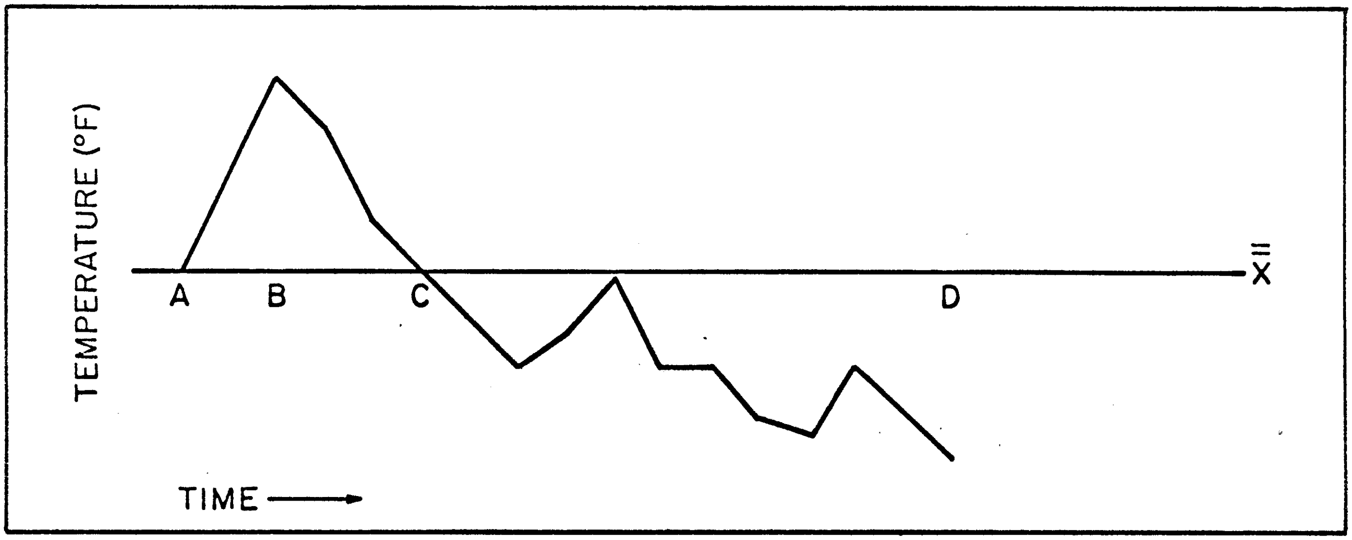

Figure 1. Example of a temperature record.

2.

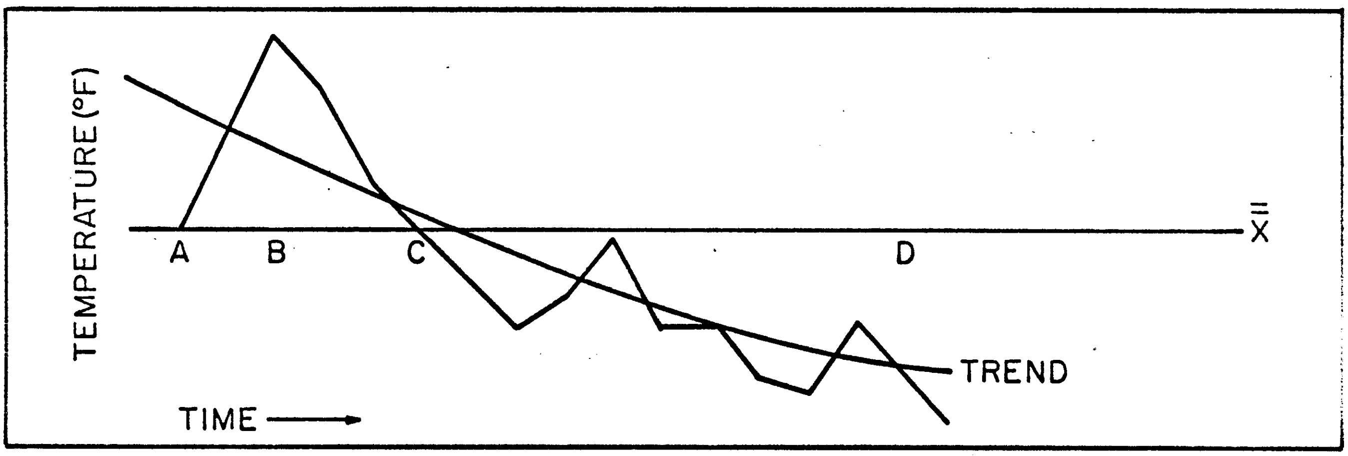

Figure 2. Example of a temperature record and associated trend.

3.

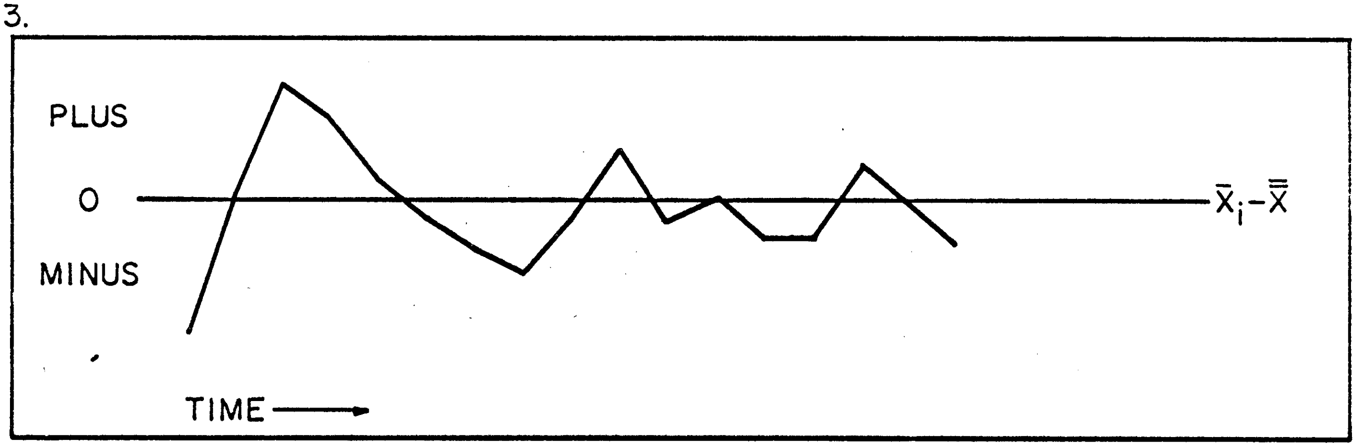

Figure 3. Example of trend-free temperature record.

used the first two harmonics to determine the periodic fluctuations of their data. But, in contrast to their data which covered 12-month periods, these data consist of a record of only three months. Therefore, since harmonic analysis can only be used on data which contains at least one cycle, another method would have to be used to determine an analytic expression for the trend. Panofsky (1958) suggests that when the trend shows definite curvature, a parabola may be fitted to the data by the method of least squares.

Figures 4 and 5 illustrate the 92-year normal curves and the second degree fitted polynomial, denoted in the term "trend". In the mathematical process of curve fitting, the convention of numbering the dates consecutively from 1 to 90 was adopted. The equations of the polynomials are as follows:

for maximum temperatures,

$$X = 43.3 - 0.270D + 0.0025D^2 \tag{4}$$

for minimum temperatures,

$$X = 29.6 - 0.318D + 0.0027D^2 \tag{5}$$

where X = Temperature

D = Date (1 December = 1, 28 February = 90).

The temperature value on the trend curve ($\overline{X}_{ti}$, i = 1, 2, 3, ... 90) was subtracted from each of 92 data points for each date ($x_{i,j}$, i = 1, 2, 3, ... 90, j = 1, 2, ... 92) and a standard deviation of these

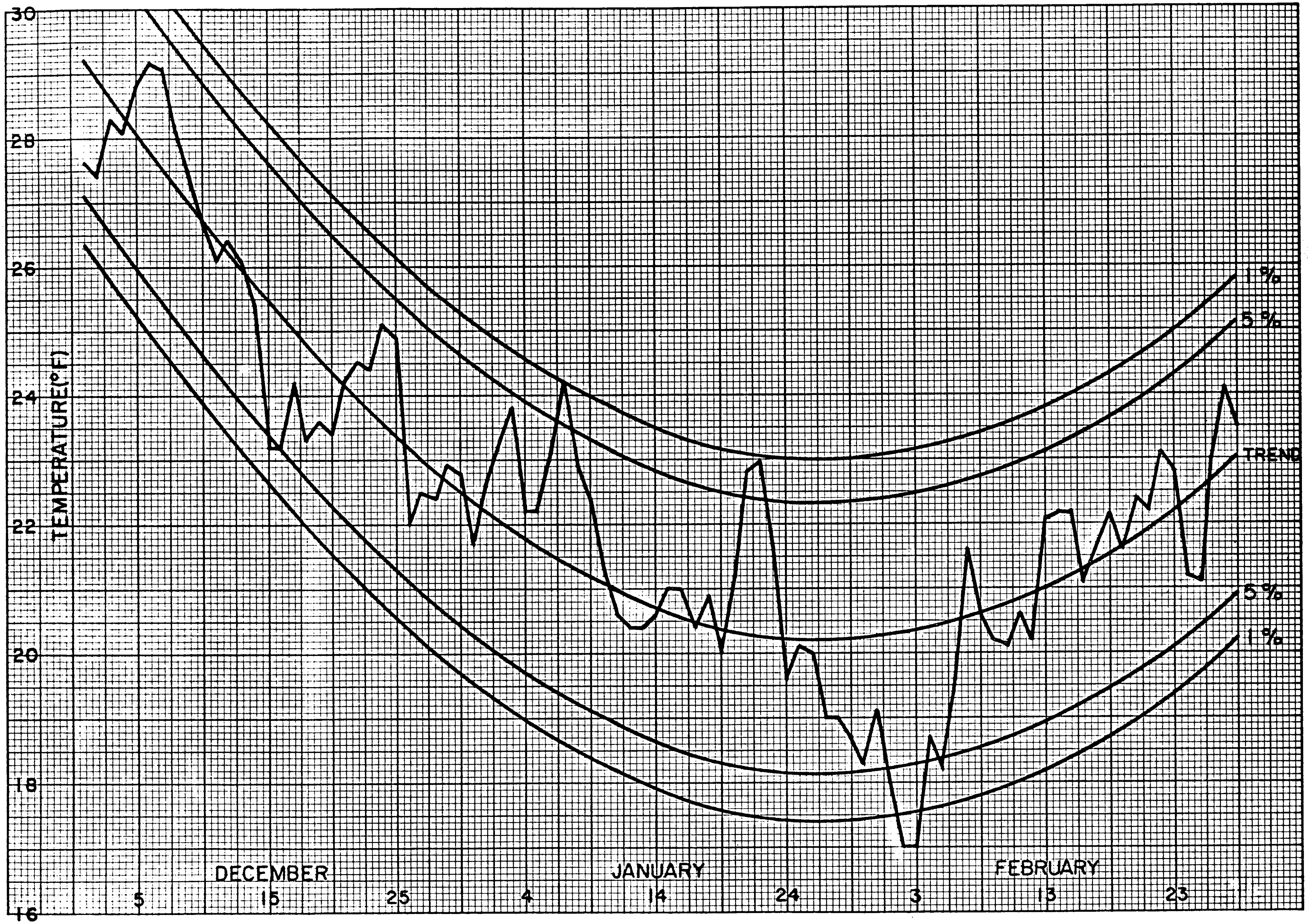

Figure 4. Average normal minimum temperature values with trend, 5%, and 1% significance levels.

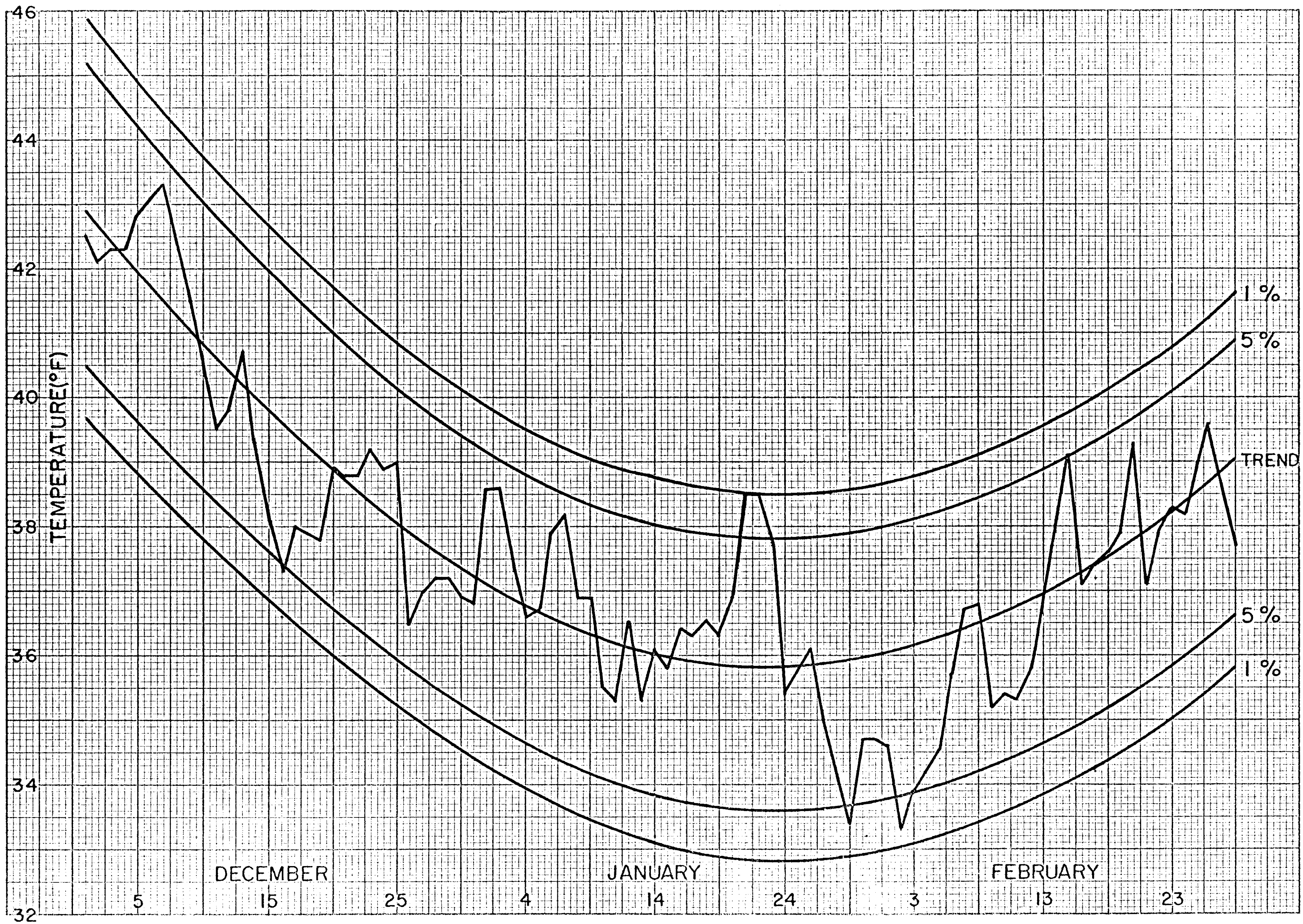

Figure 5. Average normal maximum temperature values with trend, 5%, and 1% significance levels.

departures was computed according to the following:

$$\sigma_\triangle = \sqrt{\sum_{i=1}^{90} \sum_{j=1}^{92} \frac{\triangle_{i,j}^2}{8280} - (\overline{\triangle})^2} \tag{6}$$

where

$$\triangle_{i,j} = x_{i,j} - \overline{X}_{ti} \qquad (i = 1,2,3,...90;\ j = 1,2,3...92) \tag{7}$$

In addition, a standard deviation of the departures of the 92-year normal values from the trend was computed. Let us call this σ_f:

$$\sigma_f = \sqrt{\sum_{i=1}^{90} \frac{f_i^2}{90} - (\overline{f})^2} \tag{8}$$

where

$$f_i = \overline{X}_i - \overline{X}_{ti} \qquad (i = 1,2,3,...90) \tag{9}$$

When working with a distribution of mean values of a sample, statistical theory states that the standard deviation of these means, or the standard error, as it is called, may be defined as:

$$\sigma_{\overline{A}} = \frac{\sigma_A}{\sqrt{N}} \tag{10}$$

where N equals the number of A's in each $\overline{A}$. Thus the effect of averaging random data is to reduce the standard deviation of the raw data by a factor of $\frac{1}{\sqrt{N}}$. In terms of the terminology used in this paper,

$$\sigma_A = \sigma_\triangle \qquad \sigma_{\overline{A}} = \frac{\sigma_A}{\sqrt{N}} \tag{11}$$

Table I lists values of σ_A, σ_f, and the standard error, $\sigma_{\overline{A}}$, obtained from the above calculations. It is interesting to note that the values

Table I

Values of σ_Δ, σ_f, and $\frac{\sigma_\Delta}{\sqrt{N}}$.

