Climate Change Indicators in the Fletcher Data for Wood County, Ohio (1854–1992)

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Abstract

We undertake the study of data featured in Lyle R. Fletcher's *A Century or so of Wood County Weather (1787-1991)* ((Fletcher, 1996)). We focus on tables of extreme temperatures (maxima and minima) that Fletcher compiled for the years 1854-1992. He recorded the record-setting years for each of max(maximum) (which we call maxmax), minmax (that is, min(maximum)), maxmin, and minmin, for all 366 days of the year.

Fletcher made several statements which inspired the study of this data. In contract to others whom he cited, Fletcher believed that weather is not truly cyclical but rather follows "irregular cycles" (i.e. without fixed period). He also suggested that the climate of Wood County has not changed substantially over that 140 or so years, nor will it change substantially into the future. By focusing on "a century or so of weather" (1893-1992), we conclude that his data do indeed show that the climate of Wood County has indeed changed over that time.

1 Introduction

1.1 Who was Lyle Fletcher?

1.1.1 Biography

Fletcher's collected materials have been archived at Bowling Green State University, where he ended his academic career. This biography welcomes one to the on-line catalogue of his collection:

Lyle Rexford Fletcher was born February 28, 1901 on a farm in Pulaski, Iowa. He was only a few days shy of his 100th birthday when he died in Bowling Green, Ohio on February 16, 2001. During his later years he was known by his many friends and colleagues as the leading authority on Bowling Green and Wood County history, geography, and weather. He was passionate about local history and actively served in the community.

Dr. Fletcher attended the University of Kansas, Lawrence in 1922 majoring in earth science with a minor in journalism and geography. He did not graduate but began a journalism career. He worked as a reporter for Parsons, Kansas Sun, as editor of the Daily Kansan, 1924-1925, and at Whiteside Sentinel, Morrison, Illinois before moving to Mount Vernon, Ohio to become city editor of the Mount Vernon News. In 1933 he married Helen Bebout while living there. He graduated from Ohio University in 1931 with a bachelor's degree in geography and by 1934 received a master's degree from Ohio State University. That same year he passed the civil service examination and began work in the geography division of the Bureau of the Census in Washington D.C. In 1936 he transferred to the U.S. Weather Bureau to pursue a career as a meteorologist. His daughter, Beverly Niehaus commented, "He did long-range forecasts for Eisenhower's Normandy Invasion and the A-bomb drops on Nagasaki and Hiroshima." He was assigned to work for the Iowa Weather Service as chief in Des Moines and served as an adjunct professor of agro-climatology in the department of physics at Iowa State University in Ames.

In 1946 he and his family moved to Bowling Green where he worked as assistant professor of geography at Bowling Green State University. He was chairman of the Great Lakes Division of the Association of American Geographers and served on the national *board of that organization and the National Council for Geographic Education. He wrote a monthly column, for years, on Wood County weather for the Bowling Green Sentinel-Tribune and in 1996 published a book on the history of Wood County weather. He was awarded emeritus status by the university in 1971, designated an honorary alumnus in 1986, and presented with an honorary doctorate of public service in 1995.*

In the early Seventies he became director of the Wood County Parks Commission and was credited with preventing the demolition of the Wood County Infirmary (one of the last intact county homes in Ohio). The site became the home of the Wood County Historical Museum and Center. In 1956 Dr. Fletcher had helped co-found the Wood County Historical Society. He would serve as its first secretary, curator, newsletter editor, and third president. He also planted all of the trees and shrubs on the surrounding land, later designated the Fletcher Arboretum. Paul Jones, former editor of the Sentinel-Tribune, called him "the real sparkplug of the organization from the beginning." ((Center for Archival Collections, 2012))

1.1.2 Fletcher's Graduate Studies and Professional Experience

Fletcher wrote his master's thesis on *The Amish People of Holmes County, Ohio: A Study in Human Geography* ((Fletcher, 1932)). The conclusion of his thesis was respectfully re-examined in a recent work by Darren Byler ((Byler, 2004)), who began by pointing out the obvious – how wrong Fletcher had been in his predictions about the Amish people. Fletcher wrote (in 1932) that "the study of the Amish social organism leads to the conclusion that the community will eventually disintegrate, and disappear.... How soon this will come about it is hard to say but the end of the present century should witness a tremendous contraction in their numbers. This conclusion is based on three premises – geographic factors, human nature, and history." Fletcher lived to see his prediction fail gloriously: as Byler noted in 2004, "Clearly even the casual observer can quickly discern that this has not been the case. Not only have the Amish maintained their numbers, but they have increased exponentially. Over the past century, the Ohio Amish population has doubled every 22 years; they have grown from an estimated population of 2,600 in 1920 to a conservative estimate of 53,000." Byler attempts to discern what Fletcher failed to grasp in his thesis "written 71 years ago."

We can be certain that Fletcher was delighted to be wrong in this case: as he wrote in the final words of his thesis, "...isolation, so necessary for the preservation of individualism, is being destroyed by the modern transportation system. So we leave the Amish with great admiration for their social system but with sincere doubts as to its capacity for continuity."

In this study, we, too, want to discern if there were things which Fletcher failed to grasp – only about climate, the very thing that he helped define as the average of a thirty-year stretch of weather. He is a man well-positioned to speak with great authority on the subject of meteorology, understanding it far better than we do; but we have better tools for the mathematical analysis of the time series which he so carefully preserved, and so hope to show that his thesis, that climate change is not occurring, is incorrect.

In terms of his professional expertise, the biography does not, perhaps, give him quite as much credit as a meteorologist as he deserves. Fletcher recalls in his book that when he was "stationed at the Statistical Laboratory of Iowa State University, he and Herbert Thom, also of the U. S. Weather Bureau[1], working with professors of statistics

[1] Herbert C. S. Thom was "the state climatologist and also the meteorologist-in-charge of the U.S. Weather Bureau office in Des Moines" ((Anderson, 2009)), and Fletcher's colleague. Thom's important

there reached the conclusion that a thirty year period was more justified in the calculation of averages for weather phenomena, than the entire period of record which varied generally from station to station, the values of which were used previously by the Bureau." In other words, to make reporting more consistent, he and others helped arrive at the value we use today to describe the climate of a region: an average of thirty years.

