Global Warming in Central England

Anthony Pan

9 March 2016

Abstract

I review climate trends and oscillations using temperature for central England from 1659 to 2016.

1 Introduction

Studying long-term climate trends is important for the understanding of global warming and the human impact on climate. To analyze global warming trends, I use the Hadley Centre Central England Temperature (HadCET) dataset. The HadCET dataset records seasonal temperatures in a roughly triangular area of the United Kingdom enclosed by Lancashire, London, and Bristol. The dataset encompasses a date range from 1659 to 2016, and for each year has average temperatures from the winter (December to February), spring (March to May), summer (June to August), and fall (September to November).

In my analysis, I will examine four main periods of time: the full period (1659-2016), the early period (1659-1849), the later period (1850-2016), and the most recent period (2000-2016). Within these time periods, I will look for significant trends as well as periodicity in the data.

2 Literature Review

Vaidyanathan (2016) has reported a recent controversy between scientists regarding global warning in the 21st century. While the National Oceanic and Atmospheric Administration (NOAA) concluded that global warning has not slowed down since the 2000s, a new group of scientists has challenged the NOAA's statement, claiming that global warming has slowed in the 21st century. One model showed that global warming slowed from .17 degrees C per decade previously to .11 C per decade between 2001 and 2010.

Jones and Bradley (1992) find that from 1700-1850, all their data shows some warming from the beginning to the end of the time period, with variability tending to be greatest in the winter followed by spring, autumn, and summer. They also find consistently cool and warm decades since 1700: cool decades were observed during the 1740s, 1780s, 1800s, 1810s, and 1840s, while the 1820s was a warm decade. Additionally, between 1850 and the present, Jones and Bradley find that warming is evident in all seasons except summer. They find that the greatest warming in the Northern Hemisphere occurs between 1920 and 1940, while the 1980s were only slightly warmer than the 1940s.

Benner (1998) examines the HadCET dataset for long-term climate variability between 1659 and 1998. He looks for trends in the data and find that the earliest part of the temperature record is the coldest, with consistent cold anomaly and a large departure from the mean, while the middle part of the record shows several fluctuations, and the most recent part of the data exhibits a warming trend. Benner reports that previous studies have found a general warming trend between 1659 and 1973.

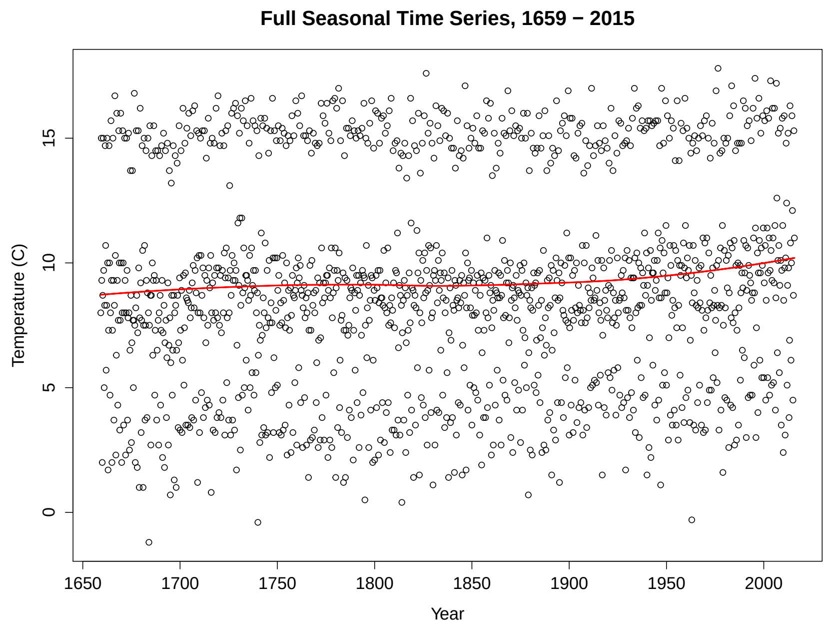
Benner also studies the oscillation in the HadCET dataset, using four methods–standard Fourier transform, Lomb-Scargle periodogram, SSA, and global wavelet spectrum–to search for significant oscillations in the monthly CET record. They find that the temperature exhibits a wide variety of significant oscillations, ranging in period from a few years to nearly two centuries.