	$\sigma_\Delta (deg^2)$	$\sigma_f (deg^2)$	$\frac{\sigma_\Delta}{\sqrt{N}} (deg^2)$
Maximum Temperatures	10.22	1.11	1.07
Minimum Temperatures	10.33	1.21	1.08

N = 92

of σ_f were slightly greater than the standard error. This can be interpreted to mean that the grouping of the data into date means is not random, but there is an indication of a more than random tendency towards formation of singularities.

The question now arises as to how significant are the ridges and valleys in the normal temperature curves presented in Figures 4 and 5. In order to answer this question, statistical significance tests must be employed. In general, these tests can only be applied to data which consist of independent samples. This infers that there should be a low autocorrelation between points. It is a well known fact that a daily temperature record does not constitute an independent-data set.

The interdependence of daily temperature has been called "coherence" by some authors (Walker, 1946). McIntosh (1953) was faced with a similar problem. He made a comparison of the frequency distributions of a non-coherent random series (very small autocorrelation), a coherent random series and the theoretical normal Gaussian distribution. The number of points falling in intervals ≥ 2 t, where:

$$t = \frac{x}{\sigma} \qquad (12)$$

x = point value of data

σ = standard deviation of data

were quite similar in all instances. McIntosh concludes that a coherent series of random temperature departures can legitimately be assumed to approximate the normal distribution.

A significance level represents the probability of a random number taking on a certain value different than the mean. Generally significance levels are computed from the relation:

$$t = \pm \frac{(x - \mu)}{\sigma} \tag{13}$$

x = point value of data

μ = mean of data

σ = standard deviation of data

and the normal distribution function. Table II presents various levels of significance and their respective values of "t". To illustrate this point, take for example, the case of a point falling outside the 1% level. This means that the ratio of its deviation from the mean value to the standard deviation is greater than the value of "t" for one percent. It can be interpreted as saying that there is less than one chance in one hundred that this value is really not significantly different from the mean value and is only a random occurrence.

It is quite evident that the larger the value of "t", the greater is the significance of any values found at that distance from the mean, and the probability that the value has been obtained by a random fluctuation is smaller. In the case of the data being investigated, the significance bands representing the various levels are parabolic curves that are parallel to the trend curve. These are presented in Figures 4 and 5.

A significance count was made using the criterion that if two dates which are significant on any level less than 5% are not three

Table II

Values of "t" and corresponding levels of significance.

Level of Significance (%)	t
1.0	2.576
2.5	2.041
5.0	1.960
10.0	1.650
20.0	1.282
50.0	0.674

days apart, only one would be included in the "count". This is necessary since the normal distribution assumes that the data are independent and as was discussed before, temperature data are not. Table III presents the "counts" for the normal maximum and minimum curves.

The significance of the counts obtained may also be found in order to determine if "k" values obtained at a particular level are different from what one could expect by random chance. In this case, "T" as defined by (14), corresponds to a significance level similar to "t" used above.

$$T = \frac{k - E}{\sigma} \qquad (14)$$

$$E = Np \qquad (15)$$

$$\sigma = \sqrt{Npq} \qquad (16)$$

where

k = number of values obtained at a particular level

N = total number of points

p = probability of an event occurring

q = probability of an event not occurring = (1-p)

E = probable number of values obtained at a particular level.

Table IV presents values of "T" for the values obtained in Table III and their corresponding levels of significance.

As one can notice immediately, the probability of obtaining these counts from a random sample by chance is quite large. Therefore, nothing conclusive can be said about the occurrence of singularities in the 92-year normal maximum and minimum temperature record.

Table III

SIGNIFICANCE COUNTS	5%	2½%	1%
Maximum Temperatures	5	3	1
Minimum Temperatures	5	3	2

Table IV

Values of "T" and significance levels for various counts.

Significance Level of Data (%)	Significance Count	N	T	Significance Level of Counts (%)
5	5	90	0.242	81
2½	3	90	0.500	62
1	1	90	0.105	92
1	2	90	1.160	25

The eleven maximum and eight minimum values which exhibited the largest significance are presented in Table V. Upon investigating the maximum curve values, one finds a sharp contrast in the levels of significance that appear during the early half of the winter (1 December-21 January) as compared to the latter half. From 7 December to 20 January, the most significant level present is the 4% level, while in the period from 21 January to 15 February all values are equal to or more significant than the 4% value. The most outstanding singularity occurs on 21-22 January. The percentages for the two days cannot be thought of as separate entities due to their proximity in time.

The minimum curve values are quite different, with all but one below the 10% level. The 2-3 February period appears as the most significant and, as a matter of fact, even more significant than the 21-22 January period in the maximum values.

To conclude, it is quite evident from this type of analysis that the reality of the January Thaw during 21-22 January cannot be accepted with confidence since the chance probability of obtaining only one value at the 1% level with a total of 90 data points is rather high.

Secondly, it appears that there is at least one other singularity that is equally as or more significant than the January Thaw. Evidently this type of averaging does not clearly bring out the singularities. It is interesting to note that Wahl (1952) presents a similar conclusion and suggests that since averaging over allyears shows only the residual effects, some other method of averaging must be devised.

Table V

Significance levels (%) of selected dates for normal maximum and minimum temperatures.

MAXIMUM TEMPERATURES \ DATE	D7	D16	J1	J2	J7	J21	J22	J29	F2	F15	F20
Level of Significance (%)	+9	-4	+13	+11	+9	+0.9	+0.9	-3	-2	+4	+9

MINIMUM TEMPERATURES \ DATE	J3	J7	J21	J22	J29	F2	F3	F14
Level of Significance (%)	+8	+1	+3	+1	-16	-0.2	-0.2	+9

D = December   + above normal

J = January   - below normal

F = February

It was with this thought in mind that it was decided to extend this analysis in order to determine another way of classifying the data.

SECTION III

INVESTIGATION OF RELATIONSHIP TO DOUBLE SUNSPOT CYCLE

Since another averaging scheme was needed, and changes in temperature can be related to variationsin the general circulation, it was decided to classify the data into groups which reflected these variations. Willett (1949) has related the 20-24 year double sunspot cycle to changes in the general circulation. Willett has suspected that there might be a predominance of singularities during certain phases of this cycle. The classification of the data according to this cycle appeared to be a convenient and logical manner to further investigate this problem.

The 20-24 year double sunspot cycle is based on the fact that alternate (major and minor) sunspot maxima have significant physical differences. The double sunspot cycle consists of the following eight three-year phases:

1) N-MM — The three years of most rapid increase in average value of the Zurich relative sunspot number (RSS) following a minor maximum.

2) MM (Major Maximum) — The three years of maximum average value of RSS.

3) MM-NN — The three years of most rapid decline in average value of RSS following the major maximum.

4) NN — The three years of minimum average value of RSS following the major maximum.

5) NN-M — The three years of most rapid increase in average value of RSS following a major maximum.

6) M (Minor Maximum) — The three years of maximum average RSS at the alternate maximum, usually but not always lower in number than the major maximum.

7) M-N — The three years of most rapid decline in average value of RSS following a minor maximum.

8) N — The three years of minimum average value of RSS following a minor maximum.

In addition to a division into these eight phases, a division into two other phases were considered: a major-half phase and a minor-half phase. The major-half phase was an average of phases 1-4 and the minor half phase was an average of phases 5-8.

Figure 6 illustrates graphically the above definition of the eight phases. It must be noted that this is an idealized curve of RSS vs time. Differences from this and in general between the two halves of the cycle are discussed by Willett (1964): "Although the basic cycle of sunspot numbers is the so-called eleven-year cycle, which has actually varied in length from seven to seventeen years between successive sunspot maxima, and from nine to fourteen years between minima, the so-called Hale or double sunspot cycle is much more clearly reflected in solar-climatic relationships, at least outside of the tropics. That there is a physical reality in the double sunspot cycle on the sun is indicated by a tendency for the sunspot number to be alternately lower

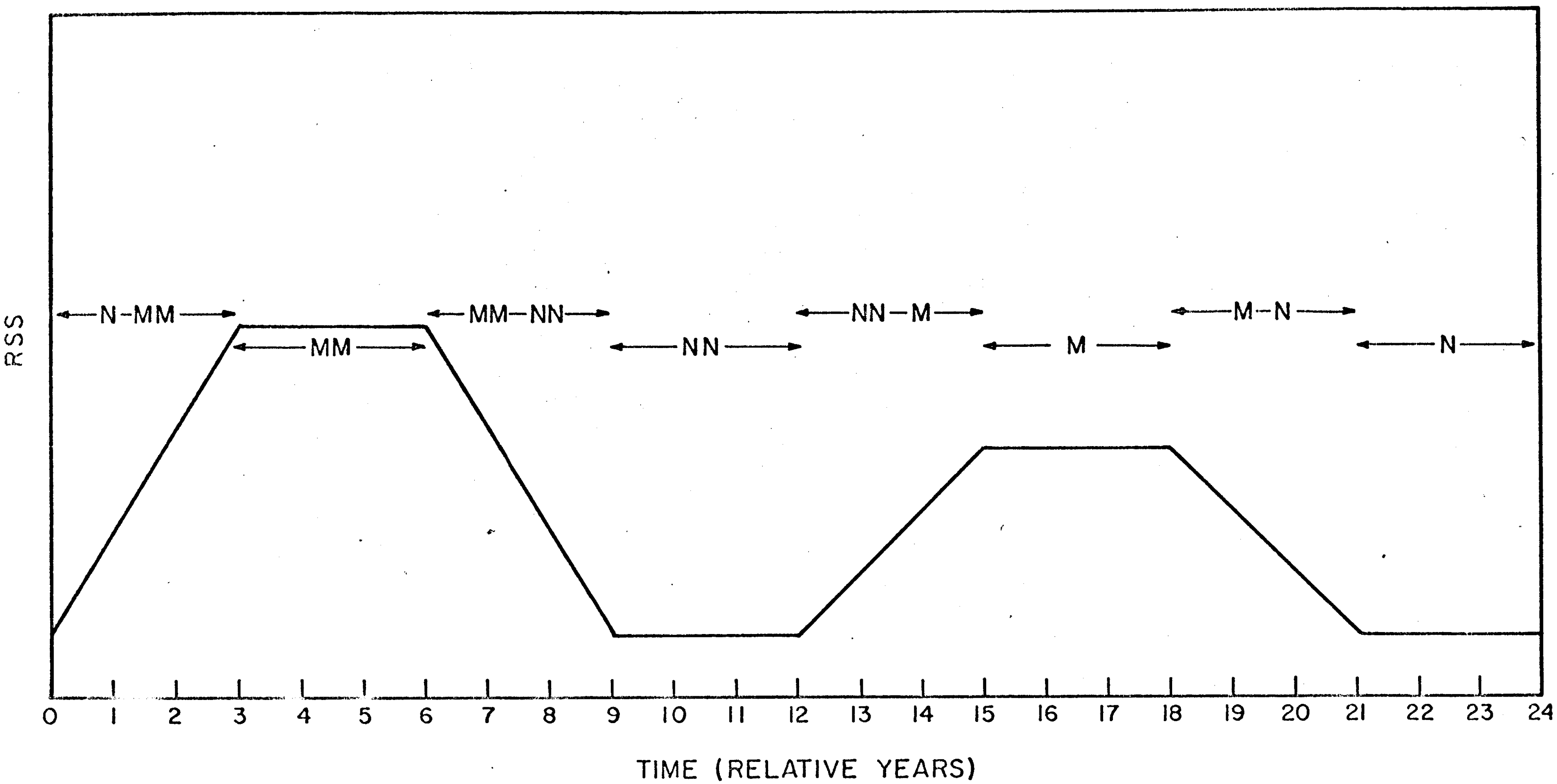

Figure 6. Schematic representation of idealized 20-24 year double sunspot cycle.

and higher with successive maxima, for the polarity of the magnetic fields associated with sunspot groups on the sun's surface to reverse from one maximum to the next, and for the corpuscular (charged particle) radiations reaching the earth from the sun to be quite differently related to alternate maxima."

The shortening or lengthening of the cycle may occasionally cause one year's overlap or an extra year between the three-year phases of the cycle. Table VI contains a summary of the classification of the years 1872-1964 according to the phases of the double sunspot cycle.

The data were classified according to Table VI and averages, standard deviations and standard errors were computed in a manner similar to that described in Section II. It is necessary to emphasize that the above calculations were made on trend-free data.

Figures 7 through 26 show the average maximum and minimum temperature values for each phase of the double sunspot cycle and also the trend curve. The 5% and 1% significance bands are also shown and will be discussed below.

Table VII lists the computed values of the standard deviations of each phase (computed from all data points in phase, not from average phase values) and their standard errors. The cycle that is present in the standard deviations appears very interesting and rather significant. If one considers a large group of random data and divides them into eight equal subgroups, one would expect to find equal standard

Table VI

Classification of years 1872-1964 by phases of Double Sunspot Cycle.