1.1.3 Personal Reflections on Fletcher

Dr. Fletcher was a personal friend of mine. Perhaps it's fairer to say an acquaintance – I was really too young to be his friend when I knew him. We were on a committee together, when I was a student at Bowling Green Junior High School, and he indicated a certain fondness for me (which I reciprocated). I can't recall what motivated me to do so, but around 1983 I took the opportunity to "interview" him at his home. We talked about many things, but we discussed war in particular. I learned, for example, that his brother had been a baloonist in the Great War (World War I), but that Fletcher himself had managed to miss out on that one because he was just a little too young. As one can see from the archive's biography above, he played a very important role in World War II.

My mother, Marilyn Long, who on rare occasion had the pleasure of being Fletcher's bridge partner, recalled that he was one of the most amazing and unorthodox bidders and players she ever encountered (and she's played with hundreds). "He would bid on practically nothing, and make it." So it seems that Fletcher's instincts were strong – at least in bridge!

1.2 Fletcher's Magnum Opus: *A Century or so of Wood County Weather*

Fletcher wrote this work over a long period of time: long enough that he reports in his introduction that his typist "...likes to point out that she wasn't a grandmother when this project was started, but has since aged appreciably and has become biological grandmother to four little people, in addition to feeling like a grandmother of this endeavor." Clearly Lyle Fletcher had a sense of humor.

In spite of the title's implication that this work is about weather, Fletcher included many interesting historical sidenotes in his book. Fletcher was a geographer, and so geography too appears prominently. As an example, he mentioned that on April 24th, 1871, "... a tidal wave or Tsunami destroyed Isigahizima, Japan, washing 9,400 people out to sea." Reading the book is thus an interesting exploration of a variety of topics. Even lexicography is featured: Lyle mentions that the word "blizzard" was introduced into the meteorologist's lexicon by the editor of the Esthervill, Iowa "Vindicator" after a March 14, 1870 – well, <u>blizzard</u>. (p. 16)

Fletcher dedicates the book to his wife: "for her support ... in my efforts to increase people's knowledge of the great air ocean in which we live." Then he brings to life the vastness yet connectedness of the great air ocean, with stories like this one: "In late July,

role in meteorology was recognized in 1963, when he received the award for "Outstanding Contribution to the Advance of Applied Meteorology" from the American Meteorological Society", "for a quarter century of contributions to applied meteorology, including furnishing climatological estimates to the armed forces during World War II, major contributions to the problems of statistical analysis of climatological data, development of wind design data, and development of a much improved formula for calculating annual and seasonal energy use for domestic heating." ((The American Meteorological Society, 1974))

1883, forest fires started in Tillamook County, Oregon, and continued into August and became the famed Tillamook Burn, the most destructive known to that time. Early morning western skies in Wood County were spectacular as a result." (p. 17) Elsewhere he notes that on "September 26, 1950, forest fires in British Columbia caused a blue sun and moon in New England." (p. 31).

Fletcher's antique use of language gives us little pearls from the past. On p. 22, Fletcher says that "Snowfall was not as great a problem in this decade, particularly as far as travel was concerned. Old Dobbin didn't mind pulling an easy running one-horse sleigh unless the snow was near a foot deep on the level." "Old Dobbin" was a once-popular name for a horse.

He also provides interesting scientific context for particular extreme weather conditions: "...the most intense one-hour rainfall occurred at Holt, Missouri, when 12 inches of rain fell in 42 minues on June 22, 1947. Rain of this intensity would suffocate an individual caught in it without facial protection." (p. 29). On "July 4, 1956, 1.23 inches of rain in one minute fell in Unionville, Maryland, a U.S. record. (A tenth of an inch of rain in ten seconds would drench a person standing in the open. Rainfall of the intensity of almost an inch and a quarter in one minute would cause a person to become a human waterfall; rain would be flowing rapidly downward off the person, and, without protection and with continue fall of this intensity, a person would drown." (p. 31)

Historical figures also make appearances (he's fonder of Columbus than many of us are today). In Fletcher's description of the decade of 1830-1839, he reports that "Some settlers planted gardens, and orchard crops soon appeared on the river slopes. Johnny Appleseed had left some fruit trees in production on the lower Maumee [river]." (p. 10)

The book is thus enlivened by Fletcher's wide-ranging interests. Yet, in the end, his desire is to capture important data, and to provide some guidance to future generations who might make use of this data – "to increase people's knowledge of the great air ocean in which we live."

2 The Data

The most important information in the book, according to Fletcher himself, is the set of tables which "present the daily highest and lowest maxima, plus the lowest and highest minimum temperatures for each of the 365/6 days of the year, indicating the day and year of occurrence." (p. 45) It is this information that we digitized, and which is at the core of our analysis.

In his introduction he notes that "Wood County has one of the longest records of weather statistics in the state, taken by authorized observers. Began in 1854 at Perrysburg by Doctor Erasmus D. Peck, daily temperature and precipitation records have been taken ever since; now at the Waste Water Treatment plant in Bowling Green."

On what is almost the last page of the book (p. 169), he gives the complete record of those who recorded this data. In particular, we note that "...in 1893 G. C. Housekeeper ... became the official reader and remained so until 1918." That G. C. Housekeeper began his records in 1893 is important, as we will see. The complete record of recordkeepers is given in the appendix (Table 1).

2.1 Entering the Data

Our math modeling class members double or triple entered the data to ensure that the data was transcribed from Fletcher's book correctly. For all four time series, each year was recorded in the case of ties, and each was considered of equal weight. Thus we have more than 366*4=1464 records – in fact, we have 1501 total "extrema years", with 1464 extreme temperatures (we needn't repeat ties).

There are two data quality issues worth noting:

a. The 14th of July has a MaxMax of "110+". According to Fletcher, "Wood County has a record of 110^o above on two occasions in 1936."(p. 61) So we replaced that 110+ by 110. However, on p. 69, he notes that "The temperature reached 110 on July 10th in 1936, but the observer detected a slightly higher value on the 14th." Nonetheless, since all other records are given as integer values, it seems appropriate to round this value to 110.
b. There was one suspicious inconsistency in the case of ties: generally Fletcher gave the years of ties in order, from earlier to later. In one case, however (MinMin, Dec. 18), he reported them in the opposite order: 1989/1945. This made us suspect that one or both years might have been wrong. Without the original data, we cannot determine if an error occurred, however.

