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Are temperatures rising in Togo?
Atakpamé

Introduction

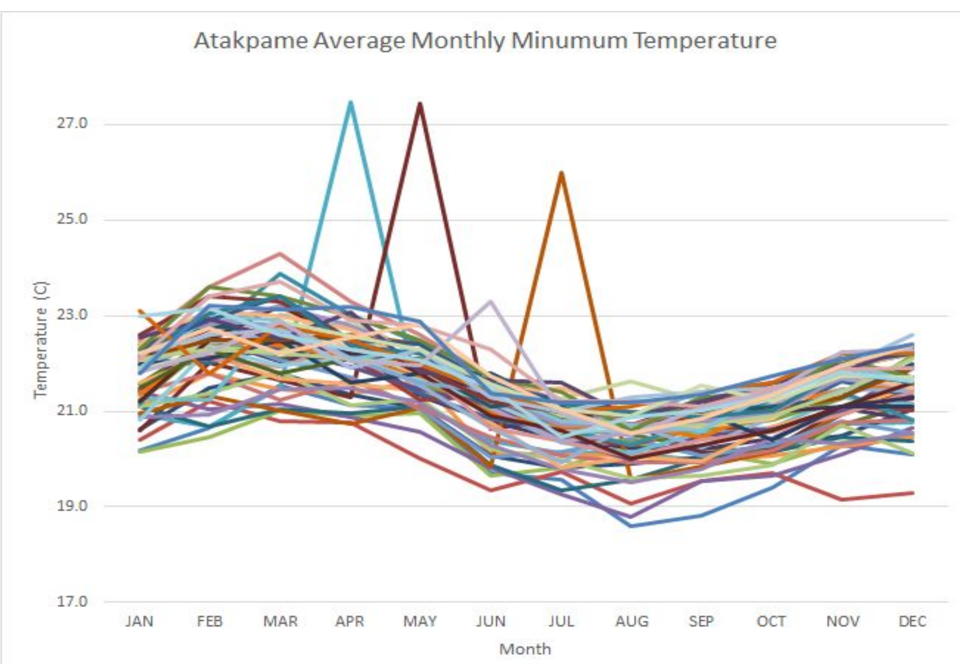
Togo is a coastal, West-African nation slivered between Benin to the east, Ghana to the west, Burkina Faso to the north, and the Gulf of Guinea to the south. The nation's capital, Lomé is located on the southernmost strip of land, bordering the ocean. Togo is a geographically miniscule country with a population to match. The nation, in its entirety, houses 7.5 million people in its villages and bustling cities. The varied and bloodied history of Togo starts markedly when it was invaded by Germany during the Age of Imperialism, during World War I he nation was taken from Germany and divided between British and French administrative zones called British Togoland and French Togoland. In time and akin to most African nations, it was eventually freed entirely in the mid to late 1900's. Political turmoil and civil unrest plagued the nation for much of its short time as an independent nation, but elections have been put in place and a democratic process has been generally followed with some recent exceptions. A coastal nation, trade is a vital component to Togo's economy, both imports and exports exceeds $700 million annually. Being a nation with largely unskilled to low-skilled labor, Togo generates most of its export revenue by selling raw or quickly processed resources such as calcium phosphates, cement, and cotton. Such industries are detrimental to the environment and can give rise to polluted waterways and the natural landscapes surrounding the operation. Togo has just five cities with a population of over 75, 000 inhabitants, and only three with over 100,000 inhabitants.

This study narrows the scope of research to a single Togolese city: Atakpame. Atakpame is a city in the Plateaux Region of Togo comprising of over 80,000 people, one of the largest in the nation. Atakpame is an agricultural center of the nation and produces much of the nation's cotton and cocoa products. Maintaining a long stretch of highway that connects several regions, Atakpame is a vital trade route within the nation and is utilized when transporting northern goods to the Gulf of Guinea. The reliance on agriculture makes the current and future state of the environment and climate an absolute necessity in the political conversation within the nation. To assist in an objective conversation about the current state of the environment in Atakpame, this study will analyze maximum and minimum monthly surface temperatures to determine if there has been an increase, decrease, or inconsequential change.