N-MM	MM	MM-NN	NN	NN-M	M	M-N	N
1890	1872	1872	1877	1879	1882	1885	1888
1891	1892	1873	1878	1880	1883	1886	1889
1892	1893	1874	1879	1881	1884	1887	1890
1915	1894	1895	1900	1903	1905	1908	1911
1916	1917	1896	1901	1904	1906	1909	1912
1917	1918	1897	1902	1905	1907	1910	1913
1935	1919	1919	1922	1924	1927	1930	1932
1936	1937	1920	1923	1925	1928	1931	1933
1937	1938	1921	1924	1926	1929	1932	1934
1955	1939	1940	1942	1945	1947	1950	1952
1956	1957	1941	1943	1946	1948	1951	1953
1957	1958	1942	1944	1947	1949	1952	1954
	1959	1960	1963				
		1961	1964				
		1962					

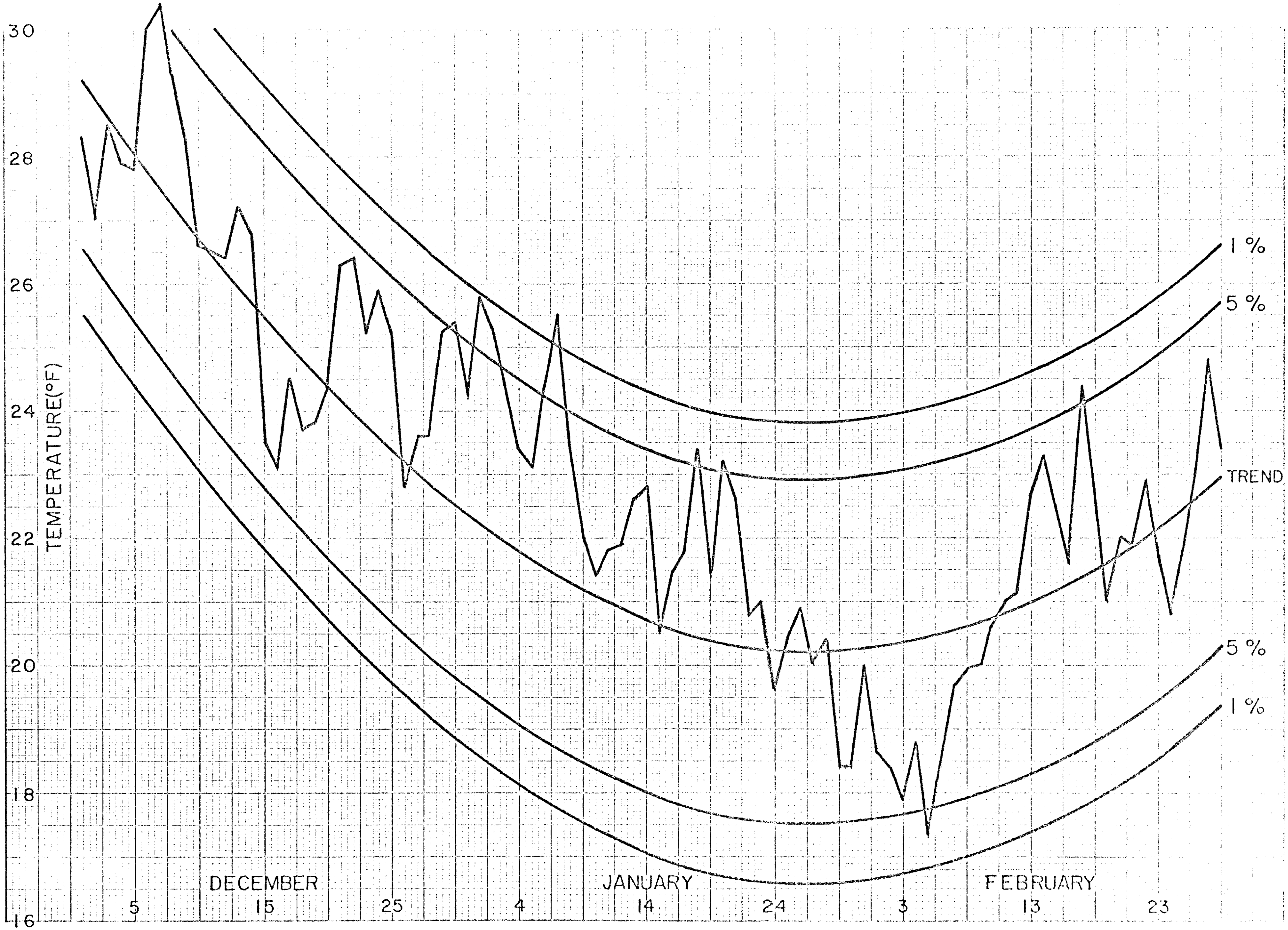

Figure 7. Average minimum temperature values for Minor-Half phase with trend, 5%, and 1% significance levels.

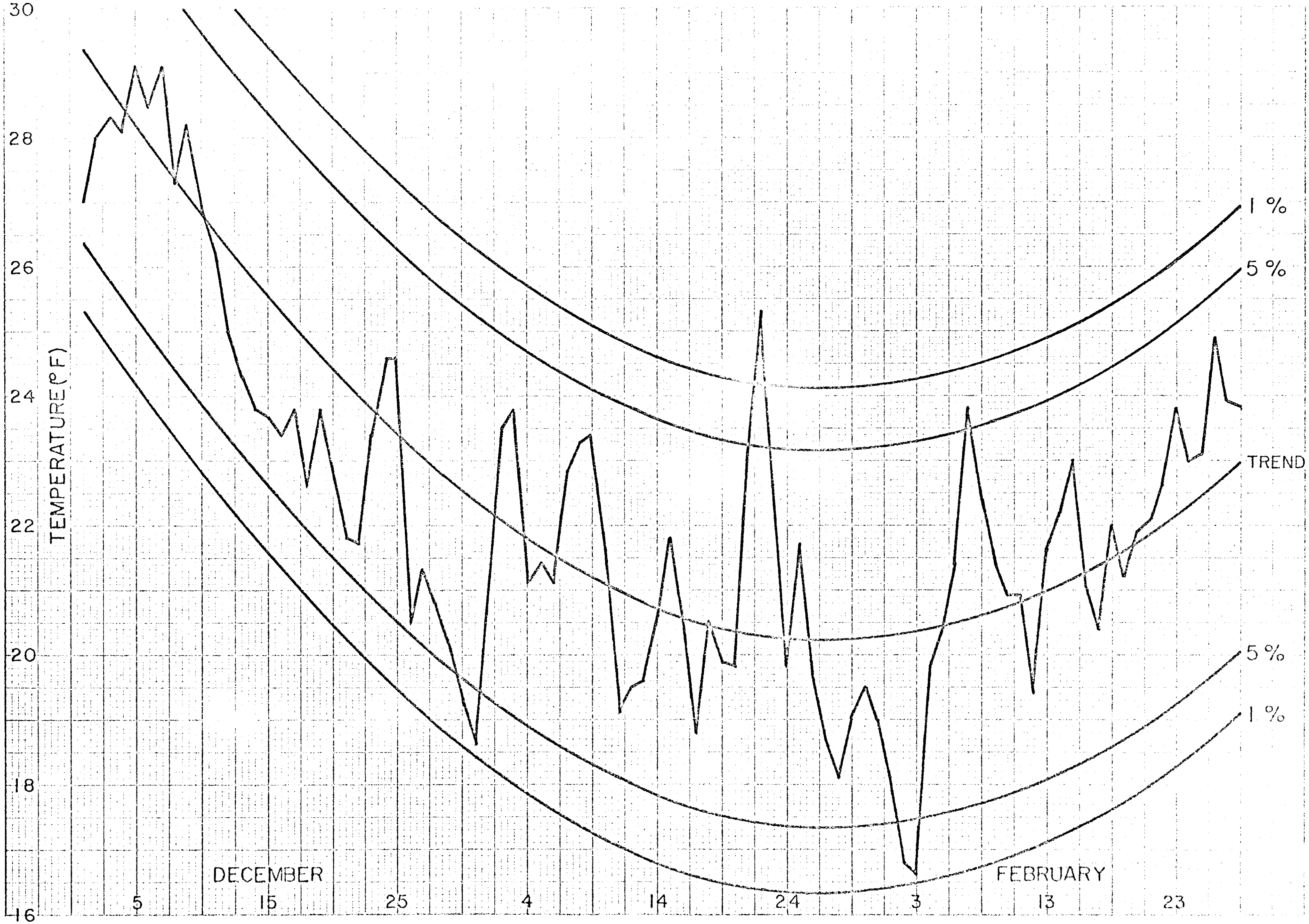

Figure 8. Average minimum temperature values for Major-Half phase with trend, 5%, and 1% significance levels.

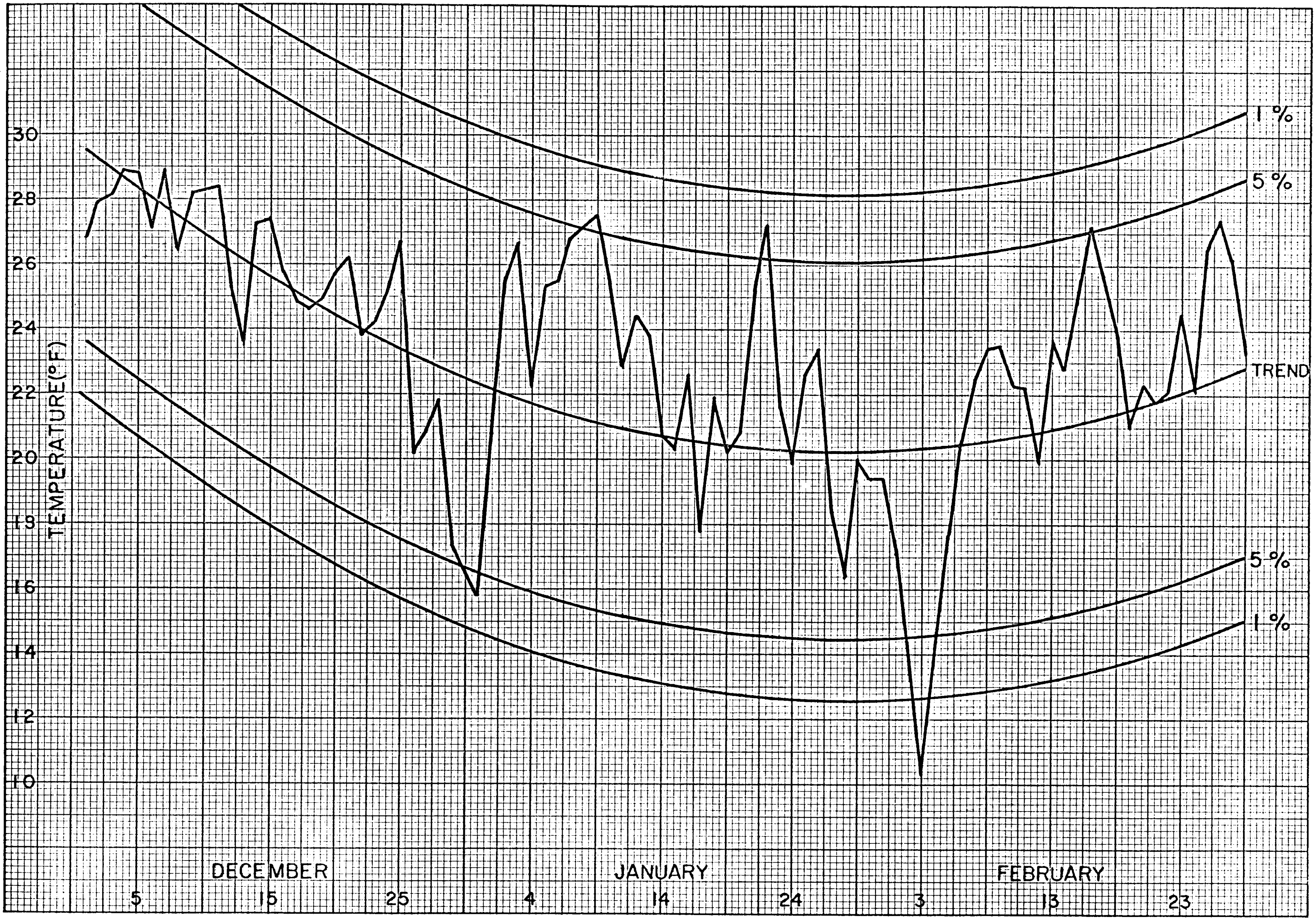

Figure 9. Average minimum temperature values for N-MM phase with trend, 5%, and 1% significance levels.

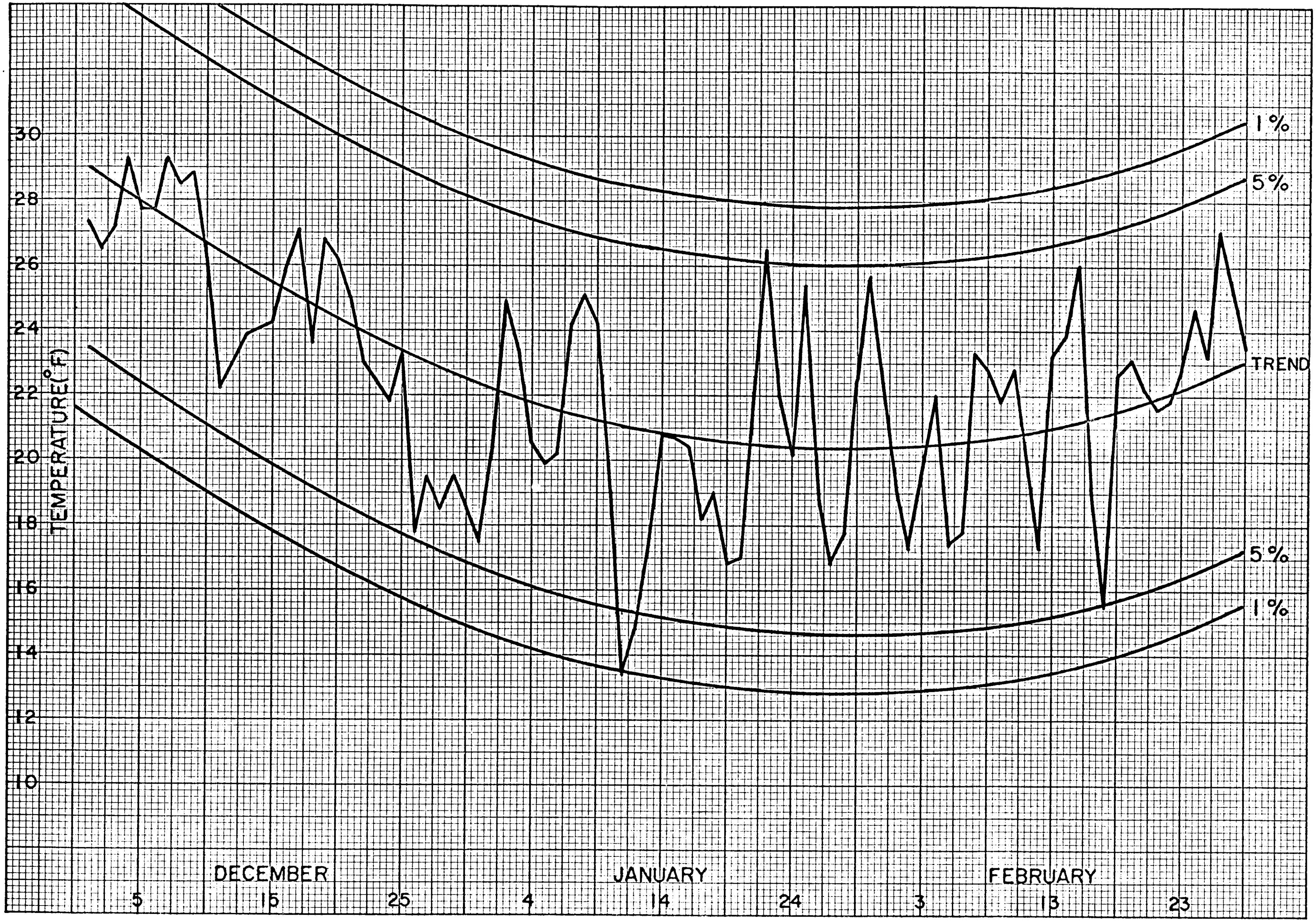

Figure 10. Average minimum temperature values for MM phase with trend, 5%, and 1% significance levels.