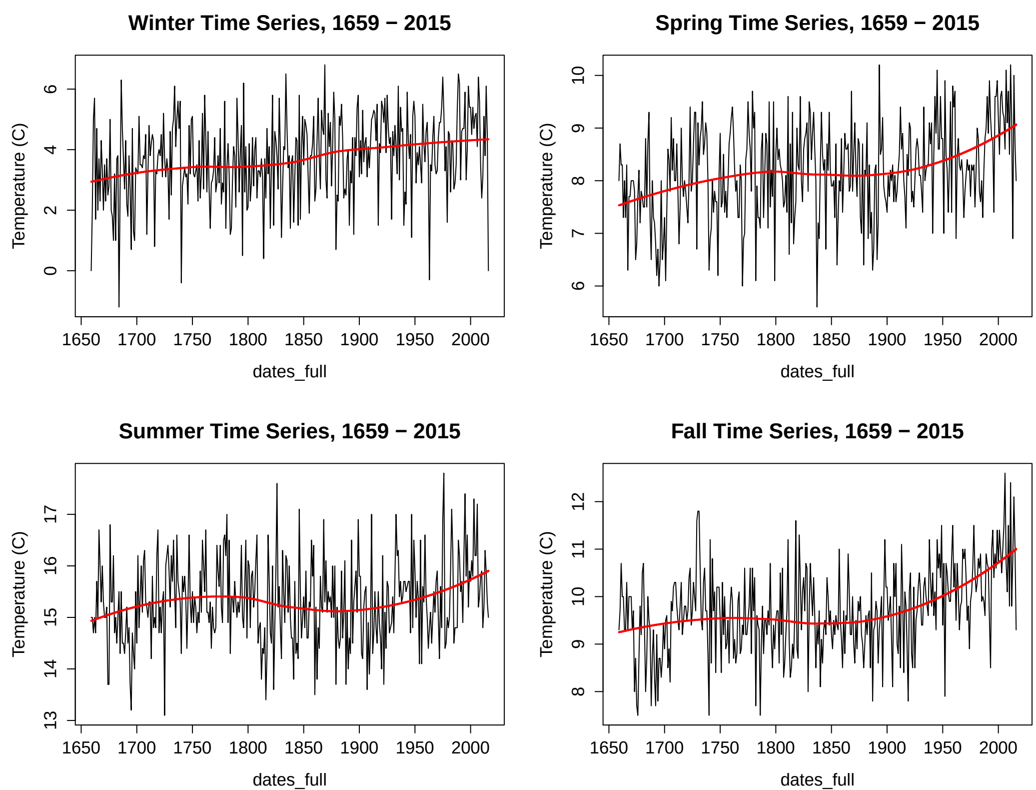
3 Analysis

1659 - 2016: Full Period

I will begin by examining the full time period of 1659 - 2016. The plot of the temperature against year for the full period is shown below. There is significant variation in year that seems to correspond with the different seasons. A local linear regression to smooth the scatter plot is shown in red, and reveals a very slight upward trend in temperature over time. The plots for individual seasons with a smoothing curve are also shown, and there seems to be an upward trend in series starting from 1850.

I will investigate this upward trend in three subsections of the data. I will compare the early period of 1659 - 1849 and with the later period of 1850 - 2016 to remain consistent with Jones and Bradley (1992). I will also examine the most recent period of 2000 - 2016 in order to test the claims of Vaidyanathan (2016)–that global warming has slowed down in the 21st century. In subsequent analysis, I will examine trends by season in order to eliminate seasonal variation in temperature.