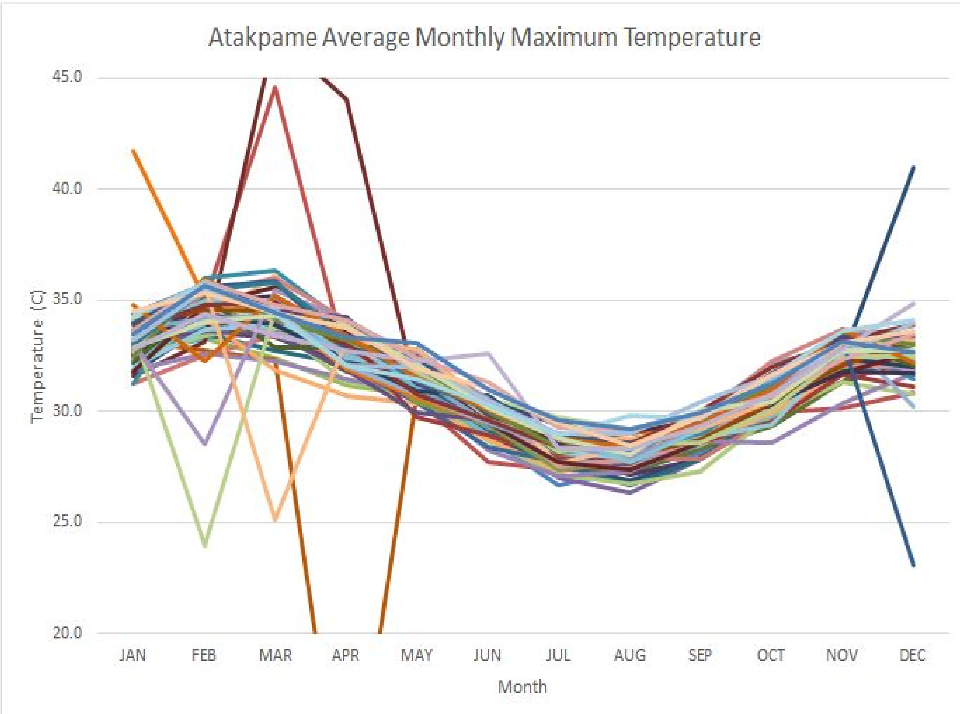
Data Preparation

We first verified the yearly means using the finer monthly data. There did not appear to be any discrepancies. Next, we graphed the two time series and identified potential outliers in the data.

The following tables display the extreme outliers in each dataset that were subsequently removed.



Average Minimum Temperature		
Year	Month	Value
1965	Apr	27.5
1968	May	27.4
1972	Jul	26