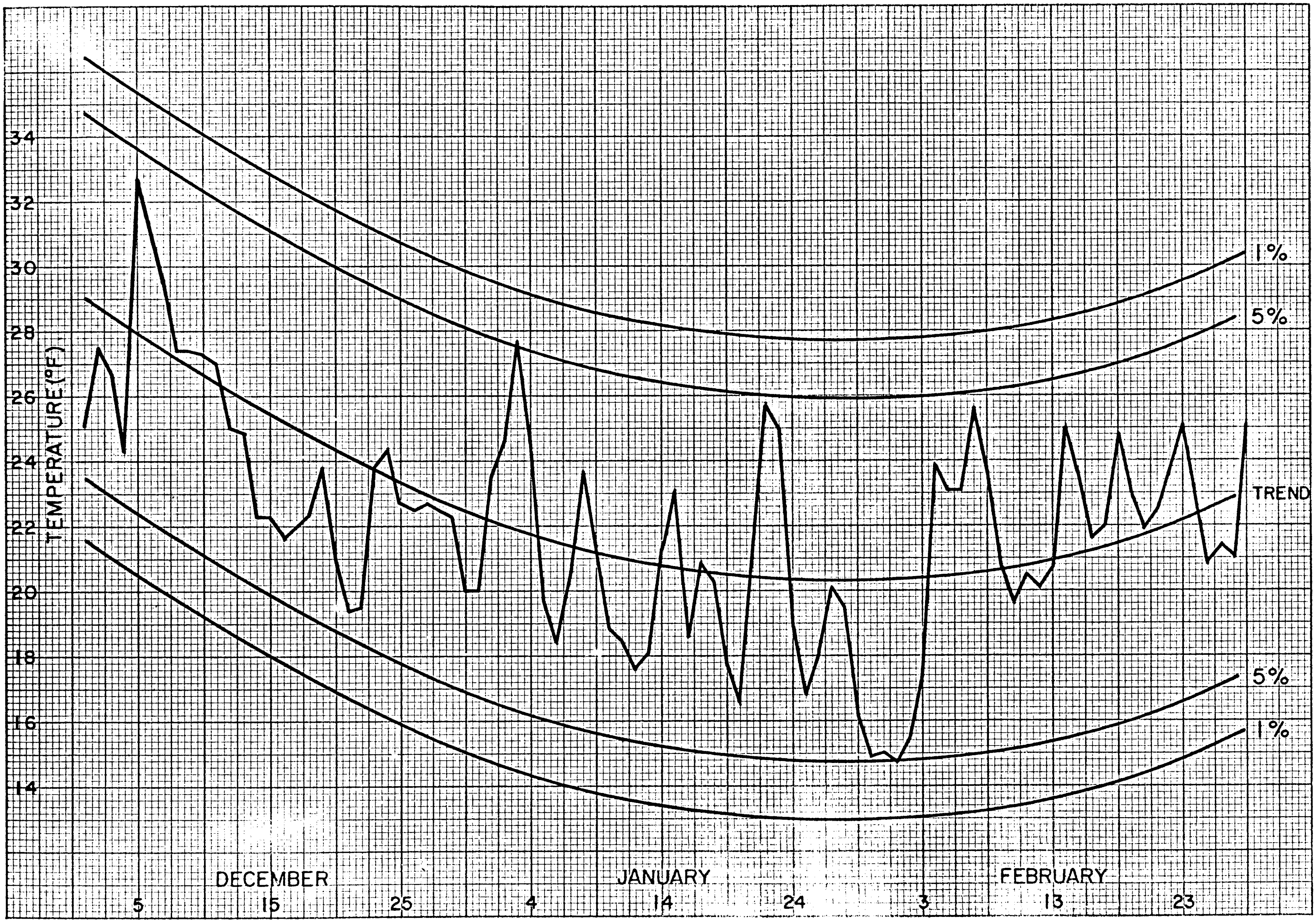

Figure 11. Average minimum temperature values for MM-NN phase with trend, 5%, and 1% significance levels.

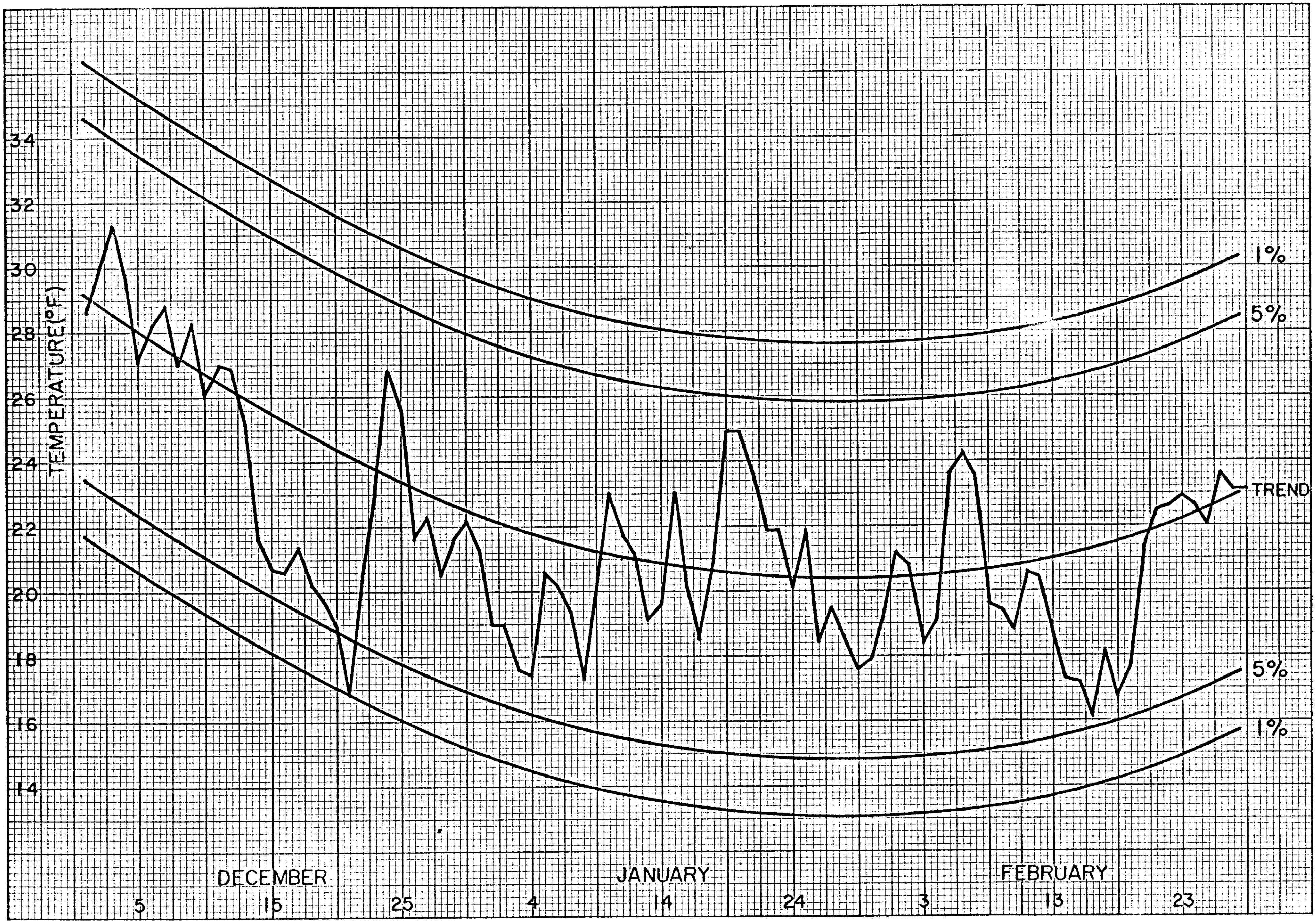

Figure 12. Average minimum temperature values for NN phase with trend, 5%, and 1% significance levels.

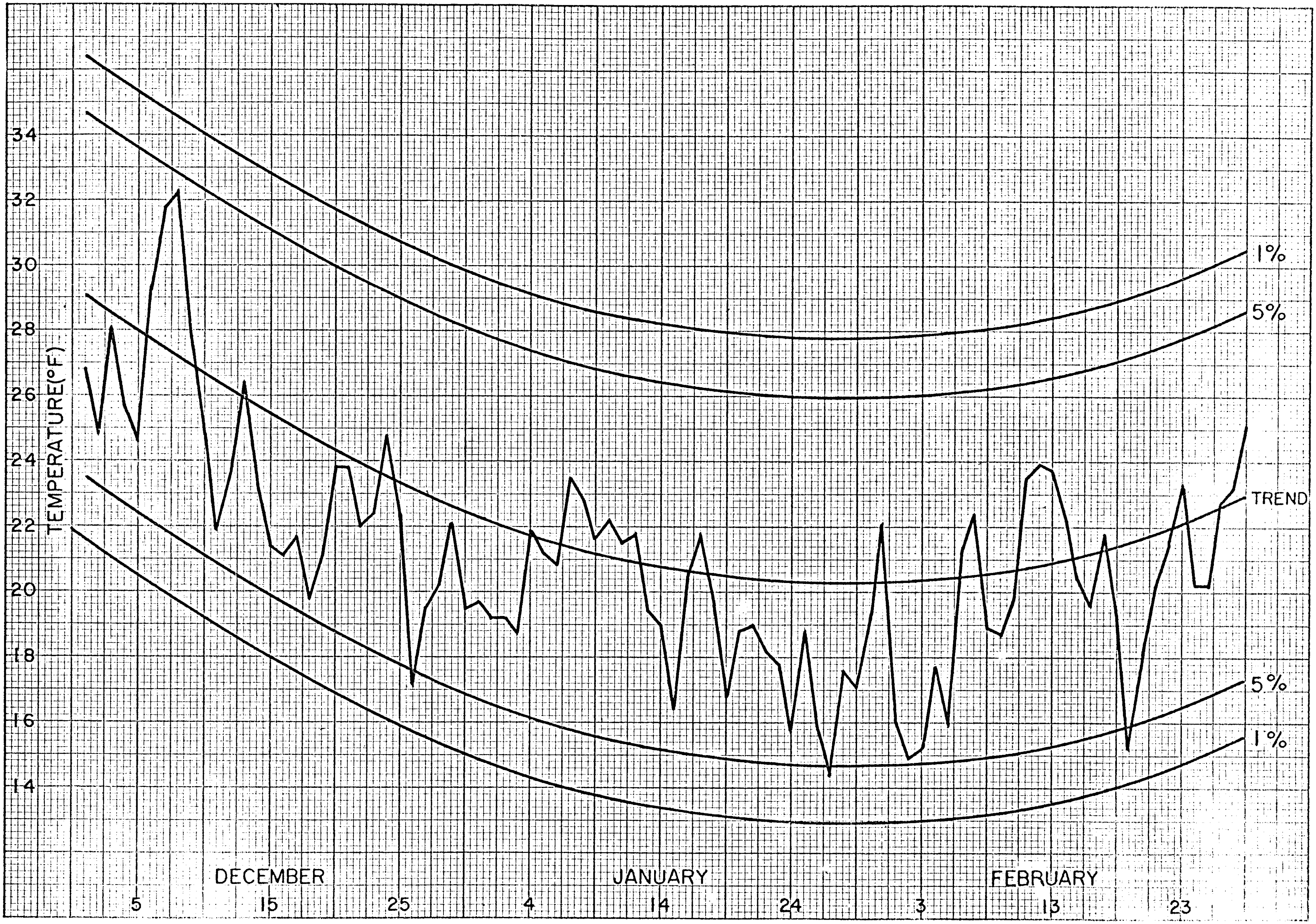

Figure 13. Average minimum temperature values for NN-M phase with trend, 5%, and 1% significance levels.

