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Racine Ly, Jean Paul Latyr Faye, and Khadim Dia

A Temperature Trend Analysis of Senegal from 1981 to 2024

No.13 April 2025

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ABSTRACT

Senegal is now facing significant challenges due to the impacts of climate variability adversely affecting various sectors of the country's economy and environment. This study analyzes temperature trends in Senegal from 1981 to 2024 using spatially detailed data and robust quantitative methods, including linear regression and seasonal decomposition. The results show a +0.57°C increase in average daily temperatures in Senegal over the 43 years from 1981 to 2024 and highlight the role of natural forcing, such as ENSO cycles, in driving interannual fluctuations. These findings provide critical insights for contextualizing climate change locally and informing adaptation strategies in Senegal. The analysis shows that it is important to contextualize fluctuations in climatic parameters with natural forcing processes and not solely attribute such changes to increased concentrations of atmospheric greenhouse gases.

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1. INTRODUCTION TO A RESILIENCE FRAMEWORK

The impact of climate change and climate variability through extreme climate events will spare no community (Romano et al. 2021; Hawkins et al. 2022; Wang et al. 2019; Christidis et al. 2021; Robinson et al. 2021). The nature of the global climate crisis differs from those emanating from the localized socio-economic characteristics of communities and countries. Due to the interconnected nature of climate systems, it is safe to assert that the realization of a climate shock will be independent of how economically developed a country is or its adaptive and response capacities. However, the resiliency of a community or country against climate shocks will be tied to their level of economic development—such capabilities depend on socio-economic status (Adger 2003; IPCC 2022).

The bulk of our knowledge of the impact of the climate crisis on livelihoods is limited by our understanding of related cause–and–effect relationships (Pindyck 2020). For instance, we know the relationship between solar radiation and crop growth (Yang et al. 2022). Therefore, the impact of a temperature anomaly on crop growth can be anticipated. However, the impact of a temperature anomaly on the distribution and proliferation of animal diseases and their consequences for human livelihoods, for example, is less understood. While extensive, our ability to represent and model the world is incomplete. Essentially, refining our understanding of the world is the main goal sought by the research community. Due to the limits of our knowledge of the dynamic relationships between a range of relevant entities, responding to and dealing with the climate crisis requires an iterative learning process. A homogeneous and final solution to addressing climate change and variability should not be expected. Good policies and approaches that yield satisfactory results in a society at one point in time must be revisited against changes in the wider context and trade-offs. Any rather utopic scenario of no trade-offs exists because we do not yet know the full extent of the impacts of decisions made to address the challenges associated with climate change. It is again a consequence of our limited understanding of the web of action and reaction chains of the world surrounding us. However, the philosophy behind tackling climate change and climate variability is that not acting is even more costly. Some progress towards mitigating the impacts of climate change should be sought, even if perfect solutions are not identified.

Despite political will and efforts of governments on the continent, coping with a changing climate and its variability is more challenging in Africa than elsewhere. Beyond the scarcity of readily available resources, adapted infrastructures, and mechanisms through which anticipatory actions and planning could be channeled to communities, a pressing challenge for Africa is that many areas have insufficient data and a thin analytical foundation on which to plan efforts to tackle the impact of climate change and climate variability (Dinku 2019; Rosenstock and Wilkes 2021; Wilkes et al. 2017). Efforts to reduce the adverse impact of climate change on the livelihoods of African households should start with data-driven preparatory planning steps for proper resource allocation effectiveness, efficiency, and maximum impact.

There is increasing discussion of the likely local impacts of climate change in communities across Africa. However, the issue is often simplified and predominantly perceived as a problem of rising temperatures (González and Sánchez 2022; De Longueville et al. 2020; Krosnick and MacInnis 2020; Shi et al. 2016). While increasing temperatures are a significant aspect of climate change, this singular focus can be misleading, as it overlooks the complex interplay of various factors that contribute to the broader impacts of climate change. In particular, the tendency to interpret natural seasonality in temperature trends as evidence of climate change can distort public understanding, leading to misconceptions that fail to account for the multifaceted nature of climate dynamics. Such an oversimplified view diminishes the recognition of other critical factors, such as changes in precipitation patterns, extreme weather events, and ecosystem shifts. All of these are integral to understanding the causes and comprehensive impacts of climate change.

Nonetheless, studying temperature trends in the context of a changing climate is a good starting point for better-informed discussions within communities on the likely local impact of climate change. Such discussions will require considering the relationship between natural forcing and temperature variability and anthropogenic forcing and temperature changes.

Natural forcing and temperature variability. Natural climate forcings cause fluctuations in the Earth's climate system, leading to variability in temperature over time. These natural forcings include variations in solar radiation, volcanic eruptions, and fluctuations in greenhouse gas concentrations. For example, variations in solar output, such as those associated with the 11-year solar cycle (Haigh and Cargill 2015), can cause minor changes in global temperatures (Lean 2009). Volcanic eruptions, which release significant quantities of aerosols, sulfur dioxide, and other gases into the atmosphere, can lead to temporary cooling by reflecting sunlight away from the Earth's surface. The eruption of Mount Pinatubo in 1991 is a well-documented case that resulted in global temperatures decreasing by about +0.5°C for two to three years (Robock 2000).

Oceanic cycles, particularly the El Niño-Southern Oscillation (ENSO) in the Pacific Ocean, significantly contribute to short-term climate variability globally. ENSO events, with their alternating warm (El Niño) and cool (La Niña) phases, can cause pronounced shifts in temperature patterns across the globe (Trenberth et al. 2002). However, these natural forcings typically operate on short-term timescales—ranging from a few years to a couple of decades—and do not account for a long-term warming trend observed in recent decades.

Anthropogenic forcing and temperature changes. Anthropogenic, or human-induced, forcing refers to the impact of human activities on climate, mainly through the emission of greenhouse gases (GHGs). Since the start of the Industrial Revolution in the 1700s and particularly since the late 1800s, activities such as burning fossil fuels, deforestation, and industrial processes have significantly increased the concentrations of GHGs in the atmosphere, particularly carbon dioxide. These gases trap heat within the Earth's atmosphere, leading to a persistent, steady increase in global temperatures (IPCC 2021).

The impact of anthropogenic forcing on global temperature changes becomes particularly evident when considering long-term trends. Unlike natural forcings, which cause short-term temperature fluctuations, anthropogenic forcings drive the long-term warming trend observed since the start of the Industrial Revolution. The Intergovernmental Panel on Climate Change (IPCC) reports that more than half of the observed global average surface temperature increase from 1951 to 2010 is likely due to increased anthropogenic GHG concentrations (IPCC 2014).

Both natural and anthropogenic forcings influence the Earth's climate, but their impacts on temperature changes differ in magnitude and persistence. Natural forcings, such as volcanic eruptions, ENSO, and solar variability, tend to cause shorter-term fluctuations in temperature on the scale of months to decades. In contrast, anthropogenic forcings, particularly the increase in GHG concentrations, are the dominant drivers of the long-term warming trend observed since the late 1800s (Hansen et al. 2006). Daily temperature data over a minimum of 30 years is necessary for climate change studies to accurately capture this long-term trend, as analysis over such a long period smooths out the noise of natural variability and highlights the underlying impact of human activities on global temperatures (Santer et al. 2019).

Senegal is now facing significant challenges due to the impacts of climate change and climate variability, adversely affecting various sectors of the country's economy and environment. Rising temperatures, erratic rainfall, and more frequent extreme weather events, such as droughts and floods, have disrupted agricultural production and coastal ecosystems. These impacts are exacerbating food insecurity and threatening livelihoods, particularly for smallholder farmers and fishermen, whose livelihoods depend heavily on predictable climatic conditions. Coastal erosion driven by rising sea levels has severely impacted Senegal's densely populated coastal zones, including the capital, Dakar. The fishing industry, which employs around 600,000 people, has also been significantly affected by climate change-related shifts in marine ecosystems, leading to reduced fish stocks and driving many fishermen to seek alternative livelihoods through migration (World Bank 2021; WMO 2023).

The socio-economic impacts of climate change are particularly pronounced in vulnerable rural and coastal communities across Senegal, where limited resources and weak infrastructure hinder efforts to enable households and local economies to adapt to climate change. Effective adaptation strategies in Senegal require robust investments in early warning systems, climate-resilient infrastructure, and sustainable land and water management practices to build resilience against growing climate risks (WMO 2023).

The trend analysis of air temperature in Senegal presented in this paper provides a nuanced understanding of temperature trends within the broader context of climate variability, ensuring that natural seasonal fluctuations are not mistakenly attributed to long-term climate change. An analysis of temperature time-series data both at the national and sub-national department levels in Senegal was conducted to study:

- Seasonality and trends in air temperatures;
- The statistical distribution of air temperatures;
- Abrupt temperature changes and the frequency and duration of hot days within a year; and
- Monthly temperature anomalies.

The paper is organized as follows: Section 2 describes the study area, the data sources used, how the dataset was constructed, and the analytical methods used. Section 3 presents the results of the analyses and discusses them. Finally, section 4 presents conclusions drawn from the analyses.

2. MATERIALS AND ANALYTICS

2.1 Study area

Senegal, located in West Africa, spans latitudes 12°N to 17°N and longitudes 11°W to 17°W, covering an area of almost 200,000 square kilometers. The country spans diverse climatic zones, transitioning from a semi-arid Sahelian climate in the north to a more humid, tropical climate in the south. The northern regions typically receive less than 400 mm of rainfall annually and have a pronounced dry season lasting up to nine months (Lo et al. 2022). In contrast, the southern regions, particularly in the Casamance area south of The Gambia, receive significantly more rainfall—between 1,000 and 1,200 mm per year—and have a shorter dry season (Bacci 2017).

Senegal's topography is relatively flat. Most of the country lies within the Sudanian and Sahelian climatic zones, making it particularly vulnerable to variations in temperature and precipitation. The country's main river, the Senegal River, flows along its northern and eastern borders, providing a critical water source for agriculture, particularly in the more arid regions. The country's coastal areas along the Atlantic Ocean, including the capital Dakar, experience a slightly moderated climate due to maritime influences.

The period from 1981 to 2024 encompasses years of notable climatic variability, including periods of severe drought in the 1980s, followed by more recent fluctuations in rainfall and temperature patterns. This period also includes significant global climate events, such as the ENSO, which have had discernible impacts on regional weather patterns in Senegal (Emmanuel 2022). The analysis of this period here focuses on temperature trends across Senegal's diverse climatic zones, providing insight into how these trends vary spatially across the country and how they have evolved over the past four decades.

2.2 Dataset

2.2.1 Dataset source

The dataset used in this study—the Modern Era Retrospective Analysis for Research and Application, Version 2 (MERRA-2)— was collected from the Prediction Of World Energy Resources (POWER) project of the National Aeronautics and Space Administration (NASA) of the US government. POWER was launched in 2003 as an extension of the Surface Meteorology and Solar Energy project, one of the earliest activities funded by NASA's Applied Science Program to deliver and allow easy access to parameters of value to planning in the renewable energy sector.