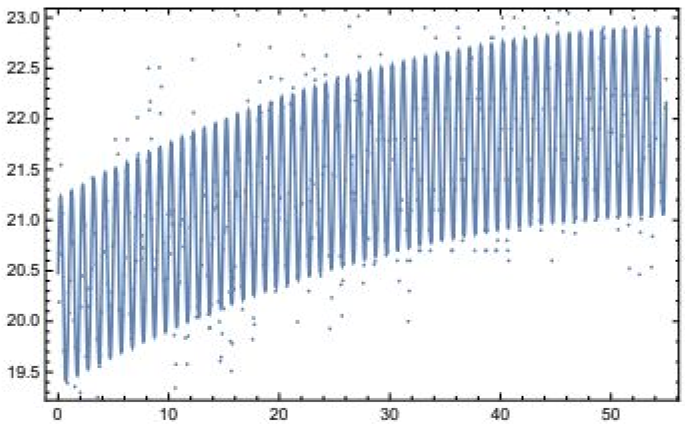


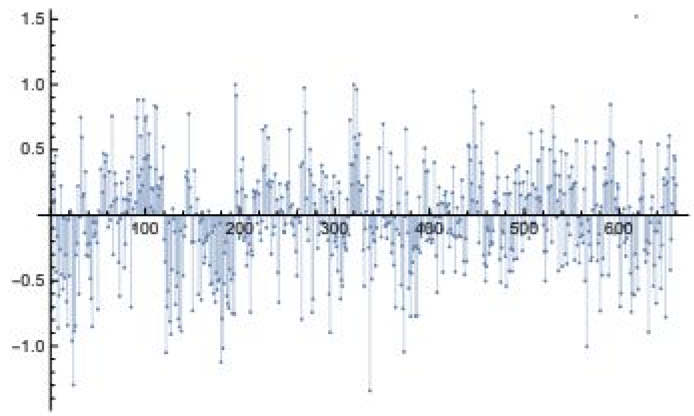
Average Maximum Temperature		
Year	Month	Value
1962	Mar	44.6
1967	Dec	40.9
1968	Mar	47
1968	Apr	44
1972	Apr	10.4
1984	Jan	41.8
1999	Feb	24
2000	Feb	28.5
2002	Mar	25.1
2003	Dec	23.1

Data Analysis

Minimum Temperature Analysis

Due to the wave-like pattern in the plot, a quadratic model with yearly oscillations was fit using Mathematica. The data was restructured into 660 pairs of a decimal year and temperature.





	Estimate	Standard Error	t-Statistic	P-Value
1	20.2947	0.0685635	295.998	$1.149705671714 \times 10^{-699}$
x	0.0592205	0.00574843	10.302	3.61724×10^{-23}
x^2	−0.000520703	0.000101054	−5.15273	3.40217×10^{-7}
Sin[2 π x]	0.904825	0.0322253	28.0781	1.76226×10^{-114}
Cos[2 π x]	0.183537	0.0322224	5.69594	1.85397×10^{-8}

The model seems appropriate due to the extremely small p-values. However, a wave-like pattern is still existent in the residuals plot indicating that the oscillations do not exactly fit the underlying model. Other oscillatory models were tested with differing periods, although none were found to be better than the yearly oscillations. This model had an **R-squared value of 66.23%**, meaning that 66.23% of the variation in the average monthly minimum temperatures in Atakpame is explained by this model.

An alternative model that was considered was a quadratic regression model with month as a categorical variable. Extreme outliers were removed before analysis.

This model was also deemed appropriate due to the extremely small p-values. A linear version was also tested, but the quadratic trend was extremely significant.

This model had an **R-squared value of 83.02%**, meaning that 83.02% of the variation in the average monthly minimum temperatures in Atakpame is explained by this model.

The errors seem normally distributed, homoscedastic, and independent.

Model Summary

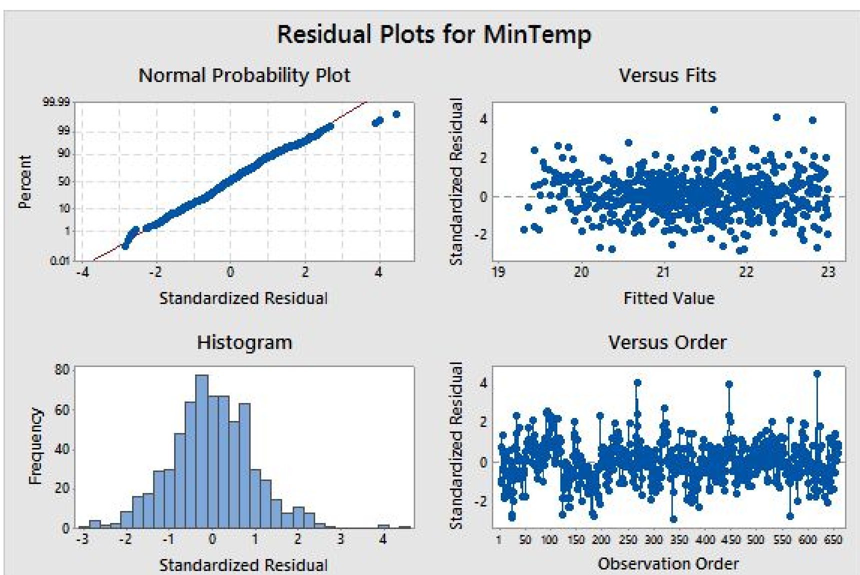
S	R-sq	R-sq(adj)	R-sq(pred)
0.387178	83.02%	82.68%	82.27%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	13	471.44	36.2643	241.91	0.000
Year	1	12.35	12.3546	82.42	0.000
Year*Year	1	12.02	12.0243	80.21	0.000
Month	11	283.27	25.7517	171.79	0.000
Error	643	96.39	0.1499		
Total	656	567.83			