2.2 Trimming the Data

Fletcher summarizes the weather of Wood County by decade, starting with 1830-1839 (that is, including even decades which preceded these important data tables). The most important observation that Fletcher makes regarding this data occurs in his summaries of the individual decades; in particular, in his summary of the decade of 1890-1899 (p. 19):

The decade of 1890 is known for some high temperatures in the middle years and a cold period at the end in which many of the temperature records for the entire Midwest were set. **Also, the introduction of taking readings from the maximum and minimum thermometers in place of the former readings from the ordinary type three times a day was instituted by the Weather Bureau.** *[our emphasis]*

With these two thermometers in the instrument shelter, readings are taken once daily, generally in the morning hours, with one thermometer indicating the highest temperature reached during the previous 24 hours, and the other indicating the lowest value in the 24-hour period. Each thermometer is then set for the next 24-hour period. The time of day the high temperature or the low temperature occurs, of course, is not recorded.

Temperature data taken previously through the years is not entirely comparable to those collected since the mid-1890s, but do form useful data for historical climatological study. *[our emphasis]*

The upshot is that, while we have data from 1854-1992, we cannot simultaneously study the data prior to the mid-1890s and that post mid-1890s. That is, the data of the earlier period is considered less reliable, based as it was on three readings (if one were lucky, I'm sure); whereas the later data was based on a scheme which provided a more reliable value for max and min for each date.

In spite of a diligent search, we were unable to determine the exact year at which the transition occurred. However, we know that G. C. Housekeeper began keeping the records in 1893, and kept them until 1918. Hence we choose to separate the data based on his tenure, and so consider only the 100 years of data from 1893-1992. Fletcher mentions the special role of Hiram Craw, who kept a long history of private temperature records from a nearby town: his records play the important role of providing surrogate data when records were missing[2].

Table 1. Meteorological data collectors for the period 1893-1992, for Wood County, Ohio: "Because of growing demand for weather data by engineers, flying and shipping interests, and others, the Weather Bureau began to recruit help in the personnel of local governments. As a result, L. B. Barnes, superintendent of the Bowling Green Waste Water Treatment Plant, assumed this responsibility, assigning the duty first to staff member Gene Swerlein. Now under Superintendent Jon W. Drescher and his deputy, Royce A. Beaverson, the readings are made by Kit Brown and Roland Putt." (p. 169) Hiram Craw had a special role, described in the text.

Keeper of the data	Dates
Hiram Craw	1877-1911
G. C. Housekeeper	1893-1918
Mr. V. C. Hostetter	1918-1928
Dr. H. K. Whitsell	1929-1930
A. L. Sloan	1930-1935
Marsh Shearer	1935-1936
Carl Woolsmert	1936-1941
Supt. L. B. Barnes, et al.	??
Supt. Jon W. Drescher, et al.	??

[2] Fletcher says that "Hirma Craw took morning observations at his home at Lovitt's [sic] Grove, two miles north of Bowling Green, from 1877 until 1911, but these records were not for the Weather Bureau and are used as fill-ins where records from Asheville are missing."(p. 169). In researching Mr. Craw, I discovered that a) Lovett's Grove exists (although I grew up in Bowling Green I'd never heard of it); b) Craw died in 1911, which explains why his temperature records ended there; c) About Hiram Craw: "Our subject and his wife have been members of the Adventist Church for some 38 years, and have taken an active part in church work. He is a man of high moral character, and holds an honored place in the community. Mister Craw has been a leader in local affairs, and has held some responsible offices. He was supervisor of his Township for six years, was Constable for two years, and assistant postmaster at Lovett's Grove for 15 years, afterward being appointed postmaster and serving two years, when the post office was discontinued. Progressive in his ideas, he saw at an early day the advantage of draining the soil, and has used tiling on his farm for a number of years." ((Lavidaloca, 2011; Leeson, 1897)). In this research, I also discovered that Lovett's Grove played an interesting role in the history of the Seventh Day Adventist branch of Christianity: it was there that Ellen White had an inspirational vision: "In this vision at Lovett's Grove (in 1858), most of the matter of the great controversy which I had seen ten years before, was repeated, and I was shown that I must write it out." ((White, 2006))

3 Analysis

3.1 Initial Hypotheses

While describing significant weather events since the founding of Wood County[3], he remarks that "At that time, some weather followers believed in the occurrence of quadrigesimal winters, or cold blustery winters in a forty-year cycle with cold winters every twenty years capped off by severe winters every forty years. The year 1780 had produced heavy snow and severe cold in Kentucky with severe flooding; this occurred again in 1800 and 1820, not only in the Great Lakes region but from the Mid-Atlantic states to New England. Severe weather again visited Wood County in 1841 and 1842, but **the author believes in only irregular weather cycles.**" [My emphasis]

Fletcher makes certain claims, which is what initially led us to investigate his data in a way which he was unable to do himself, due to many factors beyond his control, in his own time.

On page 1, he begins by defining climatology as "the scientific study of the behavior of the atmospher over any particular area for a given length of time, generally ten or more years." He asserts that "In the case of Wood County, our records have been kept for well over a century and the climatologist has a good record of weather parameters and for determining that future weather will likely remain within those parameters." In other words, **he asserts that the climate of Wood County is not changing, and will not change** – otherwise the weather would not remain "within those parameters".

3.2 Addressing the Question of Climate Change

Climate change can occur even in the absence of global climate change. This is a point which Fletcher explores at several different points in his book. Some of the factors which must be considered are structural: Wood County has changed much over the period from 1854 to 1992. In particular Dr. Fletcher mentions the loss of forest cover, once estimated at over 90% in Wood County. He claims that "removal of a high percentage of this vegetation has contributed to the more frequent occurrences of temperatures of a hundred degrees."(p. 6). In addition, he mentions the draining of the Black Swamp, which would lead to a profound change in the area (transforming it from an "ague fever" stricken swampland into some of the most fertile – and flat – farmland in the country).

Some factors may be part of the "irregular cycles" which Fletcher clearly believed in. "In regard to warm summers, the decade of 1930 to 1939 had more than twice as many readings of 100^o or more than we have had in the rest of our period of records which started in 1854."(p. 62) These were the depression years, the dust bowl years; the years when Fletcher was finishing his thesis and moving on to work in the Weather Bureau in Washington, D. C. Wood County and its weather were still a long way off. But no doubt Fletcher knew that some variation between "climate periods" of thirty years would occur simply because of these strikingly dramatic, relatively long-lived climate events that occur on occasion.