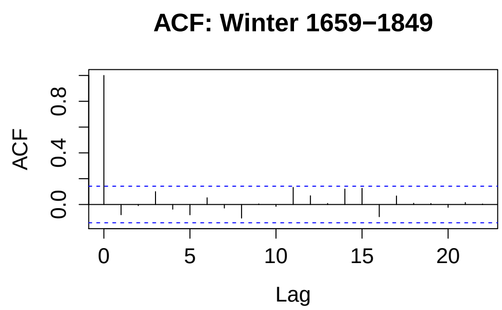


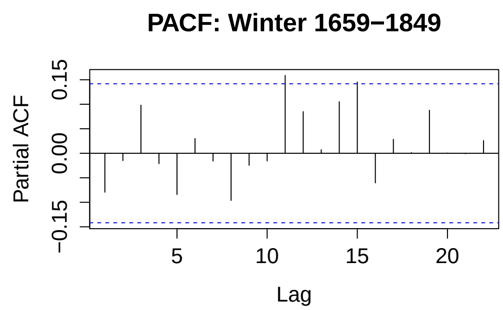


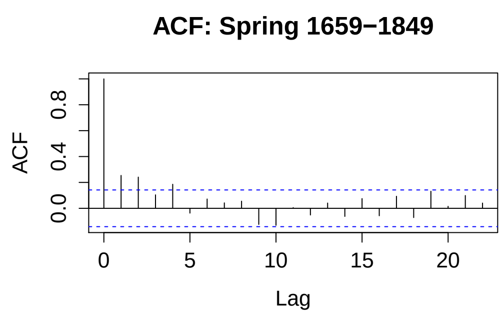
Since the early and later half of the time series seems to exhibit a different behavior, I break the long period into two different periods: an early period (1659-1849) and a later period (1850-2016) to examine trends and oscillations.

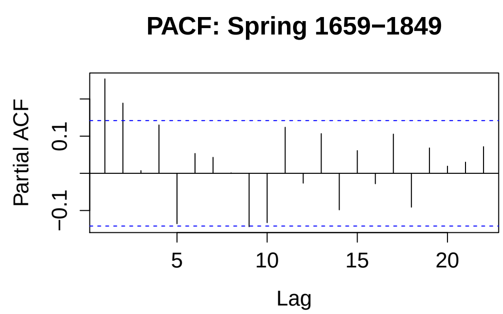
1659 - 1849: Early Period

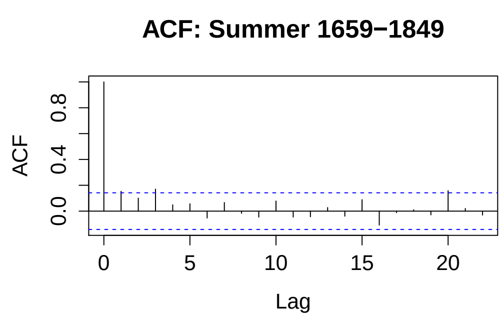
The graphs of autocorrelation and partial autocorrelation functions of each of the seasons in the early period are shown below. The data does not seem to exhibit strong dependence on its lags. We see that the spring and fall exhibits a weak moving average trend, while the spring has exhibits a weak autoregressive trend. Based on these graphs, it is not clear that there is an overall trend in temperature in the early period.

