Climatology

AN EVALUATION OF TEMPERATURE AND HEATING DEGREE-DAY TRENDS IN NEW JERSEY AS A FUNCTION OF OBSERVATION TIME

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ABSTRACT

Trends in mean annual temperature and seasonal heating degree-days at seven New Jersey stations are corrected for changes in observation time. These trends are compared to uncorrected trends during three periods which include the years from the late 1800s through 1950, 1950-1983, and for the entire period of record.

The uncorrected trends agree with past studies and show warming prior to 1950, cooling for 1950-1983, and no significant trends over the entire period. The corrected values, however, indicate warming prior to 1950, no significant trends from 1950-1983, and significant warming over the entire period.

INTRODUCTION

Mean annual temperatures have been widely used to indicate temperature trends. A study at the Blue Hill Observatory, 10 miles south of Boston, has shown a warming trend from 1880 to 1958 and a cooling trend since 1958 (3). In Jacksonville, Florida, Winterling (4) showed that a pronounced warming trend occurred from 1944 through 1957 and a cooling trend after 1957. Temperature trends in New Jersey were analyzed statistically by Brotak and Shulman (5) and showed warming from 1900 until 1950. Pronounced cooling followed during the 1950s and 1960s. This cooling was shown to persist into the 1970-1980 period by Kluepfel and Shulman (6).

Such temperature trends, however, may not be a true indicator of the natural fluctuations of climate. Landsberg (7) found that, despite overall cooling during the past three decades, temperatures at some stations have increased by $0.5^{o}F$ - $1.0^{o}F$ as a result of urbanization. Brotak and Shulman (5) concluded that significant warming during the period 1900-1969 at New Brunswick and Long Branch, New Jersey was due to their proximity to the New York City urban center.

Rumbaugh (8) found that annual mean temperatures are a function of observation time. He found that mean temperatures at Twin Falls, Idaho were as much as $1.5^{o}F$ higher when based on an observation time of 5:00 p.m. rather than midnight. Mitchell (9) showed that by changing the observation time at Columbus, Ohio from 0730 to 1830, the mean January temperature increases by $2.2^{o}F$. In Indiana, the climate between 1925 and 1945 was shown by Schaal and Dale (10) to cool $1.2^{o}F$ solely as a result of a change in the mean observation time. During this time, the number of stations which recorded their temperatures in the morning increased by nearly 45 percent. Schaal and Dale concluded that changes in observation time result in mean annual temperature differences which can be mistaken for natural climatic trends.

In New Jersey, the time of the daily climatic observation varies considerably. National Weather Service first order stations record daily maximum and minimum temperatures for the 24-hour period ending at midnight. At cooperative stations, however, observations are made either in the early morning or late afternoon. Scotto and Shulman (11) found that mean temperatures with a morning observation time are lower than those determined from midnight or late afternoon observations. They also noted that mean temperatures from late afternoon observations are higher than those from other observation times. This occurs since the diurnal temperature cycle normally reaches its minimum in the early morning and its maximum in the late afternoon. Therefore, it is likely that the diurnal minimum or maximum temperatures will be used to calculate the mean of adjacent days.

Errors in temperature derived quantities such as heating degree days (HDD) and growing degree days (GDD) also result from variations in observation time. These errors are much greater since the effect of observation time is cumulative. Since HDD can be used as an indicator of fuel usage (12), accurate seasonal HDD totals are necessary for reliable fuel consumption estimates.

Scotto and Shulman (11) determined the deviations in mean annual temperature and seasonal HDD resulting from different observation times at Newark, New Jersey (Table 1). These values were used to correct the mean temperatures and seasonal HDD totals to the true daily means. The true daily mean is defined as the average of the 24 hourly temperature readings from one midnight to the next.

In this paper, Scotto and Shulman's correction factors will be applied to the mean annual temperature and seasonal HDD values at seven New Jersey climatological stations. Trends resulting from the corrected and uncorrected values will be compared. The significance of these trends will be statistically evaluated.

