Togo, West Africa: on Track for Over Three Degrees Celsius of Warming by 2100

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Abstract. Togolese meteorologists (Direction de la Météorologie Nationale, Division Climatologique) have kept temperature and rainfall records on ten cities and towns since 1961. These record (monthly average maxima and minima) permit an analysis of temperature trends and rainfall trends through time.

Our results indicate that Togo has been warming since 1961 at a rate of around two and a half degrees Celsius per 100 years, which suggests that Togo is on track for three-plus degrees of warming over pre-industrial levels by the end of this century.

The model confirms a trend of cooling by elevation of about 5 degrees per kilometer. Furthermore, the effect of moving north from the ocean is mixed. While there is a slight **cooling** trend by increasing latitude in the minima, there is a much stronger **warming** trend by increasing latitude in the maxima, which suggests a change in rainfall variation. Interestingly enough, there is also a mixed longitudinal impact, with increasing minima from east to west, but decreasing maxima from east to west.

Togo is interested in the implications of climate changes, particularly temperature and rainfall, and the consequences for public health and diseases such as malaria, meningitis, cholera, and dengue fever. We are able to make some general statements based on the results of our analysis.

1. Introduction

1.1. Background and Context

Togo gained its independence from France in 1960, and began carrying out the ordinary functions of a sovereign state, such as the collection of important meteorological data on its cities and towns. We use the temperature and rainfall records of ten of those towns and cities in this analysis: Lome, Tabligbo, Kouma-Konda, Atakpame, Sotouboua, Sokode, Kara, Niamtougou, Mango, and Dapaong. They provide excellent coverage of Togo, from its southern-most city of Lome, to its northern-most city of Dapaong.

We have records on temperature extremes (average maximum and minimum temperature) by month, and eight of the records cover the period 1961 to 2015 (Kara is available only from 1977, and Sotouboua only from 1982). We combined all the data to construct a single model for each of the maximum and minimum temperature for the country, which we have used to create temperature maps as well as to forecast Togo's future temperature.

Rising temperature has direct implications for health, as well as potential indirect implications. For example, if increasing temperatures impact rainfall, that has obvious consequences for agriculture and less obvious consequences for public health (e.g. more flooding, or more or less standing water). We study the impact of temperature on rainfall data, which we have monthly for roughly the same periods.

1.2. Prior Relevant Temperature Modeling

Togo's location in Western Africa makes it privy to several unique climate features. Annual rainfall in West Africa is almost constant along each latitude, but decreases sharply from the south to north with a gradient of about 1 mm per kilometer. Togo is confined to a longitude of 0°-2°E and latitude of 6°-12°N[2], its length stretches it through six distinct geographic regions. Therefore, rainfall modeling that considers geographic coordinates are of particular interest. Literature has shown that spatiotemporal rainfall variability in West Africa can be categorized between two regions, north of 10°N and south of 10°N. In Togo, this results in a single rainy season present in northern Togo and a two rainy seasons regime in southern Togo. The rainy season in the north lasts from June to the end of September with annual rainfall amounts between 900-1100 mm per year. On the other hand, the rainy seasons in the south are usually from mid-April through June and from mid-September through October, with total rainfall amounts between 1000-1600 mm per year. Any variability in Togo's rainfall, the majority of which falls April through October, is characterized by the reduction in annual total precipitation and in-season drought when crops are in their reproductive phases. The Togolese agricultural sector, which employs about 70 percent of the country's workforce, is dominated by small-scale

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rainfed sustenance farming of millet, sorghum, maize, and rice. Considering staple food production is not irrigated, understanding precipitation patterns across time and space provides for maximum yield during the cropping season because it allows for a more comprehensive optimization of soil water storage, season precipitation, and time-shifts within seasonal precipitation patterns. According to some previous climate projection scenarios, Togo's location on the Guinea Coast makes it likely that agricultural productivity will be adversely affected due to the expected decrease in rainfall and rise in temperature, all tell-tale signs of global warming.

