Modeling Central England Temperatures from 1659 to 2016 with Time Series Techniques

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Abstract

Central England temperatures from 1659 to 2016 are analyzed by examining both periodic and long-term trends. From our analysis, there does not appear to be strong non-seasonal periodic fluctuations, but a long-term warming trend is evident. However, the high variability in the average yearly temperatures means that predicting next year's or even the next decade's temperatures remains a difficult task.

1 Introduction

Understanding long-term climate variability plays a crucial role in determining whether there is a global warming trend or whether the observed increase in temperature is part of the natural variability in temperature. Furthermore, if there is a global warming trend, we wish to determine whether this trend has slowed in recent years, as some have claimed [3].

The central England temperature dataset is the longest instrumental temperature time series, making it a valuable source for investigating long-term climate variability and thus, we use this dataset to conduct our analyses [1].

2 Previous work

Studies have shown that there is a warming trend as well as periodic oscillations in the temperature, possibly related to solar irradiance, sunspot numbers, and a North Atlantic Oscillation [1]. Such natural periodic oscillations can mask long-term trends in temperature [3]. Parametric and nonparametric methods have been used in previous studies to analyze possible long-term trends [2].

Building on past research, we will analyze the time series of temperatures by examining three main components: fluctuations due to seasonal variation, possible cyclic components of unknown periodicities, and long-term trends. Since seasonal fluctuations are already known to occur, its analysis will primarily assist us in examining the latter two components.

3 Results

3.1 Seasonal Fluctuations

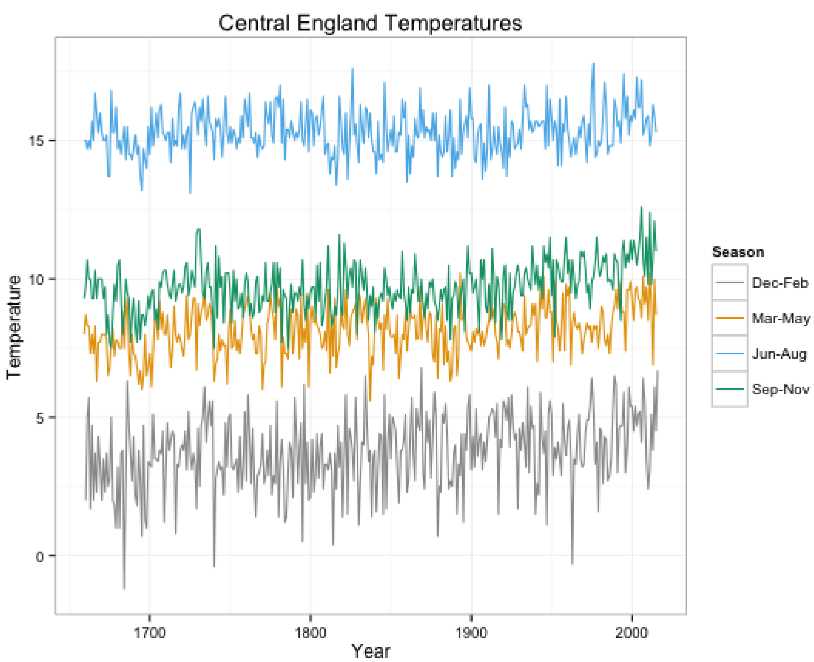


Figure 1: Each line corresponds to the average temperature in Celsius for a season of three months.

A plot of the average temperatures within each season every year from 1659 to 2016 is shown in Figure 1. At first glance, there are clear seasonal differences in the temperatures, with the summer season (June to August) being over 10 degrees warmer than the winter season (December to February) on average.

The clear seasonal difference indicates that the fluctuations in temperature due to seasons should dominate other cyclic fluctuations. Indeed, this is evident in the periodogram[1] in Figure 2. The periodogram shows a dominant spike at a frequency of 1. The period is thus $1/1 = 1$, i.e. a yearly period, which is what we expect for fluctuations due to seasons.