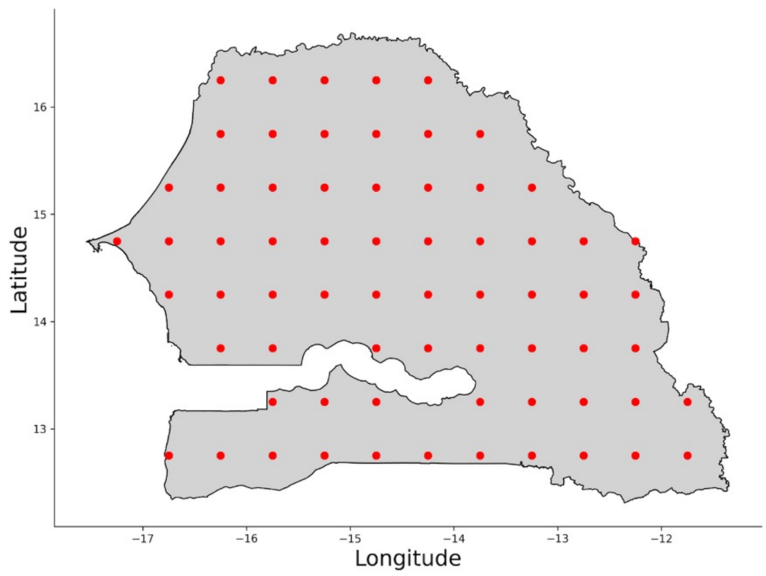
MERRA-2 was developed by combining observational data with spatial data from a frozen version of the Goddard Earth Observing System (GEOS). The subsequent data fusion process yielded several metrics related to extreme climatic events—heatwaves, multi-day precipitation totals, and monthly percentile statistics. All the metrics were developed using a daily time series dataset of air temperature measured at 2 meters above the surface of the ground (T2M) and precipitation (Alexander et al. 2016). For this study, only the daily temperature data was considered.

The MERRA-2's T2M spatial dataset offers gridded daily temperature data from around the world from 1981 to the present. The T2M parameter is a standard measurement used in meteorological studies, including climate monitoring, agricultural planning, and weather forecasting. It is a critical input for understanding and tracking surface temperature changes over time, with particular relevance to climate variability (Hobbins et al. 2022) and crop modeling studies (Kumar et al. 2022). The MERRA–2 T2M data have been thoroughly evaluated for accuracy and utility (Gelaro et al. 2017; Bosilovich et al. 2015). The spatial dataset has a native spatial resolution of 0.5 degrees latitude x 0.625 degrees longitude, which corresponds to a grid cell of around 55.6 x 67.5 kilometers in size.

2.2.2 Dataset construction

For the research for this paper, a rectangular region of interest located between latitude 12°N and longitude 17.78°W (bottom left corner) and latitude 16.88°N and longitude 11.01°W (upper right corner) was created with the NASA POWER data access viewer (Figure 2.1). For this region, gridded data on the average daily temperature at 2 meters above the surface of the ground, T2M, was downloaded for the period from January 01, 1981, to August 19, 2024. The resulting files consisted of *.csv files containing five variables: latitude and longitude of the grid cell center point, the day number within the year and the year of the record, and T2M in degrees Celsius (Table 2.1).

Figure 2.1 Senegal—region of interest for analysis with a representation of point locations for the curated daily T2M spatial dataset



Source: Authors' analysis and mapping.

Note: T2M = Daily time series dataset of air temperature (°C) at 2 meters above ground surface.

Table 2.1: Sample of curated T2M dataset for January 01, 2011, for five grid center point locations in Senegal

Latitude	Longitude	Day of year (DOY)	Year	Temperature, °C, at 2 meters above ground surface
12.75	-16.75	1	2011	23.73
12.75	-16.25	1	2011	21.89
12.75	-15.75	1	2011	21.31
12.75	-15.25	1	2011	21.20
12.75	-14.75	1	2011	21.48

Source: Authors' analysis.

Note: T2M = Daily time series dataset of air temperature (°C) at 2 meters above ground surface.

All the *.csv files for the study region were concatenated. A cleaning process was performed using Python 3.9.7 under the Anaconda's distribution Spyder 5.1.5 to eliminate all temperature values flagged as outliers or with the value −999, the missing data value for the MERRA-2 dataset. The result was a cleaned data frame containing the five features mentioned above for each latitude and longitude pair over all the days in the study period.

The resulting data frame was then transformed into a geodata frame and clipped with the Senegalese national borders to consider only point locations within the country by using the spatial join capability of the Python Geodata Frame package. The T2M grid clipped to our region of interest of Senegal consisted of 67 grid cell center points with average daily T2M data for the period from January 01, 1981, to August 19, 2024, a period of 15,937 days and more than 43 years. In cleaning the data, data for three days were discarded from the dataset due to having no values recorded. The final curated dataset contained 1,067,578 data values stored in a Python geodata frame.

Analytics. Several types of analytics were used to study the dynamics in air temperature in Senegal for the period 1981–2024. For each analysis, two levels of granularity were used—national and sub-national. An analytical period of at least 30 years was used for analyses assessing long-term temperature changes. This approach is in alignment with the IPCC's 30-year "normal" baseline period (Carter and La Rovere 2001) as defined by the World Meteorological Organization (WMO 2020) in its technical definitions relating to climate normals. However, we also used more than 43 years of dataset for some investigations.

Five types of analyses of mean daily temperatures (T2M) were undertaken: (i) trend analysis, (ii) seasonality decomposition, (iii) temperature distributions (density of values), (iv) monthly anomalies, and (v) change point detection.

Trend analysis. A linear regression analysis was performed using the dataset to quantify the long-term trend in average daily temperatures in Senegal and to assess whether there has been an increase in temperatures over the study period. A linear regression model was fitted to the data to obtain a measure of the temperature change rate over time. Average daily T2M was used as the dependent variable, and the date in ordinal form was used as the independent variable. The resulting trend was visualized by plotting the original temperature data and the fitted regression line (Halder et al. 2023).

Seasonality decomposition. A seasonal decomposition was applied to the daily average temperature data to analyze the underlying components of the temperature time series. The decomposition was performed under the assumption of an additive model where the observed time series is considered as the sum of three components: longer-term trend (Tr(t)), seasonal (S(t)), and residual (R(t)). Setting the seasonal period to 365 days enforced a yearly periodicity, reflecting the annual cycle of temperature variation.

Temperature distribution by period. A kernel density estimation analysis was used to examine the distribution of daily average temperatures across two different periods of the time series: 1991–2020 and 2021–2024. The temperature data was filtered for each period, and kernel density estimation plots were generated to visualize the density distribution of temperatures. For interpretation, the period 1991–2020 was considered to be the 'normal period.'[1]

Monthly anomalies. We analyzed data from 1981 to 2024 to assess temperature anomalies relative to monthly average values. The baseline for each month was calculated by averaging the temperature data over the entire dataset. The anomalies were calculated by subtracting the monthly baseline value from the observed temperatures, resulting in a time series of temperature anomalies. These anomalies were then organized into a matrix of months x years. A heatmap was generated to visualize the anomalies in the resultant matrix where the intensity of the color indicates the magnitude and direction of the temperature deviations.

Change point detection. To identify significant shifts in the temperature time series, we employed the Pruned Exact Linear Time (PELT) algorithm, implemented via the ruptures library in Python, on the dataset. The PELT algorithm was configured with a Radial Basis Function model to detect non-linear changes in the data. A penalty value of 10 was used to balance the sensitivity of the change point detection. The detected change points were visualized alongside the original time series, highlighting the points where the temperature trends exhibit significant shifts.

1 The Seventeenth World Meteorological Congress (WMO 2020) recommends that a 'normal period' for use in such analyses be the most recent 30-year period finishing in a year ending with zero—in our case 1991–2020.

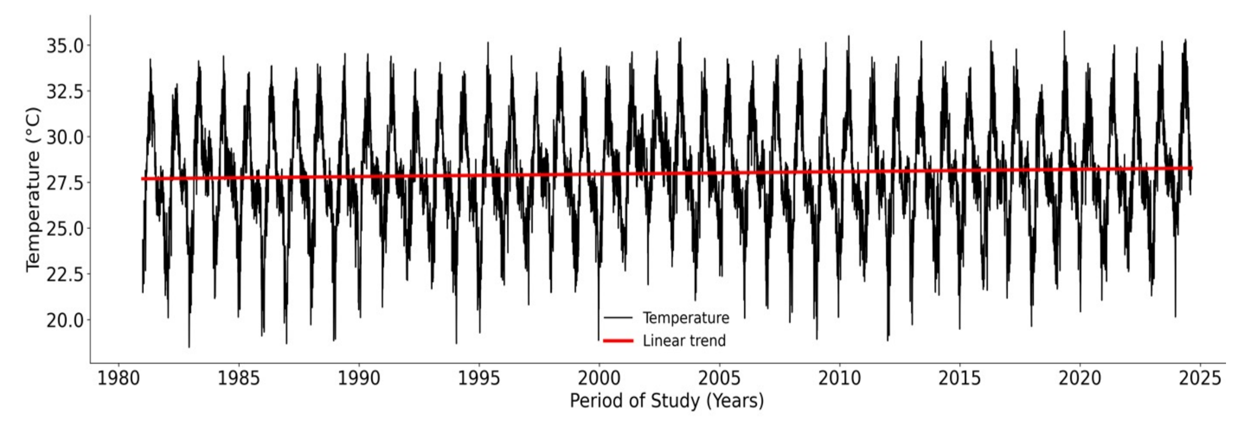
3. RESULTS AND DISCUSSIONS

3.1 National level analysis

3.1.1 Global trends and natural climate processes

The daily average temperature for Senegal for the period from January 01, 1981, to August 19, 2024, computed from all locations in the analytical spatial dataset, is plotted in Figure 3.1. Overlaid on this plot is the corresponding linear regression for the same period to estimate the long-term effect of climate change. The data fluctuates between a minimum of 18.48°C and a maximum of 35.76°C. A seasonal component is apparent in the daily average temperature plot. The linear regression is almost flat, with a temperature of 27.69°C for the first day of 1981 and a temperature of 28.27°C for the last date of the dataset. Those values suggest a variation of +0.57°C for the overall period and an approximative annual temperature increase of +0.013°C.

Figure 3.1. Senegal—daily average temperature at 2 meters above ground surface and linear regression of daily average temperatures, January 01, 1981 to August 19, 2024.



Source: Authors' analysis.
Note: Dates transformed to ordinal values for regression analysis (slope = 3.62e-05, intercept = 1.49, p_value = 1.42 e-13).