The rainfall seasons and overall climate of Togo are strongly influenced by the West African Monsoon (WAM), a large-scale coupled atmosphere-ocean-land system characterized by summer rainfall and winter drought. While WAM is a major climatological component, the relationships that couple atmosphere, ocean, and land involve multiple time and space scales that are not currently well-identified due to the complexity of the relationships, deficiencies present in current general circulation models, and the sparsity of routine observation networks in and around West Africa. However, the various factors that have been noted to affect interannual WAM variability and ergo climate include variability in sea surface temperatures (SST), continental land surface conditions, and a remote influence of the El Niño's Southern Oscillation (ENSO).

Also modeled in this paper are land surface temperatures in Togo. The literature with concern to west Africa is less robust for this topic; however, that does not lessen the importance of modelling any changes present in land surface temperatures as their variability is dependent upon physical properties, such as vegetation density, soil moisture, and other important properties that would be considered for agriculture. Variability in land surface temperatures can also be used to detect land cover changes, perform drought monitoring, and water use management. A challenge with creating accurate climate models is not only accounting of projections of external forcing, but also including the initial condition data for the prediction of internal variability that arises from unforced natural changes from factors such as ENSO, variability in the thermohaline circulation, and anomalies of ocean heat content.

2. Materials and Methods

Initial data were annual mean maximum and minimum temperatures, and our preliminary inspection led us to conclude that we needed to increase the resolution of the data even though it appeared that there is an increase across Togo. So we acquired finer measurements from the Togolese Direction de la Météorologie Nationale, and we then modeled each location individually. Although there was wide variation across Togo, our results indicated that the general trends were for increasing temperatures, with a strong oscillatory seasonal component.

We also requested and received elevation, latitude, and longitude for each site; our supposition was that elevation and latitude would play important roles, and that longitude might be important as well. In any event, since these three variables are known for any point in Togo using a simple GPS, a model built including those variables would be easy to use.

2.1. Data Cleaning

Data was collected for ten of the largest cities and villages in Togo. Initial date of collection varies between locations, most being in 1961 and spanning to 2015. The city of Kara began collecting usable data in the year 1977 while the city of Sotouboua began even later in 1982. These datasets were compiled and cleaned in order to generate the best and most accurate model. The first step of the cleaning process was to generate several new variables that are essential in this analysis. YearDec was a variable generated to calculate the monthly midpoint of a year for every observation (ex. January1961=1961.042). In addition, latitudes, longitudes, and elevation were collected to place cities and create an idea of the geography of cities. Outliers were identified utilizing the Interquartile Range(IQR) method. This method is employed by calculating the 75th and 25th quartiles of the dataset; these two are subtracted and thus the IQR is calculated. This value is then multiplied by 1.5 and is subsequently subtracted from the 25th percentile and added to the 75th percentile. Any value lower than or exceeding these two values is considered an outlier and removed from final analyses. This was done in an attempt to remove data that appeared to be inappropriately collected or represented improperly. With these observations removed, a representative sample of temperature and rainfall values were ready for use.

2.2. Temperature Model Development

2.3. Rainfall Model Development

Previous work(**???**) suggests that the two-parameter gamma distribution has been used (with mixed success) for modeling rainfall.

One of the problems of the gamma distribution is that zero rainfall values are not permissible within the probability density function (pdf), so a mixed model for rainfall must be adopted (the probability of no rainfall within a month, versus a gamma distribution of non-zero rainfall). Our objective is to model rainfall by month, and determine if there has been a trend toward either more rainfall or change in the variation of rainfall with time (which we take as a surrogate for temperature).

The two-parameter Gamma distribution $Gamma(\alpha, \beta)$ has mean $\alpha * \beta$ and variance $\alpha\beta^2$(**?**). We suggest that the general trend in Togo is towards rainfalls best modeled by $Gamma(\alpha(t), \beta(t))$, where α, β, or both are changing with time.

