Spatial variations in the trend of heatwave over West Africa

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Abstract. The spatial variation of heatwave occurrences and duration were considered using twelve definitions over West Africa. The definitions are based on different temperature thresholds and percentiles. Daily maximum temperatures were obtained from the high-resolution Princeton Meteorological Forcings for West/Central/East Africa data. Temperature threshold-based definitions of the heatwave were found to have more geographical spread in positive trends in heatwave number than percentile-based methods. Trends in the longest heatwave were more pronounced in the temperature threshold indices than percentile-based indices. Our results also showed that the areas with significant trends increased as the definition grew from 2 to 3 days using a temperature threshold of 35°C. The positive trends of the heatwave in the region should be a growing concern for public health officials.

Keywords: West Africa, heatwave, biometeorology, percentile, climate extreme

1. Introduction
Severe effects of global warming have been linked to extreme events like heatwaves, drought, and flooding [1, 2]. Heatwaves are experienced when there are sets of days and nights with sustained extreme heat as a result of the rise in temperature [3, 4, 5]. One of the key risks of the continuous increase in global temperature is the occurrence of deaths and illnesses that are heat-related during the extreme heat periods [6, 7, 8], as a result of loss of the thermoregulatory capability of the body [9, 3]. There had been several reports on heatwaves [10, 11], with an increased frequency in Europe, China, and Australia [12] as well as on the associated health impact of heatwaves [12, 3, 13]. The urban populace, the elderly, and children had been reported to be the most vulnerable groups to the health impact of heatwaves [14, 3]. The effects of heatwaves are not restricted to health only, as there had also been reports on the economic and ecological impact of heatwaves [15]. It has also been predicted that heat waves will increase in frequency, duration, and intensity with climate change [9, 16, 17, 18, 19].

According to Porter et al. [7], Africa is one of the vulnerable regions that would suffer the effect of global warming. But because of the dearth of data in the baseline values and heatwave records in Africa, most of the heatwave events have not been documented [1, 20]. However, heat spell with a temperature of over 50°C has been reported in the northeastern part of Nigeria with recorded mortality of over sixty persons (http://news.bbc.co.uk/2/hi/africa/2038164.stm). Ceccherini et al. reported an increase in the intensity and spatial distribution of heatwaves in Africa [21]. New et al. [22] and Ly et al. [23] showed a general warming trend in different African regions and West Africa respectively.

Since the health impact of heatwaves could be different in different regions due to diversity in population adaptation and acclimatization to changes [3], the development of an internationally acceptable definition of heatwave may be unrealistic. So regional heatwave definition could be more appropriate to evaluate the impact of the heatwave. The study of heatwaves has been marked with different heatwave definitions [14, 24, 15, 17, 3, 1, 12, 18, 13, 25]. A small change in heatwave definition has been found to have a significant effect on the associated impact [3].
Sustaining economic development and improving the living and health conditions of the populace depends largely on their preparedness to mitigate and adapt to climatic changes [26]. Such preparedness could be brought about from knowledge gathered in studying the trends of extreme events to enable the forecast of possible future occurrences of heatwaves. This would enable the prompt release of heat warming messages with possible health implications, to enable the public to make necessary lifestyle adjustments to reduce the health, ecological and economic impact of such extreme events. Thus, this study is aimed at studying the trends of heatwaves in the West African region using different heatwave definitions. With the hope of identifying the heatwave definition that best describes the heatwave occurrence in the region.

2. Methodology

2.1. Data
Sub-Saharan Africa has a sparse distribution of meteorological data sets. In this study, the high temporal and high-resolution data set from Princeton Meteorological Forcings for West/Central/East Africa [27, 28]. It was obtained by merging the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) reanalysis, Global Precipitation Climatology Project (GPCP), Tropical Rainfall Measuring Mission (TRMM), and Climatic Research Unit (CRU) temperature dataset at a resolution of 0.5×0.5. Meteorological data from National Climatic Data Center (NCDC) were then assimilated to improve its accuracy. Downscaling was achieved by bilinear interpolation with elevation correction. The data set is gridded at 0.1 × 0.1 resolution and obtained from 1986 to 2005. The validity and homogeneity of the data set have been reported [25].