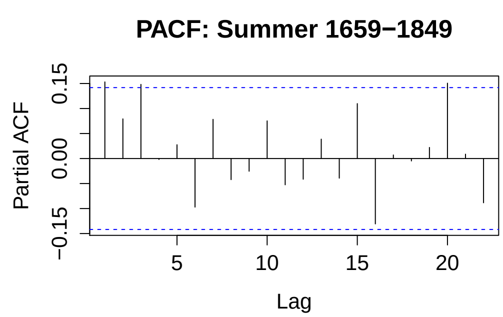


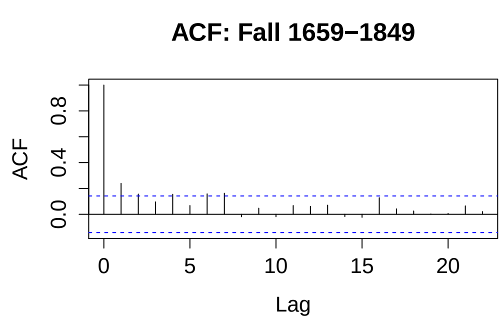


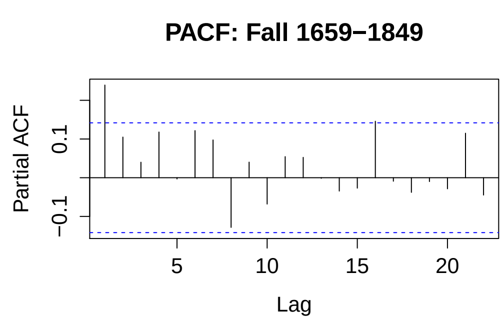








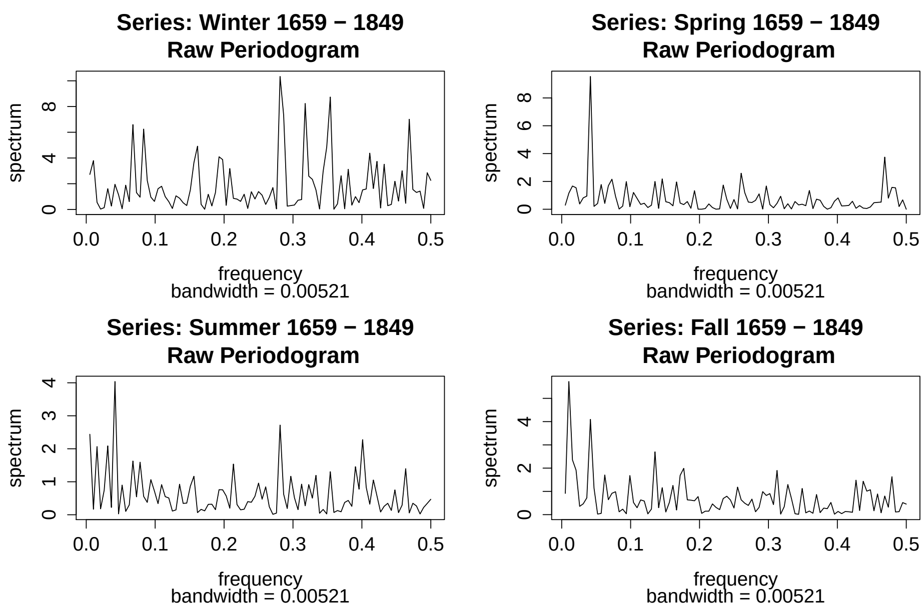




The periodograms for each of the seasons is shown below. The winter exhibits the most noise in its variation with many peaks in its spectral density. The spring exhibits the least amount of periodicity out of all the seasons, followed by autumn. I find the following periods for each of the series:

- For the winter series, I find that the spectral density maximums occur at frequencies .2813, .3518, .3177, .4688, and .0677. This corresponds to periods of 3.56 years, 2.82 years, 3.14 years, 2.13 years, and 14.77 years respectively.
- For the spring series, I find that maximums occur at frequencies .04167 and .4688, which corresponds to cycles every 24 years and every 2.13 years.
- For the summer series, I find that maximums occur at frequencies .0417, .28125, and .401, which corresponds to cycles every 24 years, 3.5 years, and 2.5 years.
- For the autumn series, I find that maximums occur at frequencies .01041, .0417, and .1354, which corresponds to cycles every 96 years, 24 years, and 7.38 years.

It is interesting that the 24 year cycle is persistent throughout the spring, summer, and autumn series. The autumn series seems to have longer periods, while the winter series seems to have shorter periods. I also tried smoothing the periodograms with a Daniell kernel with parameter m = 2, but this did not help in identifying the peaks in spectral density.