At the time Fletcher wrote this work (published in 1996) there were plenty of warnings about climage change. In the 1980s James Hansen of NASA had testified before Congress

[3] February 12, 1820

that human-caused climate change was already having an impact ((Shabecoff, 1988)); Karl et al. in 1993 had written *Asymmetric Trends of Daily Maximum and Minimum Temperature* ((Karl et al., 1993)), in which they describe how "...the rise of the minimum temperature has occurred at a rate three times that of the maximum temperature during the period 1951-90 (0.84^{o}C versus 0.28^{o}C). The decrease of the diurnal temperature range is approximately equal to the increase of mean temperature. The asymmetry is detectable in all seasons and in most of the regions studied." Although Fletcher had retired by 1971, when he was awarded emeritus status, it seems impossible to believe that the author of a work like this was not keeping up on the news in meteorology; therefore he must have been aware of these rumblings. Yet nowhere in his book does a discussion of climate change occur.

a. **Is climate change happening?**

Let us assume that climate change is **not** happening (the null hypothesis).

If that were the case, then all climates (weather averages over thirty years) would be equivalent. Every thirty year period would be the same, in terms of the number of extremes – of each type – that it contributed. The same would be true for every decade. Each time period would contribute approximately the same number of years to each time series (maxmax, minmax, maxmin, minmin) of extremes.

Consequently, we would expect to see a **uniform** distribution of extreme-years-by-decade, or extreme-years-by-climate. What we actually see is contained in Figure 1.

We have tested this uniformity on the Fletcher data, and we can reject it. We used a χ^2 tests for each of the four timeseries by decade (Table 2), and can reject a null of uniformity in each case. The difference is dramatic in the case of MinMin and MaxMax; less so in the other two cases. So the extreme extremes show the greatest violation from uniformity – the greatest "climate change".

Table 2. We tested each timeseries against an hypothesis of a uniform distribution, using a χ^2-test of independence by decade, with 9 degrees of freedom; and by climate (25-year period), with 3 degrees of freedom.

	Decadal		Climate (25-year)	
Timeseries	χ^2	p-value	χ^2	p-value
MinMin	78.97	< 0.0001	44.53	< 0.0001
MaxMin	18.42	0.0306	8.915	0.0304
MinMax	28.27	0.0009	20.91	0.0001
MaxMax	37.50	< 0.0001	21.93	< 0.0001

We can investigate climate directly, however (only we use 25-year intervals, rather than 30-year – just because we have 100 years of data, which divides nicely that way). Again, and with χ^2 values on the same order (Table 2), we can reject a null of uniformity – which we interpret as a rejection of a null no climate change – that is, climate change is happening.

b. **Given that climate change is happening, how do we determine in what way it is changing?**

Karl et al. suggest that we should see a more rapid rise in minimum temperature than maximum by a factor of 3, leading to a decrease in the diurnal temperature range approximately equal to the rise in the mean. ((Karl et al., 1993)) What's uncertain is whether we have the data to demonstrate such a rise. Furthermore they assert that "the asymmetry is detectable in all seasons". [ael: we have seasonal data, so we might be able to make a test of this.]

Our preliminary (and perhaps naive) notion was that the temperature distribution across time would be staying the same in terms of spread, but rising in mean. Indeed, according to the summary prepared by the editors of the Proceedings of the International MINIMAX Workshop, held under the auspices of NOAA National Environmental Watch and the DOE Global Change Research Program ((Kukla et al., 1993)), they conclude that "over those parts of the oceans in the middle and low latitudes, which were hitherto studied, the minimum and maximum temperatures are increasing uniformly." However our temperatures in northwest Ohio are not over any ocean, but rather under that "air ocean" Fletcher refers to in his book's dedication.

Fletcher provides means, mean(max), and mean(min) for climate periods in tables on pages 81-82 of his book, which we can study for a sign of the type of temperature distribution we should use.

Table 3. Monthly Mean, Average Max, and Average Min Temperatures for Bowling Green; Thirty Year Average, Period 1959 to 1988 (p. 81), and Period 1949-1978 (Mins, p. 82), provided by Fletcher ((Fletcher, 1996)).

Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	24.1	27.7	39.6	49.0	60.7	70.3	73.5	70.1	65.0	53.8	41.6	29.5
MeanMax	30.5	37.3	46.6	60.2	72.7	81.9	84.9	80.1	76.7	64.5	50.0	36.5
MeanMin	15.5	17.8	27.5	37.8	48.6	58.7	61.8	59.9	53.4	40.2	33.0	21.9

For example, assume a normal distribution of temperatures, with sinusoidally varying mean $\mu = 50.06+24.08\sin 2\pi(t-0.3060))$, and with $\sigma = 10$. "Wood County has an average of just above 50^o...." (50.2 he asserts on p. 64). Here we're using 50.06, in accord with a model we discuss momentarily. As for deviations from the mean, he reports that "Temperature ranges remain around 50 degrees in the extreme with the fall months at or above that value, with May the only other month at that value. May has a wide spread in possible temperatures, from around freezing to the high '90s. The four warm months of June through September had only a five-degree variance, from 45 degrees to 50 degrees, while the remaining months showed only six degrees difference."(p. 68)

The mean of this data follows a sinusoidal pattern, as indicated in Figure 4. We used non-linear regression to find a model for mean temperature of the form $mean+amplitude\sin 2\pi(t-t_0)$. The coefficients are given in Table 4.

Table 4. Model parameter estimates (and standard errors) for the mean temperature model $\mu + A\sin 2\pi(t - t_0)$ for Fletcher's data of Table 3. In this model t is in years, μ is the mean, A is the Amplitude, and t_0 is the phase shift.

Parameter	Min Est	SE	Mean Est	SE	Max Est	SE
μ	39.5675	0.38418	50.2511	0.4883	59.9276	0.672843
A	22.8968	0.523966	24.3348	0.6657	26.7048	0.917174
t_0	22.8968	0.523966	0.30373	0.004673	0.301018	0.00586869

Table 5. Model parameters for the mean extremum model of the form $\mu + A\sin 2\pi(t - t_0)$, where t is in years. In this regression, we use the complete set of all 1464 of the extrema temperatures from Fletcher's dataset, 1893-1992 – the maxmaxes, the minmaxes, the maxmins, and the minmins.

Parameter	Estimate	Standard Error
mean μ	50.0603	0.6748
amplitude A	24.0836	0.9545
phase shift t_0	0.30600	0.00630

Fletcher is clearly arguing that σ should also vary seasonally. But these are only the averages. In fact, weather wanders about these climate normals, making the irregular visits to extremes which are duly noted in Fletcher's book. Fletcher mentions that January, 1919 was a cold one, and had a mean temperature of 18.1 degrees. This jives with a seasonal value of $\mu = 20$.

