UNIVERSITAT ROVIRA I VIRGILI

CLIMATE CHANGE ANALYSIS FOR GUINEA CONAKRY WITH HOMOGENIZED DAILY DATASET.

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I CERTIFY that Abdul Aziz Barry has written this PhD Thesis, entitled "Climate change analysis for Guinea Conakry with homogenized daily dataset" under my supervision at the Center for Climate Change (C3), Department of Geography, Rovira i Virgili University.

Dr. Enric Aguilar Anfrons
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ABSTRACT

Though climate change assessments are important to allow countries to evaluate the changes and investigate consequences of climate extreme and variability on agriculture, water resources and other sectors to make appropriate decisions on mitigation and adaptation strategies, attempting to understand the climate changes on Africa is fraught with difficulties. Among these challenges is the lack of sufficiently long, high-quality and reliable climate records free of any non climatic jumps and/or shifts with a daily or higher time resolution. Thus, there is need assessing the quality of climate time series and correcting or excluding suspicious data and making adjustments for inhomogeneities wherever they are needed.

In this thesis, Guinea's 12 synoptic weather stations daily minimum and daily maximum temperatures and daily precipitation data have been carefully quality controlled using the RClimdex-ExtraQC routines. These routines contain graphical and statistical information to quality control single time series. The values identified as potentially erroneous have been carefully scrutinized and a subjective decision has been made to validate, correct or set them to missing. The resulted quality controlled dataset free of any kind of suspicious data record has been homogenized using HOMER.

Chosen indices from ETCCDI and ET-CRSCI indices have been calculated using ET-CRSCI newly developed ClimPact R package. Annual and seasonal temperatures and precipitations indices have also been computed. Additionally, eight nationwide averaged climate extremes indices, the nationwide averaged annual Tx mean and Tn mean and total precipitation indices have been use to detect teleconnection between climate indices and SOI indices.

A nonparametric trend analysis is then performed for three overlapping periods, with different starting years 1941, 1961 and 1971 but all ending the same 2010 year.

The result suggested that coherent spatial patterns of statistically significant warming changes have emerged in both Tx and Tn related extremes indices for all periods and season. Indices based on daily precipitation data showed more mixed patterns of change but, in general, significant drying patterns have been seen in most of the former periods' daily precipitation related indices while over the recent period analyses suggested non-significant changes towards wetter conditions. Overall, there have been no spatially coherent changes in extreme rainfall events across Guinea as a whole for the study period, but changes in extreme precipitation events have occurred on local scales. There are signs that cooler and wetter conditions appeared to be associated with the La Niña years.

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GLOSSARY

A

Am tropical monsoon 102

AR4 Fourth Assessment Report of the Intergovernmental Panel on Climate Change 26

AR5 Fifth Assessment Report of the Intergovernmental Panel on Climate Change 20, 26

Aw tropical savanna 90

C

CDD Consecutive Dry Days 79

CMIP3 Coupled Model Inter-comparison Project 3 26

CMIP5 Coupled Model Intercomparison Project Phase 5 34

CSDI Cold Spells Duration Index 78

D

DJF December January February 90

DTR Daily Temperature Range 40

E

ECA&D European Climate Assessment & Dataset 76

EHF Excess Heat Factor 87

ETCCDI Expert Team on Climate Change Detection and Indices 21

ET-CRSCI Expert Team on Climate Risk and Sector-specific Indices 21

ETR Extreme Temperature Range 77

G

GCM Global Climate Model 28

GCMs General Circulation Models 40

GFCS Global Framework for Climate Services 82

GHCN v3.2.0 Global Historical Climate Network version 3.2.0 20

GHCNv3 Global Historical Climatology Network Version 3 228

GHG Greenhouse Gas 27

GPCC Global Precipitation Climatology Centre V6 228

GPCC v6 Global Precipitation Climatology Centre version 6 20

H

HOMER Homogenization method in R 60

I

IPCC Intergovernmental Panel on Climate Change 20

J

JJA June July August 90

L

LN La Niña 223

LOESS local Regression 93

LSAT Land Surface Air Temperature 20

M

MAM March April May 90

N

NWA nationwide average 92

P

PDSI Palmer Drought Severity Index 29, 32, 84

PPEA Precipitation Potential Evaporation Anomaly 84
PRCPTOT Precipitation total 79

Q

QC Quality Control 43

R

RCP Representative Concentration Pathway 34
Rx1day Maximum 1 day precipitation 20

S

sc-PDSI self calibrated Palmer Drought Severity Index 33
SDII Simple Day Intensity Index 20
SOI Southern Oscillation Index 22, 223
SON September October November 90
SPEI Standardized Precipitation Evapotranspiration Index 82
SPI Standardized Precipitation Index 37
SREX IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation 32
SST Sea Surface Temperature 223
SU Summer Day 77

T

TR Tropical Nights 77

U

UNDP United Nations Development Program 21
UNFCCC United Nations Framework Convention on Climate Change 24

W

WA West Africa 20, 25
WMO CCl World Meteorological Organization Commission for Climatology 82
WMO World Meteorological Organization 42
WSDI Warm Spells Duration Index 30

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1. INTRODUCTION

It is well known that Earth is undergoing an unprecedented human induced warming process since the Industrial Revolution (IPCC Intergovernmental Panel on Climate Change, 2013). Global-scale studies of changes in climate extremes using observational data appeared early 2000s. Using global daily station data, Frich et al. (2002) found an increase in the number of warm summer nights and a significant increase in the total rainfall. Alexander et al. (2006) with the inclusion of more data points additionally noticed a general increase in the precipitation indices globally. Since then many studies have been conducted both at global and regional level. Using GHCN v3.2.0 (Global Historical Climate Network version 3.2.0), Lawrimore et al. (2011) found global warming trend; later Jones et al. (2012) and Rohde et al. (2013) also found warming trends in global LSAT (Land Surface Air Temperature). Smith et al. (2012) found wetter conditions for all latitudes included tropical areas and Becker et al. (2013) using GPCC v6 (Global Precipitation Climatology Centre version 6) concluded that downwards trends dominate the tropics precipitation since 1951.

According to the AR5 (Fifth Assessment Report of the Intergovernmental Panel on Climate Change), the rate of the global average surface temperature increased by 0.197°C ± 0.031°C/decade over 1951-2012 (Hartmann et al., 2013). Since 1979, the rate of warming is faster, with a value of 0.273°C ± 0.047°C/decade.

At regional scale Aguilar et al. (2009) found warmer and drier trends for Western Central Africa, Zimbabwe and Guinea; New et al. (2006) also found temperature extremes patterns consistent with warming and wetting trends in regionally averaged rainfall on extreme precipitation days and in maximum annual 5-day and 1-day rainfall for southern and WA (West Africa). Consistent with the global warming trend, WA temperature experienced an upward trends of 0.16 ºC/decade and 0.28 ºC/decade in Tx (daily maximum temperature) and Tn (daily minimum temperature) respectively during the last fifty years; regionally increasing trends in Rx1day (Maximum 1 day precipitation) and SDII (Simple Day Intensity Index) have also been found in a recent study, (Barry et al, 2014).

Under this warming background, it is expected that extreme events in temperature and precipitation are changing over time. Additionally, global and regional studies give a good picture of what is happening at large scale smoothing out what is happing locally.

The occurrence of extreme events is usually a concern for society because they threat with causing severe damages. With others words, the enhanced attention devoted to the study of climate extremes and their changes over time stems largely from their potential to be detrimental to human health, property, public infrastructure, agriculture, energy and others socioeconomic and biophysical systems. The list of extreme climatic events includes heat waves, droughts, heavy rains, and high winds, but also specific phenomena such as hurricanes, tornadoes, or floods. Regardless of the type of event, climate extremes generally induce excessive stress (Zhang et al. 2013, UNDP 2009).

These adverse effects of climate extremes highlight the need for their effective monitoring. Over time, this requirement has increased for many reasons that can be classified into two groups. The first is due to the expansion of human populations and associated infrastructure into vulnerable areas (Cardona et al. 2012). The second is that the characteristics of some types of extremes, such as their frequency and severity, have changed since the beginning of the twentieth century (Donat et al. 2013b, Hartmann et al., 2013). There is large consensus that several of these changes are likely due to increases in anthropogenic greenhouse gases (Hartmann et al., 2013).

In this study, chosen indices from ETCCDI (Expert Team on Climate Change Detection and Indices) and ET-CRSCI (Expert Team on Climate Risk and Sector-specific Indices) core climate change and sector specific indices are applied to Guinea daily maximum temperature (Tx), daily minimum temperature (Tn) and daily accumulated rainfall (RR) data to investigate the possible changes in climate means and extremes at national scale. Subsequently, their relationships with SOI (Southern Oscillation Index) are examined.
There is a prerequisite that long-term, high-quality and reliable climate records free of any non climatic jumps and/or shifts with a daily or higher time resolution are required for assessing the changes in climatic extremes (Brunet et al. , 2008 and Klein et al. , 2009).

Therefore, so as to construct such a dataset, non-climatic inhomogeneities such as station moves, urbanization, and observation/instrument changes that have affected observations and distorted underlying trends in the series must be accounted for. Thus, there is need assessing the quality of climate records of Guinea and making adjustments for inhomogeneities wherever they are needed. The resultant dataset is then used to assess long-term changes in daily climate extremes with confidence in the trends and statistics obtained from them. The relationship between the SOI (Southern Oscillation Index) teleconnection pattern and the climate indices is explored.

Although the observed changes in global temperatures and rainfall patterns and the increases in heavy precipitation were assessed to be qualitatively consistent with expectations of the response to anthropogenic forcings, detection and attribution studies had not been carried out nor detailed assessment at a national level especially in Western Africa countries. It is noteworthy that there is seldom any climate change study conducted at national scale available for Guinea. The availability of a relatively up to date and a homogeneous dataset is critical to understanding long-term trends and variability in the West African region and for conducting studies about future climate change in the region.

For the reasons exposed in the previous paragraph, we formulate our working hypothesis as follows:
"Climate has changed in Guinea during the last seven decades". To assess the validity of this hypothesis we will pursue the following objectives:

1) Quality control and homogenize the 12 longest stations available for Guinea
2) Compute a set of indices suitable for the evaluation of trends in temperature and precipitation daily series and evaluate their trends
3) Relate these changes to regional teleconnection patterns associated with the SOI.

The remainder of this work is organized as follows: chapter 2 expands the brief background on recent global climate change provided in this introductory section on discussing global changes in climate and the climate of Africa and Guinea; chapter 3 provides details on the data and methods employed for the development of this dissertation, introducing the employed dataset, including the 12 longest climate stations in Guinea; quality control and homogenization as well as the climate indices and the approach to their analysis; chapter 4 discusses the obtained results. This work ends with the necessary discussion, conclusions and references.

2. BACKGROUND

2.1. THE CONCEPT OF CLIMATE CHANGE

Climate Change, according to the IPCC, refers to any change in climate over time, whether due to natural variability or as a result of human activity. The IPCC uses a relatively broad definition of climate change that is considered to mean an identifiable and statistical change in the state of the climate that persists for an extended period of time. This change may result from internal processes within the climate system or from external processes. These external processes or forcing could be natural, for example volcanoes, or caused by the activities of people, for example emissions of greenhouse gases or changes in land use. Other bodies, notably the UNFCCC (United Nations Framework Convention on Climate Change), define climate change slightly differently. The UNFCCC makes a distinction between climate change that is directly attributable to human activities and climate variability that is attributable to natural causes. Thus UNFCCC defines climate change as: “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.” For the purposes of this study, either definition may be suitable depending on the context (IPCC, 2012).

A changing climate leads to changes in the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events, and can result in unprecedented extreme weather and climate events. Changes in extremes can be linked to changes in the mean, variance, or shape of probability distributions, or all of these. Some climate extremes, e.g., droughts, may be the result of an accumulation of weather or climate events that are not extreme when considered independently. Many extreme weather and climate events continue to be the result of natural climate variability. Natural variability will be an important factor in shaping future extremes in addition to the effect of anthropogenic changes in climate (IPCC, 2012).

Significant uncertainties surround the science of the future climate. Most climate change scenarios predict a decline in precipitation in the range of 0.5–40 % with an average of 10–20 % by 2025. Many of these scenarios portray a generally pronounced downward trend in flow regimes and the replenishment of groundwater. As a result of the major droughts and a number of recent floods with unusual magnitudes, specialists expect exacerbated extreme climate events in some parts of WA (West Africa). Coastal countries must count also with the predicted increase in sea level (up to 1m over a century), with possible significant losses in housing zones and economic infrastructures and the disappearance of significant areas of mangrove and coastal wetlands. However, it is important to point out that the climate change scenarios used do not consist of definite predictions but rather present plausible future climates. Considering the many possible future scenarios, what matters is the ability to manage the uncertainty. This includes reducing current vulnerability to climate variability and extreme events as well as keeping management options open enough to deal with the worst-case scenarios and to take advantage of opportunities that may arise (IPCC, 2012a).