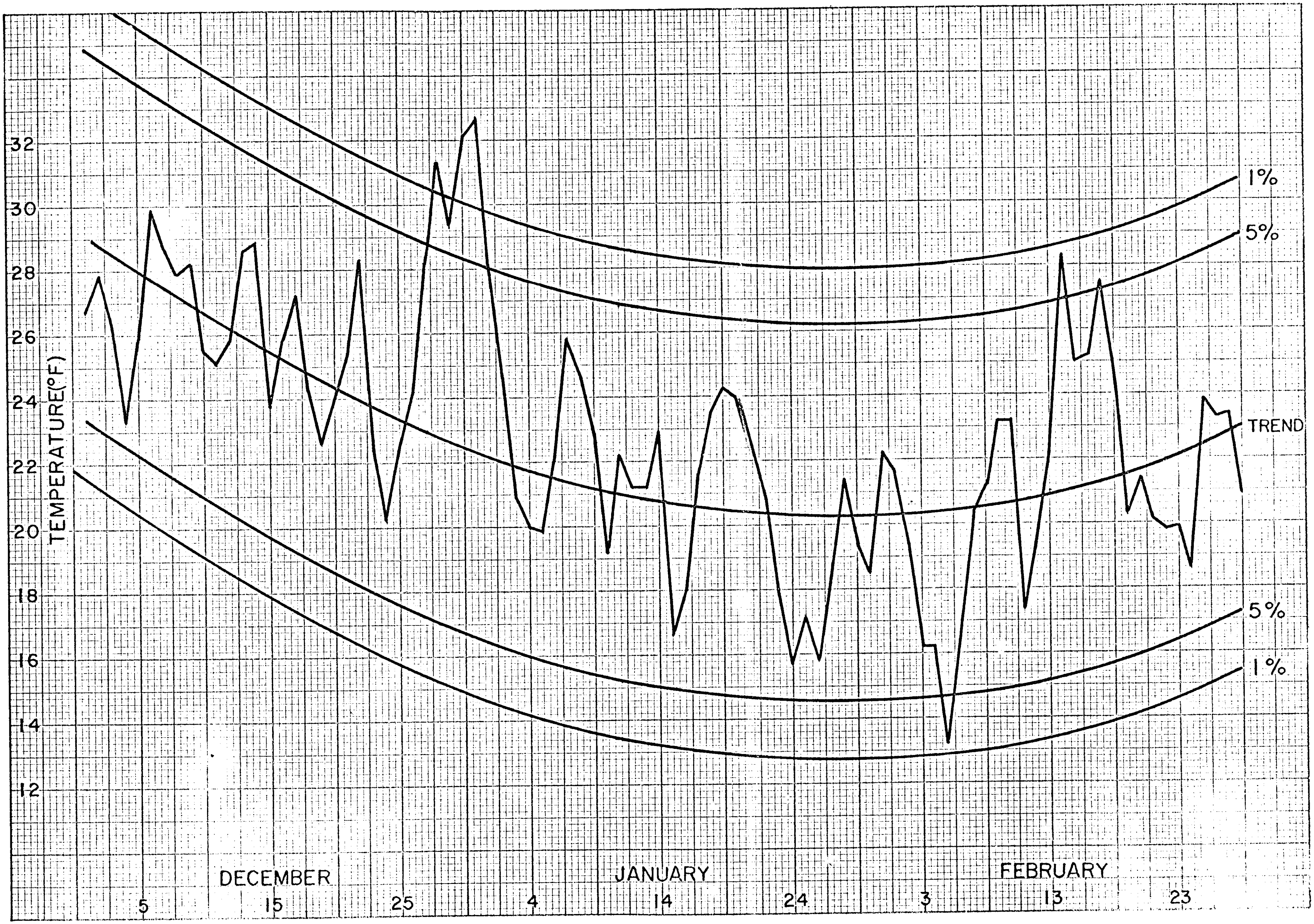

Figure 14. Average minimum temperature values for M phase with trend, 5%, and 1% significance levels.

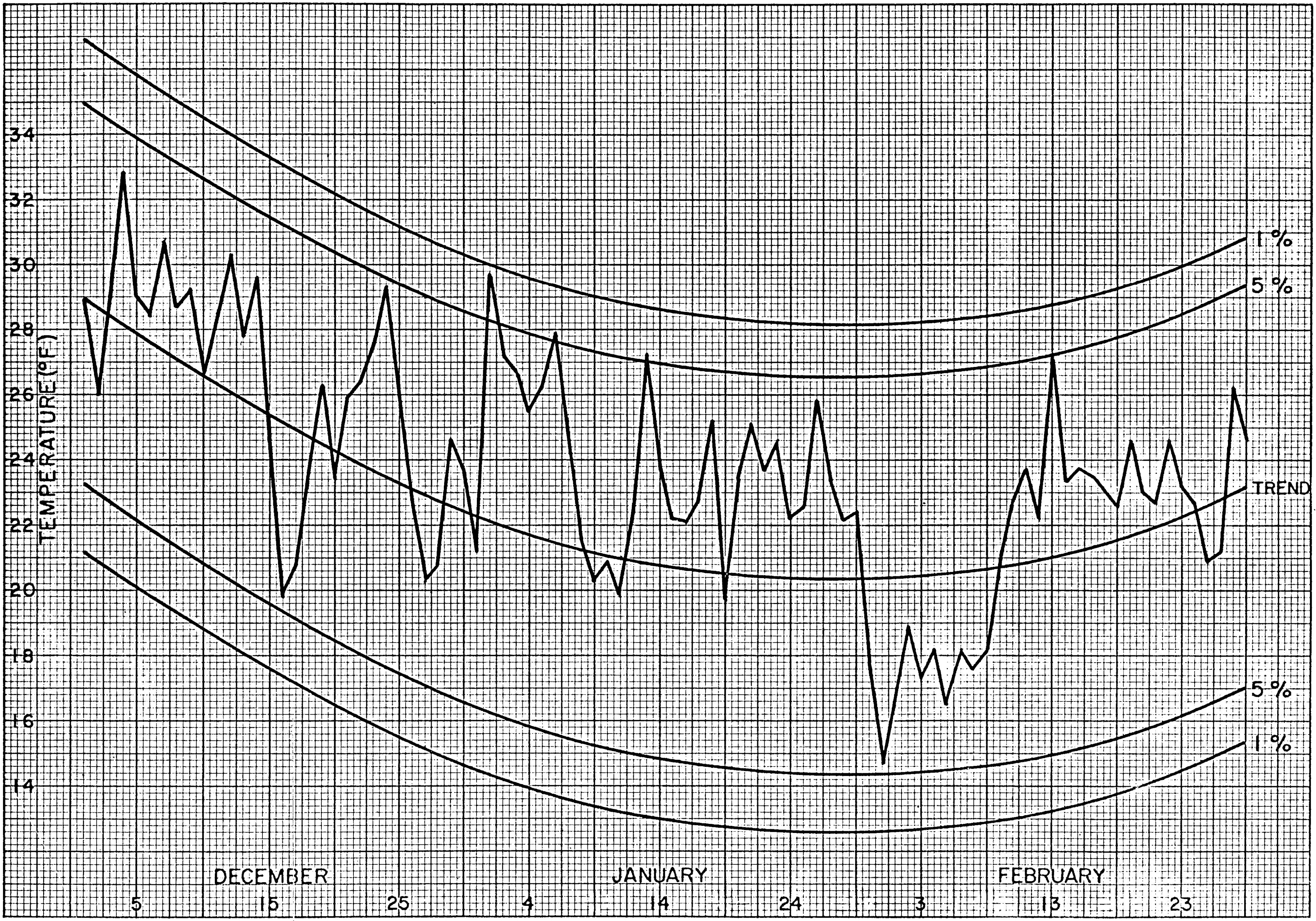

Figure 15. Average minimum temperature values for M-N phase with trend, 5%, and 1% significance levels.

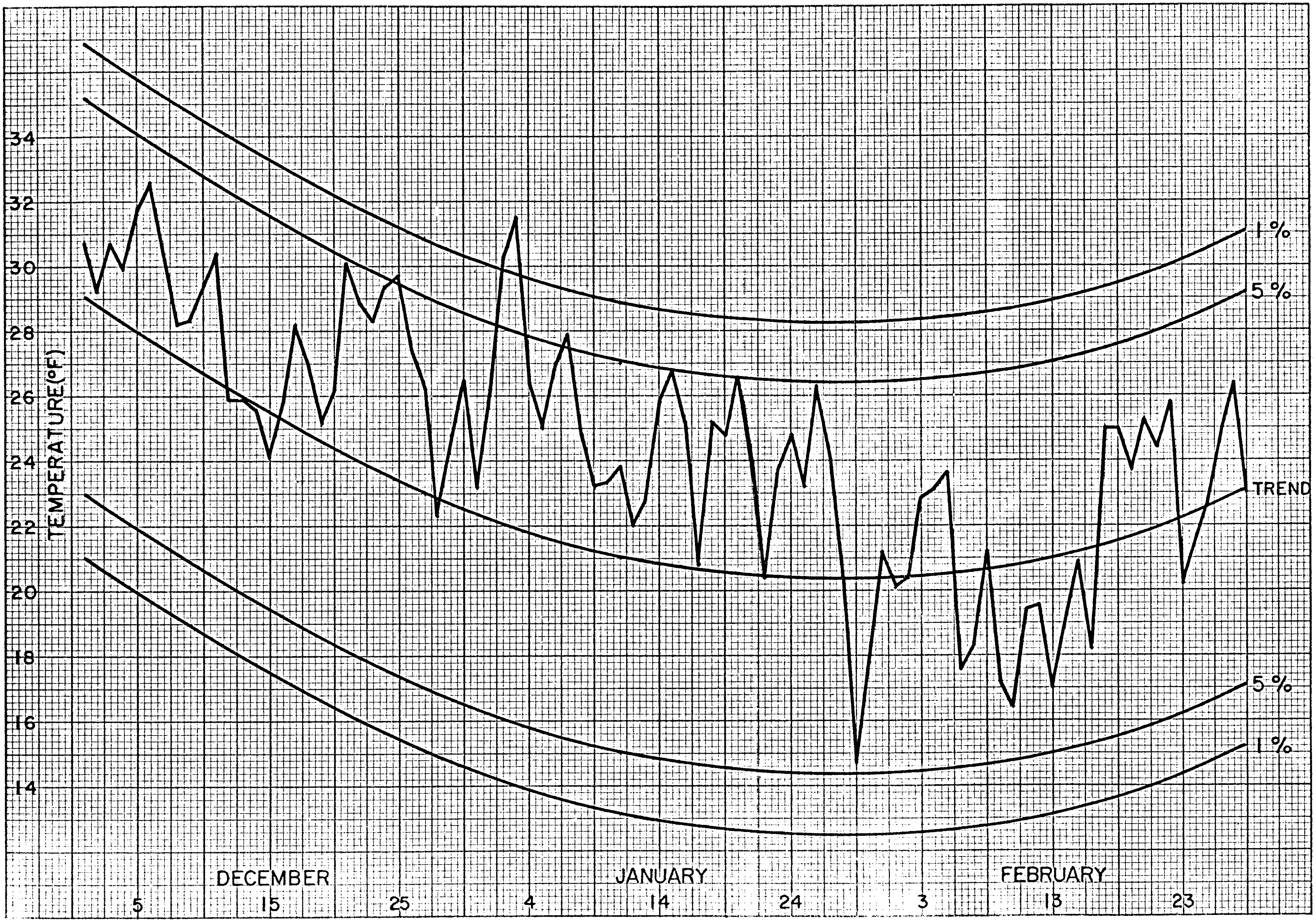

Figure 16. Average minimum temperature values for N phase with trend, 5%, and 1% significance levels.

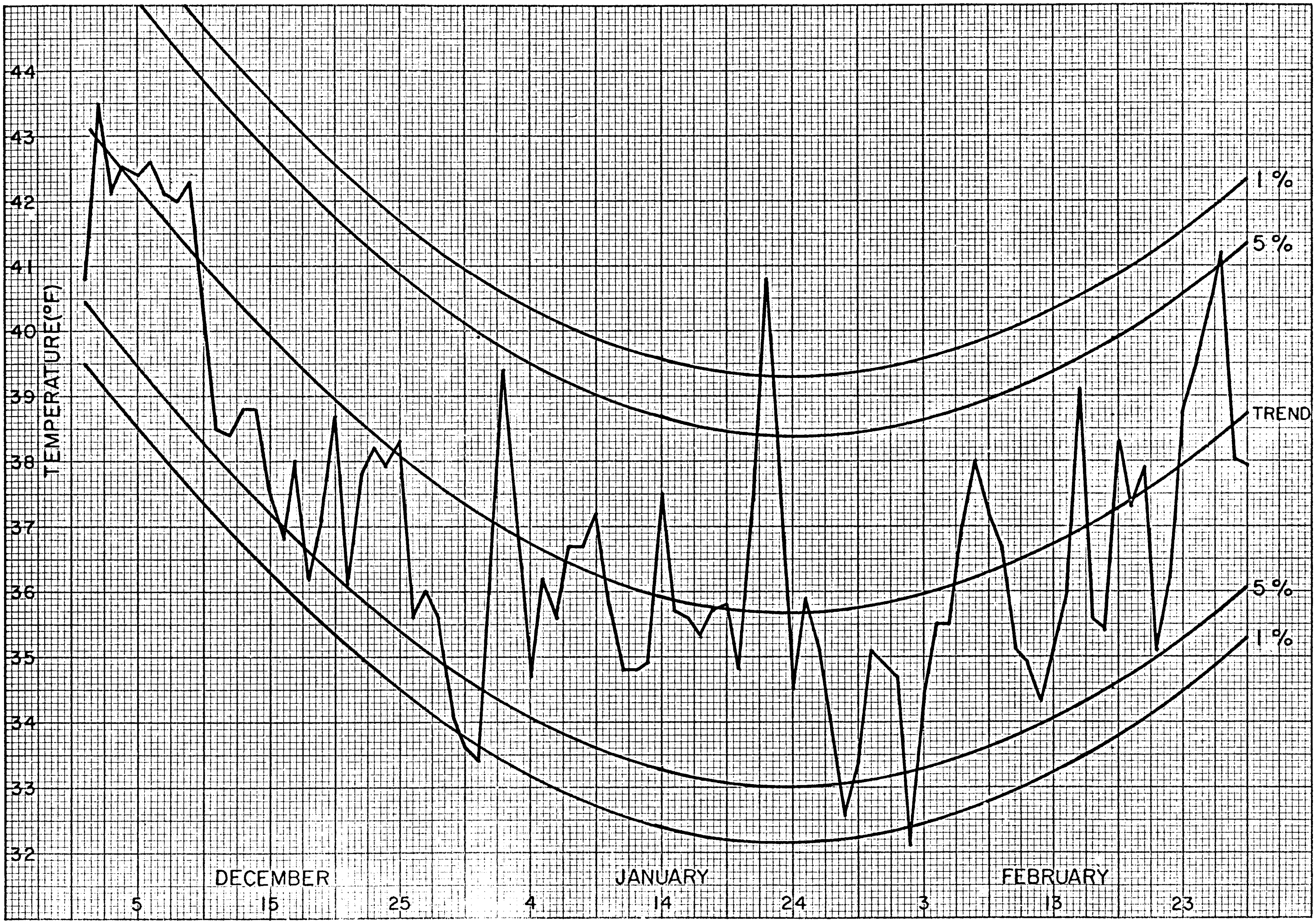

Figure 17. Average maximum temperature values for Major-Half phase with trend, 5%, and 1% significance levels.