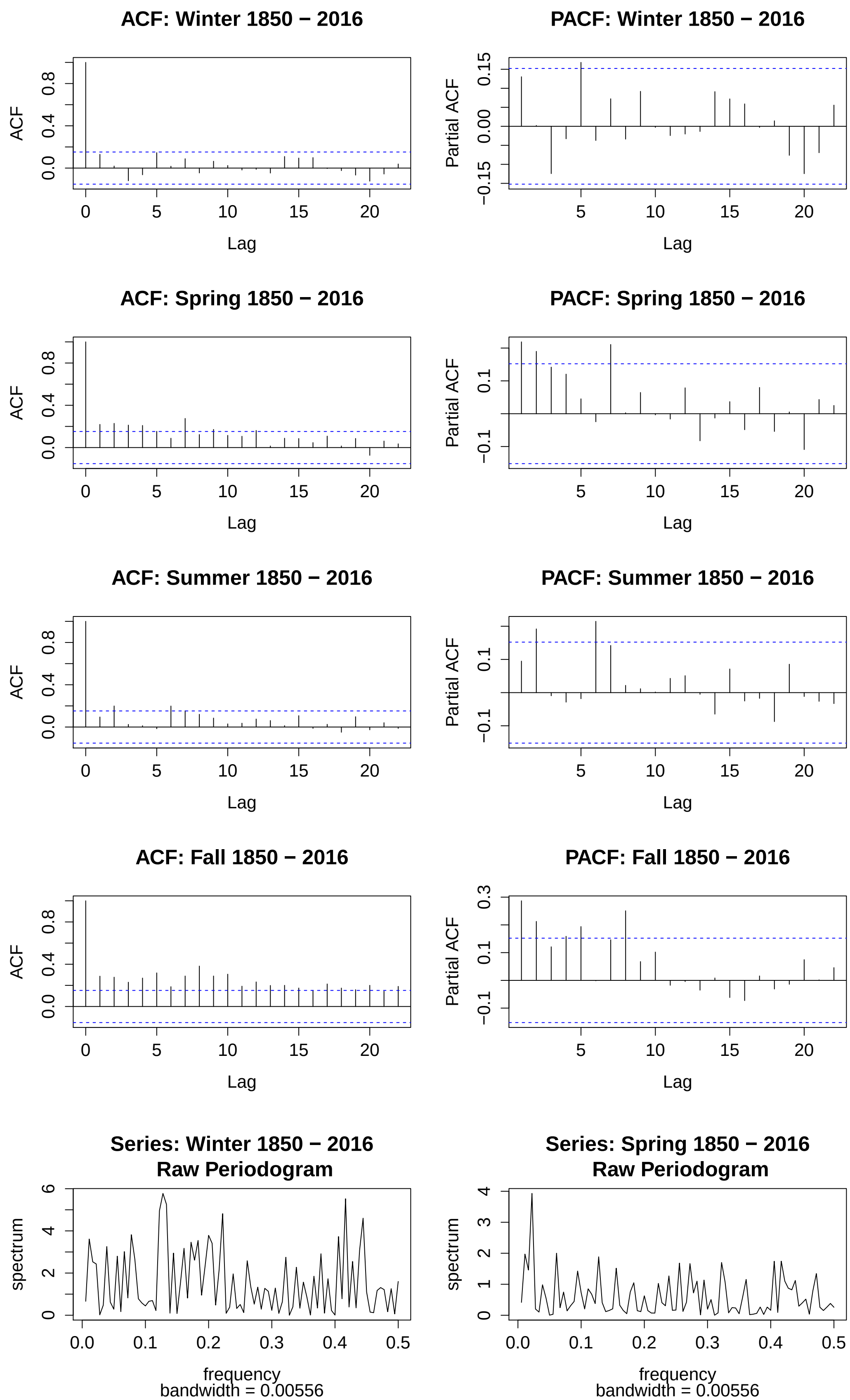
1850 - 2016: Later Period

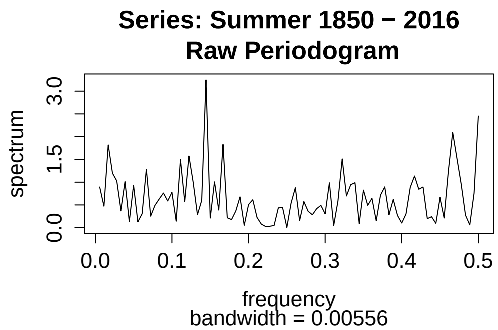
The ACF and PACF graphs for the later period are shown below. The winter series does not exhibit autoregressive or moving average tendencies. However, the spring, summer, and fall PACF's reveal that these series have autoregressive components. In addition, the ACF's for the spring and fall series are serially positive. Since the spring series' ACF tails off, it may follow an ARMA process. Since the fall series ACF does not seem to be tailing off, this could suggest that it is not stationary, or it is a long-memory process with the ARIMA form.