WA, which Guinea is part, is one of the most vulnerable regions to climate change, but the level of awareness of the magnitude of the phenomenon is not commensurate with the risks to which the region is exposed. The sometimes disastrous impacts of climate variability and extremes of the last thirty years are good illustrations of this vulnerability, as well as harbingers of the magnitude of the perils to be expected as a result of the continuation of the global warming. In spite of this, climate change is a concern for only a few scientists and government experts involved in the implementation of the UNFCCC (IPCC, 2012a).

2.2. THE CAUSES OF CLIMATE CHANGE

This section first provides a brief overview of the current understanding of human-induced changes in the mean climate and changes in extremes; next the causes of observed changes in some specific extremes are discussed. At this point, it is worth noting that studies directly addressing the causes of changes in extremes are quite limited unlike studies on human-induced changes in the mean climate.

According to AR5 (Fifth Assessment Report of the Intergovernmental Panel on Climate Change), recent detection and attribution studies strengthen the results from AR4 (Fourth Assessment Report of the Intergovernmental Panel on Climate Change) that external forcing contributed to past climate variability and change prior to the 20th century.

Climate variations and change are induced by variability internal to the climate system, and changes in external forcings, which include natural external forcings such as changes in solar irradiance and volcanism, and anthropogenic forcings such as aerosol and greenhouse gas emissions principally due to the burning of fossil fuels, and land use and land cover changes. The mean state, extremes, and variability are all related aspects of the climate, so external forcings that affect the mean climate would in general result in changes in extremes. In other words, even if there were no anthropogenic changes in climate, a wide variety of natural weather and climate extremes would still occur. But recent work has provided evidence of detection of an anthropogenic influence at increasingly smaller spatial scales and for seasonal averages (Stott et al., 2010). For instance, Min and Hense (2007) found that estimates of response to anthropogenic forcing from the multi-model CMIP3 (Coupled Model Inter-comparison Project 3) ensemble provided a better explanation for observed continental scale seasonal temperature changes than alternative explanations such as natural external forcing or internal variability. In another study, an anthropogenic signal was detected in 20th-century summer temperatures in Northern Hemisphere sub-continental regions except central North America; although the results were more uncertain when anthropogenic and natural signals were considered together (Jones et al., 2008). Anthropogenic signals have also been detected in multi-decadal trends in a USA climate extreme index (Burkholder and Karoly, 2007), in the hydrological cycle of the western United States (Barnett et al., 2008), in New Zealand temperatures (Dean and Stott, 2009), and in European temperatures (Christidis et al., 2011). Anthropogenically forced warming over the second half of the 20th century has also been detected in ocean heat content and air temperatures in all continents (Hegerl et al., 2007; Gillett et al., 2008).

Hegerl et al. (2011) found a detectable response to external forcing in summer temperatures in the period 1500–1900, for winter temperatures during 1500–1950 and 1500–2000; and throughout the record for spring. Bindoff et al. (2013) state, even if solar forcing were on the high end of estimates for the last millennium, it would not be able to explain the recent warming according both to model simulations (Feulner, 2011) and detection and attribution approaches that scale the temporal fingerprint of solar forcing to best match the data (Schurer et al., 2013). Some studies suggest that particularly for millennial and multi-millenial time scales orbital forcing may be important globally (Marcott et al., 2013) and for high-latitude trends (Kaufman et al., 2009) based on a comparison of the correspondence between long-term Arctic cooling in models and data though the last millennium (Bindoff et al., 2013). Bindoff et al. (2013) suggest that volcanic forcing and GHG (Greenhouse Gas) forcing in particular are important for explaining past changes in NH temperatures.

There is also evidence that some extremes have changed as a result of anthropogenic influences, including increases in atmospheric concentrations of greenhouse gases. According to AR5, it is likely that anthropogenic influences have led to warming of extreme daily minimum and maximum temperatures at the global scale. There is medium confidence that anthropogenic influences have contributed to the intensification of extreme precipitation at the global scale. It is likely that it has been an anthropogenic influence on increasing extreme coastal high water due to an increase in mean sea level. The uncertainties in the historical tropical cyclone records, the incomplete understanding of the physical mechanisms linking tropical cyclone metrics to climate change, and the degree of tropical cyclone variability provide only low confidence for the attribution of any detectable changes in tropical cyclone activity to anthropogenic influences.

Regarding specific extremes changes; according to Hartmann et al. (2013) the surface temperature extremes have likely been affected by anthropogenic forcing. This assessment was based on multiple lines of evidence of temperature extremes at the global scale including the reported increase in the number of warm extremes and decrease in the number of cold extremes at that scale (Alexander et al., 2006). Hegerl et al. (2007) and Christidis et al. (2005) also state that anthropogenic forcing may have substantially increased the risk of extreme temperatures, such e.g. there were reported for the western European heat wave in 2003 (Stott et al., 2004).

Recent studies on attribution of changes in temperature extremes have tended to reaffirm the conclusions reached in earlier studies. For example, Alexander and Arblaster (2009) found that trends in warm nights over Australia could only be reproduced by a coupled model that included anthropogenic forcings. Also, Gutowski et al. (2008a) concluded that most of the observed changes in temperature extremes for the second half of the 20th century over the United States can be attributed to human activity. Results from two global coupled climate models with separate anthropogenic and natural forcing runs indicate that the observed changes can be reproduced with anthropogenic forcings, but not with natural forcings. In a recent study, Zwiers et al. (2011) compared observed annual temperature extremes including annual maximum daily maximum and minimum temperatures, and annual minimum daily maximum and minimum temperatures with those simulated responses to anthropogenic forcing or anthropogenic and natural external forcings combined by multiple GCM (Global Climate Model). Then, they fitted probability distributions to the observed extreme temperatures with a time-evolving pattern of location parameters as obtained from the model simulations, and found that both anthropogenic influence and the combined influence of anthropogenic and natural forcing can be detected in all four extreme temperature variables at the global scale over the land, and also over many large oceanic areas.

The observed changes in heavy precipitation appear to be consistent with the expected response to anthropogenic forcing (increase due to enhanced moisture content in the atmosphere). Stott et al. (2010) provides more evidence of anthropogenic influence on various aspects of the global hydrological cycle, which is directly relevant to extreme precipitation changes. In particular, an anthropogenic influence on atmospheric moisture content is detectable (Santer et al., 2007; Willett et al., 2007). Wang and Zhang (2008) show that winter season maximum daily precipitation appears to be statistically significantly influenced by atmospheric moisture content, with an increase in moisture corresponding to an increase in maximum daily precipitation. This behavior has also been seen in model projections of extreme winter precipitation under global warming study led by Gutowski et al. (2008b). Climate model projections suggest that the thermodynamic constraint based on the Clausius-Clapeyron relation is a good predictor for extreme precipitation changes in a warmer world in regions where the nature of the ambient lows change little (Pall et al., 2007). This indicates that the observed increase in extreme precipitation in many regions is consistent with the expected extreme precipitation response to anthropogenic influences. Changes in precipitation extremes with temperature also depend on changes in the moist adiabatic temperature lapse rate, in the upward velocity, and in the temperature when precipitation extremes occur (O'Gorman and

Schneider, 2009a, b; Sugiyama et al., 2010). This may explain why there have not been increases in precipitation extremes everywhere, although a low signal-to-noise ratio may also play a role.

A comparison between observed and multi-model simulated extreme precipitation using an optimal detection method suggests that the human-induced increase in greenhouse gases has contributed to the observed intensification of heavy precipitation events over large Northern Hemisphere land areas during the latter half of the 20th century (Min et al., 2011). Pall et al. (2011) linked human influence on global warming patterns with an increased risk of England and Wales flooding in autumn 2000 that is associated with a displacement in the North Atlantic jet stream. According to Seneviratne et al. (2012), there is medium confidence that anthropogenic influence has contributed to changes in extreme precipitation at the global scale. New evidences are emerging for an anthropogenic influence on global land precipitation changes, on precipitation increases in high northern latitudes, and on increases in atmospheric humidity state Bindoff et al. (2013). However, this conclusion may be dependent on the season and spatial scale.

Temperature and precipitation are associated with several types of extremes, for example, heat waves and cold spells, as well as their related impacts, for example on human health, the physical environment, ecosystems and energy consumption. Temperature extremes often occur on weather time scales that require daily or higher time scale resolution data to accurately assess possible changes.

With respect to drought, Hegerl et al. (2007) conclude that it is more likely than not that anthropogenic influence has contributed to the increase in the droughts observed in the second half of the 20th century. This assessment was based on several lines of evidence, including a detection study that identified an anthropogenic fingerprint in a global PDSI (Palmer Drought Severity Index) dataset with high significance (Burke et al., 2006), although the model trend was weaker than the observed trend and the relative contributions of natural external forcings and anthropogenic forcings were not assessed.

The changes in the patterns of global precipitation in the observations and in model simulations are also consistent with the theoretical understanding of hydrological response to global warming that wet regions become overall wetter and dry regions drier in a warming world (Held and Soden, 2006). Seneviratne et al. (2012) thus assess that there is medium confidence that anthropogenic influence has contributed to some changes in the drought patterns observed in the second half of the 20th century, based on its attributed impact on precipitation and temperature changes. However, there is low confidence in the attribution of changes in droughts at the level of individual regions.

2.3. OBSERVED CHANGES IN CLIMATE

Based on Trenberth et al. (2007) and Alexander et al. (2006), Seneviratne et al. (2012) reported a statistically significant increase in the numbers of warm nights and a statistically significant reduction in the numbers of cold nights for 70 to 75 % of the land regions with data. Changes in the numbers of warm days and cold days also showed warming, but less marked than for nights, with about 40 to 50 % of the area with data showing statistically significant changes consistent with warming (Alexander et al., 2006). These studies have recently been confirmed by Hartmann et al. (2013).

According to Hartmann et al. (2013), it is certain that global mean surface temperature has increased since the late 19th century. Furthermore, each of the past three decades has been successively warmer at the Earth's surface than all the previous decades in the instrumental record, and the first decade of the 21st century was the warmest. The globally averaged combined land and ocean surface temperature data show a warming of 0.85 [0.65 to 1.06] °C, over the period 1880–2012 based on multiple independently produced datasets, and about 0.72°C [0.49°C to 0.89°C] over the period 1951–2012. For 1901–2012, almost the entire globe has experienced surface warming.

Based on this evidence and using late 20th-century extreme values as reference Hartmann et al. (2013) assessed that it was very likely that there had been trends toward warmer and more frequent warm days and warm nights, and warmer and less frequent cold days and cold nights in most land areas.

There are fewer studies available investigating changes in characteristics of cold spells and warm spells, or cold waves and heat waves, compared with studies of the intensity or frequency of warm and cold days or nights. Alexander et al. (2006) provided an analysis of trends in warm spells based on the WSDI (Warm Spells Duration Index); mostly in the mid- and high-latitudes of the Northern Hemisphere. The analysis displays a tendency toward a higher length or number of warm spells in much of the region, with the exception of the southeastern United States and eastern Canada. Donat et al. (2013a) state that driving mechanisms related to the reported changes may vary between regions and time scales, but large-scale natural variability plays a role (Haylock et al., 2006; Barrucand et al., 2008; Scaife et al., 2008; Alexander et al., 2009; Caesar et al., 2011; Renom et al., 2011), as do changes in anthropogenic GHG (Kiktev et al., 2003; Alexander and Arblaster, 2009; Min et al., 2011) and land-use and land cover change (Avila et al., 2011). There is also some, generally seasonally dependent, co-variability between temperature extremes and other atmospheric variables, such as precipitation, cloud cover, or the occurrence of storms (Robinson et al., 2002; Portmann et al., 2009), which enhances the importance of examining the variability of extreme temperature events.

There is evidence from observations gathered since 1950 of change in some extremes; for example Trenberth et al. (2007) and Seneviratne et al. (2012) concluded that it is likely that there have been increases in the number of heavy precipitation events over the second half of the 20th century within many land regions, even in regions where there had been a reduction in total precipitation amount, consistent with a warming climate and observed significant increasing amounts of water vapor in the atmosphere.

Increases had also been reported for rarer precipitation events, but only a few regions had sufficient data to assess such trends reliably. However, Trenberth et al. (2007) also stated that “Many analyses indicate that the evolution of rainfall statistics through the second half of the 20th century is dominated by variations on the interannual to inter-decadal time scale and that trend estimates are spatially incoherent (Manton et al., 2001; Peterson et al., 2002; Griffiths et al., 2003; Herath and Ratnayake, 2004)”. Overall, as highlighted by Hartmann et al. (2013), the observed temporal changes in precipitation extremes were found to be much less spatially coherent and statistically significant compared to observed changes in temperature extremes: although statistically significant trends toward stronger precipitation extremes were generally found for a larger fraction of the land area than trends toward weaker precipitation extremes, statistically significant changes in precipitation indices for the overall land areas with data were only found for the SDII, and not for other considered indices such as heavy rainfall days (Hartmann et al. (2013).