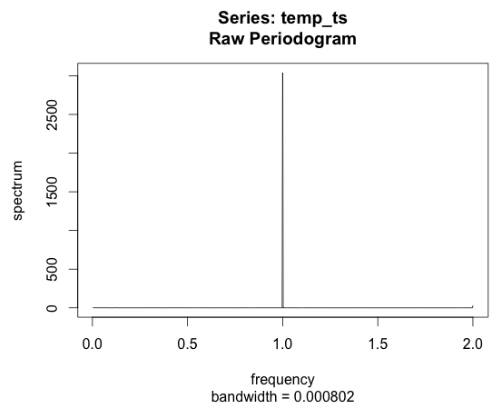


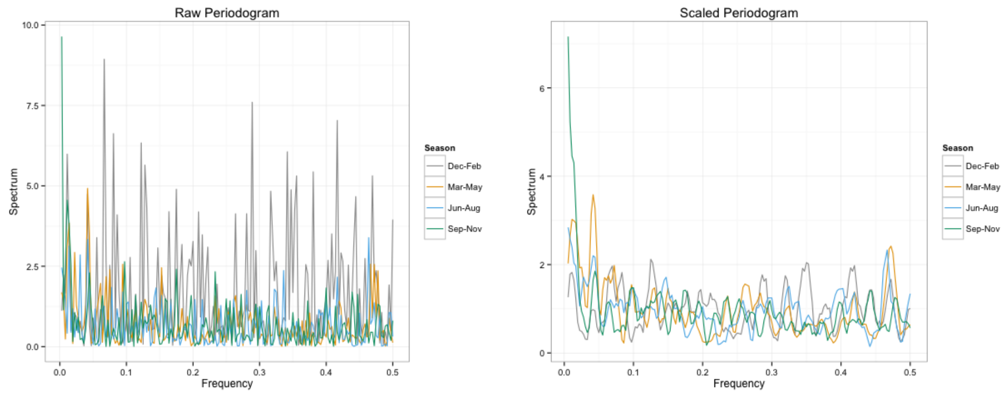
Figure 2: Periodogram of Central England's temperatures

3.2 Cyclic Fluctuations

To examine other, non-seasonal periodicities in temperature, we will analyze the time series for each season separately and see if there is any overlap in the observed spectrum peaks between the seasons. This will help us find any cyclic fluctuations common to all seasons.

The periodograms for each season are shown in the same plot in Figure 3. On the left is the periodogram with the raw spectrum and on the right is the scaled and smoothed periodogram. For the scaled and smoothed periodogram, the spectrum was smoothed using a Daniel kernel of span=5, chosen by visual inspection. To scale the values, the spectrum for each season is divided by the mean spectra for that season. Since notable peaks are judged by their relative heights, this enables us to compare the periodograms

[1]By default, the periodogram is fitted to the residuals after removing a linear trend.



(a) Raw periodogram (b) Scaled+smoothed periodogram

Figure 3: Periodogram for temperatures separated by season

for each season more effectively. From the scaled periodogram, we see that there is no clear peak that is found in all season. However, there is still a high peak at the smallest frequency for the fall season.

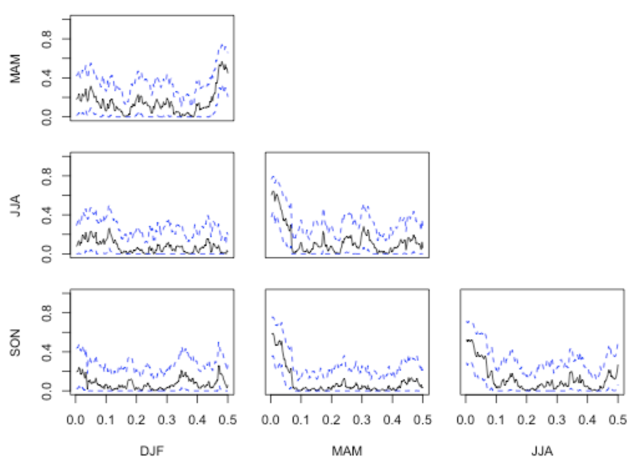


Figure 4: Squared coherency between seasons

To further examine if there are cyclic components common to all seasons, we also plotted the squared coherency with smoothing between each season's time series in Figure 4. The labels are the initials of each month (e.g. DJF = December to February). At the $\alpha = 0.01$ significance level, the coherence needs to exceed 0.226 to be significant. This only occurs at the smallest frequencies between spring, summer, and fall, which does not correspond to meaningfully interpretable cyclic fluctuations. In particular, the smallest frequency corresponds to a period of 370 years for the fall (September-November) season. This apparent periodicity has little interpretative value since that is the entire timespan of our dataset.