3.3 Our Model

We have computed models of the form $\mu + A\sin 2\pi(t - t_0)$ for all four times series, as well as for the best fitting model to all simultaneously (which we can think of as the mean model). The results are summarized in the Table 6 and in Figure 5.

4 Conclusion

We conclude that there have been dramatic changes in climate across the 100 years from 1893 to 1992. Whether we consider decadal changes, or changes more in sinc with Fletcher's thirty-year climate intervals, we discover patterns which deny an hypothesis of a uniform distribution.

What seems particularly clear is that extremes have tumbled across the decades. The tumultuous early decades of the last century have led to a relative calm in extremes over our four time series.

What is also clear, however, is that the time series have not responded uniformly: there is a significant difference in their behavior, that we describe as follows:

Table 6. Model parameters for the mean extremum model of the form $\mu + A\sin 2\pi(t - t_0)$, where t is in years. In this regression, we use the complete set of all 1464 of the extrema temperatures from Fletcher's dataset, 1893-1992 – the maxmaxes, the minmaxes, the maxmins, and the minmins.

Parameter	μ	95% CI	A	95% CI	t_0	95% CI
Grand Mean	50.0603	(48.76, 51.40)	24.0836	(22.18, 25.92)	0.30600	(0.2937, 0.3185)
MinMin	16.8251	(16.38, 17.27)	29.4705	(28.84, 30.10)	0.307752	(0.3043, 0.3112)
MinMax	38.1831	(37.74, 38.63)	31.3381	(30.71, 31.97)	0.3103	(0.3071, 0.3135)
MaxMin	61.5738	(61.18, 61.97)	15.5851	(15.03, 16.14)	0.310813	(0.3051, 0.3165)
MaxMax	83.6311	(83.26, 84.01)	20.0835	(19.55, 20.62)	0.292796	(0.2886, 0.2970)

a. MinMin and MaxMin are distinctly non-uniform; the others are also non-uniform. There is significant decadal deviation from a uniform distribution of "extreme years": some decades set many more records than others.
b. The same is true of "climates" (which, for us, were 25 years long).
c. The extremes of each of the four timeseries of temperatures follow sinusoidal curves pretty well, each with minima in mid-January, and extremes six months later in July.
d. We had expected to see the trends in Table 7, and were surprised that we did not.

Table 7.

Series	Expectation
MinMin Years	More in the early years, if global warming raises all boats.
MaxMin Years	More in the later years
MinMax Years	More in the early years
MaxMax Years	More in the later years, with rising temperatures

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Appendix A Figures, Tables, Etc.

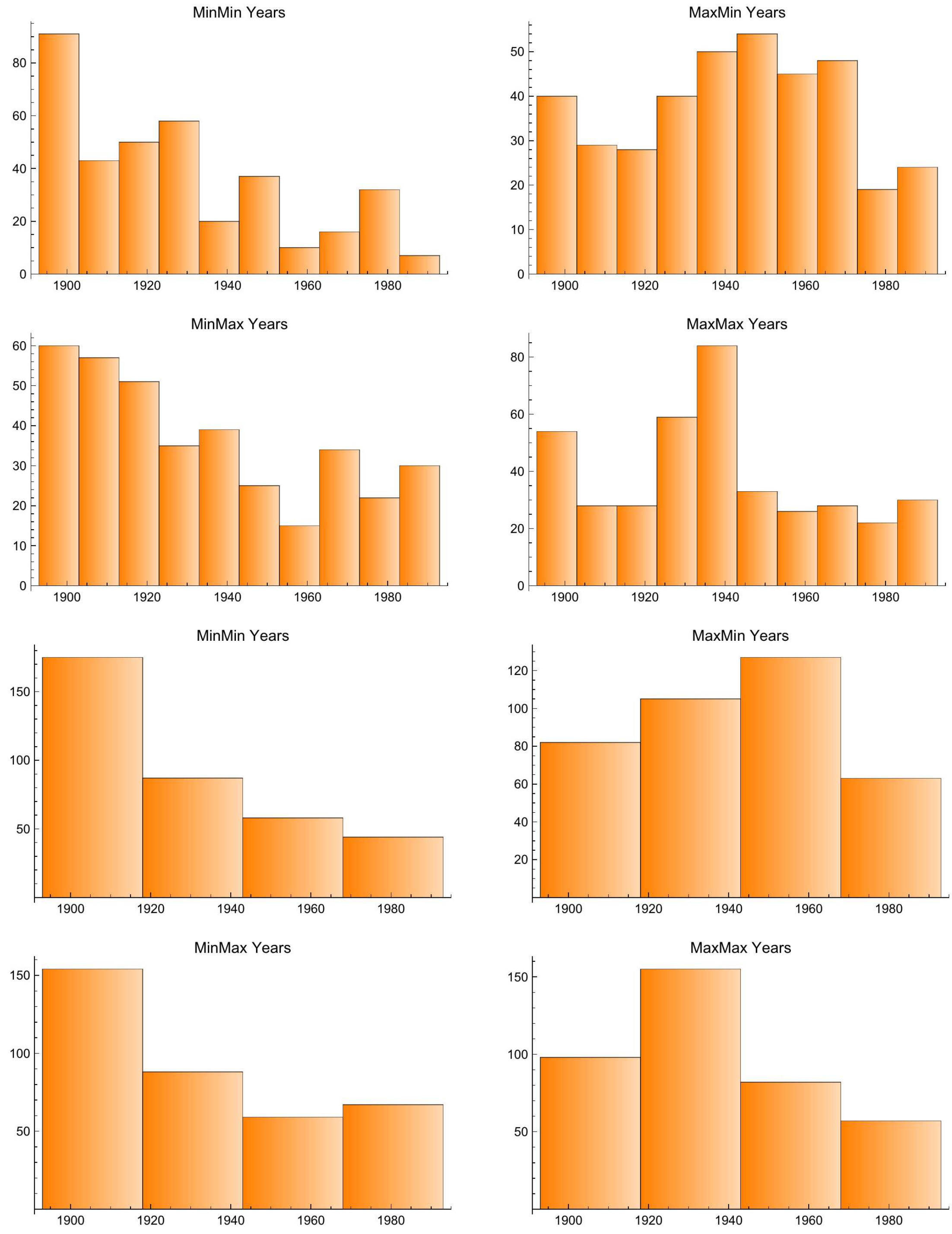


Figure 1. Bottom: Climate histograms (25-year periods from 1893-1992), which we would expect to be of uniform height under a null hypothesis of no climate change. Top: Decadal histograms (same expectation). Our climate change hypothesis – that climate change raises all boats – would suggest that the “Min” variables (MinMin and MinMax) would be skewed right, and the “Max” variables would be skewed left. The Min variables are all on the left, and the “Max” variables are on the right. So it would appear that the Min variables are behaving pretty much as we expected. The Max variables may be leaning that way, but don’t show the dramatic and expected skew like the Min variables.