Based on different studies of four different datasets, Hartmann et al. (2013) suggests that the common period of record 1901–2008 exhibits increases in the globally averaged precipitation, with three of the four datasets showing statistically significant changes. Global trends for the period 1951–2008 show a mix of statistically non-significant positive and negative trends amongst the four datasets with the in filled Smith et al. (2012) analysis showing increases and the remainder decreases.

Recent studies have updated these assessments, with more regional results now available in Donat et al, (2013a). Overall, these additional evidences confirm that more locations and studies show an increase than a decrease in extreme precipitation, but there are also wide regional and seasonal variations, and trends in many regions are not statistically significant.

Confidence in precipitation change averaged over global land areas is low for the years prior to 1950 and medium afterwards because of insufficient data, particularly in the earlier part of the record. Available globally incomplete records show mixed and non-significant long-term trends in reported global changes. Further, when virtually all the land area is filled in using a reconstruction method, the resulting time series shows less change in land-based precipitation since 1900, (Hartmann et al., 2013)

IPCC, (2012a) reported based on analyses using PDSI (Palmer Drought Severity Index) that very dry areas had more than doubled in extent since 1970 at the global scale (Trenberth et al., 2007). This assessment was, however, largely based on the study by Dai et al. (2004) only. These trends in the PDSI proxy were found to be largely affected by changes in temperature, but not in precipitation (Dai et al., 2004).

Seneviratne et al. (2012) concluded that droughts had become more common, especially in the tropics and sub-tropics since about 1970. SREX (IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation) provided a comprehensive assessment of changes in observed droughts, updated the conclusions provided by Seneviratne et al. (2012) and stated that the type of drought considered and the complexities in defining drought can substantially affect the conclusions regarding trends on a global scale. Additionally, the chosen proxy (precipitation, evapotranspiration, and soil moisture or stream flow) and time scale can strongly affect the ranking of drought events (Vidal et al., 2010). Based on evidence, Seneviratne et al. (2012) stated that there were not enough direct observations of dryness to suggest high confidence in observed trends globally, although there was medium confidence that since the 1950s some regions of the world have experienced more intense and longer droughts.

Van der Schrier et al. (2013), using monthly sc-PDSI (self calibrated Palmer Drought Severity Index), found no strong case either for notable drying or moisture increase on a global scale over the periods 1901–2009 or 1950–2009, and this largely agrees with the results of Sheffield et al. (2012) over the latter period. A comparison between the sc-PDSI calculated by van der Schrier et al. (2013) and that of Dai (2011b) shows that the dominant mode of variability is very similar, with a temporal evolution suggesting a trend toward drying. However, the same analysis for the period 1950–2009 shows an initial increase in drying in the Van der Schrier et al. (2013) data set, followed by a decrease from the mid-1980s onwards, while data used by Dai (2011b) show a continuing increase until 2000.

Confidence is low for a global-scale observed trend in drought since the middle of the 20th century, owing the lack of direct observations, methodological uncertainties and geographical inconsistencies in the trends. Based on updated studies, IPCCI (2012a) conclusions regarding global increasing trends in drought since the 1970s were probably overstated. However, this masks important regional changes: the frequency and intensity of drought have likely increased in the Mediterranean and WA and likely decreased in central North America and north-west Australia since 1950 (Hartmann et al., 2013).

On the other hand, based on soil moisture simulations with an observation-driven land surface model for the time period 1950-2000, Sheffield and Wood (2008) have inferred predominantly decreasing trends in drought duration, intensity, and severity, but with strong regional variation and including increases in some regions. They concluded that there was an overall moistening trend over the considered time period, but also a switch since the 1970s to a drying trend, globally and in many regions, especially in high northern latitudes.

In summary, there is not enough evidence at present to suggest high confidence in observed trends in dryness due to lack of direct observations, some geographical inconsistencies in the trends, and some dependencies of inferred trends on the index choice. Still there is medium confidence that since the 1950s some regions of the world have experienced more intense and longer droughts in southern Europe and WA but also opposite trends exist in other regions e.g., central North America, northwestern Australia (Hartmann et al., 2013). Finally, studies that support an increasing trend towards the land area affected by drought seem to be at odds with studies that look at trends in dryness concluded Hartmann et al. (2013)

2.4. PROJECTED CHANGES IN CLIMATE

The geographical pattern of near-term surface warming simulated by the CMIP5 (Coupled Model Intercomparison Project Phase 5) models is consistent with previous IPCC reports in a number of key aspects according to Kirtman et al. (2013). Kirtman et al. (2013) state that predictions for averages of temperature, over large regions of the planet and for the global mean, exhibit positive skill when verified against observations for forecast periods up to ten years. Near term changes in global mean surface air temperature will likely be in the range 0.3 to 0.7°C. This projection is valid for the four RCP (Representative Concentration Pathway) scenarios and assumes there will be no major volcanic eruptions or secular changes in total solar irradiance before 2035.

In Kirtman et al. (2013), cold episodes were projected to decrease significantly in a future warmer climate and it was considered very likely that heat waves would be more intense, more frequent and last longer towards the end of the 21st century. These conclusions have generally been confirmed in subsequent studies addressing both global scales (Caesar and Lowe, 2012; Orlowsky and Seneviratne, 2012; Sillmann et al., 2013b) and regional scales (Cattiaux et al., 2012; Wang et al., 2012). In the SREX assessment it is reported that increases in the number of warm days and nights and decreases in the number of cold days and nights are virtually certain on the global scale. Additionally it is projected that the mean global mean surface air temperature for the period 2016–2035 will be more than 1°C above the mean for 1850–1900, and very unlikely that it will be more than 1.5°C above the 1850–1900 mean, Kirtman et al. (2013).

It must be emphasized that detection and attribution studies have previously shown that temperature extremes have already increased in many regions, consistent with climate change projections, and analyses of CMIP5 global projections showed that this trend will continue and become more notable. Furthermore, the CMIP5 model ensemble exhibits a significant decrease in the frequency of cold nights, an increase in the frequency of warm days and nights and an increase in the duration of warm spells (Sillmann et al., 2013b). These changes are particularly evident in global mean projections and; they are also remarkably insensitive to the emission scenario considered (Caesar and Lowe, 2012).

To summarize, in most land regions and in the near-term, the frequency of warm days and warm nights will thus likely continue to increase, while that of cold days and cold nights will likely continue to decrease.

According to AR5, projections of precipitation over some land areas exhibit positive skill. The frequency and intensity of heavy precipitation events over land will likely increase on average in the near term. However, this trend will not be apparent in all regions because of natural variability and possible influences of anthropogenic aerosols.

AR4 projections of the spatial patterns of precipitation change in response to GHG forcing showed consistency between models on the largest scales but large uncertainty on smaller scales. The consistent pattern was characterized by increases at high latitudes and in wet regions, including the maxima in mean precipitation found in the tropics, and decreases in dry regions including large parts of the subtropics. Large uncertainties in the sign of projected change were seen especially in regions located on the borders between regions of increases and regions of decreases. Tebaldi et al. (2011) and Power et al. (2012) highlighted the fact that if models agree that the projected change is small in some sense relative to internal variability, then agreement on the sign of the change is not expected. This recognition led to the identification of sub-regions within the border regions, where models agree that projected changes are either zero or small concluded Power et al. (2012). Power et al. (2012) stated that the consensus among models on precipitation projections is more widespread than might have been inferred on the basis of the projections described in the AR4 (Kirtman et al., 2013).

The general pattern of wet-get-wetter (Allan et al., 2010) and dry-get-drier has been confirmed, although with deviations in some dry regions at present that are projected to become wetter by some models, e.g. East Africa. It has been demonstrated that the wet-get-wetter pattern implies an enhanced seasonal precipitation range between wet and dry seasons in the tropics, and enhanced inter-hemispheric precipitation gradients (Kirtman et al., 2013).

In the near term, and on regional or smaller scales, the magnitude of projected changes in mean precipitation was small compared to the magnitude of natural internal variability in AR4 (Kirtman et al., 2013). Deser et al. (2012) and Power et al. (2012) confirmed this result and provided more quantification.

In addition to the response to GHG forcing, forcing from natural and anthropogenic aerosols may exert significant impacts on regional patterns of precipitation change as well as on global mean temperature (Bollasina et al., 2011; Yue et al., 2011; Fyfe et al., 2012).

For the 21st century, the AR4 and the SREX concluded that heavy precipitation events were likely to increase in many areas of the globe (Kirtman et al., 2013). Since AR4, a larger number of additional studies have been published using global and regional climate models (Hanel and Buishand, 2011; Heinrich and Gobiet, 2011; Meehl et al., 2012).

For the near term, CMIP5 global projections confirm a clear tendency for increases in heavy precipitation events in the global mean, but there are significant variations across regions (Sillmann et al., 2013b). Past observations have also shown that interannual and decadal variability in mean and heavy precipitation are large, and are in addition strongly affected by internal variability e.g. El Niño, volcanic forcing and anthropogenic aerosol loads. In general models have difficulties in representing these variations, particularly in the tropics. Thus the frequency and intensity of heavy precipitation events will likely increase over many land areas in the near term, but this trend will not be apparent in all regions, because of natural variability and possible influences of anthropogenic aerosols. Simulations with regional climate models demonstrate that the response in terms of heavy precipitation events to anthropogenic climate change may become evident in some but not all regions in the near term (Kirtman et al., 2013).

Previous work reviewed in AR4 has established that extreme precipitation events may increase substantially stronger than mean precipitation amounts (Kirtman et al., 2013).
Models project near-term increases in the duration, intensity and spatial extent of heat waves and warm spells. These changes may proceed at a different rate than the mean warming. For example, several studies project that European high-percentile summer

temperatures warm faster than mean temperatures (Kirtman et al., 2013). On regional scales, mean projected changes are almost everywhere smaller than the estimated standard deviation of natural internal variability according to Kirtman et al. (2013).

Seneviratne et al. (2012) assessed that model projections indicated an increase in droughts, in particular in subtropical and mid-latitude areas (Christensen et al., 2007). An increase in dry spells length and frequency was considered very likely over the Mediterranean region, southern areas of Australia, and New Zealand and likely over most subtropical regions, with little change over northern Europe. Continental drying and the associated risk of drought were considered likely to increase in summer over many mid-latitude continental interiors, in boreal spring, and dry periods of the annual cycle over Central America.

On the global scale, Burke and Brown (2008) provided an analysis of projected changes in drought based on four indices using two model ensembles: one based on a GCM expressing uncertainty in parameter space, and a multi-model ensemble of 11 GCM simulations from CMIP3. Their analysis revealed that SPI (Standardized Precipitation Index), based solely on precipitation, showed little change in the proportion of the land surface stricken by drought, but all the other indices, which include a measure of the atmospheric demand for moisture, showed a statistically significant increase of drought with the extension of the drought stricken area by 5 to 45 %. This study also highlighted large uncertainties in regional changes in drought (IPCC, 2012).

2.5. OBSERVED AND PROJECTED CLIMATE CHANGE IN AFRICA

The climates of Africa are both spatially varied and varying temporally: spatially varied because they range from humid equatorial regimes, through seasonally-arid tropical regimes, to sub-tropical Mediterranean-type climates, and varying because all these climates exhibit differing degrees of temporal variability, particularly with regard to rainfall. Understanding and predicting these inter-annual, inter-decadal and multi-decadal variations in climate has become the major challenge facing African and Africanspecialist climate scientists in recent years (Hulme et al., 2001; AR5). In the following paragraphs we will have a look at climate change in Africa, we will start by giving an overview of Guinea climate characteristics and climate change; This will be followed by the outcome of up to date studies of African climate change and variability over the last century, based on the observational record of Africa climate, and finally we will present the projected climate change for Africa from GCM and RCM results deposited with the IPCC.

Most of Africa is insufficiently sampled by climatic observations to allow an overall and high certainty evaluation about the continental scale changes. However, there is some evidence of changes in temperature extremes from the observations gathered since 1950, since most of the regions on this continent for which data are available have exhibited warming in temperature extremes. In earlier available analyses on climate change in Africa including Kruger et al. (2006); New et al. (2006); and most recently, Aguilar et al. (2009), the results are consistent with the assessment of an increase in warm days and nights and a reduction in cold days and nights on the regional basis, although the referred studies do not necessarily consider trends in all four variables. Only a few studies report trends that are not statistically significant or even trends opposite to the global tendencies occur in some extremes, sub-regions, seasons, or decades. As a general result in Kruger and Sekele (2013) state that warm extremes have increased and cold extremes have decreased over South Africa; the trends however vary on a regional basis. In a previous study by New et al. (2006) the same result for the eastern part of southern and WA was reported. Recent available studies also suggest that the number of cold spells has decreased significantly since the 1950s (Donat et al., 2013a, 2013c). Confidence in observed trends in daily temperature extremes in Africa and generally varies from low to medium depending on the region (Kuglitsch et al., 2009; IPCC, 2012).