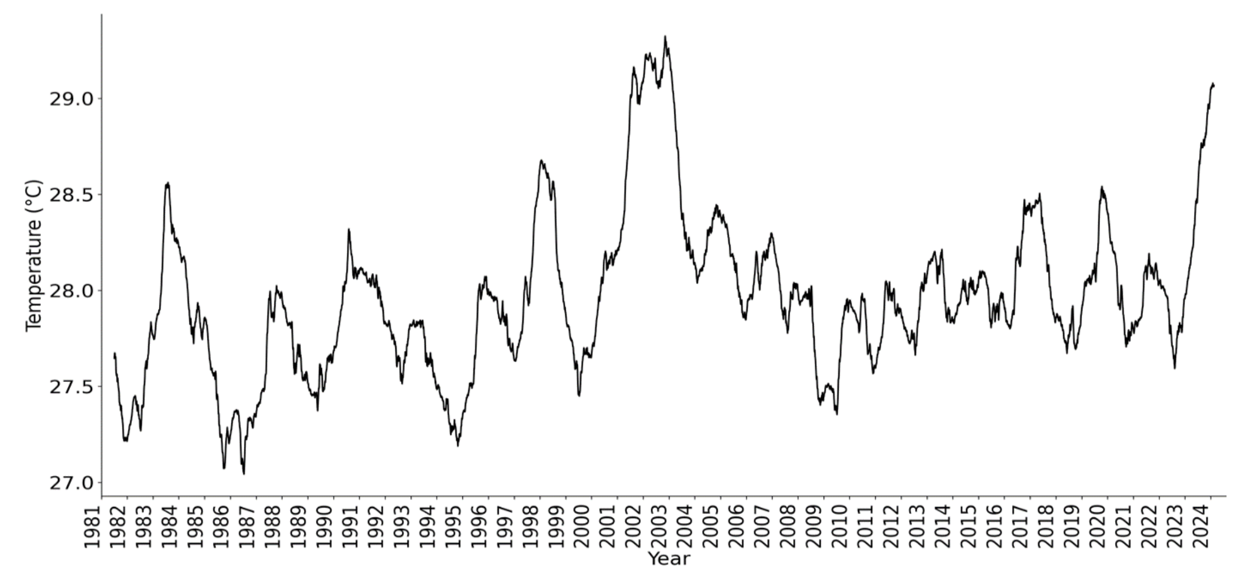
Since the time series dataset goes beyond the 30-year time horizon suggested for climate change–related studies, the temperature increase could be attributed to the long-term effect of climate change (Lai and Dzombak 2019; Samset et al. 2023; Mouhammadi et al. 2023). Figure 3.1 shows the importance of the choice of the study reference period, which could yield a different direction of change for the temperature. Here, a decadal analysis shows a different pattern in the directions of average daily temperature trends with a falling rate of 0.04°C in the 1980s, 0.01°C in the 1990s, 0.14°C in the 2000s, no change in the 2010s, and +0.32°C in the 2020s. Only in the latest decade, which is not yet complete, is an increase in daily average temperatures clear. This recent pattern is congruent with 2023 statistically being the warmest year globally since the pre-industrial area, with a global increase of +1.54 (± 0.06)°C (Rohde 2024).[2]

While helpful in identifying long-term trends, linear regression may not capture non-linear changes or sudden shifts in temperature patterns that could occur due to natural forcing or feedback. One of the seasonal decomposition results is the trend feature. These results help identify underlying patterns that might not be immediately apparent when the data also includes seasonal and noise components.

The trend component of average daily temperatures in Senegal from 1981 to August 2024 is shown in Figure 3.2. Several fluctuations are apparent, with a minimum of 27.04°C and a maximum of 29.32°C. The data shows an increasing temperature trend over the study period but with evident inter-annual fluctuations and higher minimum trend temperatures in each temperature increase and decrease cycle. For instance, the overall minimum trend temperature was reached in late 1985 and again in mid-1986, but it never was that low again. The second substantial minimum trend temperature over the period was in late 1994 at 27.25°C. This temperature minimum was never reached again subsequently. The general trend over the 43-year study period is characterized by average daily temperature increases.

2 While 2023 may be the warmest year recorded globally since the pre-industrial era, this may not be the case for Senegal.

Figure 3.2. Senegal—trend component of seasonal decomposition of daily average temperatures from January 01, 1981 to August 19, 2024.



Source: Authors' analysis.

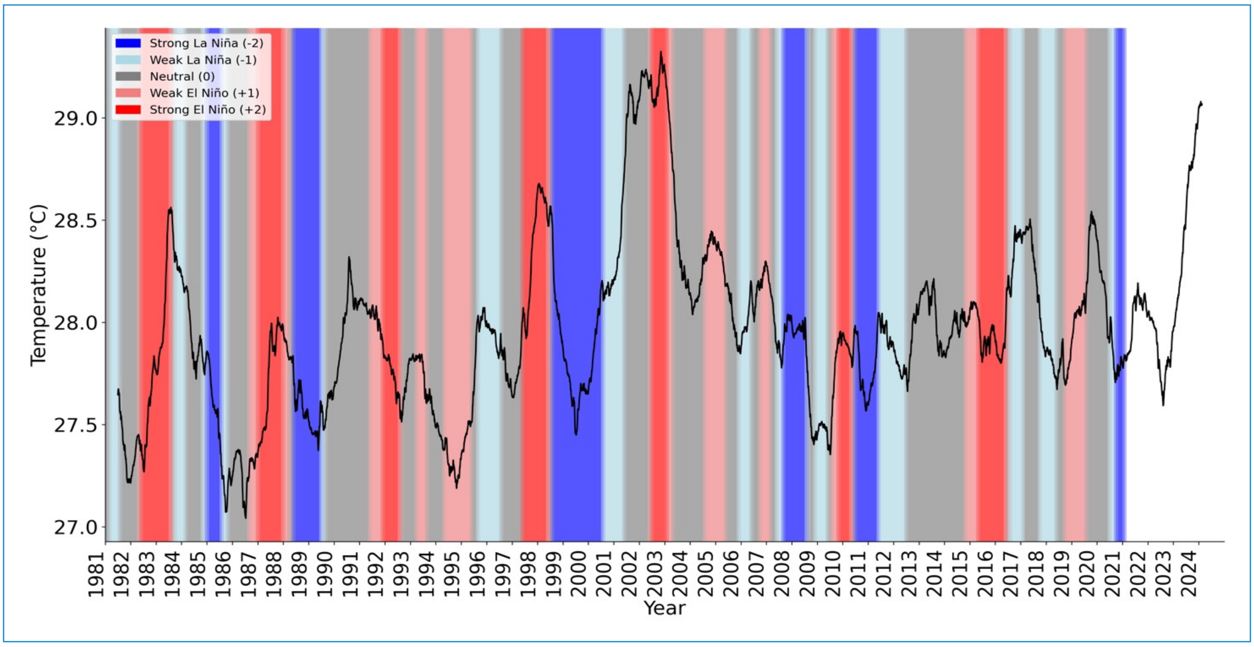
Second, the trend analysis shows that assertions that recent temperature increases are a consequence of climate change through continually increasing levels of greenhouse gases are weak. The peak trend temperature reached in 2024 was also reached in the period from 2001 to 2004 when the concentration of greenhouse gases in the atmosphere was lower (Ciais et al. 2013). Rather, it would appear that these two peaks in average temperatures are a consequence of natural forcing coming from phenomena such as El-Niño and La Niña.

However, Figure 3.2 shows that the cycles of temperature increases and decreases are more frequent since 2002 than in the period from 1981 to 2002. Climate-induced phenomena may be part of this changing pattern.[3] Increased concentrations of greenhouse gases in the atmosphere lead to global warming, increasing sea-level surface temperatures. This warming triggers the El-Niño phase of ENSO, activating the process with the diffusion of the temperature rise from the western part of the Americas to the western area of the Pacific Ocean. This leads to a chain reaction of extreme climate events, including drought, heavy rainfall, and tornados, and a generalized altering of global weather circulation patterns. Increased concentration levels of greenhouse gases do not directly cause the recurrence of extreme climate events and alterations in weather patterns. Rather, these changes are due to the activation of natural forcing processes, such as the ENSO cycle.

To further investigate this pattern in Senegal, ENSO data for three-month periods from 1981 to 2020 were obtained and analyzed using the methodology described in Arguez et al. (2019). The temporal categories used to compute the ENSO normal were 12 overlapping three-month periods per year—December/January/February, January/February/March, February/March/April, and so on through November/December/January. Five classes of ENSO severity were computed—strong La Niña (2), weak La Niña (1), neutral (0), weak El Niño (+1), and strong El Niño (+2). The ENSO data was plotted against Senegal's daily average temperature trend from the seasonal decomposition analysis (Figure 3.3). All seven El Niño events coincided with average temperature increases in Senegal, with the one in early 1992 showing a smaller amplitude.

3 Six temperature maxima and seven minima were observed between 1981 and 2002, while there were ten maxima and 11 minima between 2003 and 2024. However, the amplitude of the temperature fluctuations is larger in the earlier period.

Figure 3.3. Senegal—trend component of seasonal decomposition of daily average temperatures, with strong and weak ENSO events.



Source: Authors' analysis of El Niño-Southern Oscillation (ENSO) data.

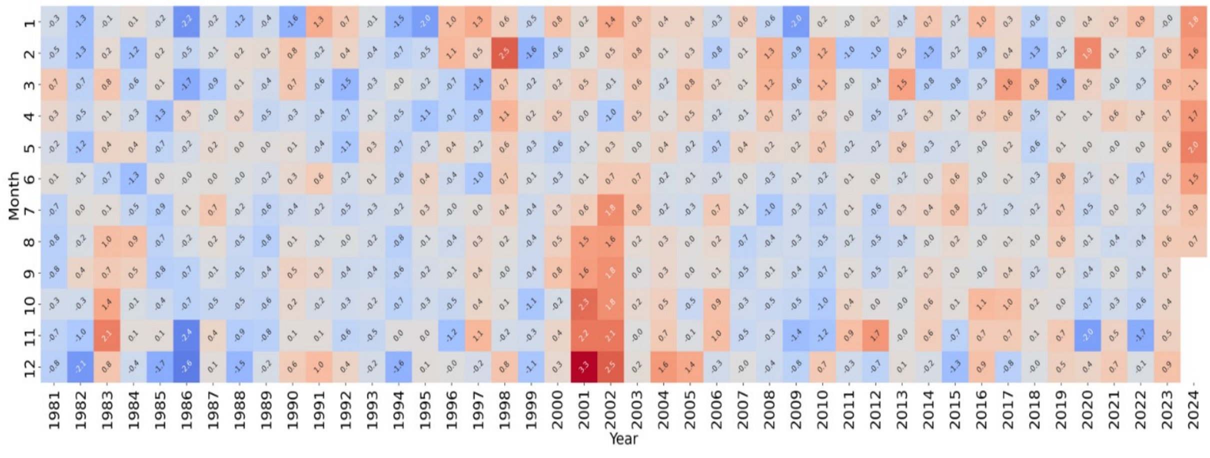
Similarly, weak El Niño occurrences are correlated with small increasing temperature patterns—late 1987, the second half of 1992, from mid-2005 to mid-2006, and from late 2015 to early 2016. The other weak El Niño periods showed clear temperature increase patterns. However, all La Niña periods embed periods of temperature decrease in Senegal. Another observation of note is that the neutral ENSO periods do not result in stagnation in mean temperature trends but rather a transitory period between the oscillations where temperature fluctuations could result from other factors.[4]

3.1.2 Positive temperature anomalies

While 2023 was statistically determined to be the warmest year globally since global meteorological data recording began (WMO 2024; UN 2024; NASA 2024), 2023 is not the warmest year Senegal has experienced. This divergence shows the importance of examining global trends within the local context. Figure 3.4 shows monthly average temperature anomalies for the period considered in this study. To date, 2001 and 2002 were the years with the most significant number of positive monthly anomalies—suggesting the most uncharacteristically warmest months in the dataset were in that period. However, those anomalies occurred in the second half of the year. The year with the highest number of monthly anomalies for January, April, May, and June over the study period was 2024. However, no comparisons between the late 2001 and late 2002 temperature anomalies and 2024 were possible, as the analytical dataset ends in August 2024.