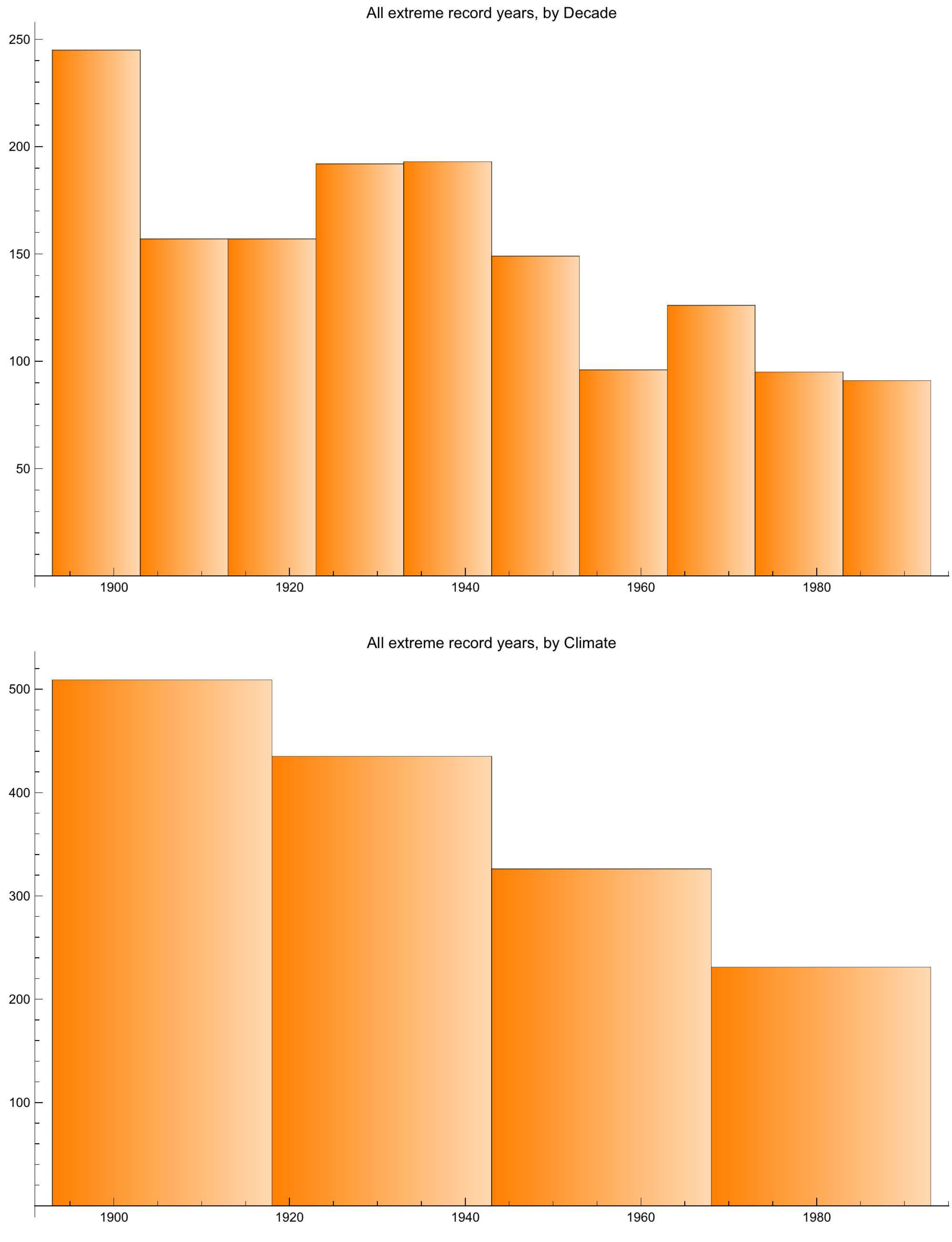
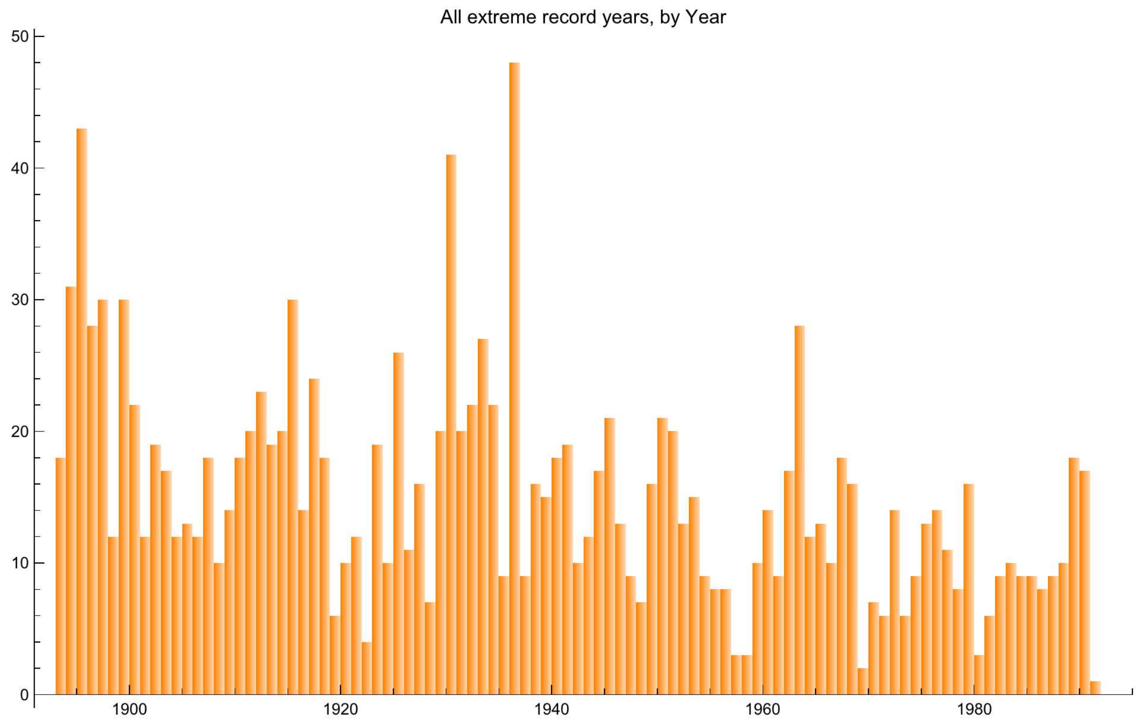


Figure 2. Bottom: Climate histograms (25-year periods from 1893-1992), for all extreme record years, regardless of which timeseries. Top: Decadal histograms. These histograms show rather dramatically that the number of extreme record years has been decreasing in recent years, as shown by the right skew of each distribution.