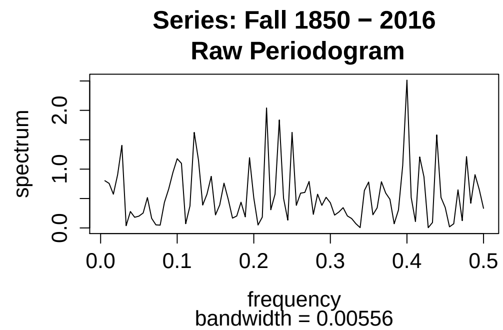
Using AIC and BIC for model selection, I find the following models for the seasonal data (in all of these models, each term is significant):

- Winter–MA(1): $x_t = 4.134 + w_t + .125w_{t-1}$
- Spring–ARMA(1, 1): $x_t = 8.375 + .953x_{t-1} + w_t - .827w_{t-1}$
- Summer–ARIMA(0, 1, 1): $\triangle x_t = -.939w_{t-1}$
- Autumn–ARIMA(0, 1, 1): $\triangle x_t = .0087 - .9393w_{t-1}$

All of these models suggest that there is an upward trend in global temperatures over the recent period, which corroborates the findings of Benner (1992).


ACF: Winter 1850 − 2016
PACF: Winter 1850 − 2016
ACF: Spring 1850 − 2016
PACF: Spring 1850 − 2016
ACF: Summer 1850 − 2016
PACF: Summer 1850 − 2016
ACF: Fall 1850 − 2016
PACF: Fall 1850 − 2016
ACF
Partial ACF
Lag
Series: Winter 1850 − 2016
Raw Periodogram
Series: Spring 1850 − 2016
Raw Periodogram
spectrum
frequency
bandwidth = 0.00556

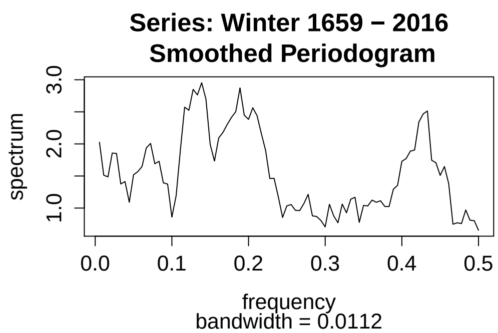


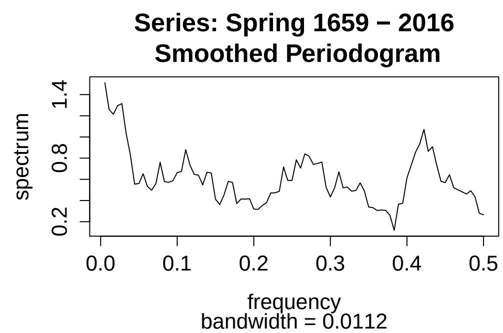


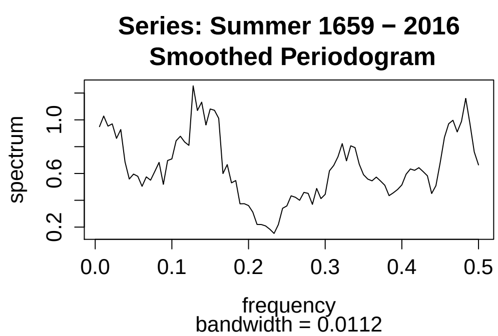
The periodograms for the data in the later period do not seem to have as clear of peaks as the earlier period. To address this problem, I smooth the periodograms using a Daniell kernel in order to better identify the peaks. The smoothed periodograms are shown below. I find the following results:

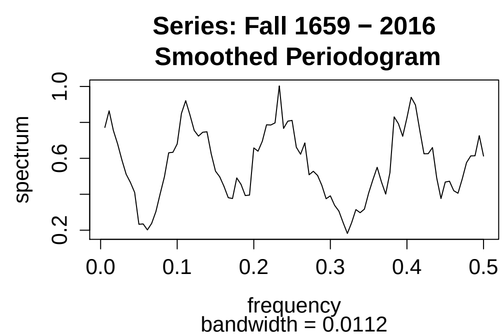
- For winter, the maximums of the periodogram corresponds to cycles every 7.2, 5.3, and 2.3 years.
- For spring, the maximums of the periodogram corresponds to cycles every 2.3 years.
- For summer, the maximums of the periodogram corresponds to cycles every 2.1 and 7.5 years.
- For fall, the maximums of the periodogram corresponds to cycles every 2.4, 4.3, and 9 years.

These results are reasonably close to the ones found in the earlier cycle.