4 For instance, the global cooling that occurred following the Mount Pinatubo eruption in 1991.

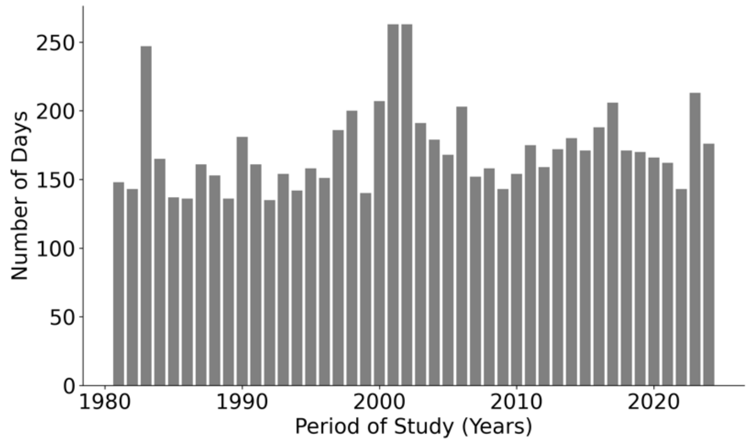
Figure 3.4: Senegal—monthly average temperature anomalies, 1981 to 2024.



Source: Authors' analysis
Note: January = 1; December = 12.

These observations are triangulated in Figure 3.5, which counts the number of days annually with a daily average temperature above 28°C for each year since 1981. 2001 and 2002 ranked top with 263 days, followed by 1983 with 247 days and 2023 with 213 days. While 2023 is not the warmest year for Senegal since 1981, it remains among the most prolonged periods where temperatures exceeded the threshold of 28°C.

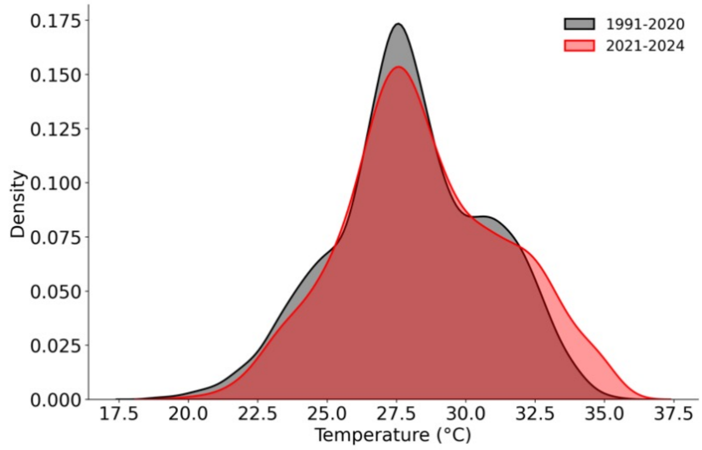
Figure 3.5: Senegal—days annually with average temperature above 28°C, 1981–2024.



Source: Authors' analysis.
Note: The choice of 28°C is based on a study by Faye et al. (2021), in which that temperature level was identified as the daily minimum temperature with the highest mortality risk among the elderly population in Senegal.

There has been an increased frequency of temperature extremes since 2021 compared to the period from 1991 to 2020 (Figure 3.6). Since 2021, there has been a notable increase in the days with an average temperature above 32.5°C and relatively fewer days with cooler average temperatures below 25.0°C.

Figure 3.6: Senegal—density distribution of daily average temperature, contrasting 1991–2020 with 2021–2024.



Source: Authors' analysis.
Note: January = 1; December = 12.

In summary, at the national level, average daily temperatures in Senegal over the period from 1981 to 2024 have:

- Increased by 0.57°C, with an approximate annual increase of +0.013°C.
- Interannual fluctuations in temperature in Senegal are most likely caused by natural forcing—principally due to the ENSO cycle. However, an additional contributing factor to the temperature increase is the reduced amplitude of the cooling phases.
- The warmest year in Senegal over this period was not 2023, despite being the warmest year globally. Rather, it was 2002. However, 2024, although the data is not yet complete, may prove to be the warmest year for Senegal—the average temperature was 30.27°C through August.
- There has been an increase in extreme temperature observations since 2020 compared to the period from 1991 to 2020.
- Recent heatwaves and other extreme weather events might not be a direct impact of climate change as a consequence of an increase in greenhouse gases. Rather, increased concentrations of greenhouse gases yield higher temperatures, which in turn activate natural processes, such as the ENSO cycle, that contribute to extreme weather events.

3.2 Sub-national level analysis

While the first section of this study focused on Senegal as a whole, this section focuses on the sub-national level. The objective is to explore temperature dynamics at a smaller scale in which communities will feel the impact of temperature fluctuations. Here, the distribution of the average daily temperature changes since 1981 across the departments of Senegal (Figure 3.7) and the potential influence of natural forcing, particularly the ENSO cycles, on temperature fluctuations is examined.

Figure 3.7. Map of the regions and departments of Senegal.

Source: Amitchell125, CC BY-SA 4.0 via Wikimedia Commons.

The daily time series dataset of air temperature measured at 2 meters above the surface of the ground (T2M) was used for the national and departmental level analyses. For the departmental analysis, this spatial dataset was overlaid with the second-level administrative borders—Senegal's departments. The operation retained the data locations within Senegal and attributed each department to the point location data that fell within their borders. When several point locations were in the same department, their average daily temperatures were computed and assigned to that department. Twelve of the 45 total departments in Senegal had no point location within their borders. Therefore, the analysis focused on average daily temperature data for 33 departments.

3.2.1 Temperature anomalies and extremes

This analysis examines the monthly temperature anomalies across the 33 departments in Senegal over the 43 years from 1981 to 2024. Temperature data were aggregated monthly for each department, and long-term monthly averages were computed. Significant trends, extreme events, and overall climate patterns are identified by evaluating the deviations of the average monthly temperatures from the long-term averages. Anomalies were calculated as the difference between the observed monthly temperatures and the long–term averages. Statistical analyses were performed to quantify the changes over time, including calculating means, standard deviations, and linear regression trends.

General trends, 1981–2024. Across all departments, the overall mean monthly temperature anomaly from 1981 to 2024 was effectively neutral at approximately −0.00017°C. This suggests that, while anomalies are observed, the average over the entire period aligns closely with the long-term norm. However, the overall standard deviation of 0.71°C indicates significant variability in average monthly temperatures compared to the long-term average. The linear trend across all 33 departments showed a statistically significant warming trend of +0.0109°C per year (p-value = 0.035), confirming a gradual increase in temperatures over the study period.

Selected department-specific trends 1981–2024. While average monthly air temperature trends for all 33 departments could be presented, here we provide a basic description for four of the 33.

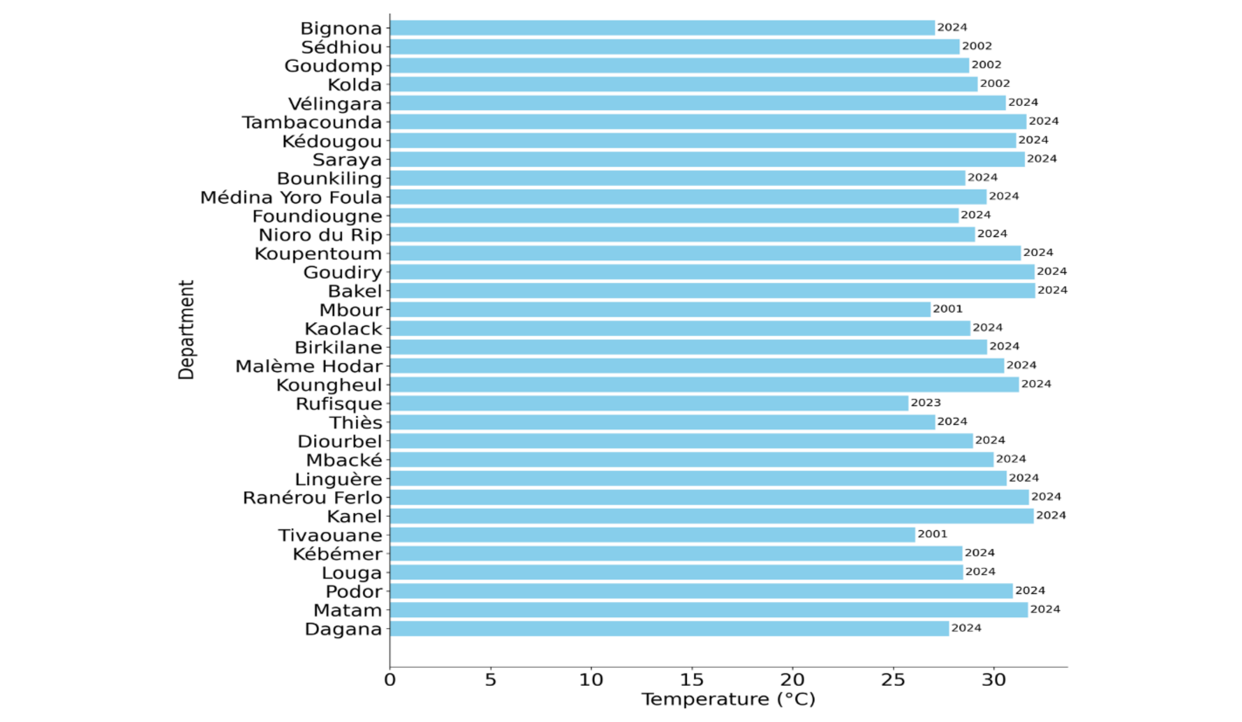
- Bakel department in the Tambacounda region exhibited one of the most pronounced warming trends across the 33 departments, with a slope of +0.0161°C per year (p-value = 0.022). The maximum anomaly recorded was +3.58°C in 2013, and the minimum was –3.10°C in 1982, reflecting significant temperature swings over the years.
- Like Bakel, Matam in the Matam region showed a strong warming trend with a slope of +0.0155°C per year (p-value = 0.012). The department experienced extreme anomalies, with a maximum of +3.29°C in 2014 and a minimum of –3.09°C in 1984.
- Dakar shows a warming trend of +0.0098°C per year over the study period, but this value has a marginal pvalue of 0.051, suggesting only a slight trend toward higher temperatures. The most extreme anomalies were observed in Dakar in 2024 (+2.32°C) and 1984 (–2.38°C).
- The Saraya department in the Kédougou region had its highest positive anomaly of +3.68°C in 2019 and its lowest negative anomaly of –3.47°C in 1986. With a robust warming trend of +0.0243°C per year (p-value = 0.0002), Saraya is one of the most rapidly warming areas of Senegal.