PROCEDURE

Average monthly temperatures were extracted from Climatological Data for New Jersey (13) for the stations in Table 2. A summary of the length of record and missing data at these stations is given in Table 3. Observations for the period 1892-1896 were missing and were omitted from the study. Since these missing data were near the beginning of the period of record, no attempt was made at data reconstruction. Missing data for the period 1924-1929 at Newark, however, were reconstructed using the reduction to standard series technique (14). This reconstruction was performed since the missing data occurred in mid period. Elizabeth was found to be climatically homogeneous with Newark and its data were used in the reconstruction.

When individual mean monthly temperatures were missing at a station, the average mean monthly temperature for the period of record was substituted. Generally, less than 1 percent of the mean monthly temperatures were missing at each station, however, 2 percent were missing at Belvidere and 5 percent at Hightstown. The months of July, January, February and August at Hightstown had 10, 8, 7 and 6 percent of the mean monthly temperature observations missing. These data were distributed such that a greater proportion were missing from HDD seasons than from the 12-month calendar years. The 1913-1914 HDD season, for example, had 10 mean monthly temperatures missing, whereas only 6 and 4 were missing from the years 1913 and 1914. The missing data during the 1918, 1925, and 1933 HDD seasons were similarly distributed and, therefore, these HDD seasons were omitted at Hightstown, while the temperature data for the calendar years were retained.

Since HDD statistics are generally unavailable, having been recorded only in relatively recent years, and since their conventional computation would be tedious, monthly HDD data were derived from the mean monthly temperatures. The relationship between HDD and mean monthly temperature is given by Thom (15) as:

$$NE(D)=N(65-E(t)+\ell\sqrt{N}\,\sigma_m)$$

where NE(D) is the monthly HDD total; E(t) is the mean monthly temperature; σ_m is the standard deviation of monthly mean temperature for the period of record; and N is the number of days per month. ℓ can be established as a function of h. Where h is given by:

$$h = \frac{65-E(t)}{\sigma_m\sqrt{N}}$$

Since the function of h has limiting properties $\ell = -h$ for $h < -0.70$ and $\ell = 0$ for $h > 0.78$. Intermediate values of ℓ are given by plotting observed ℓ values against h. Observed values of ℓ are given as:

$$\ell = \frac{E(D)-65+E(t)}{\sqrt{N}\,\sigma_m}$$

where E(D) is the observed monthly HDD total. Once computed, the monthly HDD values were summed to give seasonal, July to June, HDD totals.

To determine the effectiveness of Thom's procedure, the computed seasonal HDD totals were compared to the actual seasonal HDD values at New Brunswick for the period 1953-1982. The mean seasonal HDD error over the 30 years was 0.50 percent with the greatest seasonal error being 1.66 percent in the 1959 season.

Observation time histories for each station were compiled using data from Climatololgical Data for New Jersey (Table 2). The actual hour of observation was unavailable prior to 1939, since observations were recorded only as early morning, late afternoon, or midnight. All stations except Newark and Atlantic City recorded an observation hour in the late afternoon in 1939 and had recorded their observation time as late afternoon prior to 1939. Newark and Atlantic City recorded midnight observations during both periods. Therefore, the observation hour prior to 1939 was assumed to be the same as the 1939 hour.

The mean annual temperatures and seasonal HDD at each station were then standardized using the correction factors for Newark developed by Scotto and Shulman. Correction factors for stations other than Newark were unavailable. The factors for Newark were used at all stations since Scotto and Shulman found only small differences in the observation hour correction at LaGuardia Airport, New York and Pittsburgh, Pennsylvania. It was believed that any local differences in the correction factor would be insignificant.

Time series were plotted for each station using corrected and uncorrected mean annual temperature and seasonal HDD values. Regression analyses (16) of these values against time were run at each station for three time periods. These periods included the years from the start of observation to 1949, 1950-1983, and the entire length of record. The first two periods correspond to periods of warming and cooling respectively as documented by Brotak and Shulman (5), and Kluepfel and Shulman (6). A t-test (17) was run on the slopes of the regression lines to determine if they were statistically significant.