According to IPCCI (2012a) there is low to medium confidence in regional trends in heavy precipitation in Africa due to the partial lack of data and data analysis, and due to the lack of consistency in reported trends. Seneviratne et al. (2012) and Trenberth et al. (2007) reported an increase in heavy precipitation over southern Africa, but this appears to depend on the region and precipitation index examined (Kruger, 2006; New et al., 2006; Seleshi and Camberlin, 2006; Aguilar et al., 2009). Central Africa exhibited a decrease in heavy precipitation over the last half century (Aguilar et al., 2009), however, data coverage for large parts of the region was poor. Precipitation from heavy events has decreased in western central Africa, but with low spatial coherence (Aguilar et al., 2009). Rainfall intensity averaged over southern and WA has increased (New et al., 2006).

Camberlin et al. (2009) analyzed changes in components of rainy seasons' variability over the time period 1958-1987 in Equatorial East Africa, but did not specifically address trends in heavy precipitation. There were decreasing trends in heavy precipitation over parts of Ethiopia during the period 1965-2002 (Seleshi and Camberlin, 2006). There is medium confidence that since the 1950s some regions have experienced a trend to more intense and longer droughts, in particular in WA, but in some other regions droughts have become less frequent, less intense, or shorter (Seneviratne et al., 2012).

There are still large uncertainties regarding observed drought trends in Africa stated AR5. Data availability, quality and length of record remain issues in drawing conclusions on the continental scale. Additionally, the type of drought considered and the complexities in defining drought can substantially affect the conclusions regarding trends on a large scale. Nonetheless, there is some agreement between studies over different time frames and using different drought indicators regarding the increasing drought occurrence in WA according to AR5. New analyses continue to support the AR4 and SREX conclusions. Hartmann et al. (2013) also indicated that it is likely that the frequency and intensity of drought has increased in the Mediterranean and WA. Recent available studies also suggest that the number of cold spells has reduced significantly since the 1950s (Donat et al., 2013a, 2013c).

According to Perkins et al. (2013), owing to lack of studies over Africa but also in part owing to differences in trends depending on how heat waves are defined, confidence in heat waves changes is medium.

Based on updated studies, AR4 conclusions regarding global increasing trends in drought since the 1970s were probably overstated (Hartmann et al., 2013). However, this masks important regional changes: the frequency and intensity of drought have likely increased in the Mediterranean and WA.

Overall, Africa assessments are consistent with the global assessments provided previously. It should be noted, however, that the assessed uncertainty is larger at the regional level than at the continental or global level. Global-scale trends in a specific extreme may be either more reliable or less reliable than regional-scale trends, depending on the geographical uniformity of the trends in the specific extreme. Hence, Seneviratne et al. (2012) assess that in terms of absolute values, the 20-year extreme annual daily maximum temperature will likely increase by about 2 to 5°C by the late 21st century, and by about 1 to 3°C by mid-21st century, depending on the region and emissions scenario.

A widespread decrease in the maximal annual temperature range over WA, the Sahel, and the Congo basin is expected. Both twenty first century Tx and Tn are projected to increase, but the magnitude of the increase is greater for the Tn. Mid twenty first century Tx and Tn are projected to increase in all regions with regional and seasonal variations that affect the daily temperature range. The DTR over WA and Central Africa during the boreal spring and fall, over the Sahel during May–September, and over the Congo basin during the boreal winter and spring is projected to decrease. Conversely, the DTR (Daily Temperature Range) will increase over the Horn of Africa during the boreal winter and over Kenya– Tanzania during the boreal summer associated with greater warming of Tx due to a decrease in atmospheric relative humidity (Vizy et al., 2012; Kirtman et al., 2013).

Simulations by 12 GCMs (General Circulation Models) projected an increase in heavy precipitation intensity and mean precipitation rates in east Africa, more severe precipitation deficits in the southwest of southern Africa, and enhanced precipitation further north in Zambia, Malawi, and northern Mozambique (Shongwe et al., 2009, 2011).

The number of dry days is predicted to decrease over the Congo basin and over central Africa and the Sahel east of 08East in the mid-twenty-first century. Inversely, over East Africa, the number of dry days is projected to increase.

Extreme wet days are predicted to increase over WA, the southern Sahel, the Ethiopian Highlands, and over Somalia. Over Congo basin decrease is projected in the number of extreme wet days. Extreme wet day rainfall intensity is projected to decrease over most western Africa countries and increase over the horn of Africa.

Over WA both the number of dry and intense rainfall days during the boreal summer are projected to increase indicating that the summer rainfall will be delivered in fewer, but more intense events.

Over the Sahel the number of extreme dry days is projected to decrease, while the number of extreme heavy rainfall days increases. Rainfall is projected to intensify over the Congo during the boreal spring and weaken in the fall and winter, with opposite results to the east over Kenya and Tanzania. These changes in extreme precipitation will have important implications for the agricultural sector as most of Africa relies on rain-fed agricultural practices. An improved understanding of how rainfall will be delivered over the annual cycle will support the development of adaptation strategies (Vizy et al., 2012; Kirtman et al., 2013).

Available global and regional studies of hydrological drought (Hirabayashi et al., 2008; Feyen and Dankers, 2009) project a higher likelihood of hydrological drought by the end of this century, with a substantial increase in the number of drought days (defined as stream flow below a specific threshold) during the last 30 years of the 21st century over central and southern Africa.

Significant increase in the number of heat wave days is predicted over most of the Sahel and Saharan Africa. There is also a projected increase in heat wave days in northernmost WA and central Africa primarily during boreal springtime.

Death and hospitalizations linked to heat waves are likely to increase over the Sahara and Sahel, but also to extend equator ward over tropical Africa into areas that up to now do not experience such events.

By the mid twenty first century there will likely be a shift to warmer extreme temperatures over sub-Saharan and tropical Africa, although the severity of these changes is not uniform across the annual cycle and is regionally dependent (Vizy et al., 2012; Kirtman et al., 2013).

3. DATA AND METHODS

In this section we describe the dataset employed in this work and the approaches applied to quality control and homogenize raw data, compute and analyze climate indices.

3.1. DATASET DESCRIPTION

The dataset employed in this work contains daily maximum temperature, daily minimum temperature and daily accumulated precipitation data from twelve weather stations located in areas characterized by different climatic conditions. These stations are managed by National Meteorological Service of Guinea, which provided the data used in this study. Stations' network coverage is sparse, but uniformly distributed across the country and located both in low and high altitude ranging from 26m to 1026m. Network comprises only conventional weather stations with vertically fixed mercury-in-glass minimum and maximum thermometers in wooden Stevenson screen and Hellmann pluviometers with 200cm2 orifice. Stations are located in sites following the WMO (World Meteorological Organization) standards. Data are recorded from four (0900UTC, 1200UTC, 1500UTC and 1800UTC) to eight (0000UTC, 0300UTC, 0600UTC... 2100UTC) times per day. The spatial distribution of these sites is shown in Figure 3-1 and their characteristics are presented in Table 3-1. The data that we used in this study is representative of the daily maximum and minimum air temperature, and daily total precipitation. Of the twelve stations, ten have records that start in 1941 for precipitation. At Koundara precipitation records begin very late in 1970. Temperatures observations start some years later than the precipitation for the majority of the stations, Faranah, Kissidougou and Koundara having started last. Monthly time series were calculated from daily observation values. WMO, (2011) recommends that a monthly value should not be calculated if more than ten daily values are missing or five or more consecutive daily values are missing. In the case of elements for which the monthly value is a sum of daily values rather than a mean such as for rainfall, a monthly value should be calculated only if either all daily observations are available, or if any missing days are incorporated in an observation accumulated over the period of missing data on the day when observations resume. In our case monthly temperature is calculated only if no more than ten daily values are missing and for monthly total precipitation no more than four daily observations are missing. Details on the QC (Quality Control) check of daily data and details on the homogeneity check are given later in this section.

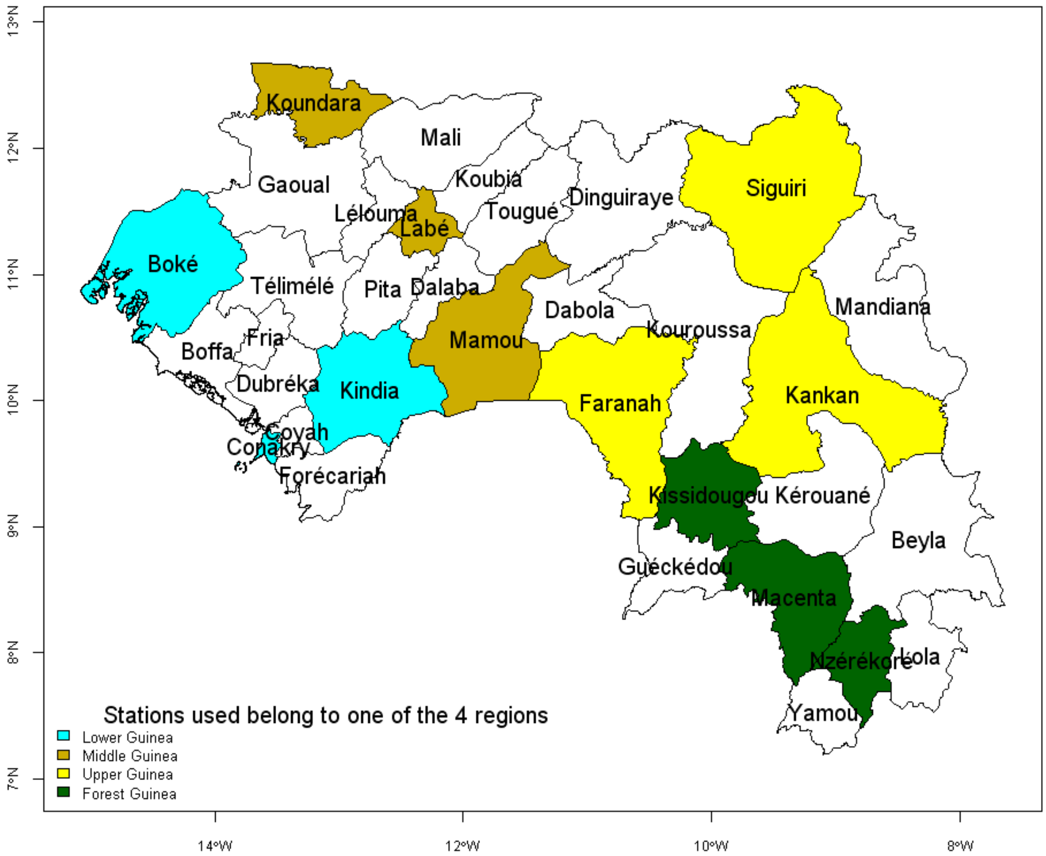


Figure 3-1: Study area with the geographical locations of Guinea synoptic weather stations used in this study highlighted in color according to the region they belong to

Table 3-1: Stations location and length of raw data used in this thesis

Station Name	WMO Code	Lat. North	Long. West	Alt. (m)	Covered period						Missing data (%)		
					RR		Tx		Tn		RR	Tx	Tn
Boke	61816	10.93	14.32	69	1941	2010	1941	2010	1941	2010	1.53	7.4	4.35
Conakry	61832	9.57	13.62	26	1941	2010	1941	2010	1941	2010	0.16	0.65	0.48
Faranah	61833	10.03	10.83	459	1941	2010	1975	2010	1971	2007	4.16	11.2	1.40
Kankan	61829	10.38	9.3	384	1943	2010	1947	2010	1945	2010	0.51	8.69	6.41
Kindia	61818	10.05	12.87	459	1941	2010	1941	2010	1941	2010	0.28	0.85	0.53
Kissidougou	61834	9.42	10.13	525	1941	2009	1974	2009	1976	2009	3.98	3.32	7.79
Koundara	61802	12.57	13.52	90	1970	2010	1976	2010	1989	2010	9.03	10.59	0.25
Labe	61809	11.32	12.3	1026	1941	2010	1941	2010	1941	2010	0.36	2.23	4.29
Macenta	61847	8.53	9.5	544	1941	2010	1941	2005	1941	2005	1.39	11.17	2.62
Mamu	61820	10.37	12.3	719	1941	2010	1941	2010	1941	2010	1.14	1.73	1.82
N'Zerekore	61849	7.75	8.3	470	1941	2010	1957	2010	1957	2010	1.21	1.97	2.18
Siguiri	61811	11.43	9.17	366	1941	2010	1944	2004	1945	2008	1.98	11.93	5.57

Climate change analysis from observed climate time series require the availability of long enough climate time series. Unfortunately few long term climate time series are free of changes in the conditions and practice of observations and therefore, it is rare that they are usable in their original state. This means that the quality of the original data is not always high enough for obtaining reliable spatial-temporal comparisons with their direct use. In fact, the statistical characteristics of climate time series may have several kinds of artificial disturbances that do not reflect real changes in climate. It may happen that climate analysis is made based on data that are incorrect, and thus the conclusions can be biased. It is, therefore essential before any analysis of a climate time series, first to ensure the quality and homogeneity of the data (Peterson et al. 1998b). Measurement/observation or digitizing errors may have been introduced and missing data may also be frequent.