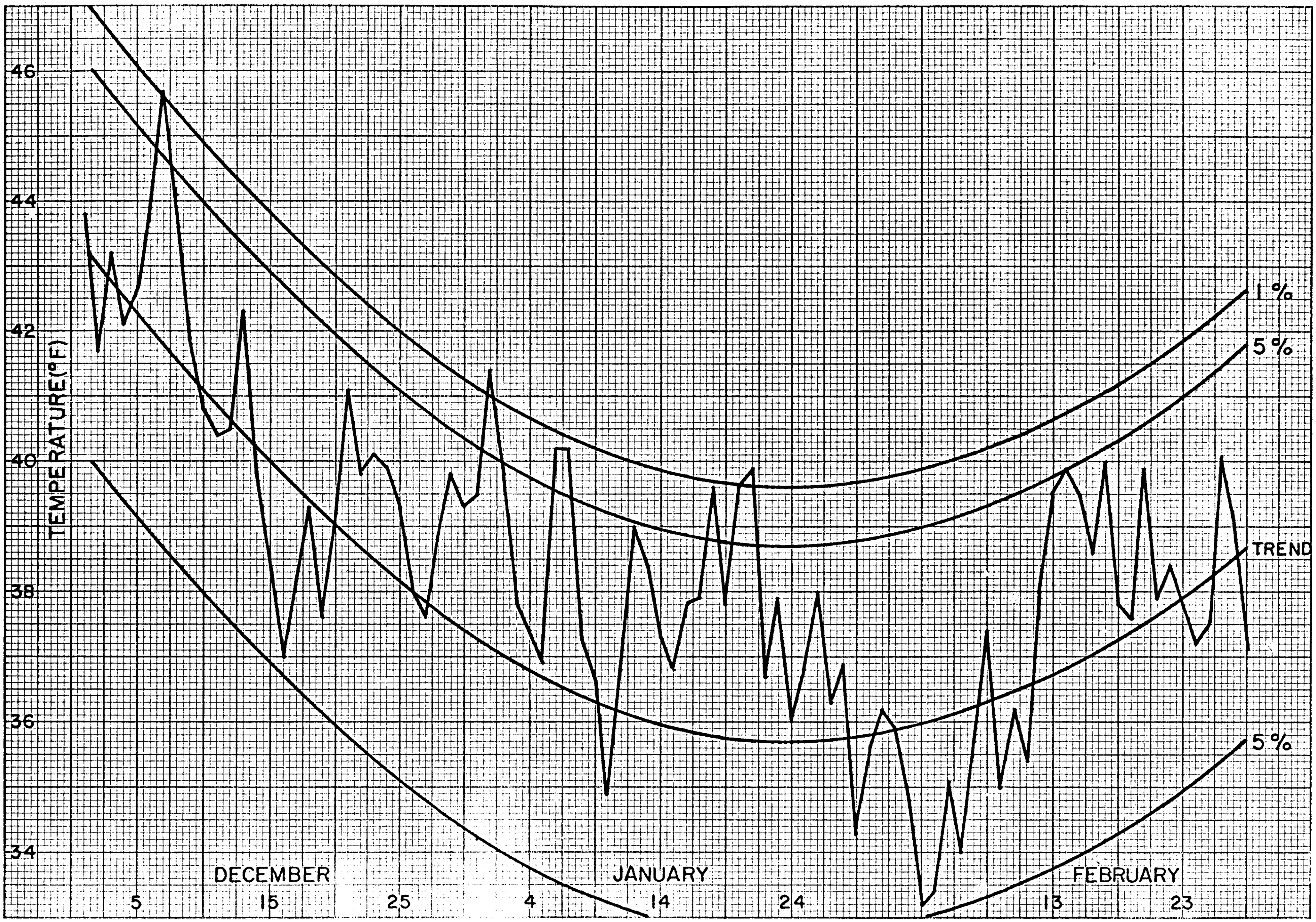

Figure 18. Average maximum temperature values for Minor-Half phase with trend, 5%, and 1% significance levels.

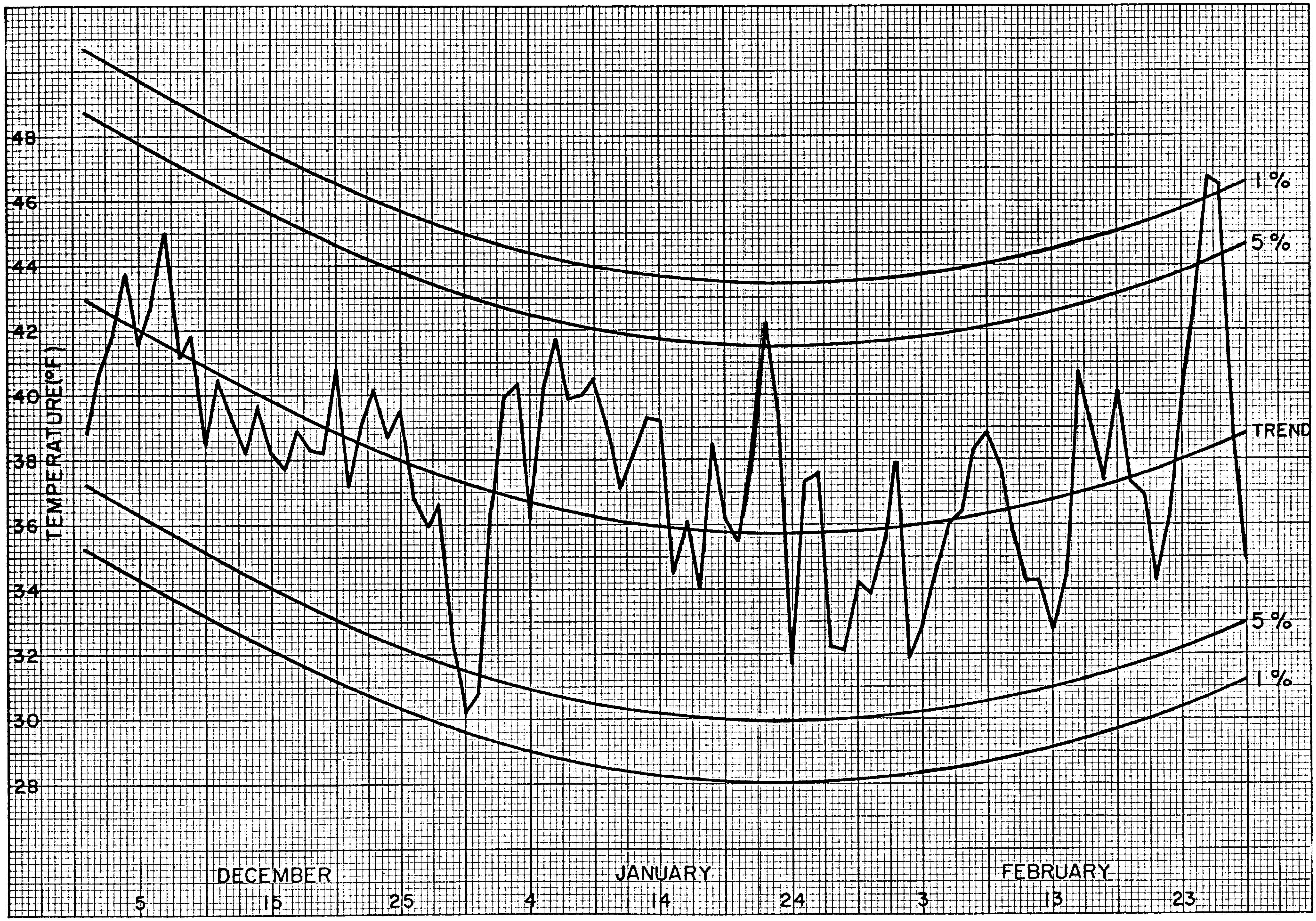

Figure 19. Average maximum temperature values for N-MM phase with trend, 5%, and 1% significance levels.

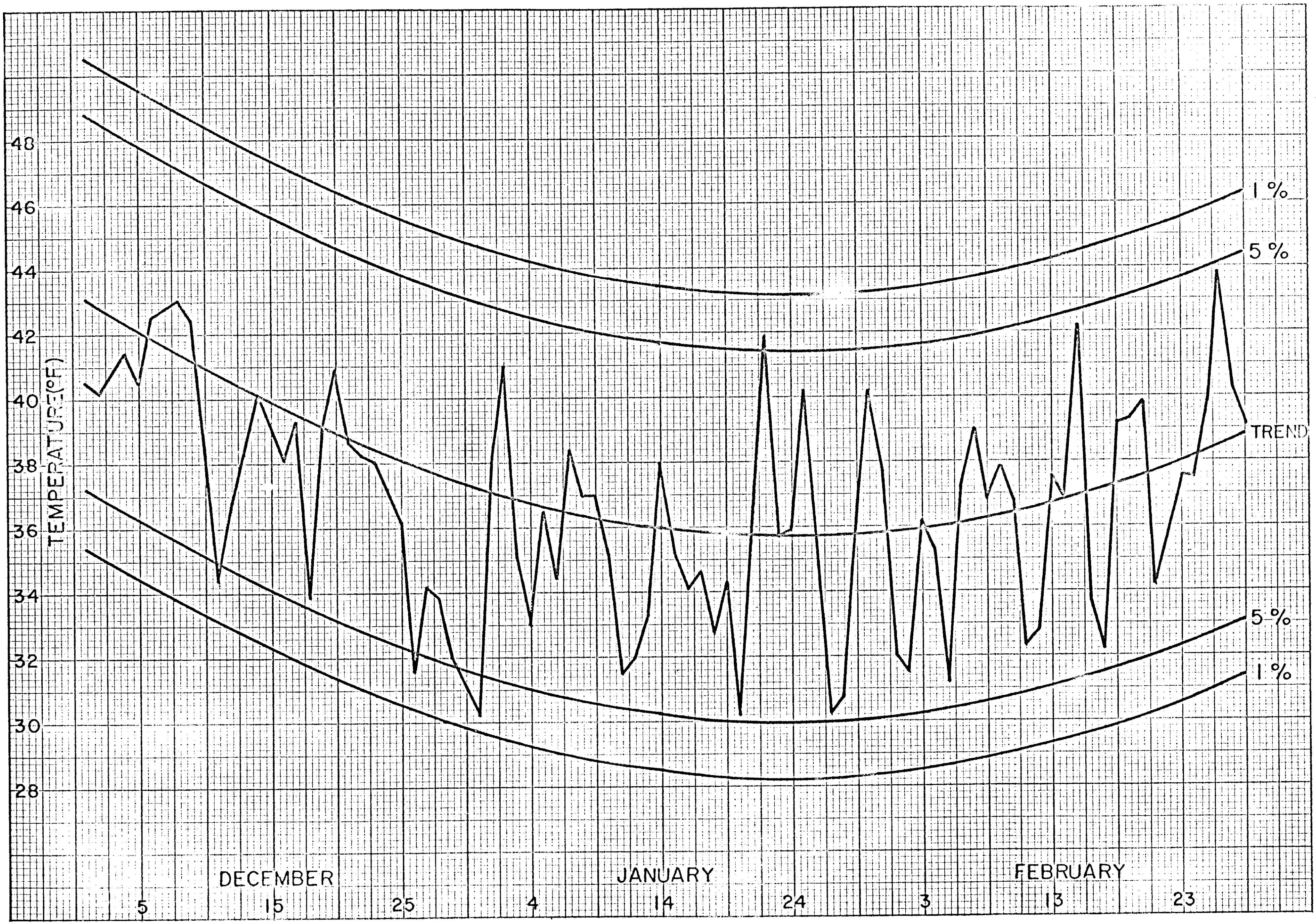

Figure 20. Average maximum temperature values for MM phase with trend, 5%, and 1% significance levels.

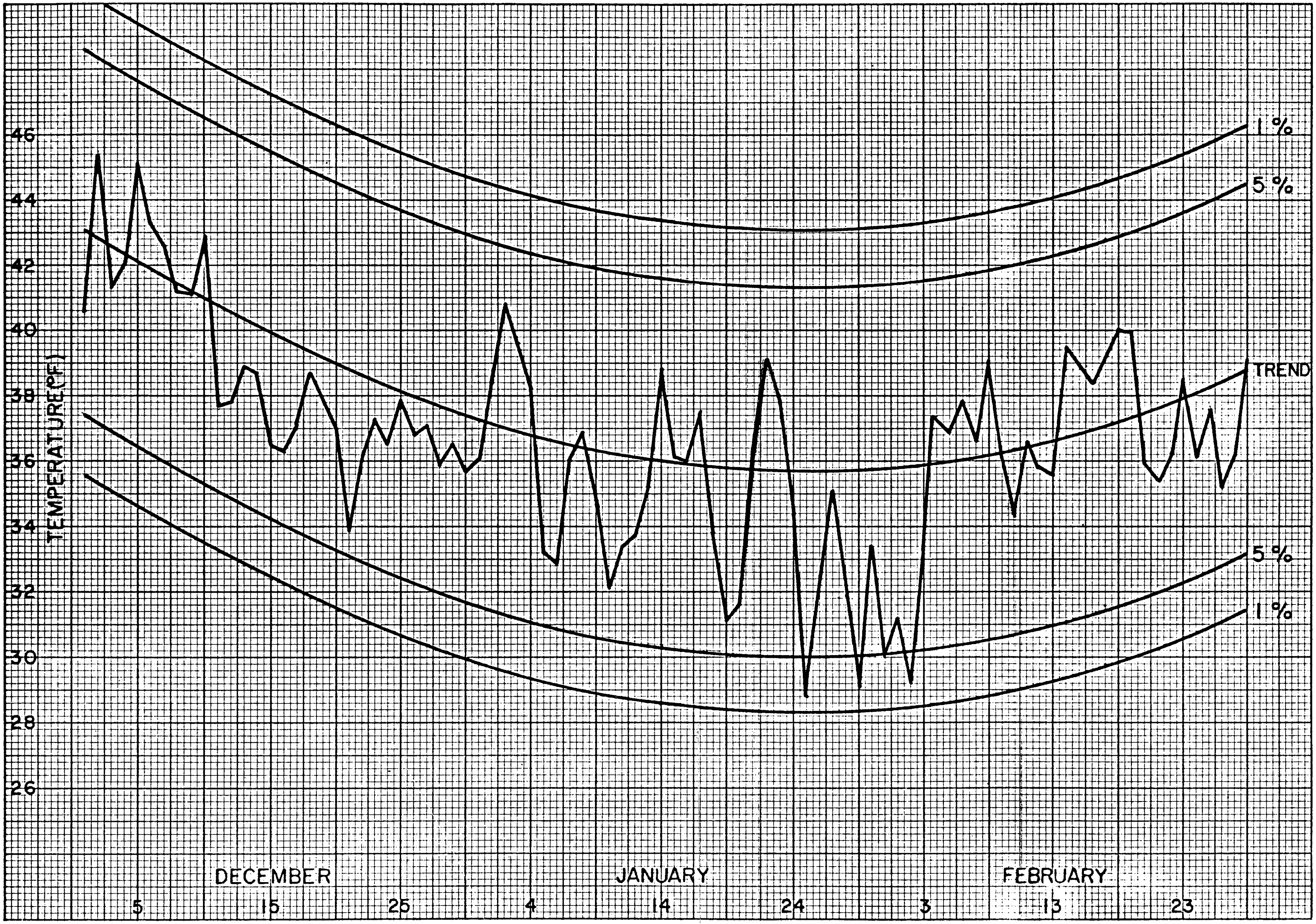

Figure 21. Average maximum temperature values for MM-NN phase with trend, 5%, and 1% significance levels.