RESULTS

The corrected and uncorrected mean annual temperature values show warming at all stations during the pre-1950 period. According to the t-test, this warming was statistically significant at all stations (Table 4). Mean annual temperature trends during 1950-1983 and over the entire period varied in both direction and significance and are summarized in Table 4. As expected, the corrected and uncorrected seasonal HDD trends were similar to those of temperature. The slopes of these trends and their statistical significance are shown in Table 5.

Prior to 1950, the corrected and uncorrected mean annual temperature and seasonal HDD trends at each station, except Newark, were identical since the observation time at these stations was constant. During 1940 Newark's observation time was 1:30 a.m. resulting in a 0.05 unit decrease in the slope of the corrected HDD trend. The slopes of the corrected and uncorrected mean annual temperature trends, however, remained equal as did the significance levels in all cases.

Comparison of the corrected and uncorrected trends during the 1950-1983 period showed that significant positive HDD trends at Belvidere, New Brunswick and Hightstown remained positive but became statistically insignificant when the correction factor was used. Significant mean annual temperature cooling trends at New Brunswick, Hightstown and Indian Mills continued to show cooling, but became insignificant during 1950-1983 once the correction factor was applied. The significance of the regression line slopes for seasonal HDD and mean annual temperatures differed at individual stations. This is due to the fact that during the period from June to September few HDD are accumulated and seasonal HDD values do not represent the effects of temperature variation over the entire year.

The most pronounced differences between the corrected and uncorrected trends occurred over the entire length of record. At Charlotteburg the uncorrected seasonal HDD values showed an increase with time which was judged to be insignificant by the t-test (Fig. 1). However, applying the correction factor resulted in a statistically significant decrease in HDD over time (Fig. 2). During this period, uncorrected mean annual temperatures showed no trends at Charlotteburg, but showed significant warming after the correction factor was applied. At Belvidere the uncorrected mean annual temperatures showed cooling, significant at the 10 percent level (Fig. 3). Once the Belvidere temperatures were corrected for observation time changes, however, the new trend showed warming, significant at the 5 percent level (Fig. 4). The correction of seasonal HDD values also caused a trend reversal at Belvidere. Uncorrected values increased with time while corrected values showed a decrease. However, neither trend was statistically significant.

CONCLUSIONS

Comparison of the slopes and significance levels of the corrected regression lines in Tables 4 and 5 indicates the differences that result from observation time changes. At most New Jersey stations, the uncorrected mean temperature and seasonal HDD values confirm the results of Kluepfel and Shulman and show significant cooling from 1950-1983. The corrected values during this period, however, generally show no significant warming or cooling at most stations. During the period 1900-1980, Kluepfel and Shulman found no significant trends in temperature. However, the corrected mean annual temperature and seasonal HDD values during this period showed warming at most stations.

Ignoring changes in the time of observation can lead to erroneous conclusions regarding temporal trends in temperature and HDD. In some cases, apparent warming or cooling trends become insignificant once corrected for observation time. It is also possible for nonsignificant temperature variations to show statistically significant warming or cooling after observation time is standardized. In some cases, such as Belvidere between 1897 and 1983, the effect of observation time change can be great enough to cause a reversal in the slope of the regression line of temperature with time from significantly positive to significantly negative.

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Table 1. Mean annual temperature and seasonal heating degree-day correction factors for different observation times at Newark, New Jersey (Scotto and Shulman, 1985).

Time	Temperature Correction	HDD Correction	Time	Temperature Correction	HDD Correction
0000	.25	40.14	1200	-.80	219.70
0100	.12	.85	1300	-1.01	292.14
0200	.24	-31.88	1400	-1.22	356.51
0300	.38	-61.93	1500	-1.37	386.51
0400	.48	-93.28	1600	-1.32	375.46
0500	.62	-120.22	1700	-1.08	320.06
0600	.43	-125.68	1800	-.86	250.34
0700	.25	-104.44	1900	-.65	206.66
0800	.06	-32.63	2000	-.43	166.18
0900	-.10	-42.10	2100	-.27	126.88
1000	-.32	108.07	2200	-.16	98.03
1100	-.59	156.82	2300	-.06	67.19

Table 2. Stations used by county, elevation (in feet above sea level), latitude and longitude.