Extreme anomalies. Extreme temperature anomalies were observed across several departments. Vélingara recorded the most extreme positive anomaly, +4.74°C in 2010, while Sédhiou had an anomaly of +4.35°C in 2014. The most extreme negative anomaly was –3.42°C in Ranérou Ferlo in 1984.

Year 2024. 2024 stands out across all 33 departments as a year of significant positive anomalies. In Tambacounda, the maximum monthly average temperature anomaly reached +3.91°C, while in Dakar, the August 2024 anomaly was +2.32°C. These values are among the highest seen since 1981, indicating that 2024 may represent an intensification of the warming trend observed in recent decades.

2024 may provide a new record for average air temperatures in Senegal since 1981. Indeed, 27 of the 33 departments recorded their highest mean monthly temperature over the last 43 years in 2024 (Figure 3.8). However, this is yet to be confirmed since the dataset used ended in August 2024 and does not provide all the daily air temperature data for 2024.

Figure 3.8. Highest annual mean temperature and year recorded for the 33 departments of Senegal.

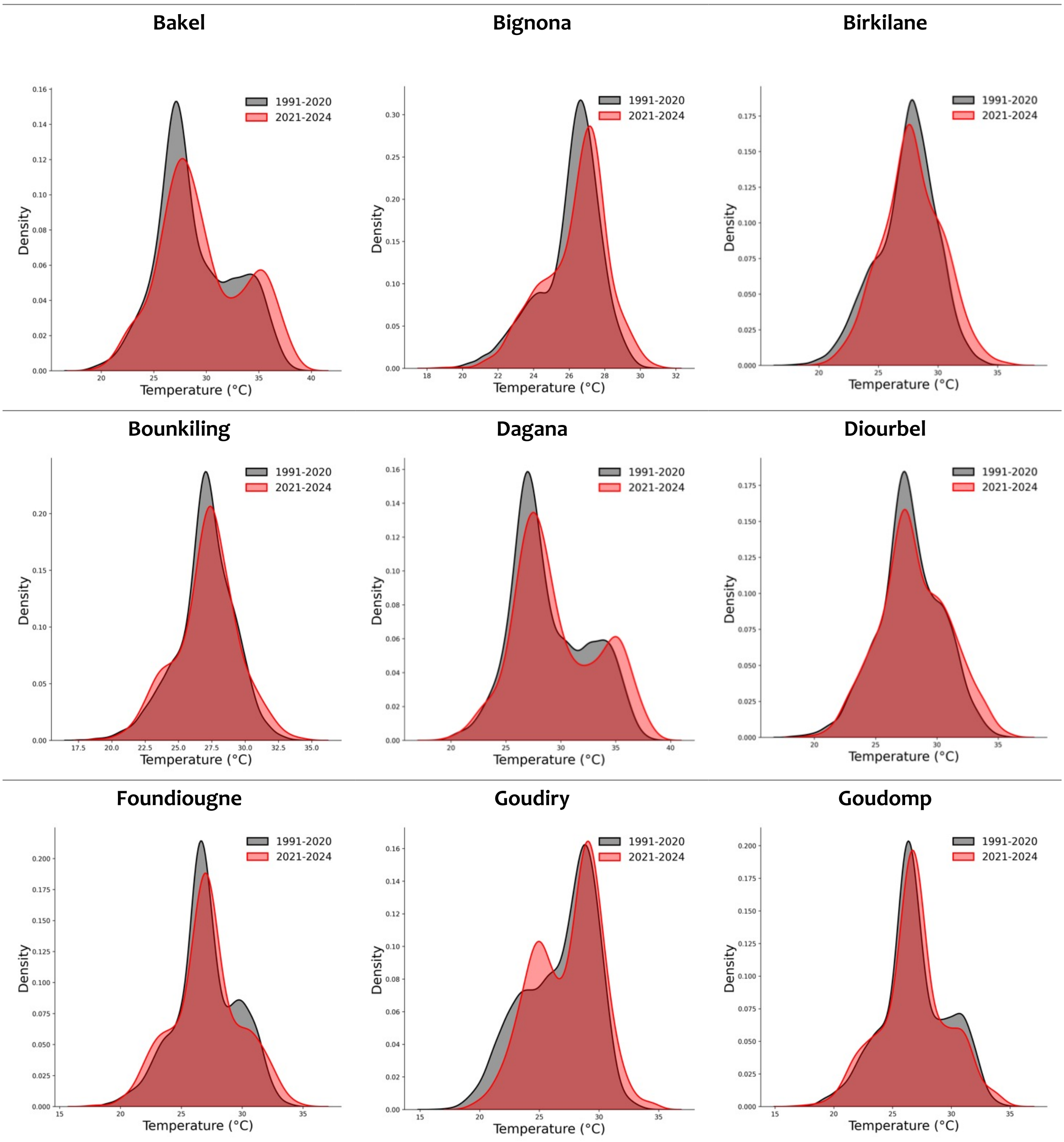


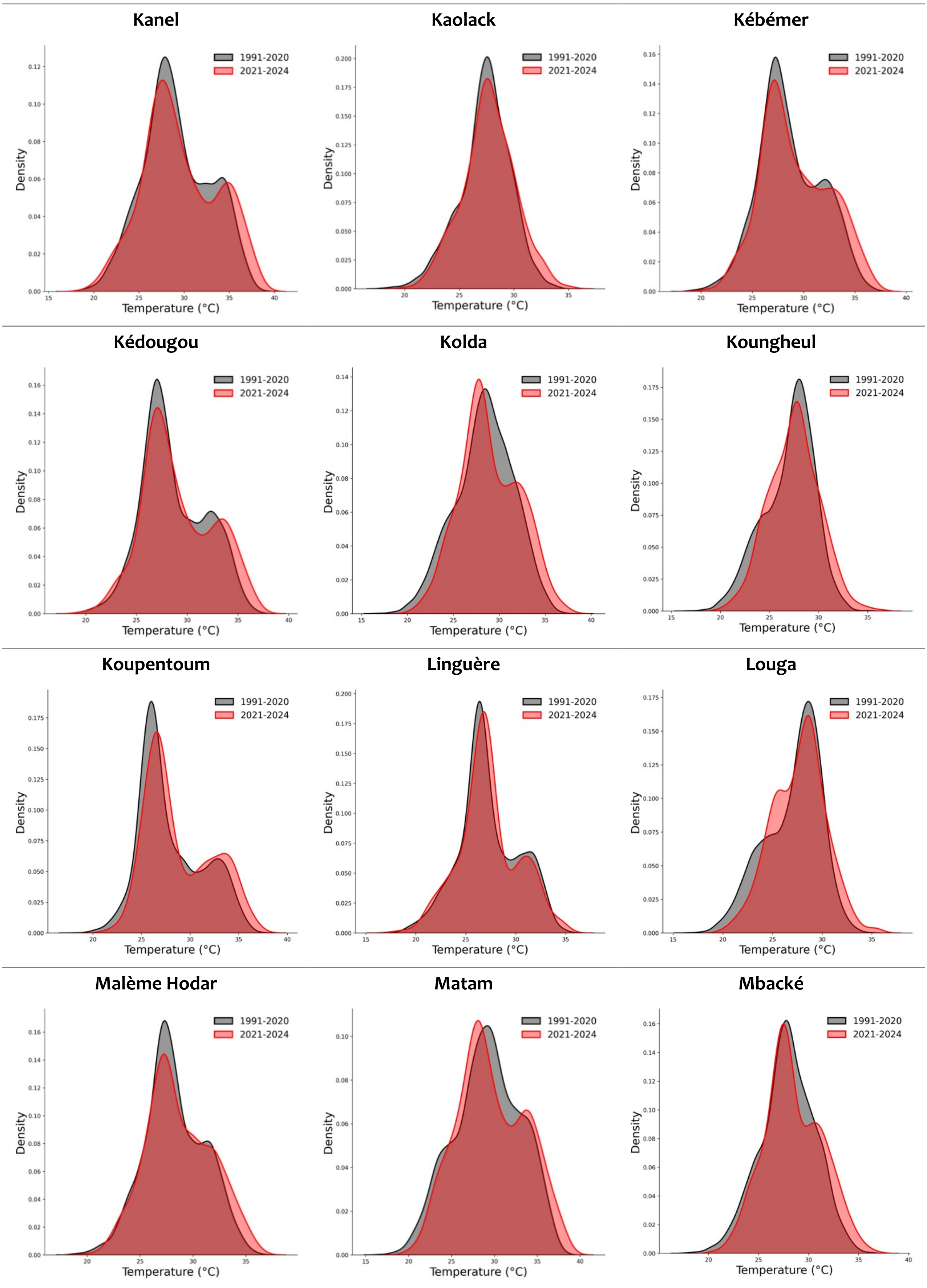
Source: Authors' analysis.

A contrast of the average monthly temperature distribution for the period from 1991 to 2021 with that for 2021 to 2024 was examined in each of the 33 departments (Figure 3.9). The distributions are presented as a density, meaning the area under the curve is unity. The temperature density plots for each of the two periods for each department were overlayed to identify any shifts between the two. The data shows that similar to the national trend, most departments experienced an increased frequency of higher temperatures from 2021–2024.

In most departments, there is a higher temperature density above 30°C in the 2021–2024 period—some even reached maxima of 40°C. Another observation in the contrasting temperature density plots is the emergence of a bimodal pattern in the data. The bimodal mode was already perceptible for some departments in the earlier period from 1991 to 2021. However, for the 2021 to 2024 period in other departments, it is a new emerging pattern or more pronounced than seen in the earlier period.

Figure 3.9. Density distribution of daily average temperature for 33 departments in Senegal, contrasting the period 1991–2020 with 2021–2024.