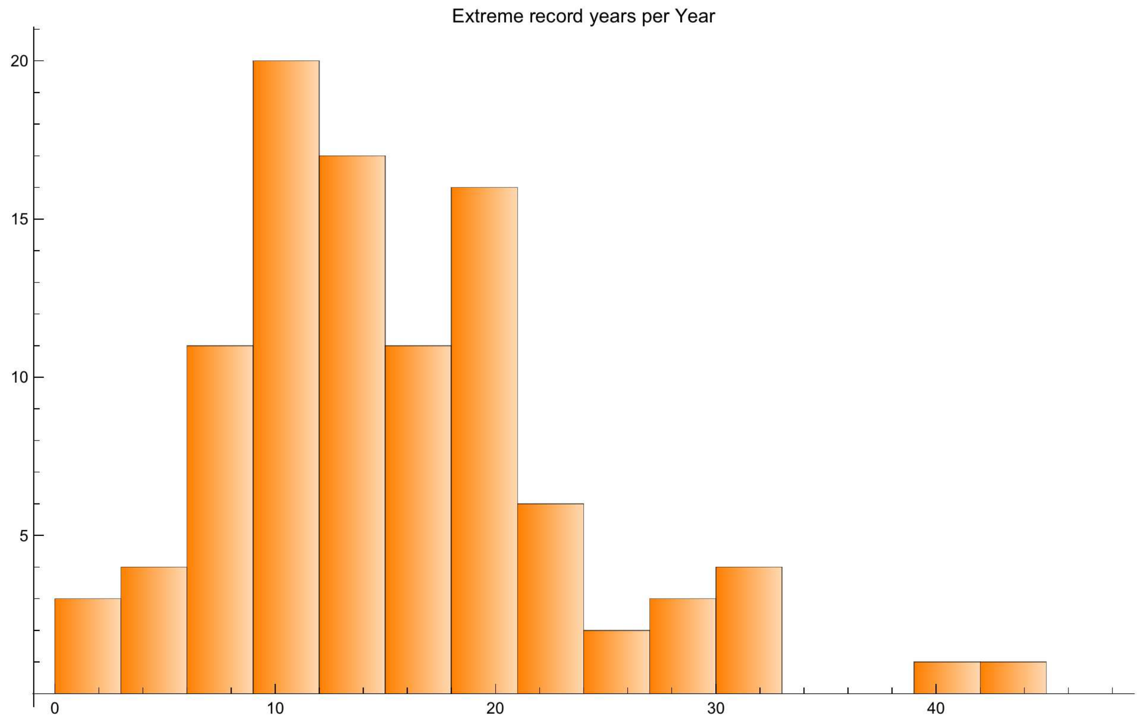


Figure 3. Top: histogram showing the number of extreme record years from every year, 1893-1992. There are some remarkable years (e.g. 1936, with 48 records), and some remarkable periods (with either many or few records). There might have a slight edge effect at 1991-1992. Fletcher noted that his data ended in 1991, then seemed to include 1992 in some records. There are zero extremes in 1992, however. Bottom: the distribution of counts of records per year. There is a strong right skew.

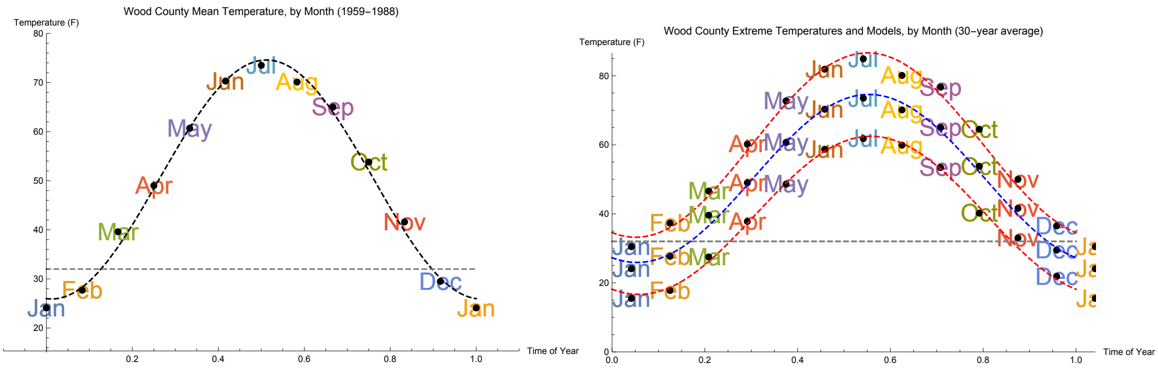


Figure 4. Left: we created a model for mean temperature of the period 1959-1988 using non-linear regression, approximately $50.3 + 24.3 \sin 2\pi(t - 0.30)$, where t is in years. We based it upon the average mean temperatures from Fletcher's work. This says that the annual mean is on the order of 50.3 degrees Fahrenheit, with a seasonal amplitude swing of about 24.3 degrees. The phase shift of 0.30 says that the mean of 50.3 occurs about a quarter of the way into the year – around April 19th, with a minimum of 26 degrees around the 19th of January). Right: we incorporate models of the Max and Min monthly values as well.