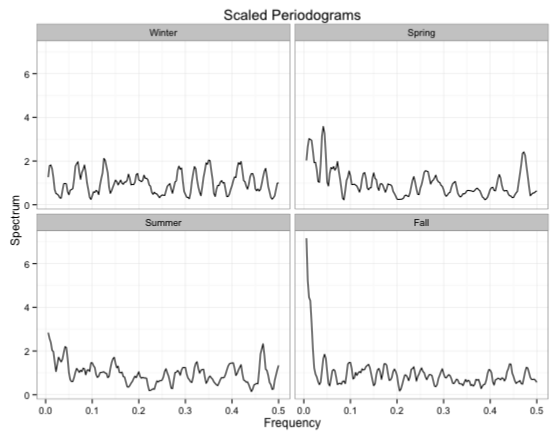


Figure 5: Periodograms for each season

In Figure 5, we plot the scaled and smoothed spectrum periodograms separately for each season to determine if there are cyclic components unique to particular seasons. As was the case in the combined periodogram plot, however, there are no obvious peaks in the periodograms, other than for the fall season, which has a peak at a very small frequency.

Other than this peak, the most promising peak occurs at a frequency of 0.08, corresponding to a period of ≈ 12.5 years, in the spring season. Noting that the spectrum values follow a chi-squared distribution with 2 degrees of freedom, its confidence interval is (0.687, 100.040), which does not indicate that it is significant, since several other peaks exceed 0.687.

An alternative way to analyze whether there are non-seasonal cyclic components in temperatures is to use the yearly average temperatures, which is the average of the temperatures for each season of a given year. The smoothed periodogram for the average yearly temperatures is shown in Figure 6. In this case, there is still no clear peak with the possible exception of a very small frequency corresponding to a long period. As previously dis-

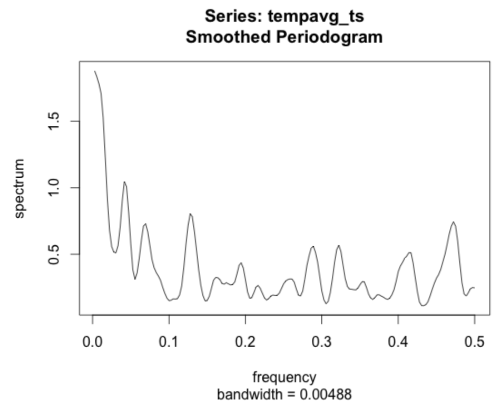


Figure 6: Periodogram for yearly average temperatures

cussed, this peak has little interpretative value. Thus, we conclude that there are no strong non-seasonal periodicities.

3.3 Long-Term Trend

To determine what the long-term trend is, we aim to detrend the series and convert it into a stationary time series. For examining the long-trend, we will use the yearly average temperatures.

To estimate the trend, we use a variety of parametric and nonparametric methods. A linear fit to the data yields a coefficient of 0.0027, with a p-value of < 0.01. The significance of this coefficient suggests that there is a warming trend over the years, with an average increase of 0.002 degrees every year. A quadratic fit to the data yields a coefficient $1.04 * 10^{-5}$ for the squared term, with a p-value of 0.03. The significance of this coefficient suggests that the warming trend is accelerating in recent years. A nonparametric method using kernel smoothing was also fitted, with a bandwidth of 20 years.