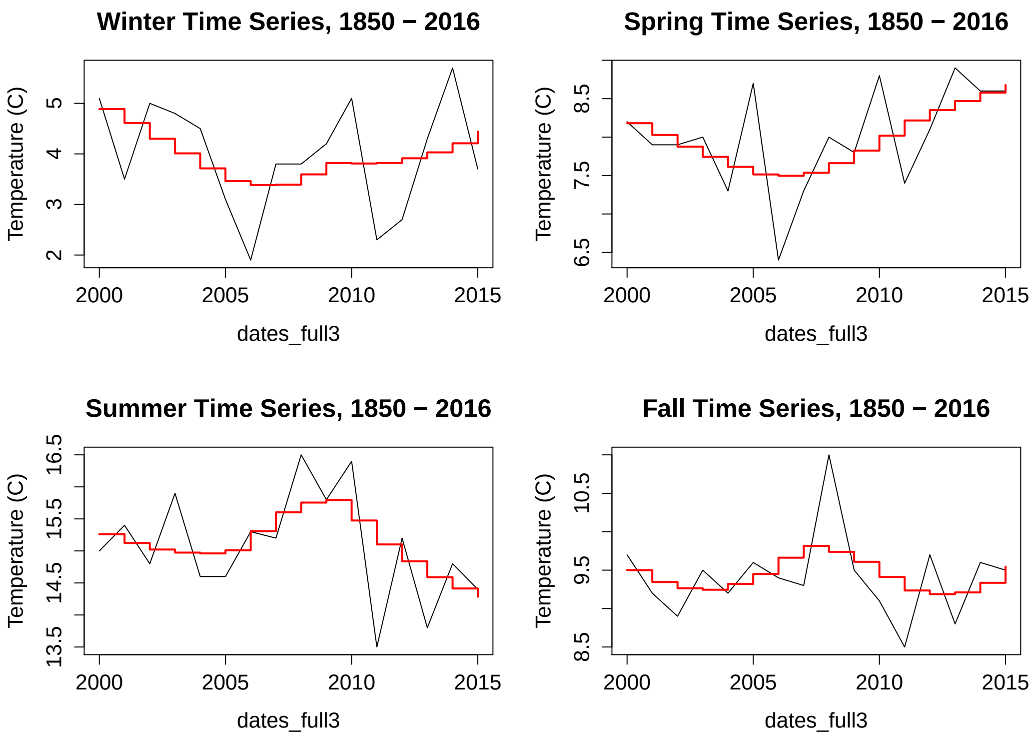




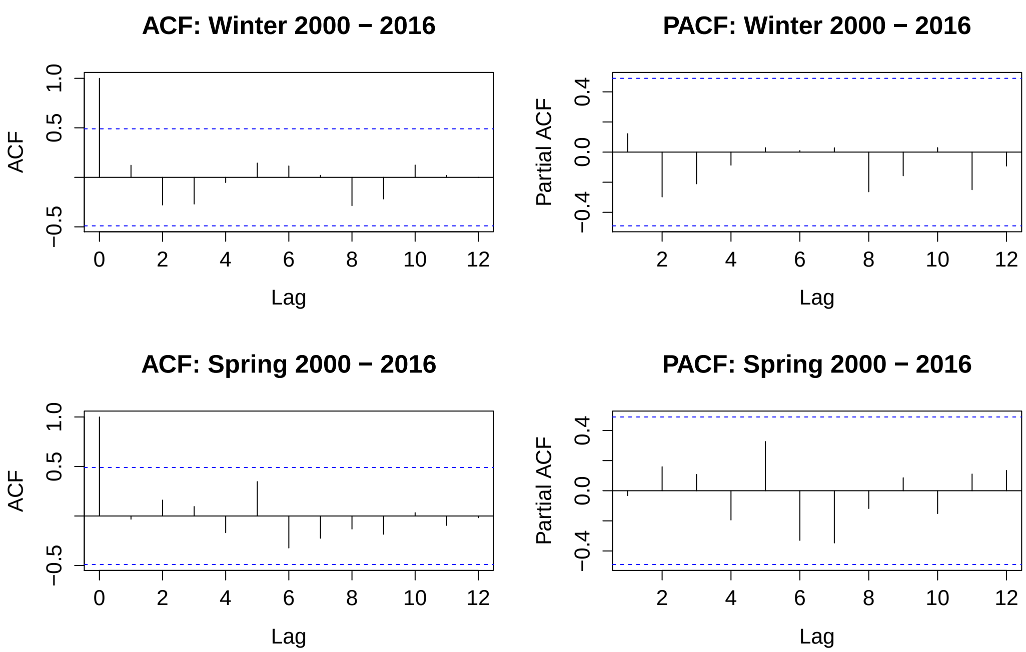


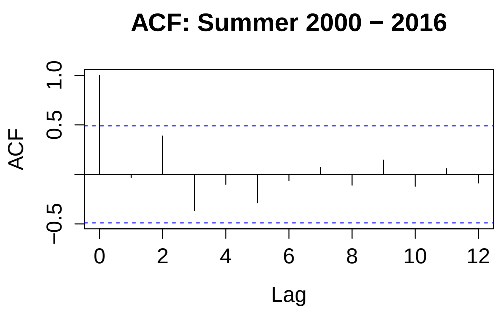
2000 - 2016: Most Recent Period

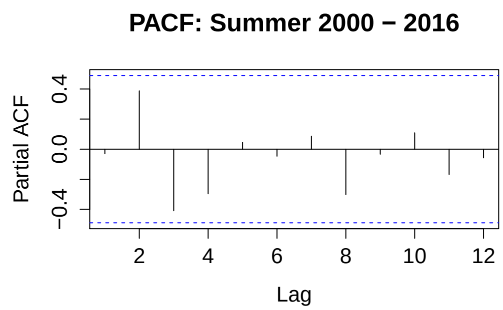
The time series graphs for each season for the most recent period of the 21st century are shown below, with a smoothing curve in red. There is no apparent trend in any of the graphs.

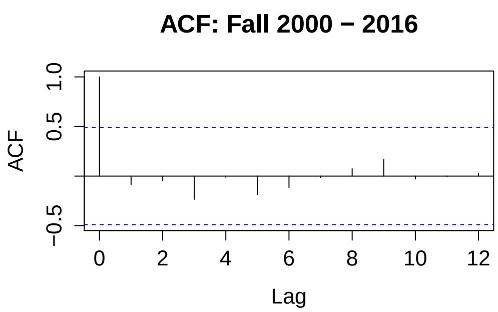


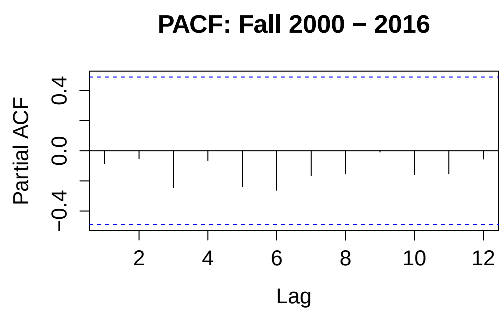
The ACF and PACF of each of the seasons are graphed below. None of the lags are significant for either the ACF or the PACF. After checking autoregressive and moving average models for significance, AIC, and BIC, I find that there is no evidence of an autoregressive or moving average component in the 21st century data. Therefore, I have found evidence to support the claim made by Vaidyanathan (2016) that global warming has slowed during the 21st century. However, the sample size is very small for the 21st century, so sampling variation may be masking the true trend in climate.











References

[1] Benner, Timothy C. "Central England temperatures: longterm variability and teleconnections." *International journal of climatology* 19.4 (1999): 391-403.

[2] Harvey, David I., and Terence C. Mills. "Modelling trends in central England temperatures." *Journal of Forecasting*22.1 (2003): 35-47.

[3] Jones, Philip D., and Raymond S. Bradley. "Climatic variations over the last 500 years." *Climate since* AD 1500 (1992): 649-665.

[4] Jones, P. D., and Mike Hulme. "The changing temperature of Central England." *Climates of the British Isles: present, past and future* (1997): 173-195.

[5] Matyasovszky, I. "Further results of the analysis of central England temperature data." *Theoretical and applied climatology* 39.3 (1989): 126-136.

[6] Vaidyanathan, Gayathri (February 25, 2016) "Did Global Warming Slow Down in the 2000s, or Not? Scientists clarify the recent confusion." http://www.scientificamerican.com/article/did-global-warming-slow-down-in-the-2000s-or-not/