According to Gandin (1988), the errors associated with meteorological records can be classified into three main groups: random, systematic, and rough errors. Random errors are intrinsic to the measurement definition, an approximation of the real atmospheric state, and so they are unavoidable. Systematic errors are associated with a more or less persistent factor that introduces a certain bias in the reported values. Biases can be produced by any practice that causes a systematic deviation from the prescribed practices of climate observations or by changes in the technical conditions of the observations. For instance, this can be the result of a recalibration of the recording instrument, changes in exposure or type of the sensor, changes in the observing time, etc. e.g., Karl et al. (1986);

Parker et al. (2000); Aguilar et al. (2003); Thompson et al. 2008; Trewin (2010). The techniques developed to identify and correct these biases in climate time series are known as homogeneity adjustments or homogenization (Alexanderson 1986; Karl and Williams 1987; Peterson et al. 1998a).

Rough errors (most usually called non-systematic) are associated with a malfunctioning of the sensor or mistakes introduced during data processing, transmission, reception, or storage. Recognition and suppression of this third type of erroneous record are the objectives of any QC process (Gandin, 1988), meanwhile the attempt to detect and correct systematic errors is done through homogenization.

The 12 stations employed in this dissertation have been carefully quality controlled using the RClimdex-ExtraQC routines. These routines contain graphical and statistical information to quality control single time series. The values identified as potentially erroneous have been carefully scrutinized and a subjective decision has been made to validate, correct or set them to missing.

For each of the 12 stations used in this study we present the results of quality control Figure 3-2 to 3-13. Monthly boxplots (upper left panel on Figures 3-2 to 3-13) and annual time series boxplots (upper right panel on Figures 3-2 to 3-13) identify potential outliers amplitude and temporal location, while the graph of frequency (lower left panel on Figures 3-2 to 3-13) points out rounded precipitation time series.
In the remainder of this section, we specify the different tests contained in the above mentioned software.

Dates checking: identifies duplicated dates, missing dates or invalid dates such as 30th of February.

Rounding test: check if the series are rounded. In precipitation zero values are omitted.

Out of climatological range detection: based on fixed threshold, identifies raw data exceeding a user defined number of standard deviation (usually 4).

Outlier detection: based on inter-quartile range exceedance, identified as outlier values exceeding the difference between the first quartile and the third quartile range for temperatures raw data and values exceeding the difference between the first quartile and the fifth quartile range for precipitation data.

Inter-diurnal differences based on fixed threshold values: Identifies days with too large or too small temperature range.

Coherence between Tn and Tx: Identifies erroneous days cooler than the nights.
Repetitive values control: Identifies 3 or more consecutive repetitive values in daily or night time temperature.

Jump test: identifies consecutive days where the difference between day time temperatures is at least 20 ºC or the difference between night time temperatures is at least 20 ºC.

First, dates were checked to see if there are missing dates or repetitive dates or invalid dates. None of these anomalies was identified in the stations raw data. On contrary, several groups of four or more than four consecutive days with identical values were identified and set to missing. In this regards, the maximum repetitive consecutives values was identified in Tn at Macenta with several repetitive blocs totalizing 166 raws data; and the minimum was detected in Koundara with only three blocs having a total of four raws data. Unusual very low Tn = 0 values were identified at Labe on the 01-03/03/2009 and set to missing. Difference between consecutive daily observations was also checked to see if the changes in consecutive daily observation fall within the climatologically expected limits. In this regards few isolated cases of inconsistencies were also observed. For example daily Tx of the current day colder than the daily Tn of the previous day or current daily Tn warmer than previous daily Tx was detected at Koundara, Macenta and Mamu on the followings days 20-21/06/2005, 26-27/07/1937 and 28-29/08/1931 respectively. Likewise, several jump were identified in Tx and Tn as indicated in Table 3-2.

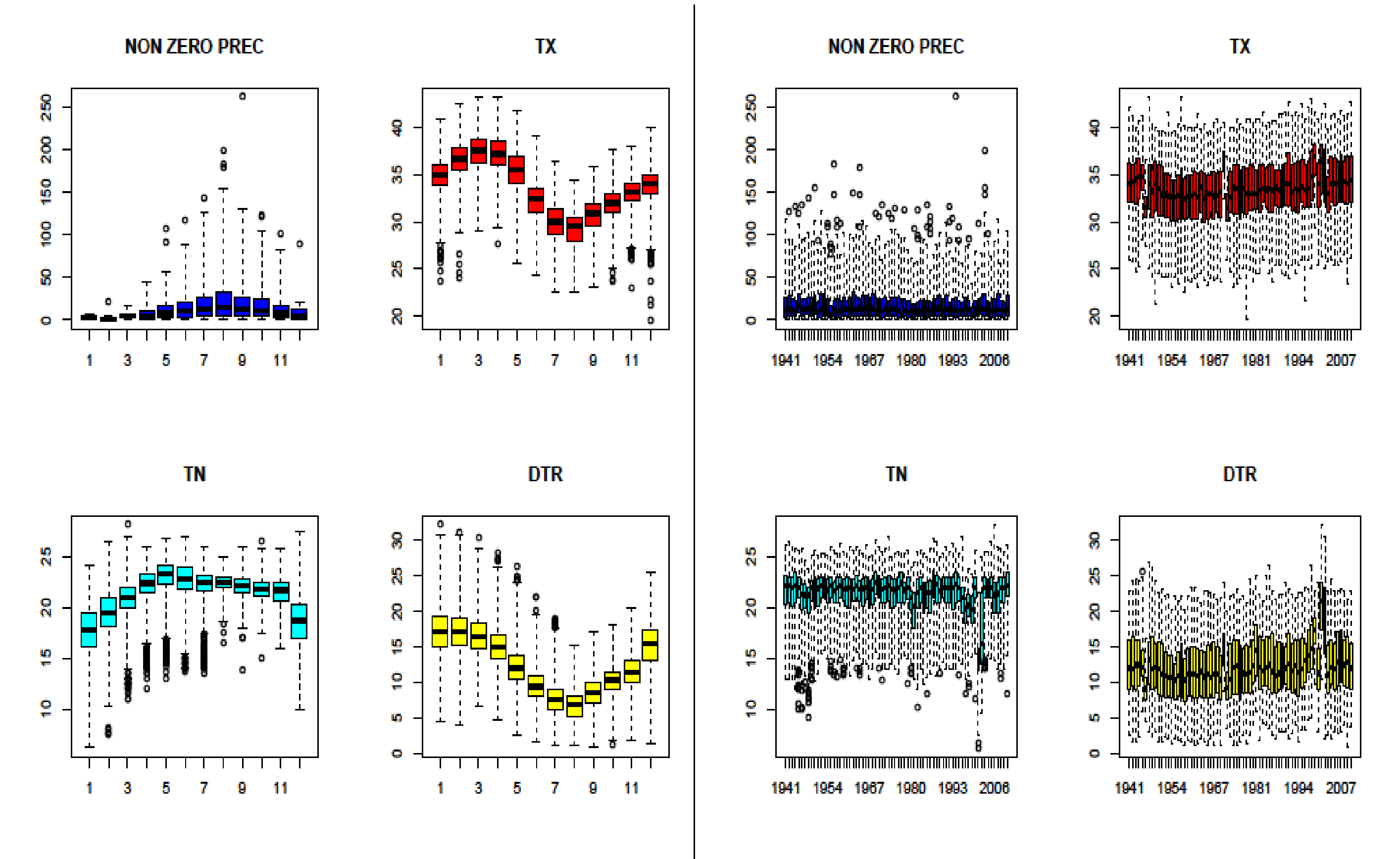
Very few digitizing errors were identified: For example 8 ºC was digitized at Mamu, on the 13/01/2000 instead of 18ªC, similar error was also detected in Labe on 02/03/2007 where 1.2ªC was keyed in instead of 11.2ªC.

In addition QC also identified outliers in daily precipitation, Tx and Tn. Outliers that were identified by either statistical tools or box plots were visually assessed to find out if they were part of a cold or warm spell; and unusual high/low values were occasionally compared to nearby stations. Subjective judgment was then applied to validate or to set the identified outlier to missing. With respect to the precipitation RClimDex Extra-QC box plots were analyzed to dismiss identified outliers despite of the large variety of distributions from which daily rainfall is derived in such a climatologically diverse region. The number of outliers and the number of jump set to missing are indicated into brackets in Table 3-2 where results are summarized.

Table 3-2: Summary of conducted quality control

Station Name	WMO Code	Repetitive Values		Outliers			Jump		Number of raw set to missing		
		Tx	Tn	Tx	Tn	RR	Tx	Tn	RR	Tx	Tn
Boke	61816	53	53	52(4)	219(10)	20	15(13)	2(1)	0	70	64
Conakry	61832	38	32	28(5)	18(12)	46(1)	0	0	1	42	44
Faranah	61833	21	5	42(3)	5	13	7(5)	0	0	29	5
Kankan	61829	38	40	54(7)	20	16	24(17)	8(8)	0	62	48
Kindia	61818	30	47	71(5)	224(77)	13	13(6)	0	0	41	124
Kissidougou	61834	24	21	24(2)	24	33	1	0	0	27	21
Koundara	61802	10	4	25	4	7	7(7)	1	0	17	4
Labe	61809	28	23	74(6)	45(8)	19	8(5)	4(3)	0	39	34
Macenta	61847	53	166	134(17)	67	32	5(4)	4(4)	0	74	170
Mamu	61820	43	32	36(1)	30(4)	24	5(4)	7(4)	0	48	40
N'Zerekore	61849	25	24	26(3)	36(1)	34	1(1)	0	0	29	25
Siguiri	61811	14	10	55(9)	21	23	19(10)	3(2)	0	33	12

The number of outliers and the number of jump set to missing are indicated into brackets



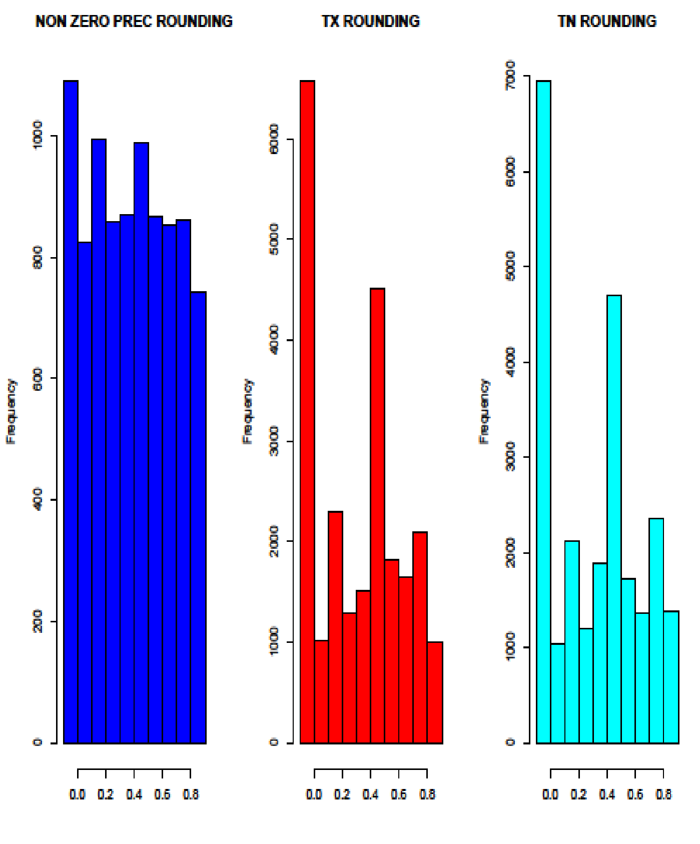


Figure 3-2: Boke QC summary: Monthly boxplots (upper left panel) for the precipitation above 0 mm, for Tx, for Tn and for DTR. Theses graphs identify as circle those values that exceed the third quartile + 3 times the interquartile range for Tx and Tn (5 times the interquartile range for precipitation) and those that do not reach the first quartile - 3 times the interquartile range (5 times the interquartile range for precipitation). Those values are suspicious outliers. The same graphs are presented as annual time series boxplots (upper right panel) for the precipitation above 0 mm, for Tx, for Tn and DTR. Lower left panel shows the frequency diagrams of the decimal 10 possible values for precipitation above 0 mm, for Tx and for Tn. Frequency diagrams help identifying rounded time series.