Kanel
1991-2020
2021-2024
Density
Temperature (°C)
Kaolack
1991-2020
2021-2024
Density
Temperature (°C)
Kébémer
1991-2020
2021-2024
Density
Temperature (°C)
Kédougou
1991-2020
2021-2024
Density
Temperature (°C)
Kolda
1991-2020
2021-2024
Density
Temperature (°C)
Koungheul
1991-2020
2021-2024
Density
Temperature (°C)
Koupentoum
1991-2020
2021-2024
Density
Temperature (°C)
Linguère
1991-2020
2021-2024
Density
Temperature (°C)
Louga
1991-2020
2021-2024
Density
Temperature (°C)
Malème Hodar
1991-2020
2021-2024
Density
Temperature (°C)
Matam
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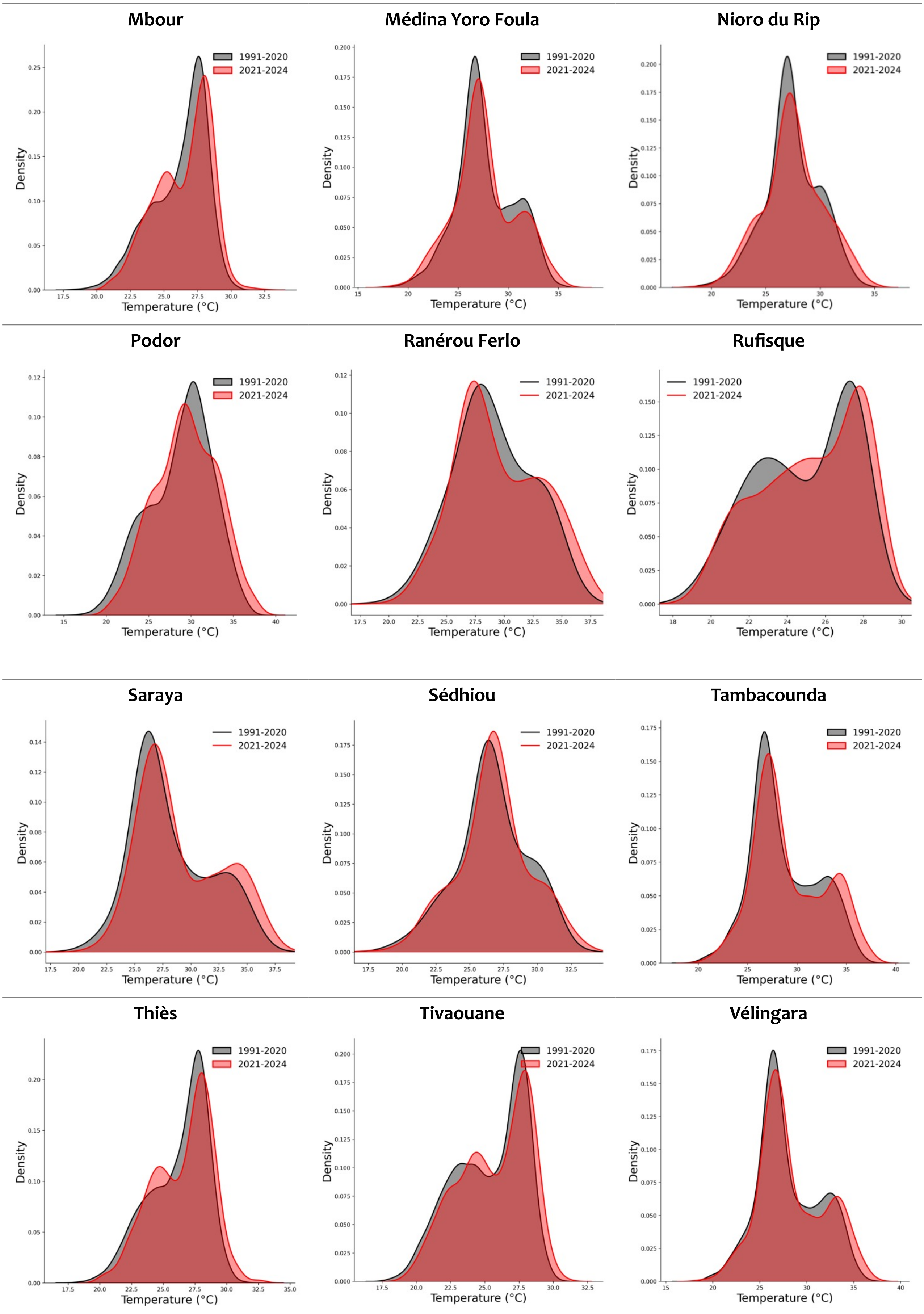
2021-2024
Density
Temperature (°C)
Mbacké
1991-2020
2021-2024
Density
Temperature (°C)

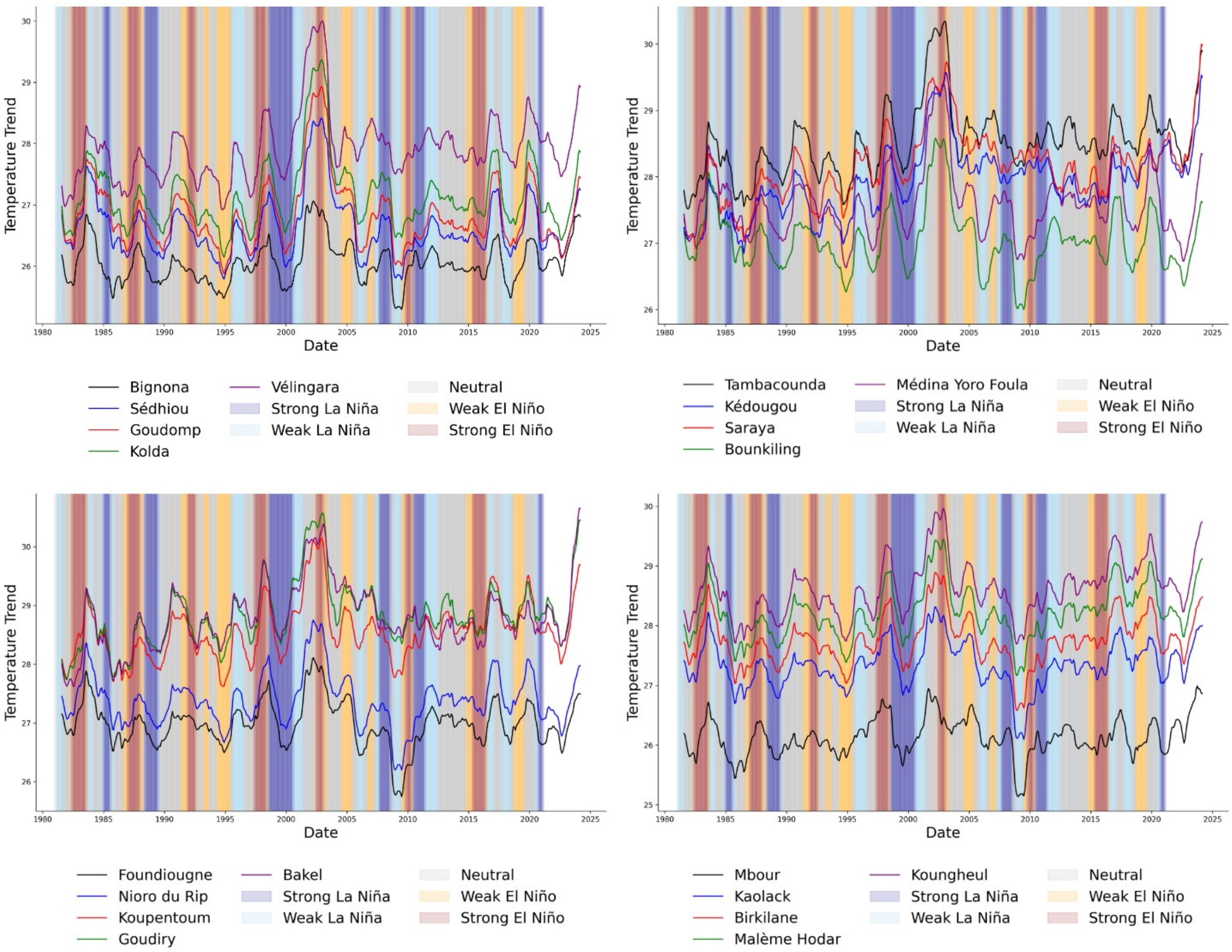


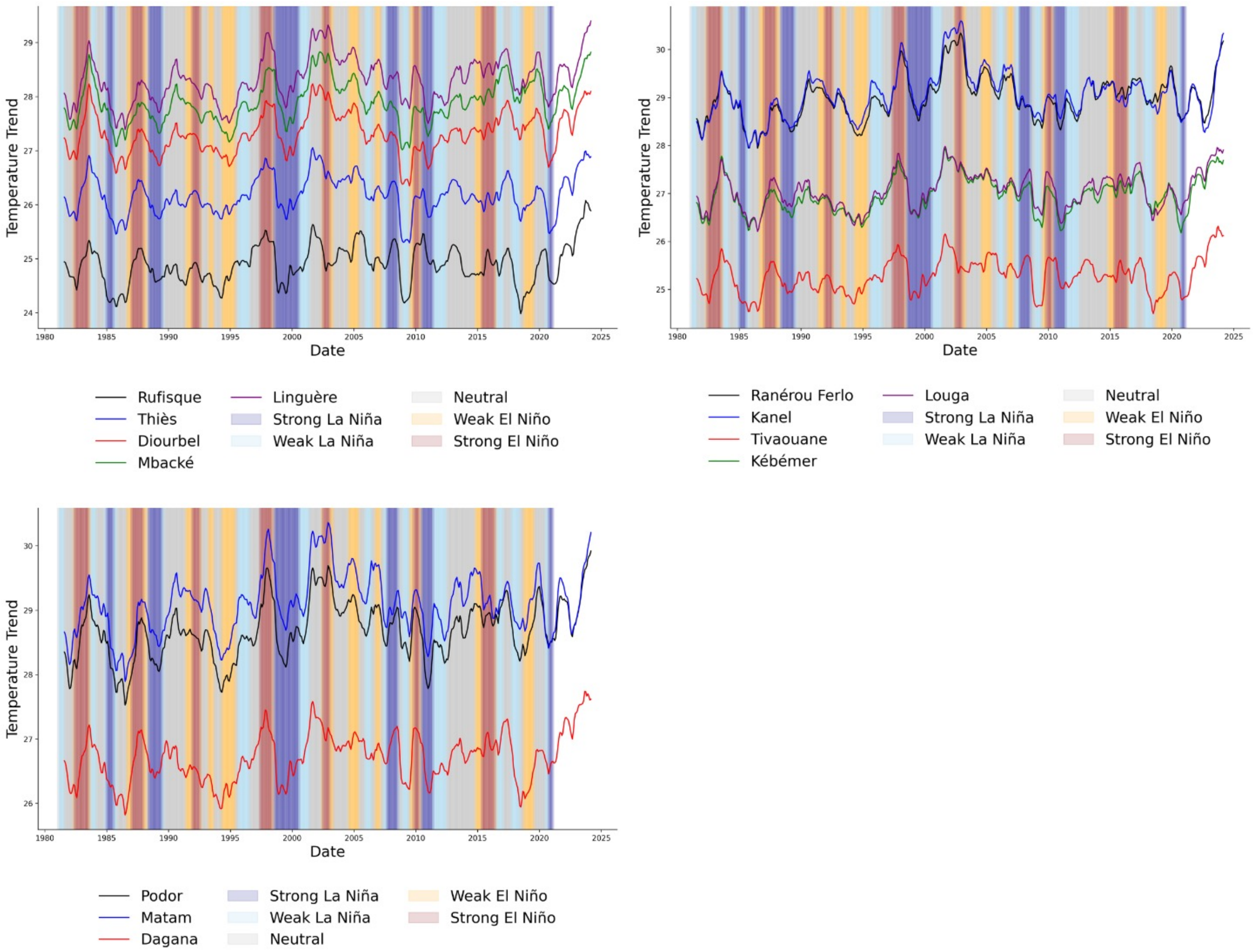
Source: Authors' analysis.