The estimated fits to the data are shown in Figure 7. Regardless of what fit we use, there is a clear overall warming trend over the last 350 years. However, with the nonparametric fit, the trend dips in the 2000s, confirming the apparent slowdown in global warming [3]. We also see that there is a lot of variability in the temperatures in the short-term from year to year, which can mask the warming trend in the long-run.

We further examine the long-term trend by season, by fitting smoothed curves to the plot in Figure 1. This will allow us to see more clearly whether

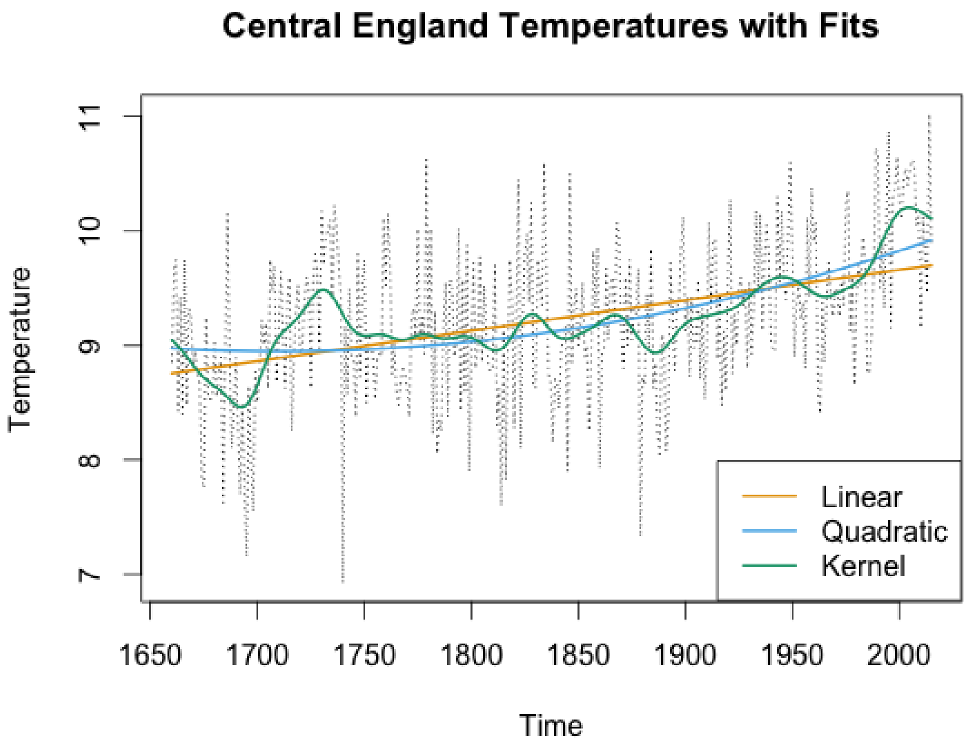


Figure 7: Plot of yearly average temperatures with different fits

the warming trend varies by season. Using kernel smoothing, we obtain the plot in Figure 8. It appears that there is an upward trend for the last 50 years particularly in the fall season. Over the last 300 years, summer temperatures have risen the least compared to other seasons. Lastly, the rise in temperatures seems to have stagnated in the last 10 years. However, this change in direction is not an unusual phenomenon. As we can see from the plot, despite the long-term rise in temperature over the centuries, there are notable dips in 1730s, a long period stagnation from 1730 to 1800, and a dip in the 1940s, among others. It is over the long-term that we see a gradual warming trend spanning centuries.