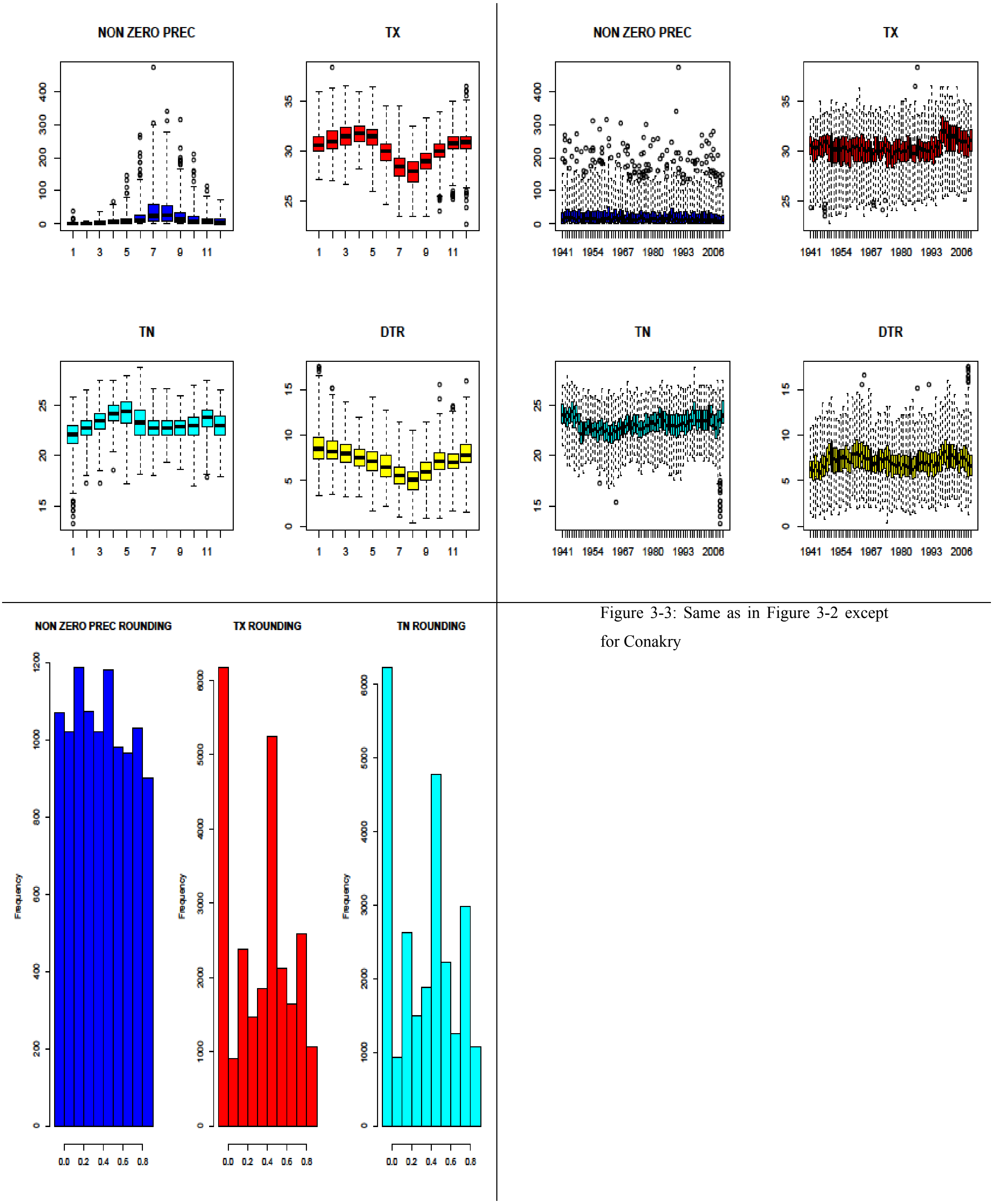


Figure 3-3: Same as in Figure 3-2 except for Conakry

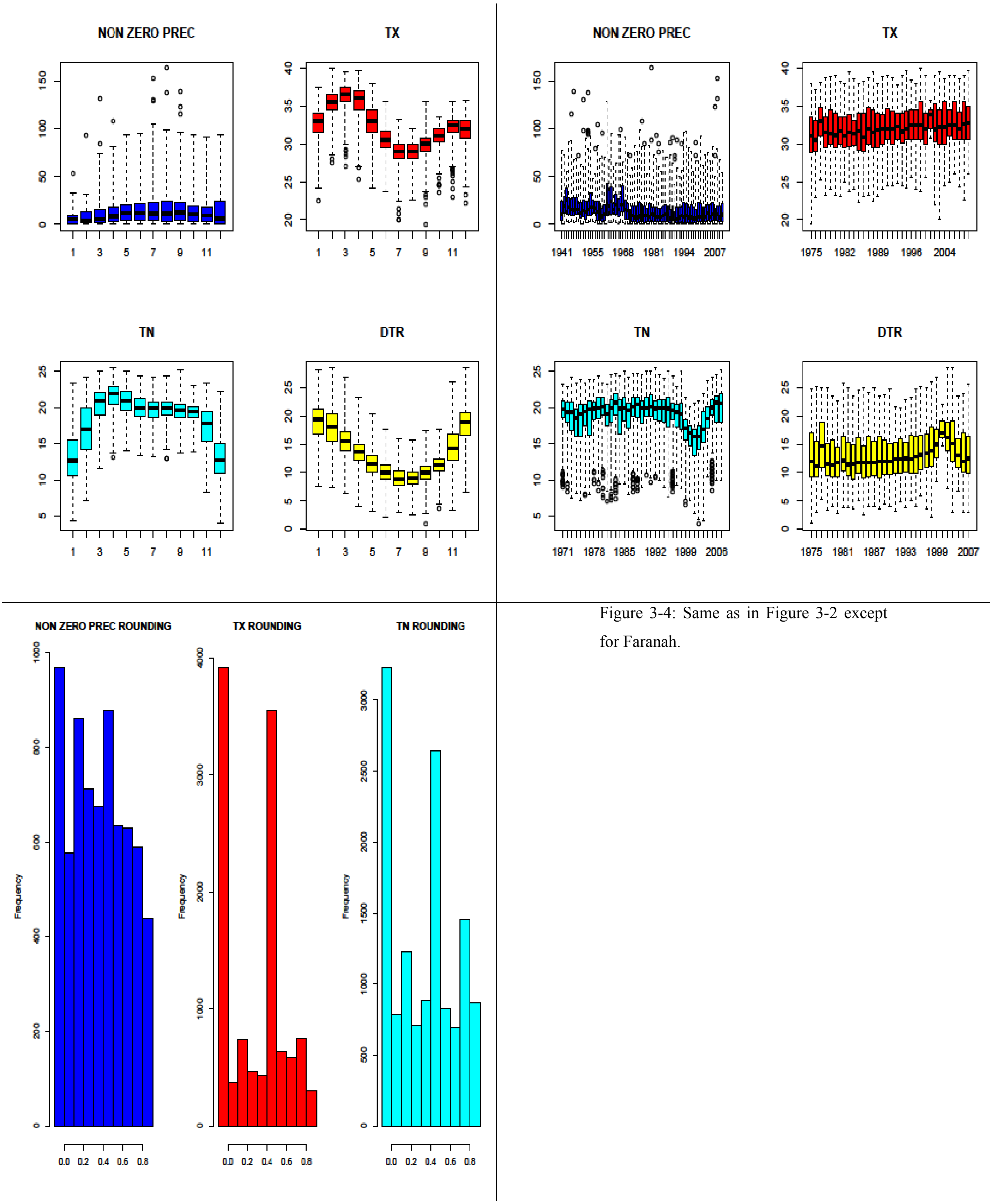


Figure 3-4: Same as in Figure 3-2 except for Faranah.

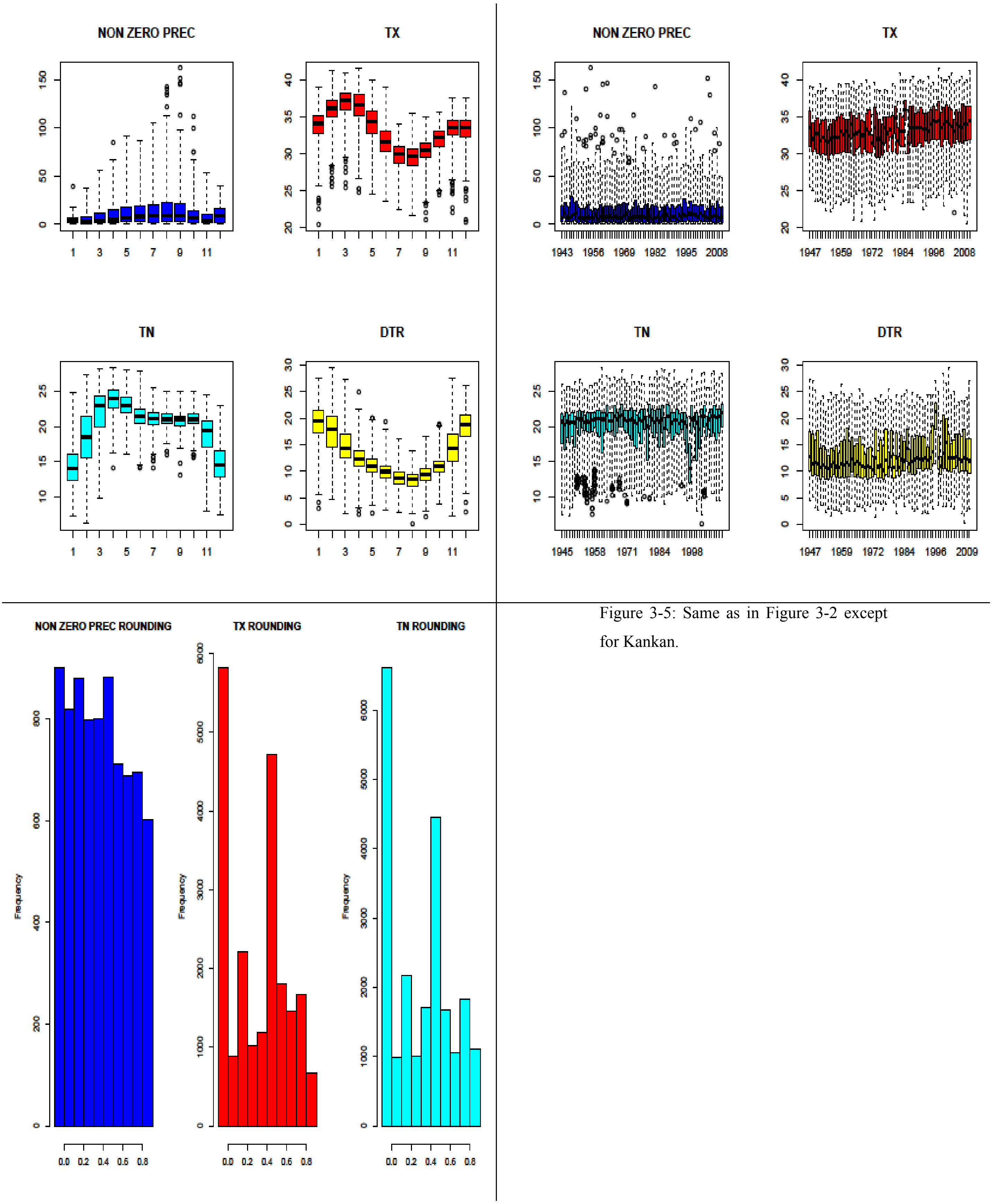
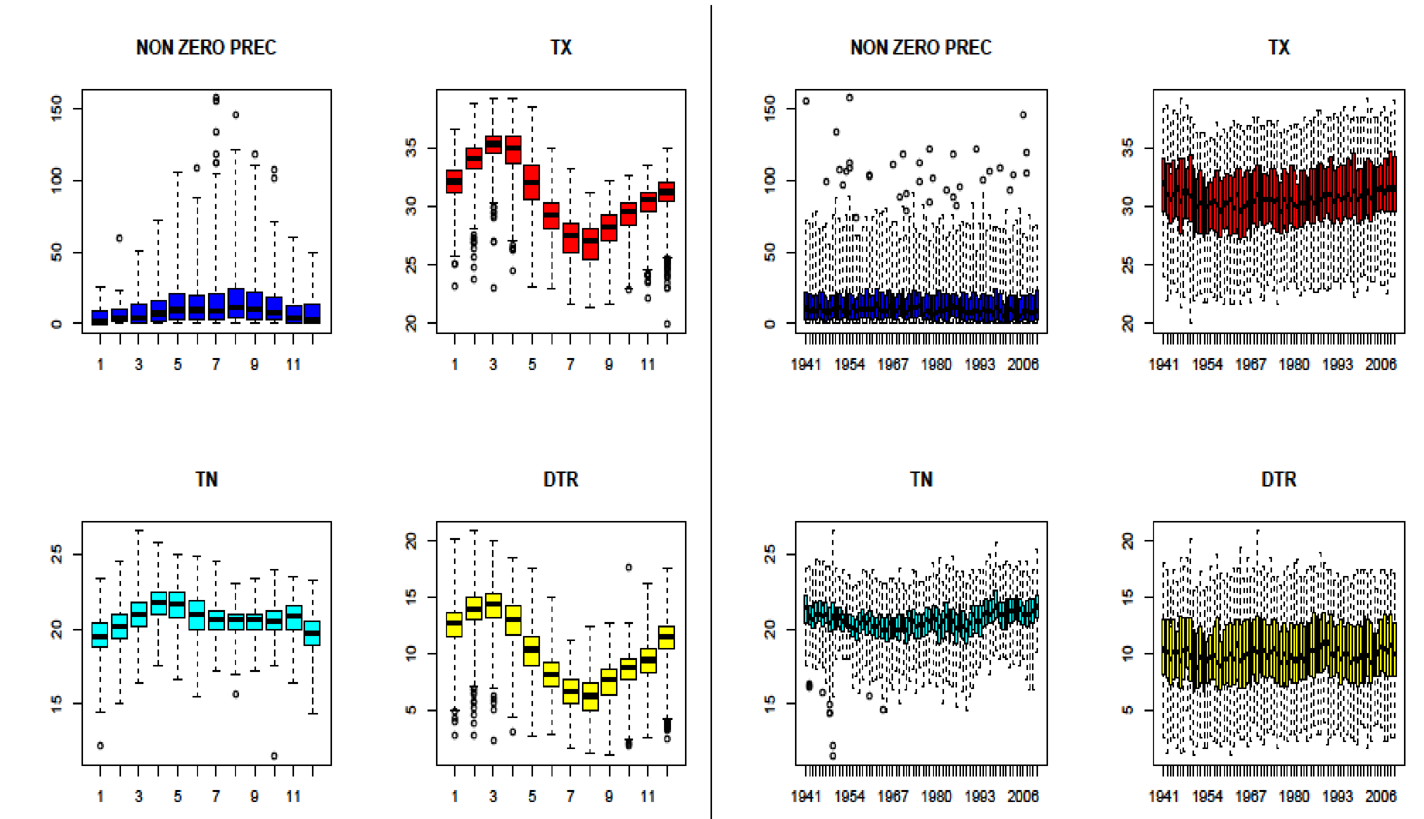