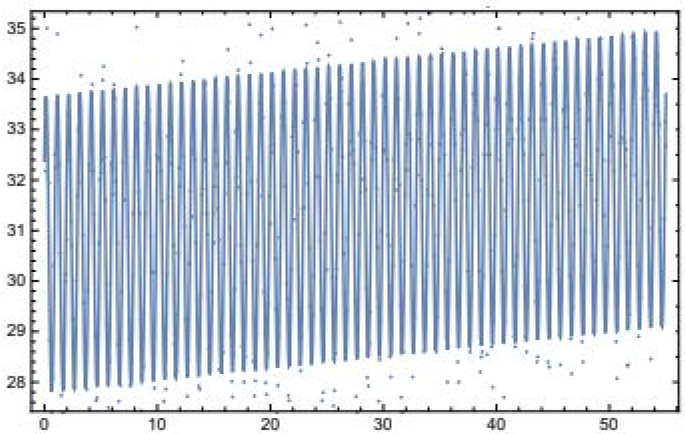
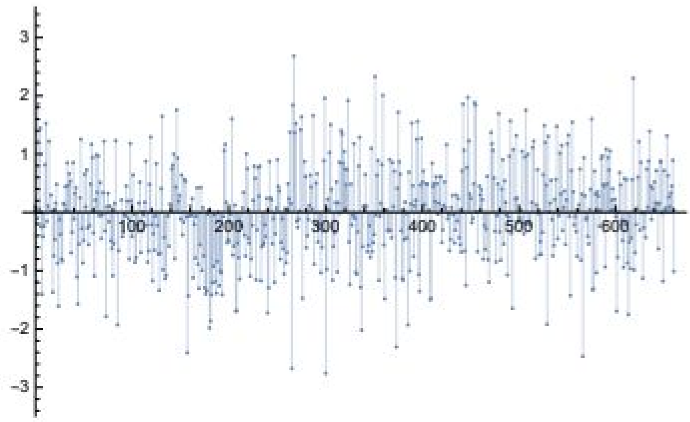
Regression Equation

Month			
Apr	MinTemp	=	-2414 + 2.418 Year - 0.000600 Year*Year
Aug	MinTemp	=	-2416 + 2.418 Year - 0.000600 Year*Year
Dec	MinTemp	=	-2415 + 2.418 Year - 0.000600 Year*Year
Feb	MinTemp	=	-2414 + 2.418 Year - 0.000600 Year*Year
Jan	MinTemp	=	-2414 + 2.418 Year - 0.000600 Year*Year
Jul	MinTemp	=	-2416 + 2.418 Year - 0.000600 Year*Year
Jun	MinTemp	=	-2415 + 2.418 Year - 0.000600 Year*Year
Mar	MinTemp	=	-2414 + 2.418 Year - 0.000600 Year*Year
May	MinTemp	=	-2414 + 2.418 Year - 0.000600 Year*Year
Nov	MinTemp	=	-2415 + 2.418 Year - 0.000600 Year*Year
Oct	MinTemp	=	-2415 + 2.418 Year - 0.000600 Year*Year
Sep	MinTemp	=	-2416 + 2.418 Year - 0.000600 Year*Year



Maximum Temperature Analysis

Similarly to the minimum temperature analysis, a oscillatory model was fit to the maximum temperature data. A quadratic term was initially considered, but it was not significant and so a linear trend with oscillations was used instead.

	Estimate	Standard Error	t-Statistic	P-Value
1	30.7254	0.131259	234.083	$2.742000150555 \times 10^{-634}$
x	0.0238126	0.00412899	5.76717	1.24205×10^{-8}
Sin[2 π x]	2.4126	0.0927101	26.023	4.15844×10^{-103}
Cos[2 π x]	1.65835	0.0927019	17.8891	1.36846×10^{-58}

The model seems appropriate due to the extremely small p-values. However, a wave-like pattern is still present in the residuals plot indicating that the oscillations do not exactly fit the underlying model. Other oscillatory models were tested with differing periods, although none were found to be better than the yearly oscillations. This model had an **R-squared value of 61.03%**, meaning that 61.03% of the variation in the average monthly maximum temperatures in Atakpame is explained by this model.