In the special case where the daily rainfall is a given by $Gamma(\alpha_{day}, \beta_{month})$ (where day is the day of the month), then the accumulated daily rainfall given monthly (i.e., our rainfall data) is a sum of gamma distributions, and hence also gamma[1]:

$$Rainfall(year, month) \sim Gamma\left(\sum_{i=1}^{days} \alpha_i, \beta_{month}\right)$$

3. Results

3.1. Temperature Model

Elevation has been shown to have a significant effect on temperature(**?**), on the order of $5 - 10^o C$ per kilometer in that study of Jaipur, India. Our model confirms this (on the lower end), with the temperature dropping approximately 4.95 ± 0.07 degrees/km for maxima, 5.74 ± 0.09 degrees/km for minima. Relationships between surface temperature and longitude, latitude, sea surface temperature, and ENSO circulations were also established and proven to be significant.

Table 1. Surface Temperature Models.

Minimum Temperature

Parameter	Dependent Variable
$\sin(DecYear2\pi)$	0.59732
$\cos(DecYear2\pi)$	–1.00163
$\sin(\frac{DecYear2\pi}{1/2})$	0.12960
$\cos(\frac{DecYear2\pi}{1/2})$	–0.87516
$\sin(\frac{DecYear2\pi}{1/3})$	–0.10277
$\cos(\frac{DecYear2\pi}{1/3})$	–0.22623
$\sin(\frac{DecYear2\pi}{13})$	–0.06166
$\cos(\frac{DecYear2\pi}{13})$	–0.04199
$\sin(\frac{DecYear2\pi}{20})$	0.02849
$\sin(\frac{DecYear2\pi}{20})$	0.07459
DecYear	0.02739
Latitude	–6.22475
Latitude×Longitude	–0.88023
Longitude	15.07136
Longitude^2	–3.69825
Latitude^2	0.41700
Elevation	–0.00151
ENSO	–0.00616
SST	0.29451
Constant	31.17225

Maximum Temperature

Parameter	Dependent Variable
$\sin(DecYear2\pi)$	1.34081
$\cos(DecYear2\pi)$	1.78711
$\sin(\frac{DecYear2\pi}{1/2})$	–0.21333
$\cos(\frac{DecYear2\pi}{1/2})$	–0.59972
$\sin(\frac{DecYear2\pi}{1/3})$	–0.07605
$\cos(\frac{DecYear2\pi}{1/3})$	–0.39639
$\sin(\frac{DecYear2\pi}{1/4})$	–0.05782
$\cos(\frac{DecYear2\pi}{1/4})$	–0.16546
$\sin(\frac{DecYear2\pi}{13})$	–0.06706
$\cos(\frac{DecYear2\pi}{13})$	0.10259
DecYear	0.01284
Latitude	7.72365
Latitude×Longitude	0.62966
Longitude	-11.28104
Longitude^2	3.12675
Latitude^2	-0.44202
Elevation	–0.00882
ENSO	–0.00663
SST	0.47106
Constant	–8.37022

3.2. Rainfall Model

Table 2. Rainfall Model.

Parameter	Dependent Variable
$\sin(DecYear2\pi)$	–33.96627
$\cos(DecYear2\pi)$	–66.76497
$\sin(\frac{DecYear2\pi}{1/2})$	19.58924
$\cos(\frac{DecYear2\pi}{1/2})$	–20.83339
$\sin(\frac{DecYear2\pi}{1/3})$	8.98517
$\cos(\frac{DecYear2\pi}{1/3})$	–1.02394
$\sin(\frac{DecYear2\pi}{1/4})$	–6.42061
$\cos(\frac{DecYear2\pi}{1/4})$	6.17596
DecYear	-0.12389
Latitude	231.44500
Latitude×Longitude	28.92292
Longitude	-495.87750
MinTemp	3.11358
MaxTemp	–23.47286

3.3. City-by-City Validation and Discussion: Sensitivity Analysis

In the end, our model attempts to predict the temperature and rainfall of any city in Togo. It should certainly, then, predict fairly well the results for any individual city whose meteorological data was used in the creation of the model. In this section, we predict the results for each of the cities in our study, and compare the predicted to the original data.