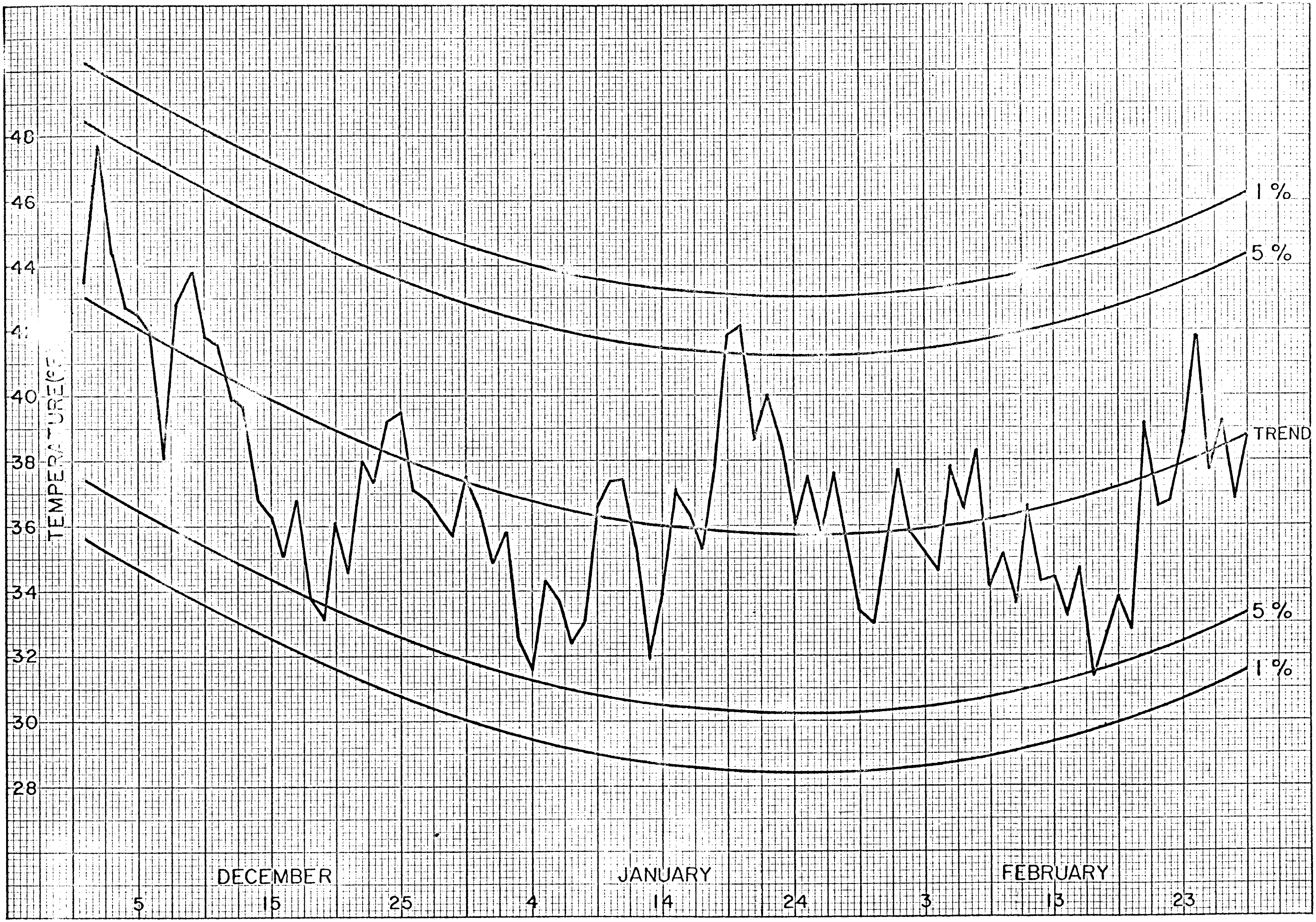

Figure 22. Average maximum temperature values for NN phase with trend, 5%, and 1% significance levels.

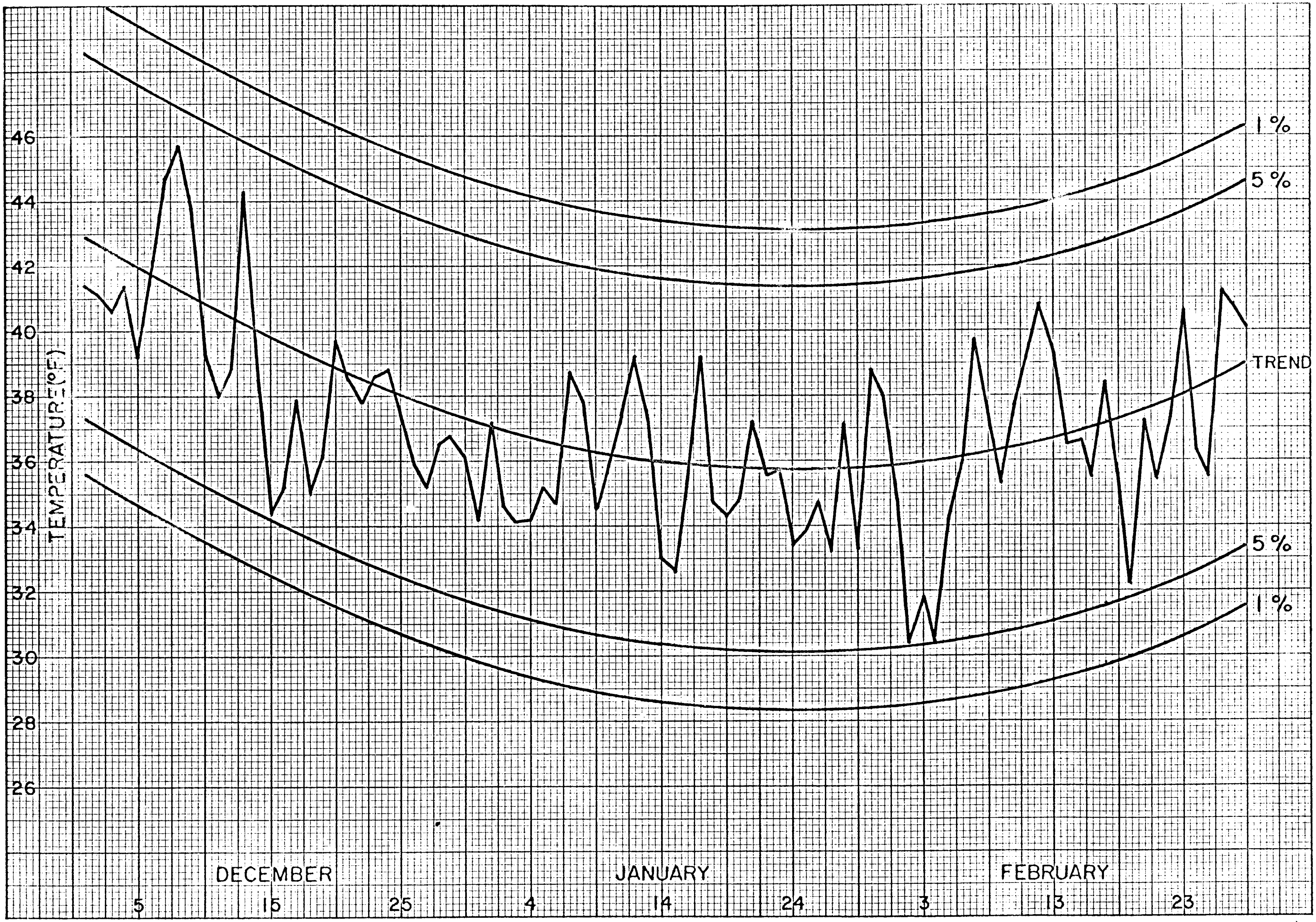

Figure 23. Average maximum temperature values for NN-M phase with trend, 5%, and 1% significance levels.

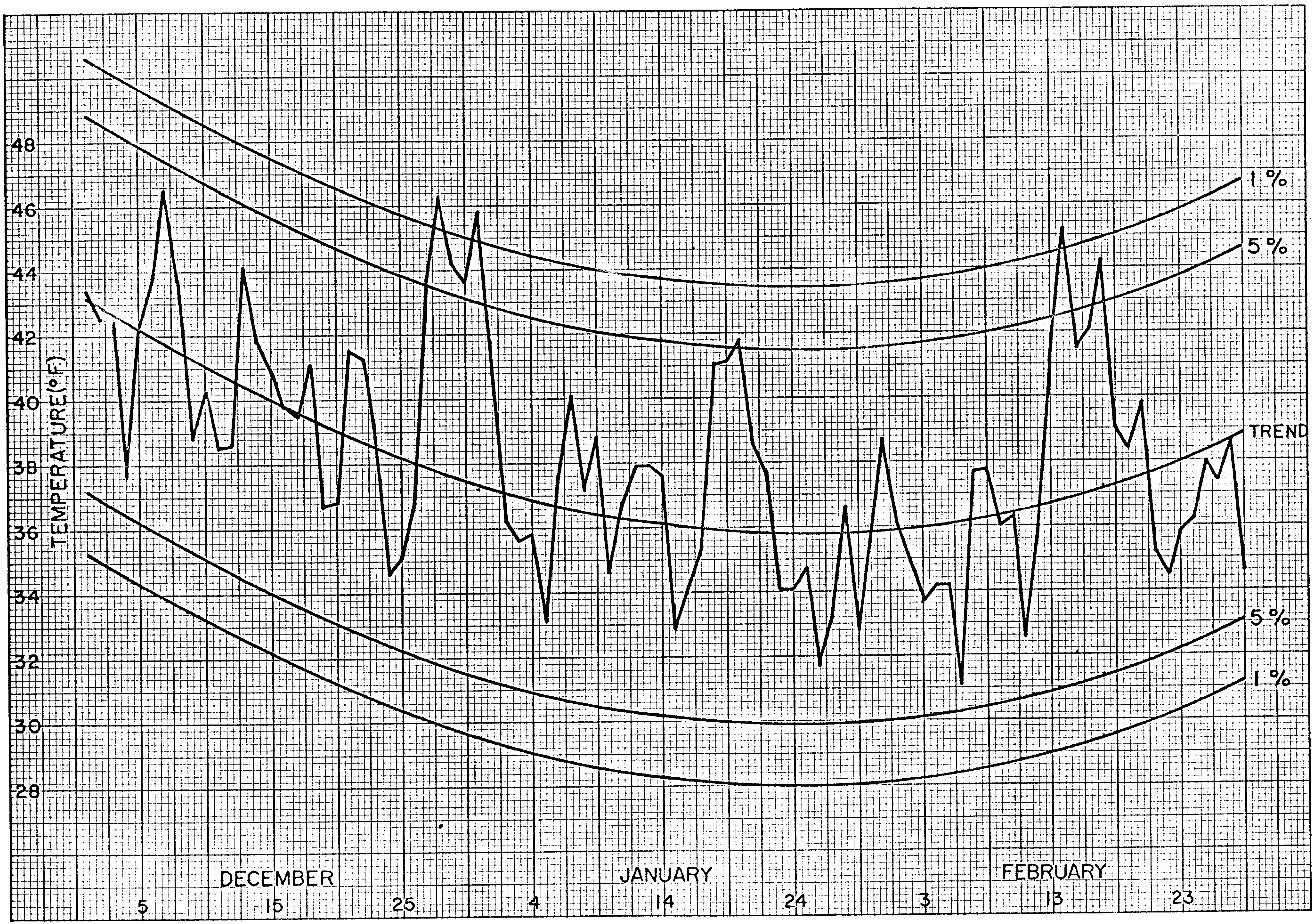

Figure 24. Average maximum temperature values for M phase with trend, 5%, and 1% significance levels.

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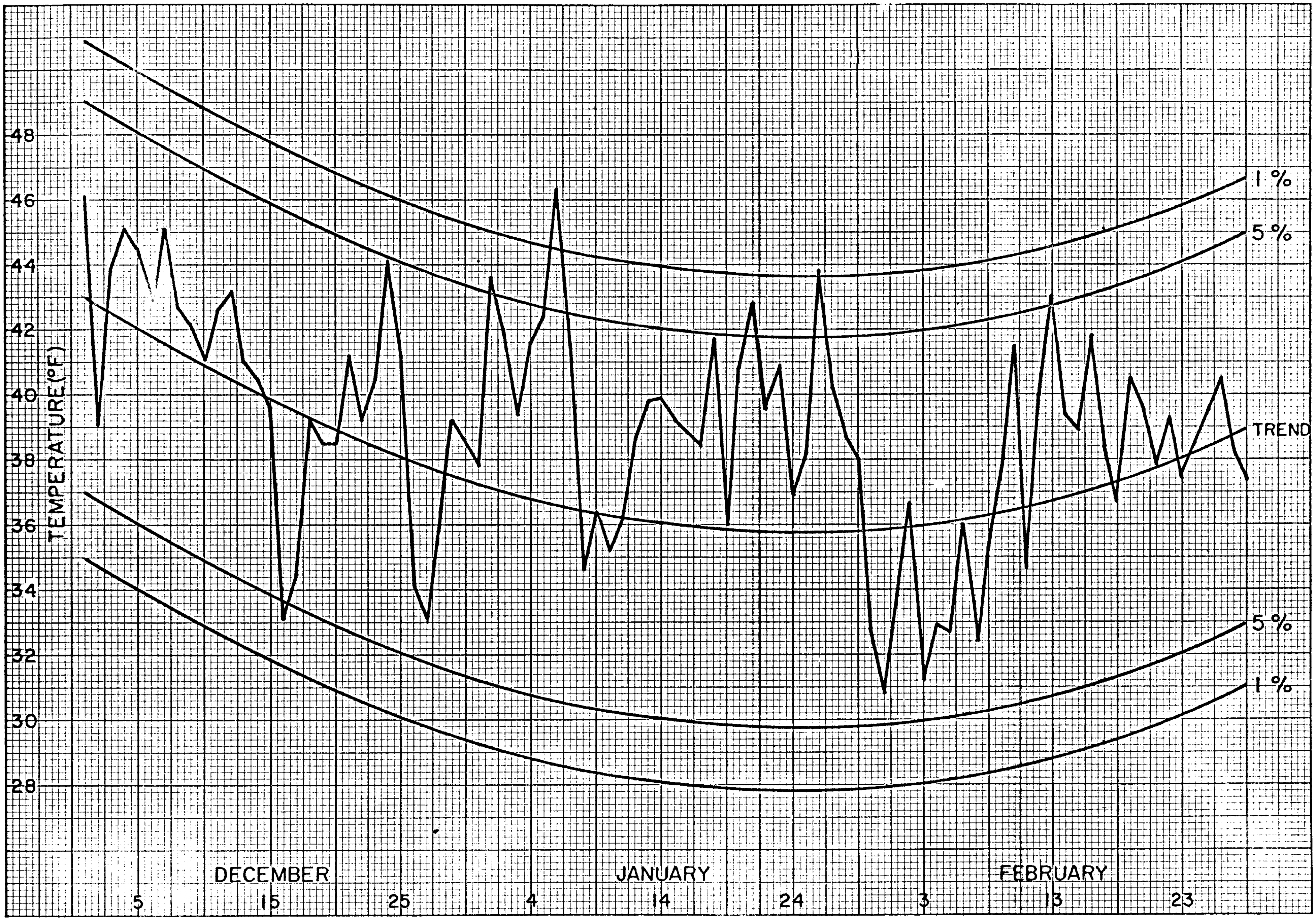

Figure 25. Average maximum temperature values for M-N phase with trend, 5%, and 1% significance levels.