Station	County	Elevation	Latitude	Longitude
Belvidere	Warren	275	40° 51'	75° 05'
Charlotteburg	Passaic	760	41° 02'	74° 26'
Newark	Essex	30	40° 42'	74° 10'
New Brunswick	Middlesex	125	40° 29'	74° 26'
Hightstown	Mercer	100	40° 16'	74° 34'
Indian Mills	Burlington	100	39° 48'	74° 47'
Atlantic City	Atlantic	10	39° 23'	74° 26'

Table 3. Summary of missing data and observation time changes. Where hours indicate observation time changes by year; X indicates years prior to the start of observation; H indicates heating degree-day seasons omitted; M and R indicate years of missing or reconstructed data.

Station	1887	1892-1896	1897	1902	1913	1918	1924	1925	1926-1929	1933	1940	1951	1952	1960	1963	1968	1973
Belvidere	X	X	5 pm	→	→	→	→	→	→	→	→	→	→	→	7 am	→	→
Charlotteburg	X	X	4 pm	→	→	→	→	→	→	→	→	8 am	7 am	→	→	→	→
Newark	12 am	M	12 am	→	→	→	→	→	R	12 am	1:30 am	12 am	→	→	→	→	→
New Brunswick	5 pm	M	5 pm	→	→	→	→	→	→	→	→	→	→	→	→	8 am	→
Hightstown	X	X	8 pm	8 pm	H	H	8 pm	H	8 pm	H	8 pm	→	→	6 pm	→	→	7 am
Indian Mills	X	X	X	8 pm	→	→	→	→	→	→	→	→	7 pm	→	→	→	→
Atlantic City	12 am	M	12 am	→	→	→	→	→	→	→	→	→	→	→	→	→	→

Table 4. Regression slopes for uncorrected and corrected mean annual temperature values versus time during the three periods studied, with asterisks indicating significance level. *1%, **5%, ***10%.

Station	Before 1950		1950-1983		Before 1983	
	Uncorrected	Corrected	Uncorrected	Corrected	Uncorrected	Corrected
Belvidere	.05*	.05*	-.10*	-.04**	-.01***	.01**
Charlotteburg	.04*	.04*	-.05**	-.04**	0	.02*
Newark	.03*	.03*	.01	.01	.03*	.03*
New Brunswick	.03*	.03*	-.05*	0	.01**	.02*
Hightstown	.02**	.02**	-.04*	-.01	.01**	.01**
Indian Mills	.02***	.02***	.07*	0	0	0
Atlantic City	.05*	.05*	-.03**	-.03**	.02*	.02*

Table 5. Regression slopes for uncorrected and corrected seasonal heating degree-day values versus time during the three periods studied. Asterisk indicates significance at the 1% level.

Station	Before 1950		1950-1983		Before 1983	
	Uncorrected	Corrected	Uncorrected	Corrected	Uncorrected	Corrected
Belvidere	-11.51*	-11.51*	25.08*	6.64	1.47	-0.39
Charlotteburg	-12.81*	-12.81*	16.47*	13.91*	1.69	-6.13*
Newark	-7.48*	-7.43*	0.27	0.27	-7.99*	-7.99*
New Brunswick	-7.24*	-7.24*	18.62*	2.71	-2.55*	-5.69*
Hightstown	4.43	4.43	13.37*	2.99	-1.82	-0.82
Indian Mills	-4.69	-4.69	1.03	8.30	1.08	2.26
Atlantic City	-12.68*	-12.68*	7.30*	7.30*	-6.39*	-6.39*