3.3.1. Lomé

3.3.2. Tabligbo

3.3.3. Kouma-Konda

3.3.4. Atakpamé

3.3.5. Sotouboua

3.3.6. Sokodé

3.3.7. Niamtougou

3.3.8. Kara

3.3.9. Mango

3.3.10. Dapaong

4. Discussion

4.1. Health Impacts of Increasing Temperature

The Intergovernmental Panel on Climate Change has reported a 0.74±0.18°C from 1906 to 2005 and it is projected that annual average runoff and water availability will decrease from 10-30% by the middle of 21st century. The changes in climate do not only have troubling implications for the global population in terms of loss of food and water security, but more direct health impacts in the form of the spread of food, water, and climate-related, non-communicable disease. The contamination of air, water and food are expected to lead to bioaccumulation of pollutants associated with a myriad of diseases, including (but not limited to) diabetes, cardiovascular diseases, chronic obstructive pulmonary disease, and cancers. In Togo, the populace is at risk for an increase in the incidence of major infectious diseases such as meningococcal meningitis, schistosomiasis, bacterial and protozoal diarrhea, hepatitis A, and typhoid fever. Increased temperatures will also lead to a rise in heat exhaustion, cramps, strokes, and death in vulnerable populations. These projections are of major concern to the Togolese due to the fact that Togo is in an especially vulnerable region projected to warm disproportionately because of the ENSO's effect over Togo and its location in the temperate latitudes.

4.2. Effect of Increasing Temperature on Rainfall, and Economic Impacts

One of the main consequences from increased temperatures is increased rainfall. As temperatures dramatically increase, the amount of evaporation also increases. High levels of water vapor in the atmosphere lead to more rainfall. In addition, more evaporation can lead to more intense precipitation, such as snow storms and heavy rain. The amount of rain varies across the world due to climate change causing shifts in the air and ocean currents. Therefore, some regions experience less rainfall than others. According to the article, *Togo*, Togo is in an area that will experience a rise in temperature and decrease in rainfall based off climate scenarios. There has also been a poor distribution of rainfall throughout the year. These scenarios reflect what our modeling team has found. Agriculture plays a large role in the economy of Togo; many Togolese people rely on sustenance farming as their source of food. With temperatures increasing and precipitation decreasing, this way of life could be threatened. These factors could lead to sporadic and unforeseen flooding or drought times, less reliable planting dates, and shorter growing seasons for crops. With a large trade imbalance already seen, it could be difficult to import the necessary food needed to replace lost crops on short notice. These effects would contribute to a slow economy as deficits grow and people become malnourished and ill.

4.3. Summary

From the projected models, an increase in temperature and decrease in precipitation is predicted in the coming years for Togo. The extent to which these outcomes come to fruition will dictate the severity of the many possible adverse effects expected to be seen in the climate and for the people of the country. To be prepared, measures should be taken to better counteract these possible scenarios. Areas to focus on should be in the public health and food production sectors, as well as transitioning the economy to better suited for possible dramatic changes from year to year in agricultural output.

Appendix A: Data Treatment and Analysis Details

A1. Problems Encountered

A2. To Remove or Impute (Estimate?)

Appendix B: Outlier Detection

B1. Methods

B2. Outlier Summary

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Notes

1. (we'll need a reference, better than https://math.stackexchange.com/questions/250059/sum-of-independent-gamma-distributions-is-a-gamma-distribution !:).

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Table 1. Geographical Coordinate information for the cities and towns of Togo.

There are roughly four and a half degrees of latitudinal difference, and one and a quarter degree of longitudinal difference in these towns. Minimum elevation is about 20m (Lomé), and maximum elevation is around 640m (Kouma-Konda).

Longitude	Latitude	Elevation (m)	Location
1.25315	6.17455	19.60	Lomé
1.50789	6.60475	40	Tabligbo
0.572	6.95617	641	Kouma-Konda
1.12143	7.53838	400	Atakpamé
0.98	8.56	380	Sotouboua
1.15176	8.99517	387	Sokodé
1.20357	9.62788	342	Kara
1.083333	9.8	462	Niamtougou
0.46916	10.36191	146	Mango
0.22809	10.836	230	Dapaong