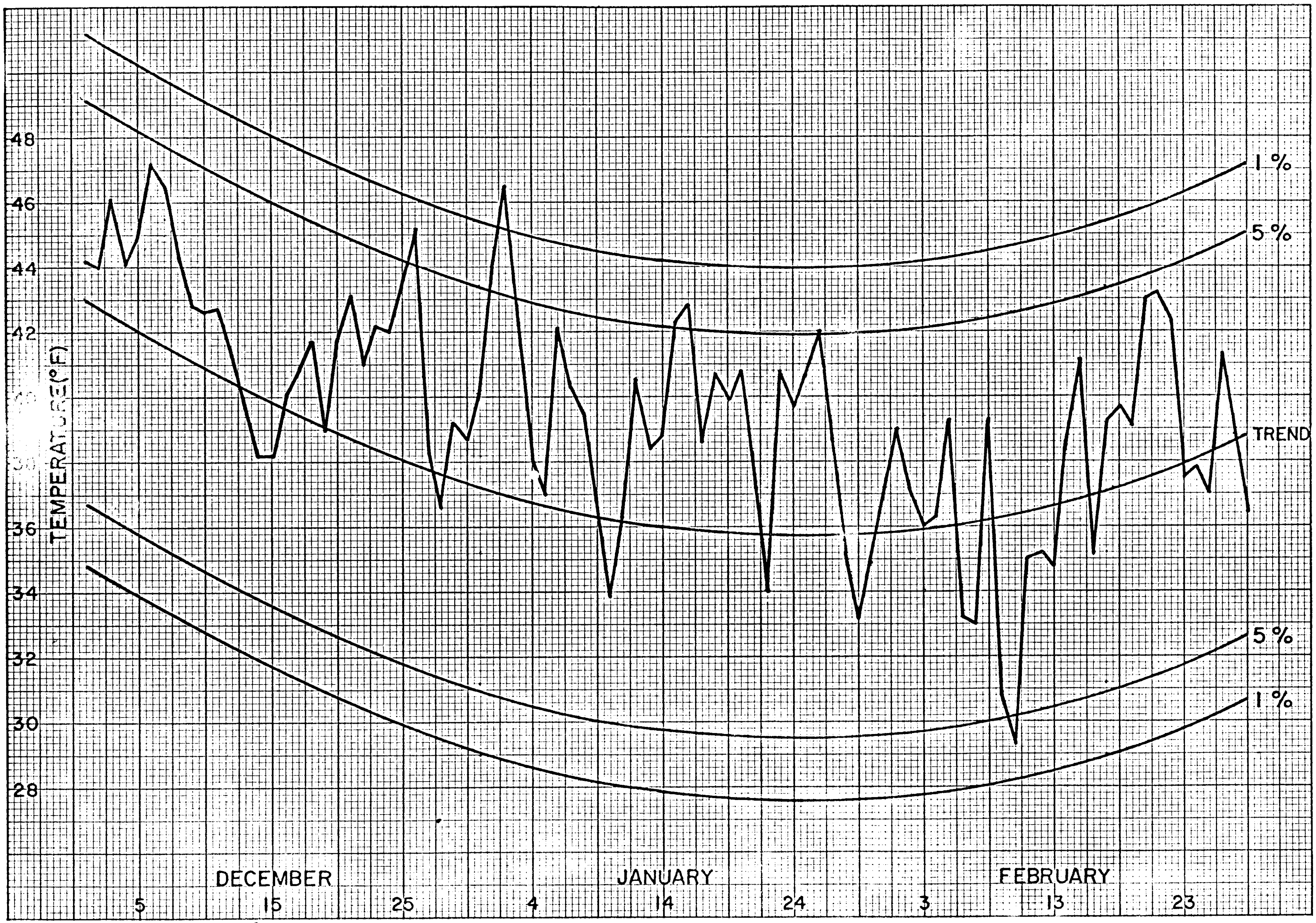

Figure 26. Average maximum temperature values for N phase with trend, 5%, and 1% significance levels.

Table VII

Standard deviations and standard errors of maximum and minimum temperatures for phases of Double Sunspot Cycle.

STANDARD DEVIATIONS (deg^2)			STANDARD ERROR (deg^2)	
Maximum Temperatures	Minimum Temperatures	Phase	Maximum Temperatures	Minimum Temperatures
10.09	10.28	N-MM	2.91	2.97
9.90	10.15	MM	2.86	2.93
9.51	9.93	MM-NN	2.75	2.87
9.43	9.80	NN	2.72	2.83
9.73	10.05	Major	1.35	1.39
9.97	9.98	NN-M	2.88	2.88
10.28	10.24	M	2.97	2.96
10.62	10.53	M-N	3.07	3.04
10.97	10.58	N	3.17	3.05
10.51	10.42	Minor	1.52	1.50

deviations for each group or values which were not greatly different. If this were not the case, the question of the validity of the assumption that the data is random can be raised. But if the data are classified in such a way that the variability of each group was not random, then one could expect widely differing values of the standard deviations.

To determine the chance that this cycle is a random occurrence or significant result, a statistical "F" Test (see Panofsky, 1958) was applied to the data. An "F" value is a ratio of the variance between the groups being tested and the variance within the groups being tested. If the variation within the groups is larger, then the variation between groups may be just a random fluctuation. There are tables available which give different significance levels and corresponding values of "F". If the value of "F" exceeds this tabulated value then the group-mean values are significantly different at that level.

For the maximum curve values, an "F" value was obtained which states that this cycle was significant on the 0.0000015% level while the cycle of minimum curve standard deviations was significant on the 0.06% level. Thus the variation of the variability of temperature between the eight phases of the double sunspot cycle is much more significant than the variation within each phase and thus the cycle is significant and, in view of the level of significance, undoubtedly real.

The significance bands placed on the individual phase curves are shown in Figures 7 through 26. Upon inspection, it will be found that anomalous values occur on certain dates during some phases, but not during others. Even the preferred date of the January Thaw on 21-22 January appears insignificantly different from the mean value during a few phases. Table VIII contains a significance count for each of the ten phases for both maximum and minimum values. Table IX shows the level of significance of the counts as was shown in Section II. These results, similar to those in Section II, are not too impressive.

Looking at the 5% and 2½% category, one cannot find a phase which has a count that would not be expected just by chance. The 1% category has three maximum and one minimum phases that can be considered significant. If the categories are summed individually for maximum and minimum values, only the 1% maximum category shows any semblance of significance.

Table Xa and Xb contain a tabulation of the significance levels of certain dates during each of the phases. The dates were chosen from the 92-year normal curves as representing the most probable dates of singularities. Most dates are significant only during a particular phase or two at most. The January Thaw period has interesting and opposing values. The 21 January date appears to be significant during the minor-half phases while 22 January is significant during the major-half phases. As a matter of fact, there appears to be a tendency for anomalous dates from 1 December to 21 January to show more significance

Table VIII

Significance counts.

Phase	MAXIMUM TEMPERATURES			MINIMUM TEMPERATURES		
	$\leq 5\%$	$\leq 2\frac{1}{2}\%$	$\leq 1\%$	$\leq 5\%$	$\leq 2\frac{1}{2}\%$	$\leq 1\%$
N-MM	4	4	2	5	2	1
MM	7	1	0	3	1	1
MM-NN	4	3	0	1	0	0
NN	3	1	1	1	1	1
Major	6	4	3	4	3	3
NN-M	1	0	0	3	0	0
M	5	4	3	5	4	2
M-N	7	3	2	4	1	0
N	5	3	1	7	1	1
Minor	7	5	3	6	2	1
Normal	5	3	1	5	3	2
Sum	54	31	16	44	18	12

Table IX

Values of "T" and significance levels for various counts.

Significance Level Being Counted (%)	Count	N	T	Significance Level of Count (%)
5	7	90	1.210	22.6
5	54	990	0.685	49.0
5	44	990	-0.840	40.0
2½	4	90	1.170	24.0
2½	31	990	1.270	20.0
2½	18	990	-1.380	16.8
1	3	90	2.220	2.6
1	16	990	1.930	5.4
1	12	990	0.665	51.0

Table Xa

Significance levels (%) of selected dates for phases of Double Sunspot Cycle.

MAXIMUM TEMPERATURES										
PHASE \ DATE	D7	D16	J1	J2	J7	J21	J22	J29	F2	F15
N-MM	+23	-55	-86	+30	+23	+39	+ 3	-58	-17	+19
MM	+65	-63	+73	+15	+48	+78	+ 3	+73	-13	+ 6
MM-NN	+69	-25	+61	+16	-88	+83	+22	- 1	- 1	+47
NN	-21	-11	-44	-69	-14	+28	+11	-38	-97	-42
Major	+66	- 5	-94	+ 6	+83	+21	+0.01	- 8	-0.5	+10
NN-M	+27	-48	+94	-42	+42	+60	-98	-38	- 6	-92
M	+ 9	-92	+20	-81	+21	+33	+50	-31	-73	+12
M-N	+24	- 4	+ 3	+13	+10	+ 2	+20	+47	+82	+52
N	+11	+ 6	+ 3	+0.2	+22	+11	-59	-41	+68	+19
Minor	+0.6	-10	+0.4	+ 6	+ 1	+0.7	+51	-32	-47	+ 9

D = December   + Above Normal

J = January   - Below Normal

F = February

Table Xb

Significance levels (%) of selected dates for phases of Double Sunspot Cycle.

MINIMUM TEMPERATURES								
PHASE \ DATE	J3	J7	J21	J22	J29	F2	F3	F
N-MM	+11	+ 7	+11	+ 2	-94	- 2	-0.3	+
MM	+61	+34	+56	+ 3	+44	-31	-79	+
MM-NN	+ 4	-78	+67	+ 6	-15	- 9	-31	+
NN	-13	-48	+26	+57	-36	+86	-48	-
Major	+20	+35	+ 7	+.08	-42	- 2	- 1	+
NN-M	-27	+47	-62	-47	-28	- 6	- 8	+
M	-73	+14	+52	+87	-79	-76	-16	+
M-N	+11	+26	+12	+26	+47	-65	-32	+
N	+0.2	+ 3	+24	+98	- 7	+98	+41	-
Minor	+ 7	+0.3	+11	+72	-20	-17	- 8	+

J = January   + Above Normal

F = February   - Below Normal

during the minor half with the exception of the 14 February minimum and 20 February maximum.

For a closer look at this, average values of significance were computed for each phase by using the absolute value of the individual levels. In addition, an average was computed for each of the two apparent halves of the winter season. The results of these calculations are shown in Table XIa and XIb. They illustrate the apparent differences in the winter season noted above, although not unambiguously. The significance levels involved are all rather large and it is very difficult to show distinctly by this method the time preference for the major- and minor-half phases.

Another method to illustrate this discrepancy in the winter season involves the use of a weighted mean. If the reciprocals of the values in Table Xa and Xb are computed and averages of these values are computed in the same manner as was used for Table XIa and XIb, the occurrence of a value at the 1% level is weighted 10 times more than an occurrence at the 10% level. Although this might not be the best weighting scheme, it will suffice to illustrate this point.

Table XIIa and XIIb present the results of applying this scheme. Large values indicate high significance.

It is possible to conclude from these results that there is a tendency for anomalies to occur in the first half of the winter during

Table XIa

Average absolute value of significance levels (%) of selected dates for phases of Double Sunspot Cycle.

MAXIMUM TEMPERATURES			
PHASE \ DATE	All Days	J22-F15	D7-J21 F20
N-MM	39.6	24.2	48.4
MM	43.5	23.8	54.9
MM-NN	42.6	17.8	56.9
NN	39.2	47.0	34.7
Major	33.6	4.6	50.1
NN-M	58.1	58.5	57.9
M	42.4	41.5	42.9
M-N	28.1	50.2	15.4
N	22.6	46.8	8.7
Minor	15.3	34.8	4.2
Normal	6.0	2.5	8.0

D = December

J = January

F = February

Table XIb

Average absolute value of significance levels (%) of selected dates for phases of Double Sunspot Cycle.

MINIMUM TEMPERATURES			
PHASE \ DATE	All Days	J22-F3	D15-J21 F14
N-MM	23.6	24.6	22.8
MM	48.7	39.2	56.2
MM-NN	32.6	15.2	46.4
NN	39.1	56.8	25.0
Major	23.7	11.3	33.6
NN-M	35.8	22.2	46.6
M	53.6	64.5	44.8
M-N	39.3	42.5	36.8
N	46.8	61.0	35.4
Minor	21.9	29.2	16.1
Normal	7.3	4.4	9.6

D = December

J = January

F = February

Table XIIa

Average reciprocal of significance levels (%) of selected dates for phases of Double Sunspot Cycle.

MAXIMUM TEMPERATURES			
PHASE \ DATE	All Days	J22-F15	D7-J21 F20
N-MM	0.06	0.12	0.03
MM	0.07	0.15	0.02
MM-NN	0.20	0.52	0.02
NN	0.04	0.04	0.04
Major	9.34	25.6	0.07
NN-M	0.03	0.05	0.02
M	0.04	0.04	0.04
M-N	0.13	0.03	0.19
N	0.54	0.03	0.84
Minor	0.65	0.05	0.99
Normal	0.12	0.55	0.27

D = December

J = January

F = February

Table XIIb

Average reciprocal of significance levels (%) of selected dates for phases of Double Sunspot Cycle.

MINIMUM TEMPERATURES			
PHASE \ DATE	All Days	J22-F3	D15-J21 F14
N-MM	0.52	1.09	0.08
MM	0.06	0.10	0.02
MM-NN	0.08	0.09	0.07
NN	0.04	0.02	0.05
Major	1.59	3.51	0.52
NN-M	0.05	0.09	0.02
M	0.14	0.02	0.22
M-N	0.04	0.03	0.05
N	0.62	0.05	1.08
Minor	0.44	0.06	0.74
Normal	1.41	2.77	0.32

D = December

J = January

F = February

the minor half of the double sunspot cycle and to occur in the second half during the major half.

SECTION IV

CONCLUSIONS

To summarize, there are four conclusions that may be drawn from this investigation:

1) That it is impossible on the basis of Boston temperature data to establish the reality of the "January Thaw" or any other singularities using normal curves due to the small difference between the actual count of significant anomalies and the number to be expected by chance.

2) When the data are classified according to the 20-24 year double sunspot cycle it is once again not possible to prove any presence of singularities.

3) The variation in the variability of temperature is quite cyclic in character and parallels the 20-24 year double sunspot cycle. This is the one clearly significant relationship between the temperature regime at Boston and the double sunspot cycle that emerges from this study.

4) There appears to be a division in the winter season. Higher anomalous values appear during the minor half of the double sunspot cycle for the period from 1 December to 21 January while for the remainder of the winter they occur during the major half of the cycle. This is consistent with the fact that major blocks in the general

circulation tend to occur most strongly and regularly during the latter half of the winter and during the major half of the double sunspot cycle.

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