An alternative model was considered for the maximum temperature data. A linear regression model with month added as a categorical variable was fit to the data. A quadratic term was tested but was not significant. Extreme outliers were removed before this analysis.

This model was also deemed appropriate due to the extremely small p-values.

This model had an **R-squared value of 91.83%**, meaning that 91.83% of the variation in the average monthly maximum temperatures in Atakpame is explained by this model.

The errors seem normally distributed, homoscedastic, and independent.

Model Summary

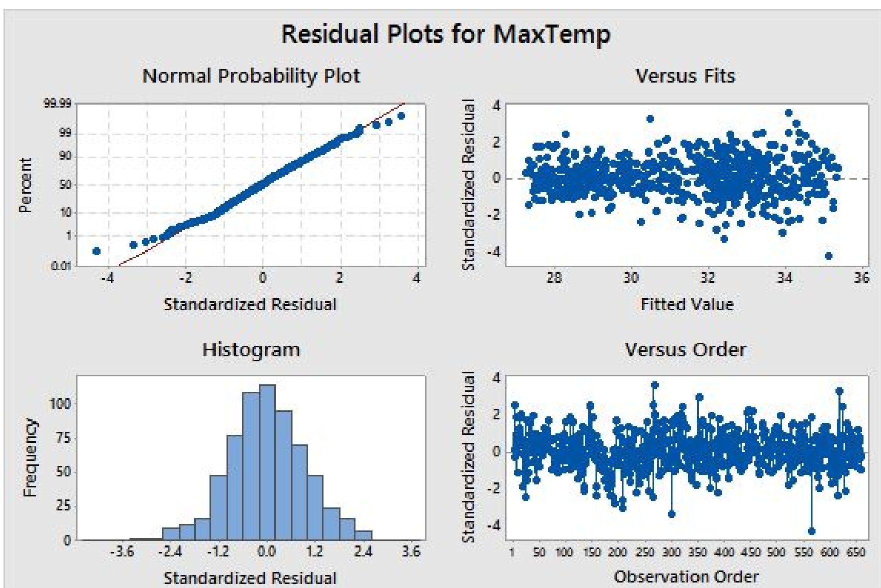
S	R-sq	R-sq(adj)	R-sq(pred)
0.659796	91.83%	91.67%	91.49%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	12	3115.1	259.593	596.31	0.000
Year	1	153.4	153.419	352.42	0.000
Month	11	2956.6	268.782	617.42	0.000
Error	637	277.3	0.435		
Total	649	3392.4			

Regression Equation

Month			
Apr	MaxTemp	=	-28.19 + 0.03064 Year
Aug	MaxTemp	=	-32.87 + 0.03064 Year
Dec	MaxTemp	=	-28.42 + 0.03064 Year
Feb	MaxTemp	=	-26.40 + 0.03064 Year
Jan	MaxTemp	=	-27.92 + 0.03064 Year
Jul	MaxTemp	=	-32.65 + 0.03064 Year
Jun	MaxTemp	=	-31.18 + 0.03064 Year
Mar	MaxTemp	=	-26.70 + 0.03064 Year
May	MaxTemp	=	-29.41 + 0.03064 Year
Nov	MaxTemp	=	-28.38 + 0.03064 Year
Oct	MaxTemp	=	-30.33 + 0.03064 Year
Sep	MaxTemp	=	-31.91 + 0.03064 Year



Conclusions

The best models appear to be the quadratic trend model with a categorical variable for the average minimum temperatures and the linear trend model with a categorical variable for the average maximum temperatures. However, all models considered indicated that over time the average temperatures in Atakpame are rising. It seems as if the average minimum temperatures are rising faster than the average maximum temperatures.

We would like to get more details on exactly how the data was collected. Specific information on exactly how the monthly maximum and minimum temperatures were calculated is crucial to our analysis. If any abnormal or extreme events have occurred (i.e. a drought) we would like to know so that we may explain the outliers identified in the data. There were several values found in the data, thirteen values to be exact, that are considered outliers. This significant number of values reiterates the need for collection information, so that a better understanding or prevalence of a pattern may become apparent.