3.2.2 Temperature trends and El Niño-Southern Oscillation (ENSO) cycles

This section examines the impact of ENSO cycles—El Niño, La Niña, and neutral periods—on average temperature trends across the 33 departments of Senegal from 1981 to 2024. The aim is to understand how these natural climate phenomena affect each department's local temperature anomalies and long-term temperature trends. Similar to the national-level analysis, a seasonal decomposition was performed for each department, and the trend component was isolated and overlayed with time windows corresponding to strong and weak ENSO events (Figure 3.10).

Figure 3.10. Trend component of seasonal decomposition of daily average temperature for 33 departments in Senegal, with strong and weak cycles of ENSO.





Source: Authors' analysis.
Note: ENSO = El Niño-Southern Oscillation.

We combined a maximum of five departments in each graph—six graphs with temperature trends for five departments and one with three departments to present the results for all 33 departments. To facilitate the interpretation of each graph for the 33 departments, summary bullet points are provided here for five departments. After that, a summary of the general insights obtained is provided.

- **Bakel** shows a notable warming trend with a linear trend slope of +0.0161°C per year. During El Niño events, Bakel experiences a mean temperature anomaly of +0.12°C, while La Niña events bring a cooling effect with a mean anomaly of –0.23°C. A mean anomaly of +0.02°C characterizes the neutral periods. The variability in Bakel is significant, with a standard deviation of +0.98°C across the ENSO phases, indicating that these global climate phenomena strongly influence temperature fluctuations.
- **Bignona** exhibits a moderate warming trend with a linear trend slope of +0.0051°C per year. The mean temperature anomaly during El Niño periods is +0.08°C, compared to a cooling anomaly of –0.19°C during La Niña. The neutral phases show a mean anomaly close to zero (+0.01°C), suggesting stable conditions. The standard deviation in Bignona is lower at +0.87°C, reflecting less extreme temperature variations than in Bakel.
- **Birkilane** demonstrates a more pronounced warming trend with a linear trend slope of +0.0082°C per year. El Niño events lead to a mean temperature anomaly of +0.10°C, whereas La Niña events result in a cooling anomaly of –0.20°C. Neutral periods in Birkilane have a mean anomaly of +0.03°C. The standard deviation is +0.92°C, indicating moderate temperature variability during ENSO phases.

- **Bounkiling** shows a similar warming trend with a linear trend slope of +0.0076°C per year. The mean anomaly during El Niño is +0.11°C, while La Niña brings a mean cooling anomaly of 0.22°C. Neutral periods have a mean anomaly of +0.04°C. The standard deviation of +0.95°C suggests that Bounkiling experiences notable temperature fluctuations influenced by ENSO cycles.
- **Dagana** presents a weaker warming trend with a linear trend slope of +0.0043°C per year. El Niño periods lead to a mean temperature anomaly of +0.07°C, whereas La Niña events result in a mean anomaly of –0.18°C. The neutral periods show a mean anomaly of +0.02°C. The variability is relatively low, with a standard deviation of +0.85°C, indicating more stable temperature conditions than the other four departments examined in detail here.

The remaining departments across Senegal exhibit similar warming trends and temperature variability influenced by ENSO cycles. Departments such as Matam, Saraya, and Tambacounda show significant warming and substantial variability during ENSO phases, with El Niño events generally resulting in warmer average temperatures and La Niña bringing cooling effects. Coastal regions like Dakar show more moderate warming and less pronounced temperature fluctuations, reflecting the buffering effect of their proximity to the ocean. Inland departments, particularly those in the Sahelian zone, display stronger correlations with ENSO phases, leading to more extreme temperature anomalies during El Niño and La Niña events.

El Niño events are generally associated with positive temperature anomalies across Senegal, indicating warmer conditions, while La Niña periods tend to bring cooler temperatures. Neutral periods typically show more stable conditions but still contribute to the overall warming trend observed across the country from 1981 to 2024. The strength and variability of these trends vary depending on the department's geographical location, with inland regions experiencing more pronounced impacts from ENSO cycles than coastal areas.

4. CONCLUSION

This study examined trends and variations in daily average temperatures in Senegal from January 1981 to mid-August 2024. It was done on two scales—at the national and department levels, the latter being the second-level administrative division of the country. For both, statistical analyses were performed to shed light on temperature increases that could be attributed to global warming and those that seem more related to interannual oscillations associated with natural forcing processes, particularly ENSO cycles.

Change in expected temperature patterns is one of the most direct ways individuals and communities in Senegal are experiencing climate change. Hotter air temperatures affect their thermal comfort, health, and livelihoods, particularly agriculture-related ones. The combination of observations of those real impacts and the increased accessibility of information on the changing climate creates a blurry line between what of the changes in air temperature in Senegal are natural and what are based on human activities. This paper tried to shed light on those two aspects, emphasizing the natural forcing aspects of ENSO. The results from this analysis offer insightful systematic information and a clear overview for policymakers and other decision-makers about the dynamics in average air temperatures in Senegal and the causes of any changes observed over the past several decades.

At the national level, a linear regression was fitted to the entire data set. This analysis shows that the country experienced a temperature increase of +0.57°C for the 43-year study period, an annual increase rate of +0.013°C. This was likely caused by anthropogenic forcing. However, the overlay of the trend component of the seasonal decomposition of the air temperature dataset with El Niño, La Niña, and neutral periods of the ENSO cycle shows good correspondence. El Niño periods seem to be correlated with temperature increases, while La Niña periods are associated with decreases. These correlations suggest that an increase in temperature cannot be strictly or solely attributed to climate change resulting from increased atmospheric greenhouse gas concentrations. Indeed, the spike in high temperatures observed in Senegal in 2024 was not novel—a period of higher temperatures was observed in 2002 and 2003 when greenhouse gas concentration levels were lower than in 2024. However, it is worth noting that temperature oscillations in Senegal have been more frequent since 2000 compared to the period from 1981 to 2000. Also evident is an increase in the frequency of higher temperatures from 2021 to 2024 compared to the period from 1991 to 2020. These patterns in the analysis suggest that policy interventions should integrate ENSO data to optimize agricultural planning and mitigate risks during extreme events.

The analysis at the department level shows trends similar to the overall national trend, even though the amplitude of fluctuations changes from one department to another. Across all departments, a statistically significant warming trend of +0.0109°C per year exists.

The analysis described in this paper shows that it is important to contextualize fluctuations in climatic parameters with natural forcing processes and not solely attribute such changes to what is commonly called "the climate crisis" as a consequence of increased concentrations of atmospheric greenhouse gases. This does not mean temperatures are not increasing over time, but the amplitude of the increase is not the same in all countries, as seen in this paper for Senegal. It also does not mean that actions should not be taken to mitigate or adapt to a changing climate. However, such actions should be aligned with the localized dynamics of the climate. Indeed, the risk of basing any climate action on global trends will result in what is likely to be an inappropriate and oversized set of responses and policies, which in the long run could be more harmful to natural ecosystems and livelihoods than if no action had been taken. When it comes to climate, the analysis here shows that while policy debates around climate change may be at the global level, coordination at the regional level, and actions at the local level, the data that should be examined to inform any actions has to be tailored to the local needs—in other words, what a changing climate means to local households and communities.

The analysis here could be the basis for further analysis relevant to agriculture. The viability of forecasting near-term temperature trends using machine learning models or deep learning models should be assessed as a viable alternative to climate science–based forecasting techniques. Similarly, the results of the analyses here could be incorporated into efforts to estimate the best sowing and harvesting periods for select crops, supplementing information on the growing degree days needed for crops to mature and also incorporating data on rainfall and vegetation indices, among others. Beyond agriculture, the results could also be used to estimate energy demand for cooling purposes in

Senegal. This could be done by computing cooling degree days across the country, defined as the number of degrees Celsius by which a building needs to be cooled for thermal comfort at a defined temperature threshold. However, such a study will require collecting information about buildings and their cooling equipment, the energy sources for operating the equipment, and demographics.

This work can be improved in several ways. The temperature dataset used for the analysis started in 1981. It would be interesting to go back to earlier periods for which temperature data is available for locations in Senegal—to periods when atmospheric greenhouse gas concentrations globally were significantly smaller—to further disentangle the impacts of human activities on the climate. The second area in which this study can be improved is by filling the missing relationship between greenhouse gas emissions in Senegal and the temperature dynamics studied. How important are locally emitted greenhouse gases to the temperature dynamics observed? Unfortunately, such geographically and temporally disaggregated activity-based emissions data for Senegal are not readily available. Finally, another area of improvement inherent to the format of the dataset used is its spatial resolution. This format does not enable spatial analyses of changes in air temperature in Senegal at a finer scale than the department level. More detailed, finer-scale analyses of temperature trends may provide new insights into Senegal's dynamic climate.

REFERENCES

Adger, W.N. 2003. "Social Capital, Collective Action, and Adaptation to Climate Change." *Economic Geography*, 79 (4): 387–404. https://doi.org/10.1111/j.1944-8287.2003.tb00220.x

Alexander, L.V. 2016: "Global Observed Long-term Changes in Temperature and Precipitation Extremes: A Review of Progress and Limitations in IPCC Assessments and Beyond." *Weather and Climate Extremes*, 11: 4-16. https://doi.org/10.1016/j.wace.2015.10.007

Arguez, A., A. Inamdar, M.A. Palecki, C.J. Schreck, and A.H. Young. 2019. "ENSO Normals: A New U.S Climate Normals Product Conditioned by ENSO Phase and Intensity and Accounting for Secular Trends. *Journal of Applied Meteorology and Climatology*, 58 (6): 1381–1397. https://doi.org/10.1175/jamc-d-18-0252.1

Bacci, M. 2017. "Characterization of Climate Risks for Rice Crop in Casamance, Senegal." In *Renewing Local Planning to Face Climate Change in the Tropics*, edited by M. Tiepolo, A. Pezzoli, and V. Tarchiani. *Green Energy and Technology*: 57-72. Cham: Springer. https://doi.org/10.1007/978-3-319-59096-7_4

Bosilovich, M.G., S. Akella, L. Coy, R. Cullather, C. Draper, R. Gelaro, R. Kovach, Q. Liu, A. Molod, P. Norris, K. Wargan, W. Chao, R. Reichle, L. Takacs, Y. Vikhliaev, S. Bloom, A. Collow, S. Firth, G. Labow, G. Partyka, S. Pawson, O. Reale, S.D. Schubert, and M. Suarez. 2015. *MERRA-2: Initial Evaluation of the Climate*. Technical Report Series on Global Modeling and Data Assimilation, Volume 43. Greenbelt: Goddard Space Flight Center, National Aeronautics and Space Administration (NASA). https://ntrs.nasa.gov/api/citations/20160005045/downloads/20160005045.pdf

Carter, T.R., and E.L. La Rovere. 2001. "Developing and Applying Scenarios." In Climate Change 2001: Impacts Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, edited by J.J. McCarthy, O.F. Canziani, N.A. Leary, D.J. Dokken and K.S. White. Cambridge and New York: Cambridge University Press. https://www.ipcc.ch/site/assets/uploads/2018/03/wg2TARchap3.pdf

Christidis, N., M. McCarthy, D. Cotterill, and P.A. Stott. 2021. "Record-breaking Daily Rainfall in the United Kingdom and the Role of Anthropogenic Forcings." *Atmospheric Science Letters*, 22 (7): e1033. https://doi.org/10.1002/asl.1033

Ciais, P., C. Sabine, G. Bala, L. Bopp, V. Brovkin, J. Canadell, A. Chhabra, R. DeFries, J. Galloway, M. Heimann, C. Jones, C. Le Quéré, R.B. Myneni, S. Piao, and P. Thornton. 2013: "Carbon and Other Biogeochemical Cycles." In *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley. Cambridge and New York: Cambridge University Press.