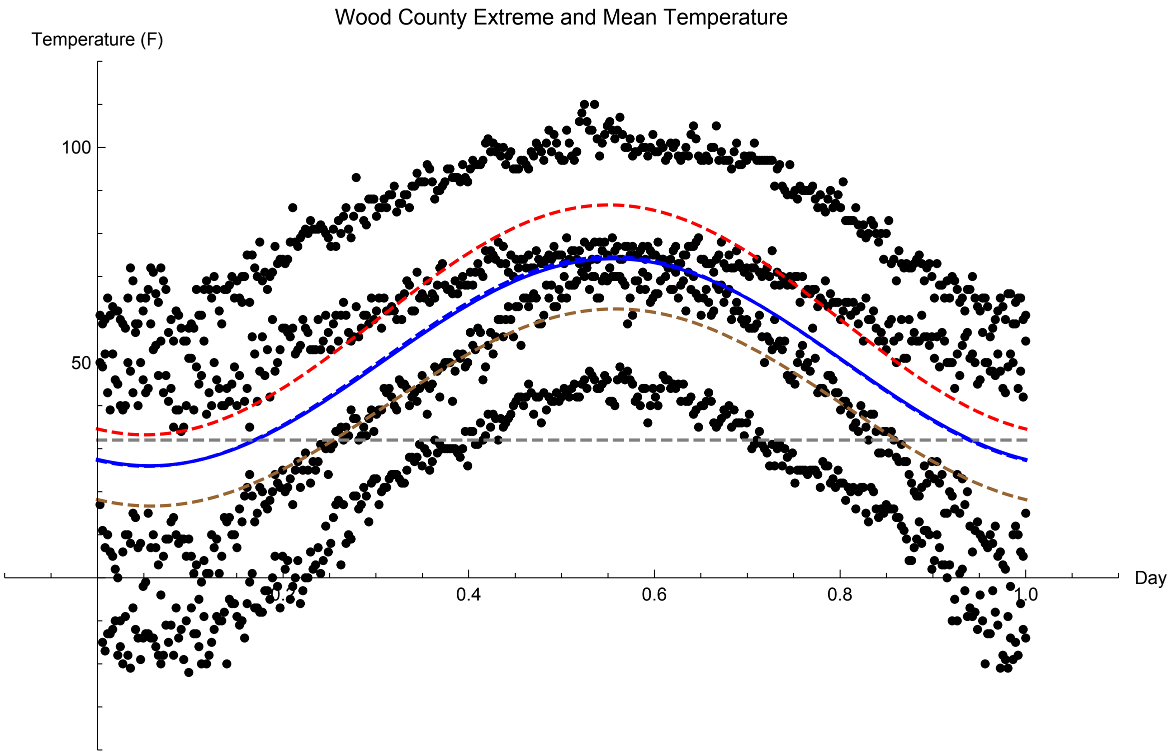


Figure 5. This graphic features a model for mean temperature computed by linear regression from all of the extrema of the Fletcher data; it has essentially the same parameters as the model for mean monthly temperature from above. $50.1 \ + \ 24.1 \sin 2\pi(t - 0.31)$, where t is in years. We based it upon the average mean temperatures from Fletcher's collected extrema record temperatures. This says that the annual mean is on the order of 50.1 degrees Fahrenheit, with a seasonal amplitude swing of about 24.1 degrees. The phase shift of 0.31 says that the mean of 50.1 occurs about .31 of the way into the year – around April 23rd, with a minimum of 26 degrees around the 22nd of January). The dashed curves are the models from the monthly data cited above. The astonishing thing is that the model for mean temperature computed from all of the extrema data is essentially the same as the dashed blue model, which is difficult to distinguish from the solid model. The other two dashed models are for the max and min monthly values.

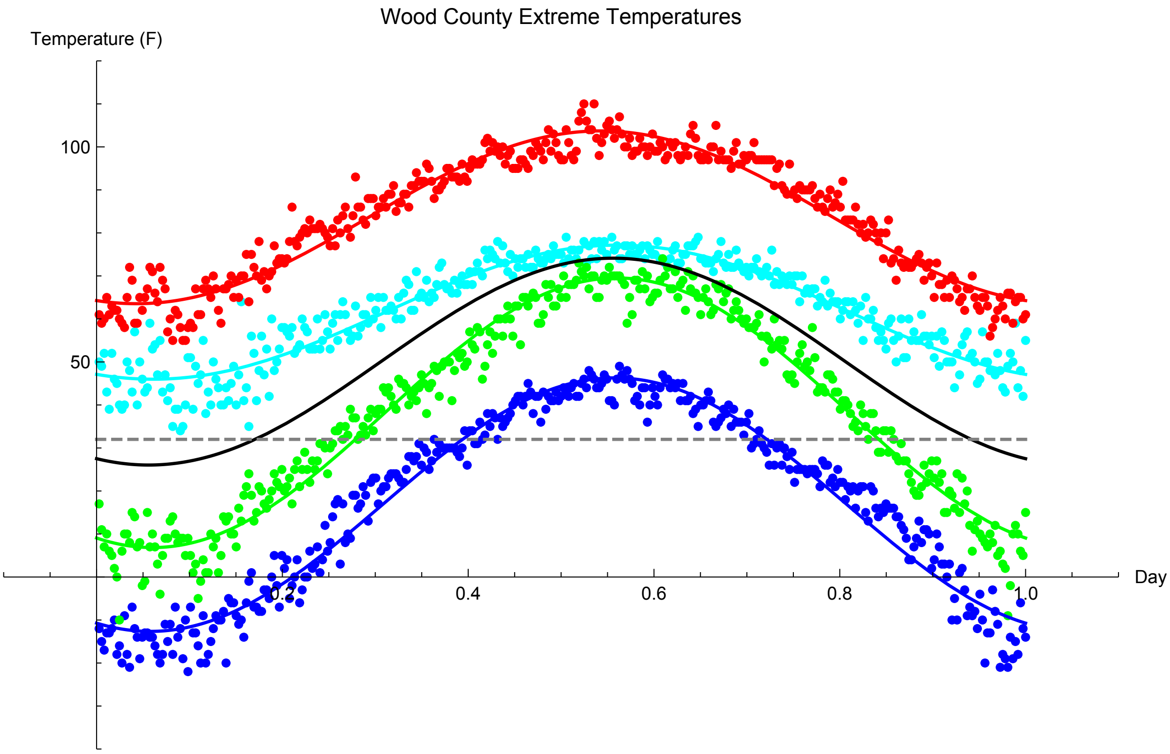


Figure 6. This graphic compares the models ($\mu + A \sin 2\pi(t - t_0)$) and the data of each of the temperature extrema of the Fletcher data (parameters given in Table 6). One can see clearly that there are regions of poor fit of the sine functions. For example in the case of the MinMin, the "biceps" along the arms (near the inflection point in the model) have the data floating up above the model. The same problem seems to occur for MaxMax.