Figure 3-5: Same as in Figure 3-2 except for Kankan.



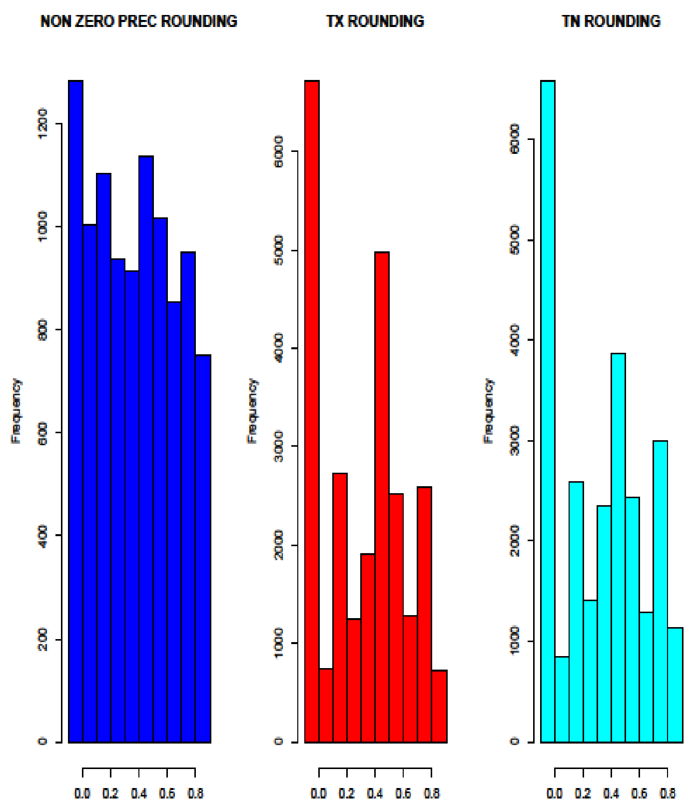
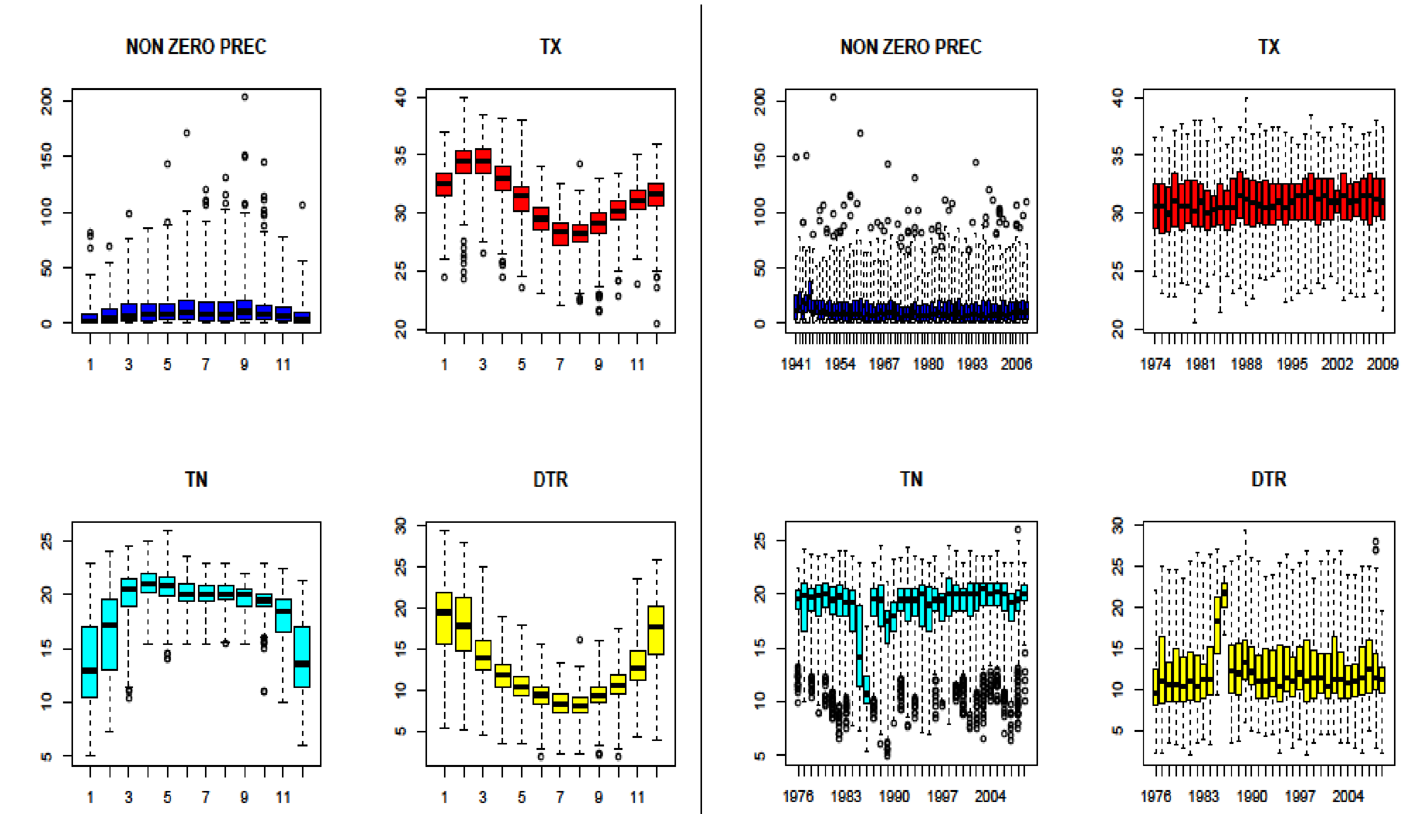


Figure 3-6: Same as in Figure 3-2 except for Kindia.



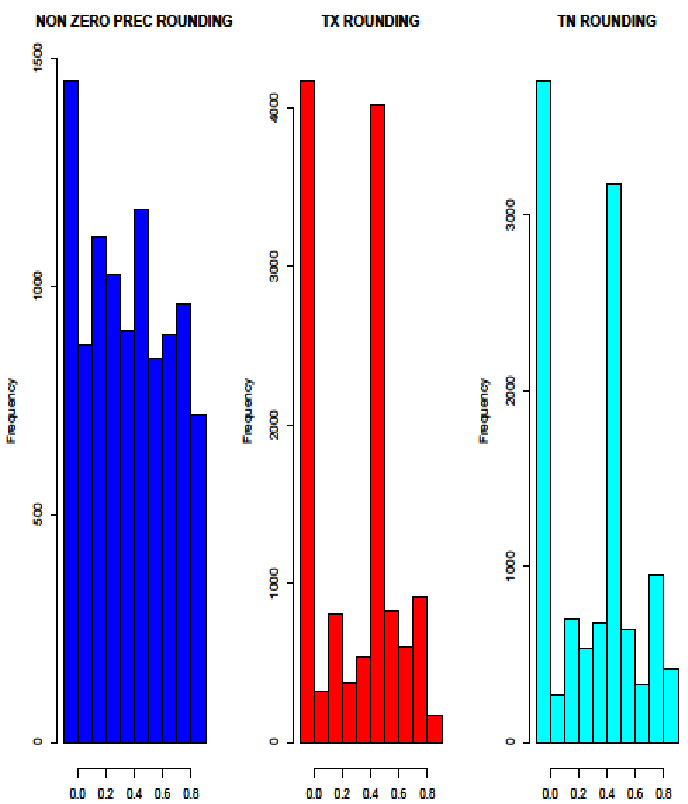


Figure 3-7: Same as in Figure 3-2 except for Kissidougou.