2.2. Study area
West Africa lies between Latitude 0°N−23°N and Longitude −20°W−15°E. The region is bounded in the south and west by the Atlantic Ocean and the Sahara Desert in the north. This boundary impacts the climate of the region. Temperature and precipitation follow northward graduation. Mean temperature increase from the south coast to the Sahara while the intensity of precipitation decreases. The Sahel region lies between 14°N and 18°N [29]. A vast proportion of the area has one rainfall regime lasting from one - six months. A small part of West Africa close to the coast (Ghana and ivory Coast) has two rainfall regimes [30].

2.3. Heatwave definitions
Heatwave can be defined based on a given threshold or percentile being exceeded for days using maximum temperature, minimum temperature, average temperature, or a combination of parameters. In this study, eight (8) definitions of heatwave based on maximum temperature (T max) were analyzed. Temperature thresholds (35°C, 37°C) and percentile thresholds (90th, 97th) percentiles for 2 and 3 consecutive days are considered. The temperature thresholds considered in this study are shown in Table 1. Two heat wave indices are also defined, (1) Heat wave number (HWN), this is the number of heatwave events per year, (2) Heatwave duration (HWD) which is the length of the longest heatwave event measured in a given year.

2.4. Trend analysis
To determine the trend in heatwave indices, a simple linear regression was used. The heatwave indices, \( Y_i \) at time \( t_i \) can be related by the linear expression \( Y_i = mt_i + c \), where \( m \) is the slope or trend which can be evaluated as

\[
m = \frac{\sum x^2 \sum y - \sum x \sum xy}{N \sum x^2 - (\sum x)^2}
\]  

(1)

The non-parametric Mann-Kendall test was used to determine the statistical significance of trends, if any, in the series. The test statistic is computed as:
\[ S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \text{sgn}(x_j - x_k) \]  

where \( n \) is the length of the time series \( x_1, \cdots, x_n \), \( \text{sgn}(\cdot) \) is a sign function while \( x_j \) and \( x_k \) are values in years [31].

3. Results and discussion

The statistical properties of maximum temperature in the West African region are shown in Figure 1. The maximum values of maximum temperature were highest along the coast of Nigeria, Guinea, and Senegal. The minimum values of maximum temperatures could be observed to be lower north of the Sahel and maximum from the Sahel to the coast of West Africa. The mean values of maximum temperature are uniform in the region except for the highlands (Guinea Highlands and Cameroon mountains) which have lower means than the rest of the region. Small but significant positive trends were found in maximum temperature along the Sahel region while the rest of the region shows negative trends.

The trend in heatwave number over the study region is shown in Figure 2. Temperature threshold-based definition of heatwave showed more distribution of positive trends in heatwave number than percentile-based methods. With a threshold of 35°C (HW1, HW2), significant positive trends were found to concentrate on the Coast of Senegal, Guinean highlands, and areas around Lake Chad. The trend weakens as the days considered increased from 2 to 3 days. With the trend level of 0.5 heatwave numbers per year, the heat wave number is expected to grow by 10 events in the next twenty years. Sparse distribution of significant positive trends was observed in the northwest region with HW1 definition. As the number of days grew from 2 to 3, the significant trend spread to the copious area. Generally, the areas with significant trends increased as the definition grew from 2 to 3 days. Small patches of areas with significant negative trends were observed in HW1 and HW2 definition just above the Guinea Highland and around Lake Chad.

HW4 has the same temperature threshold as HW3 but three consecutive days were considered. Larger regions were observed to have significant trends in HW4 compared with HW3. Significant positive trends were also observed in the Guinea Highlands, Senegal, and the Niger Republic. However, the spread and values were lower than that obtained in the HW1 and HW2 definitions. However, the northwest region witnessed higher trend values and wider spread than observed in HW1 and HW2. Similar patterns were seen in the HW4 definition but with lower trend values and more areas.