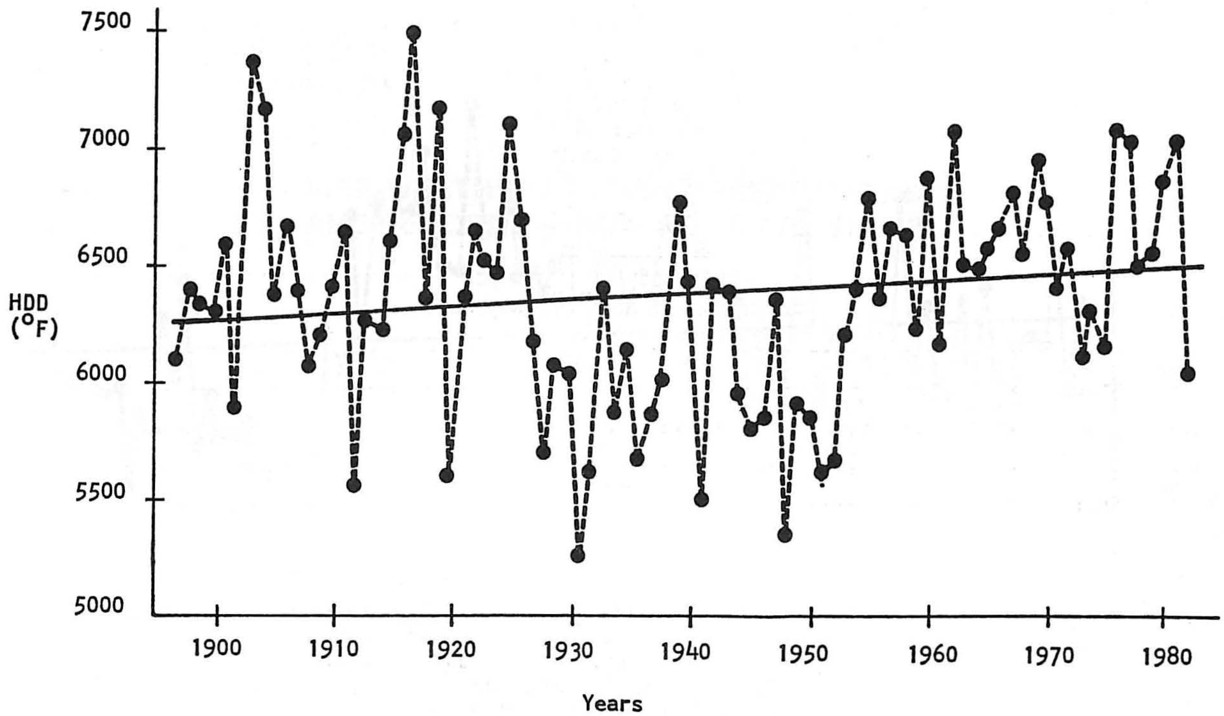

Figure 1. Regression line of uncorrected seasonal heating degree-days (°F) versus time at Charlotteburg, N. J. from 1897-1983.