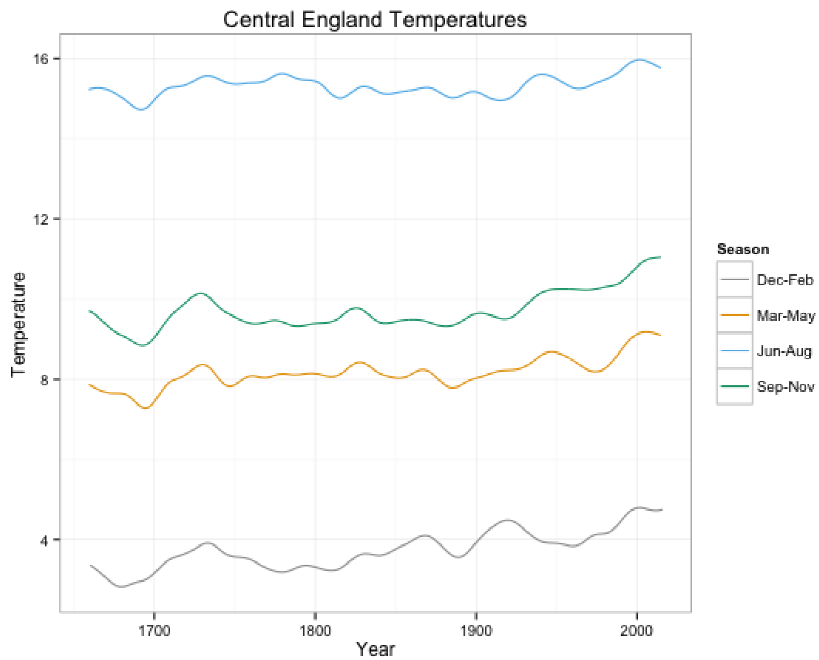


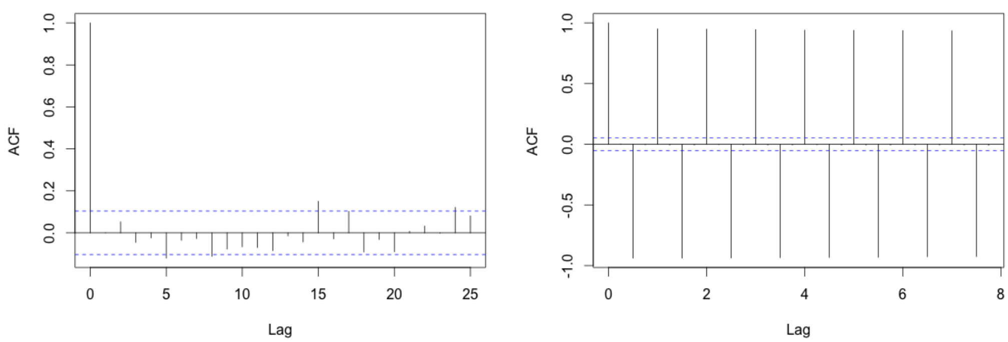
Figure 8: Smoothed fitted lines to seasonal temperatures

3.4 Autocorrelation

After detrending the yearly average temperatures using the nonparametric estimate, we examine the autocorrelation of the residual series in the left panel of Figure 9. The autocorrelation is close to 0 for a lag ≥ 1. This suggests that the detrended series is white noise with a sample variance of 0.315. Due to the high variance, this makes it difficult to predict future year's temperatures other than the general warming trend indicated by our fitted lines in Figure 6.

Furthermore, the ACF plot confirms our earlier conclusions regarding the absence of a non-seasonal cyclic component. Compare the autocorrelation function for the residual yearly average temperatures on the left panel to the autocorrelation function for the residual seasonal average temperatures[2] in the right panel of Figure 9. The seasonal average temperatures is the original time series, when we did not take the average of the temperatures

[2]This series was also detrended with a nonparametric fit.



(a) ACF of yearly average residuals (b) ACF of seasonal average residuals

Figure 9: Plots of autocorrelation function (ACF)

for every year. With this series, the seasonal periodicity can be clearly seen in its autocorrelation function, similar to its prominence in the periodogram in Figure 2.

4 Conclusions

While there is a long-term warming trend spanning the last 300 years, it is more difficult to draw conclusions about short-term trends in temperature. For example, it appears that the recent downward trend cannot be explained by any cyclic components, since we did not find any strong non-seasonal periodicities in the temperatures. However, it's still possible that the recent cooling may be explained by changes in the Pacific Decadel Oscillation (PDO), where warmer or cooler ocean temperatures affect global temperatures [3]. In addition, the high variability in temperatures from year to year adds noise to the signal, resulting in imprecise predictions for future years' temperatures.

References

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