De Longueville, F., P. Ozer, F. Gemenne, S. Henry, O. Mertz, and J.Ø. Nielsen. 2020. "Comparing Climate Change Perceptions and Meteorological Data in Rural West Africa to Improve the Understanding of Household Decisions to Migrate." *Climatic Change* 160: 123–141. https://doi.org/10.1007/s10584-020-02704-7

Dinku, T. 2019. "Challenges with Availability and Quality of Climate Data in Africa." In *Extreme Hydrology and Climate Variability: Monitoring, Modelling, Adaptation and Mitigation*, edited by Melesse, A.M., W. Abtew, and G. Senay, 71–80. Amsterdam: Elsevier. https://doi.org/10.1016/b978-0-12-815998-9.00007-5

Emmanuel, I. 2022. "Linkages between El Niño-Southern Oscillation (ENSO) and Precipitation in West Africa Regions." *Arabian Journal of Geosciences*, 15: 675. https://doi.org/10.1007/s12517-022-09942-2

Faye, M., A. Dème, A.K. Diongue, and I. Diouf. 2021. "Impact of Different Heat Wave Definitions on Daily Mortality in Bandafassi, Senegal." *PLoS ONE*, 16 (4): e0249199. https://doi.org/10.1371/journal.pone.0249199

Gelaro, R., W. McCarty, M.J. Suárez, R. Todling, A. Molod, L. Takacs, C.A. Randles, A. Darmenov, M.G. Bosilovich, R. Reichle, K. Wargan, L. Coy, R. Cullather, C. Draper, S. Akella, V. Buchard, A. Conaty, A.M. da Silva, W. Gu, G.-K. Kim, R. Koster, R. Lucchesi, D. Merkova, J.E. Nielsen, G. Partyka, S. Pawson, W. Putman, M. Rienecker, S.D. Schubert, M. Sienkiewicz, and B. Zhao. 2017. "The Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2)." *Journal of Climate*, 30 (14): 5419–5454. https://doi.org/10.1175/jcli-d-16-0758.1

González, J.B., and A. Sánchez. 2022. "Multilevel Predictors of Climate Change Beliefs in Africa." *PLoS ONE*, 17 (4): e0266387. https://doi.org/10.1371/journal.pone.0266387

Haigh, J.D., and P. Cargill. 2015. *The Sun's Influence on Climate*. Princeton: Princeton University Press.

Hansen, J., M. Sato, R. Ruedy, K. Lo, D.W. Lea, and M. Medina-Elizade. 2006. "Global Temperature Change." *Proceedings of the National Academy of Sciences*, 103 (39): 14288–14293. https://doi.org/10.1073/pnas.0606291103

Hawkins, L.R., J.T. Abatzoglou, S. Li, and D.E. Rupp. 2022. "Anthropogenic Influence on Recent Severe Autumn Fire Weather in the West Coast of the United States." *Geophysical Research Letters*, 49 (4): e2021GL095496. https://doi.org/10.1029/2021gl095496

Hobbins, M., T. Jansma, D.P. Sarmiento, A. McNally, T. Magadzire, H. Jayanthi, W. Turner, A. Hoell, G. Husak, G. Senay, O. Boiko, M. Budde, P. Mogane, and C.F. Dewes. 2023 "A Global Long-Term Daily Reanalysis of Reference Evapotranspiration for Drought and Food-Security Monitoring." *Scientific Data*, 10: 746. https://doi.org/10.1038/s41597-023-02648-4

IPCC (Intergovernmental Panel on Climate Change). 2014: *Climate Change 2014: Synthesis Report*. Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the IPCC. Geneva: IPCC.

IPCC (Intergovernmental Panel on Climate Change). 2021: *Climate Change 2021: The Physical Science Basis*. Contribution of Working Group I to the Sixth Assessment Report of the IPCC. Geneva: IPCC. doi:10.1017/9781009157896

IPCC (Intergovernmental Panel on Climate Change). 2022. *Climate Change 2022: Impacts, Adaptation, and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the IPCC. Geneva: IPCC. https://doi.org/10.1017/9781009325844

Krosnick, J.A., amd B. MacInnis. 2020. *Climate Insights 2020: Overall Trends*. Washington, DC: Resources for the Future. https://media.rff.org/documents/Climate_Insights_Overall_Trends_Final_RCFAejQ.pdf

Kumar, P., A. Choudhary, P.K. Joshi, R. Prasad, and S.K. Singh. 2022. "Multiple Crop Yield Estimation and Forecasting Using MERRA-2 Model, Satellite-Gauge and MODIS Satellite Data by Time Series and Regression Modelling Approach." *Geocarto International*, 37 (27): 16590–16619. https://doi.org/10.1080/10106049.2022.2112301

Lai, Y., and D.A. Dzombak. 2019. "Use of Historical Data to Assess Regional Climate Change." *Journal of Climate*, 32 (14): 4299–4320. https://doi.org/10.1175/jcli-d-18-0630.1

Lean, J.L. 2009. "Cycles and Trends in Solar Irradiance and Climate." *Wiley Interdisciplinary Reviews Climate Change*, 1 (1): 111–122. https://doi.org/10.1002/wcc.18

Lo, A., A.A. Diouf, I. Diedhiou, C.D.E. Bassène, L. Leroux, T. Tagesson, R. Fensholt, P. Hiernaux, A. Mottet, S. Taugourdeau, D. Ngom, I. Touré, B. Ndao, and M.A. Sarr. 2022. "Dry Season Forage Assessment across Senegalese Rangelands Using Earth Observation Data." *Frontiers in Environmental Science*, 10: 931299. https://doi.org/10.3389/fenvs.2022.931299

NASA (National Aeronautics and Space Administration). 2024. "NASA Analysis Confirms 2023 as Warmest Year on Record—NASA." *News Release*, January 12. https://www.nasa.gov/news-release/nasa-analysis-confirms-2023-as-warmest-year-on-record/

Pindyck, R.S. 2020. *What We Know and Don't Know about Climate Change, and Implications for Policy*. National Bureau of Economic Research Working Paper 27304. https://doi.org/10.3386/w27304

Robinson, A., J. Lehmann, D. Barriopedro, S. Rahmstorf, and D. Coumou. 2021. "Increasing Heat and Rainfall Extremes Now Far Outside the Historical Climate." *npj Climate and Atmospheric Science*, 4: 45. https://doi.org/10.1038/s41612-021-00202-w

Robock, A. 2000. "Volcanic Eruptions and Climate." *Reviews of Geophysics*, 38 (2): 191–219. https://doi.org/10.1029/1998rg000054

Rohde, R. 2024. *Global Temperature Report for 2023* Berkeley, CA: Berkeley Earth. https://berkeleyearth.org/global-temperature-report-for-2023/

Rosenstock, T.S., and A. Wilkes. 2021. Reorienting Emissions Research to Catalyse African Agricultural Development. *Nature Climate Change*, 11 (6): 463–465. https://doi.org/10.1038/s41558-021-01055-0

Samset, B.H., C. Zhou, J.S. Fuglestvedt, M.T. Lund, J. Marotzke, and M.D. Zelinka. 2023. "Steady Global Surface Warming from 1973 to 2022 but Increased Warming Rate After 1990." *Communications Earth & Environment*, 4 (1): 400. https://doi.org/10.1038/s43247-023-01061-4

Santer, B.D., C.J.W. Bonfils, Q. Fu, J.C. Fyfe, G.C. Hegerl, C. Mears, J.F. Painter, S. Po-Chedley, F.J. Wentz, M.D. Zelinka, and C.-Z. Zou. 2019. "Celebrating the Anniversary of Three Key Events in Climate Change Science." *Nature Climate Change*. 9: 180–182. https://doi.org/10.1038/s41558-019-0424-x

Shi, J., V. Visschers, M. Siegrist, M. and J. Arvai. 2016. "Knowledge As a Driver of Public Perceptions About Climate Change Reassessed." *Nature Climate Change* 6: 759–762. https://doi.org/10.1038/nclimate2997

Trenberth, K.E., J.M. Caron, D.P. Stepaniak, and S. Worley. 2002. "Evolution of El Niño–Southern Oscillation and Global Atmospheric Surface Temperatures." *Journal of Geophysical Research Atmospheres*, 107 (D8): AAC 5-1–AAC 5-17. https://doi.org/10.1029/2000jd000298

Wang, C., L. Tseng, C. Huang, S. Lo, C. Chen, P. Chuang, N. Su, and K. Tsuboki. 2019. "How Much of Typhoon Morakot's Extreme Rainfall is Attributable to Anthropogenic Climate Change?" *International Journal of Climatology*, 39 (8): 3454–3464. https://doi.org/10.1002/joc.6030

Wilkes, A., A. Reisinger, E. Wollenberg, and S. van Dijk. 2017. *Measurement, Reporting and Verification of Livestock GHG Emissions by Developing Countries in the UNFCCC: Current Practices and Opportunities for Improvement*. CCAFS Report no. 17. Wageningen: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) and Global Research Alliance for Agricultural Greenhouse Gases (GRA).

WMO (World Meteorological Organization). 2020. *WMO Climatological Normals.* Geneva: WMO. https://community.wmo.int/en/wmo-climatological-normals#:~:text=The%20most%20significant%20of%20these,Normals%20for%201991%20to%202020

WMO (World Meteorological Organization). 2023. *State of the Climate in Africa.* WMO-No. 1360. Geneva: WMO. https://doi.org/10.18356/9789263113603

WMO (World Meteorological Organization). 2024. "WMO Confirms That 2023 Smashes Global Temperature Record." Geneva: WMO. https://wmo.int/news/media-centre/wmo-confirms-2023-smashes-global-temperature-record

World Bank. 2021. *Senegal—Climate Change Knowledge Portal*. Washington, DC. https://climateknowledgeportal.worldbank.org/country/senegal

Yang, Y., G. Liu, X. Guo, W. Liu, J. Xue, B. Ming, B, Xie, K. Wang, P. Hou, and S. Li. 2022. "Quantitative Relationship Between Solar Radiation and Grain Filling Parameters of Maize." *Frontiers in Plant Science*, 13: 906060. https://doi.org/10.3389/fpls.2022.906060

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