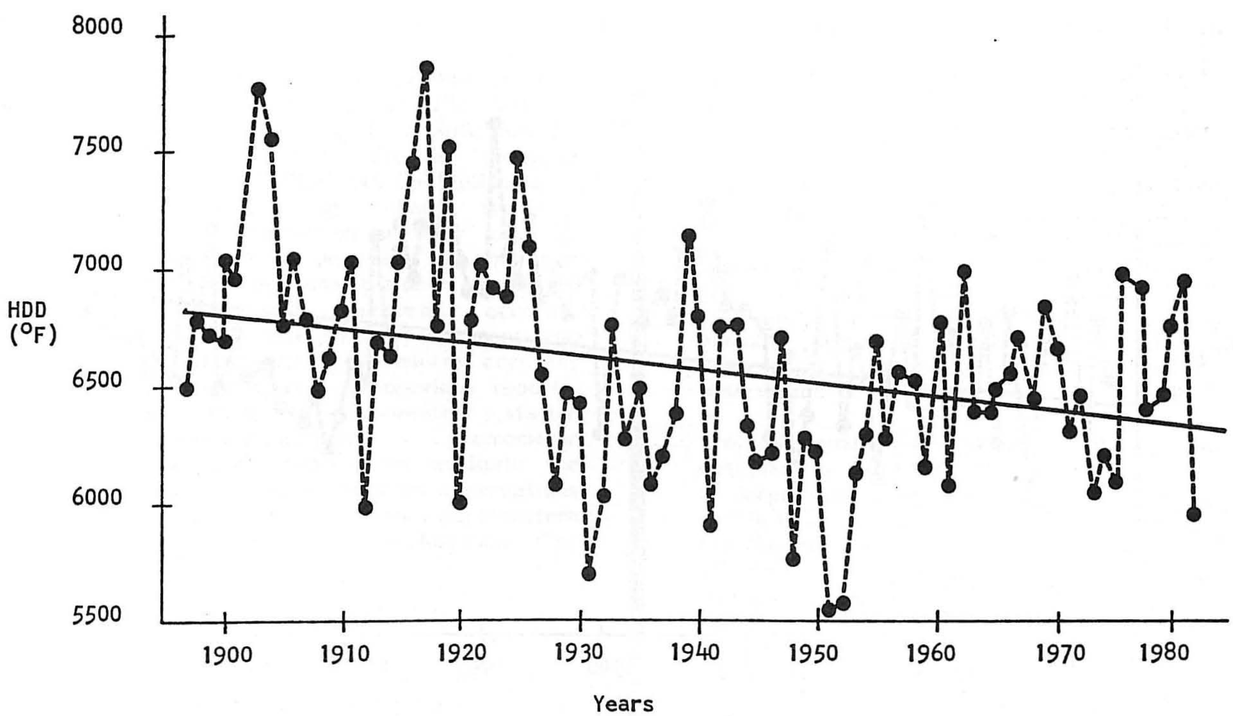

Figure 2. Regression line of corrected seasonal heating degree-days (°F) versus time at Charlotteburg, N.J. from 1897-1983.