The increasing trend in the Guinean highlands observed in the temperature threshold definitions was also observed in the percentile-based definitions (HW5, HW6, HW7, HW8). The trend is more pronounced in HW6 than in HW5. Furthermore, the trends were observed to cover a vast portion of the Sahel and Coastal region of West Africa. Significant trends, which were not prominent in the temperature threshold-based definitions, could be observed in Ghana, Benin, and some areas of Nigeria. The trend observed in HW5 over the Guinea highlands was increased in the HW6 definition. However, the region of negative trend (HW5) in the Niger Republic shrunk when the definition was changed to HW6.

Definition HW7 and HW8 showed the same pattern with little differences. Both definitions reported significant trends in the Guinea highlands and surrounding regions extending as far as the Northwest area. Also, both definition shows significant positive trends in areas around Lake Chad which extended to Central West Africa and coastal areas of Nigeria. The trend values were lower than those obtained from definitions HW5 and HW6. The small patch of negative significant trends observed above the Sahel showed little differences in coverage area between definition HW7 and HW8.

The length of a heatwave event, in any definition, is very important as it determines the impact and effect of the heatwave on the general populace. Trends in length of heatwave events using eight different definitions were considered (Figure 3). Significant positive trends were found to be prevalent in the Sahel region of West Africa with HW1. Regions around Lake Chad showed the highest concentration of positive trends. Some regions along the coast also showed significant positive trends.
Definitions HW1 and HW2 showed similar trend patterns in the length of heatwave event trend over the region. As the temperature threshold from 35°C to 37°C, there were no trends observed along the coastal regions of West Africa.

The 90th percentile definitions HW5 and HW6 also showed the same pattern of trend distribution over the region. The trends also have a relatively lower range compared to the temperature-based threshold definitions. Contrary to what was observed in the temperature-based definitions, significant positive trends were prevalent along the coastal regions except for Liberia and Sierra Leone. Significant negative trends clustered along the northern region were also observed in both definitions. Increasing the percentile threshold to the 97th percentile causes sparsely distributed positive trends over the region. Both HW7 and HW8 confirm the significant negative trends in the northern part of the region. A small region in central Africa showed the only positive trend for these heatwave definitions.

4. Conclusion

Heatwave is a relatively uninvestigated weather phenomenon in sub-Saharan Africa. Due to the paucity of data, the direct impact of the heatwave in the region remains largely unknown. The widely diverse climate of West Africa makes the task of a uniform definition of the heatwave in the region almost impossible. In this study, we investigated the trend in heatwave over West Africa using eight different definitions. Two indices were considered in this study, the longest heatwave and the number of occurrences of the heatwave. Results from this study showed significant trends in the heatwave number across the region from all definitions considered.

### Table 1: Heatwave definitions used in this study

| Symbol | Definition                                                                 | Reference |
|--------|---------------------------------------------------------------------------|-----------|
| HW1    | The daily maximum temperature ≥ 35°C for 2 or more consecutive days        | [32]      |
| HW2    | The daily maximum temperature ≥ 35°C for 3 or more consecutive days        | [32]      |
| HW3    | The daily maximum temperature ≥ 37°C for 2 or more consecutive days        | [32]      |
| HW4    | The daily maximum temperature ≥ 37°C for 3 or more consecutive days        | [33]      |
| HW5    | The daily maximum temperature ≥ 90th percentile for 2 consecutive days     | [25]      |
| HW6    | The daily maximum temperature ≥ 90th percentile for 3 consecutive days     | [25]      |
| HW7    | The daily maximum temperature ≥ 97th percentile for 2 consecutive days     | [25]      |
| HW8    | The daily maximum temperature ≥ 97th percentile for 3 consecutive days     | [25]      |
Figure 1: Statistics of maximum temperature (a) maximum value (b) minimum value (c) mean value, and (d) significant trend, over West Africa.

Figure 2: Significant trends, at 95% confidence interval, in heatwave number per year for the eight different heatwave definitions.
Figure 3: Significant trends, at 95% confidence interval, in longest heatwave event per year for the eight different heatwave definitions.

5. Conflict of Interest

The authors declare that they have no competing interests

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