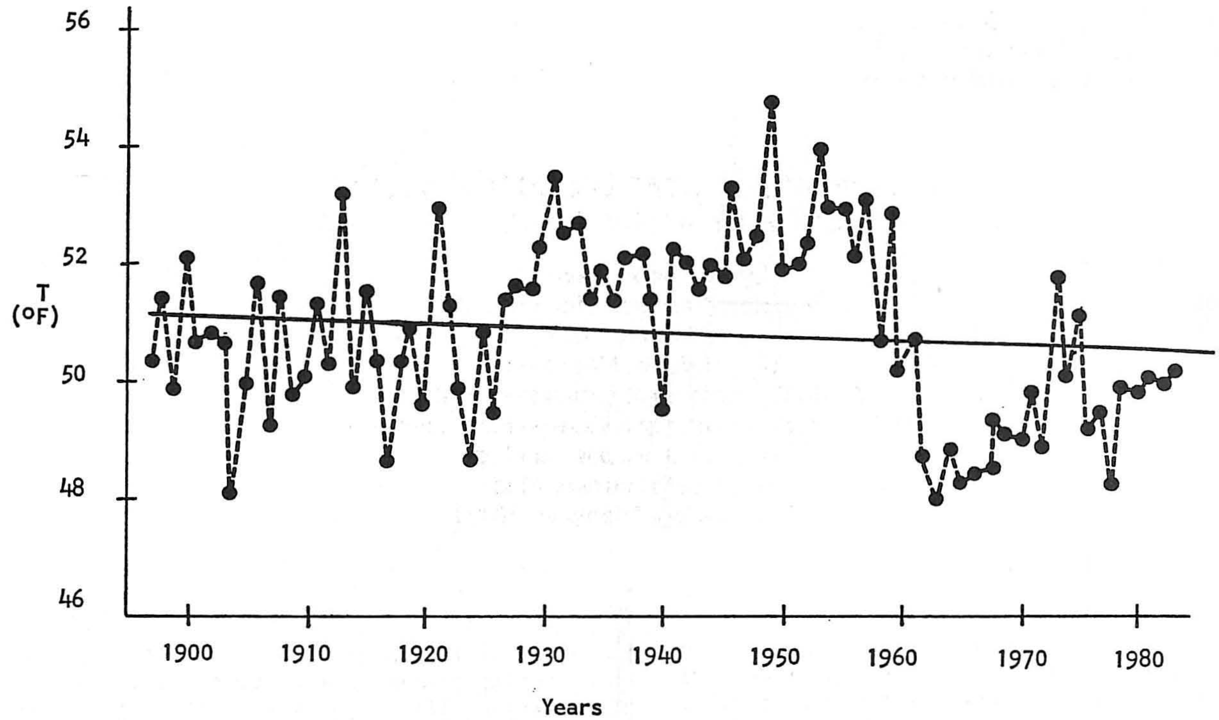

Figure 3. Regression line of uncorrected mean annual temperature (°F) versus time at Belvidere, N.J. between 1897-1983.

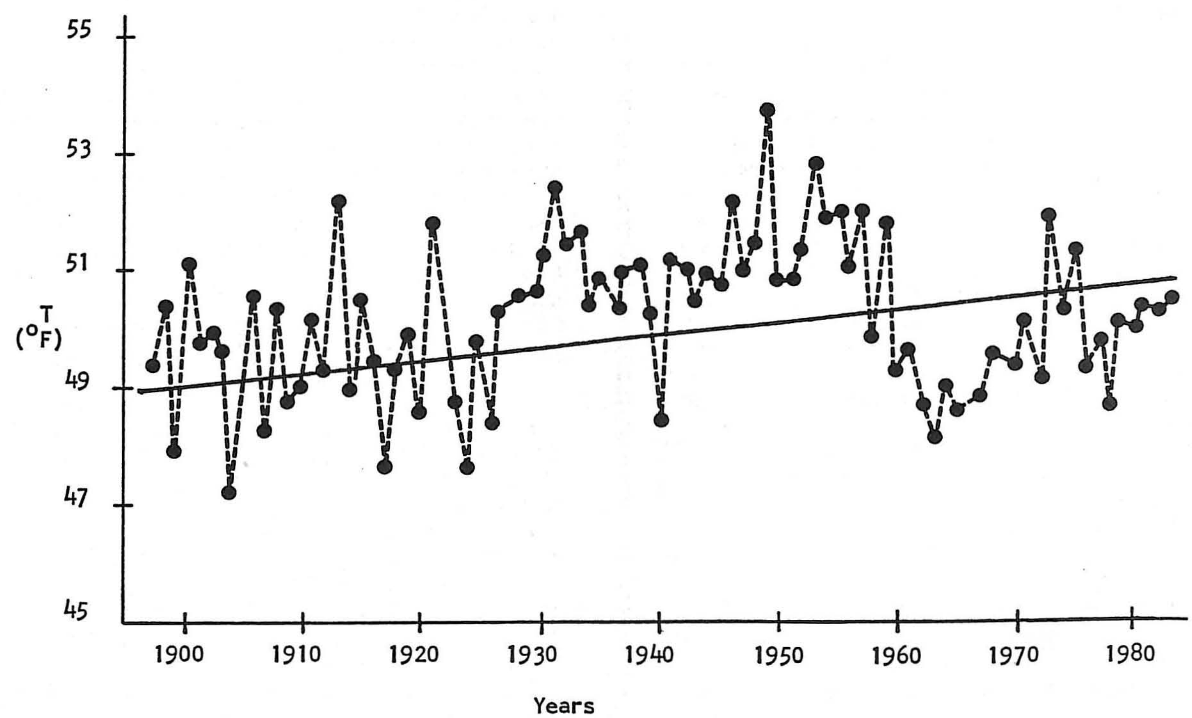

Figure 4. Regression line of corrected mean annual temperature (°F) versus time at Belvidere, N.J. between 1897-1983.