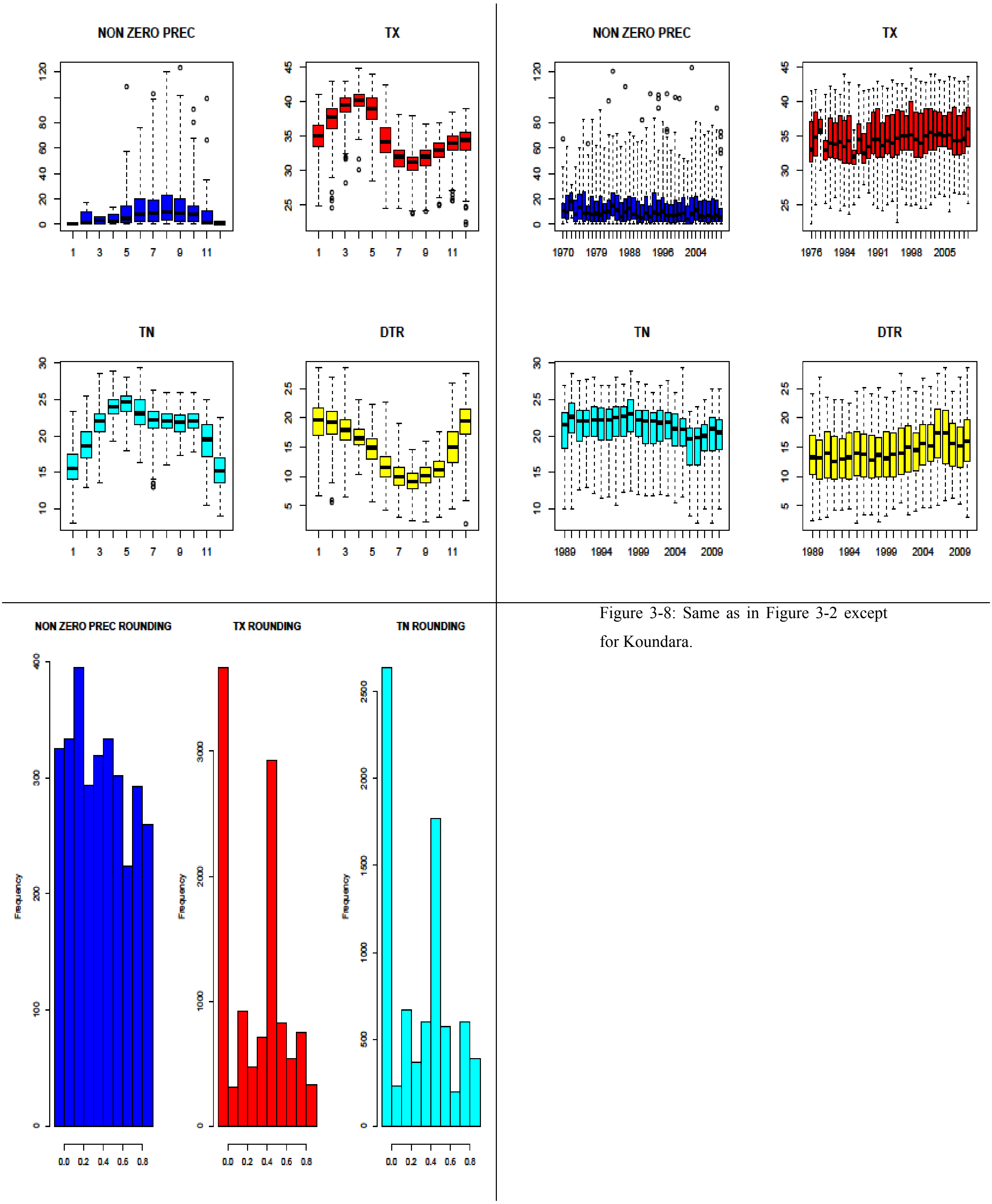
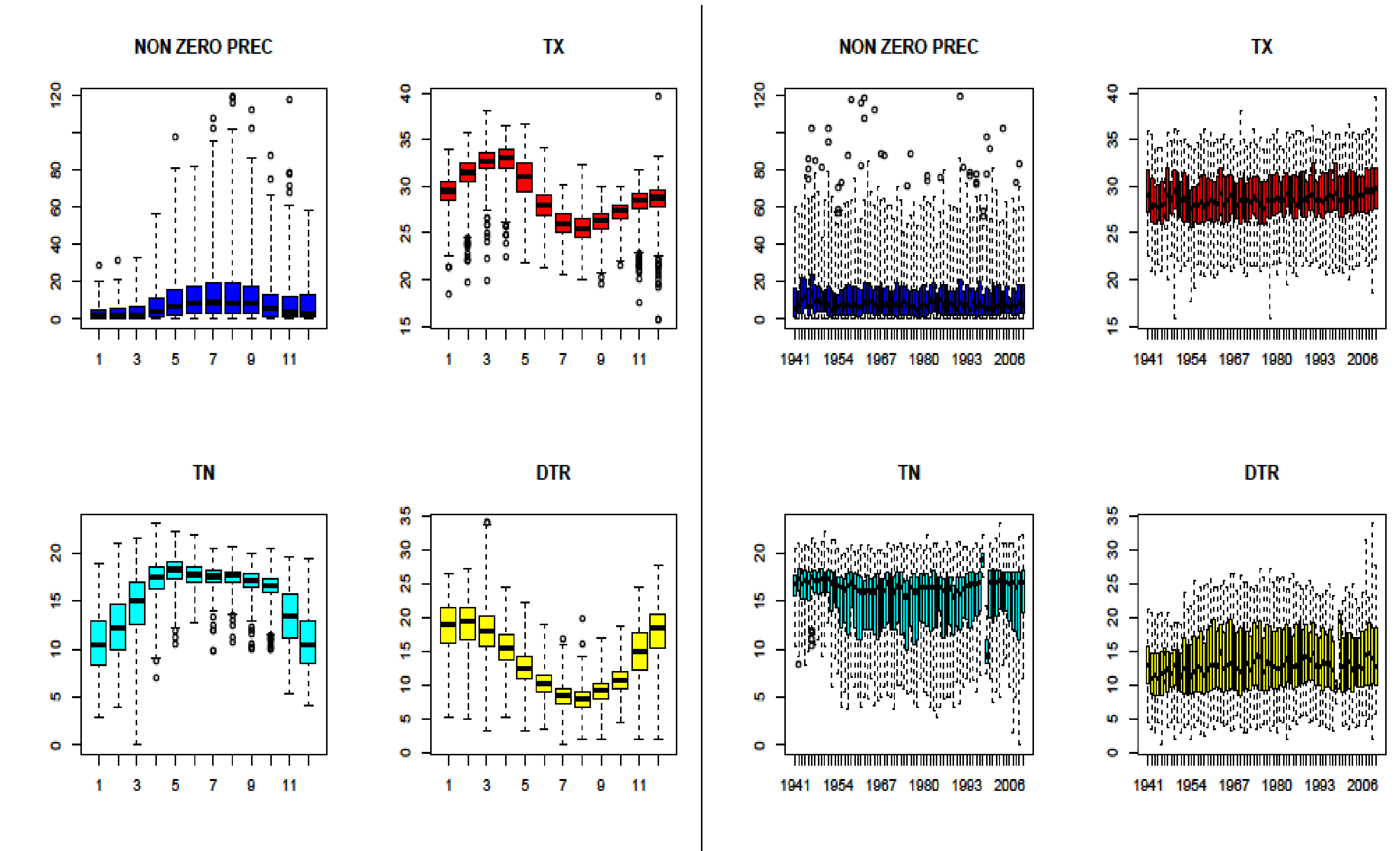


Figure 3-8: Same as in Figure 3-2 except for Koundara.



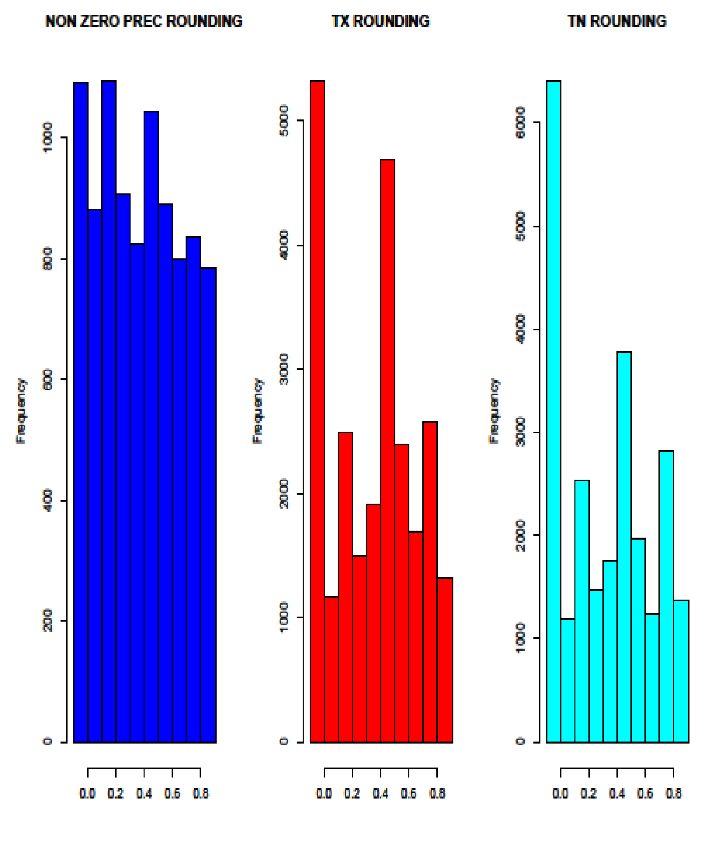
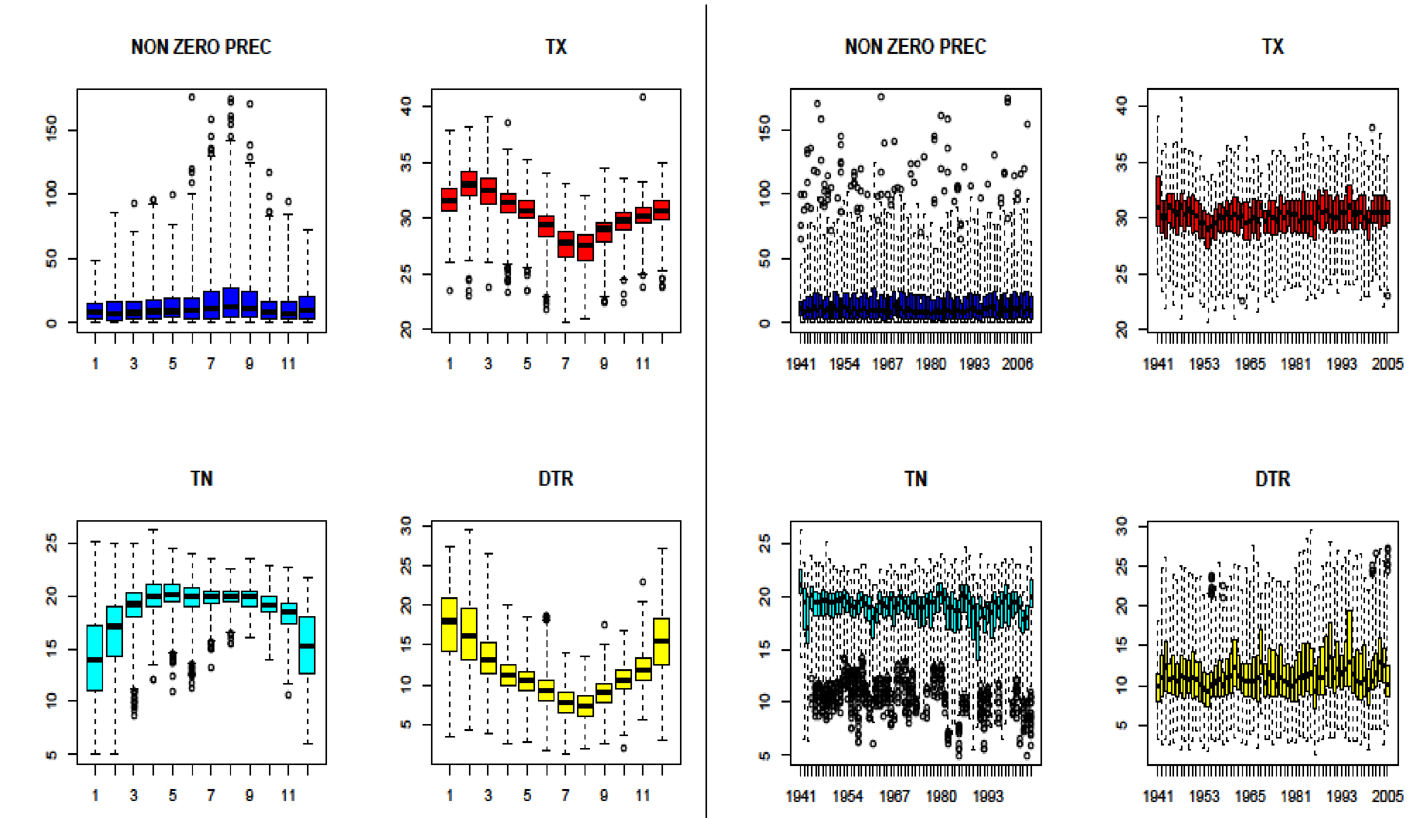


Figure 3-9: Same as in Figure 3-2 except for Labe.



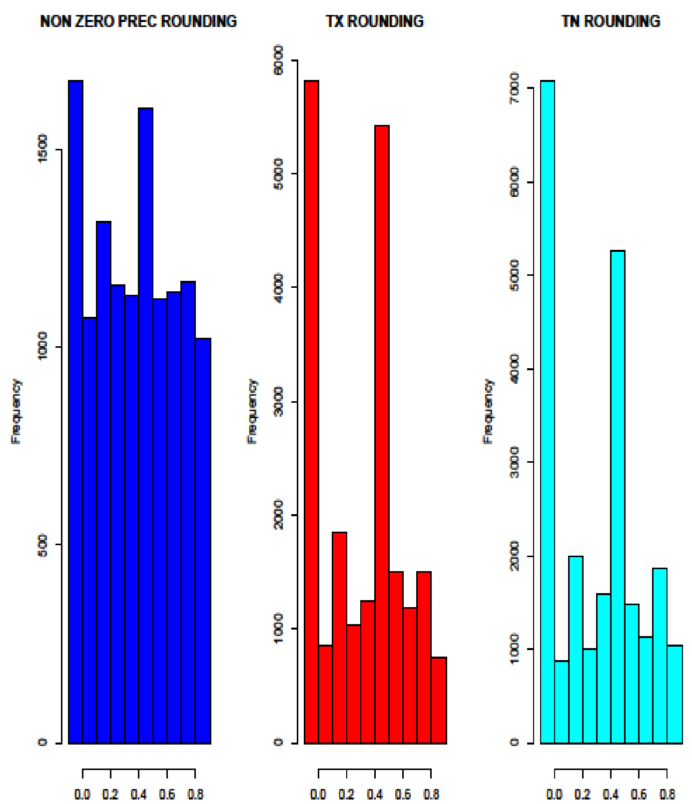


Figure 3-10: Same as in Figure 3-2 except for Macenta.

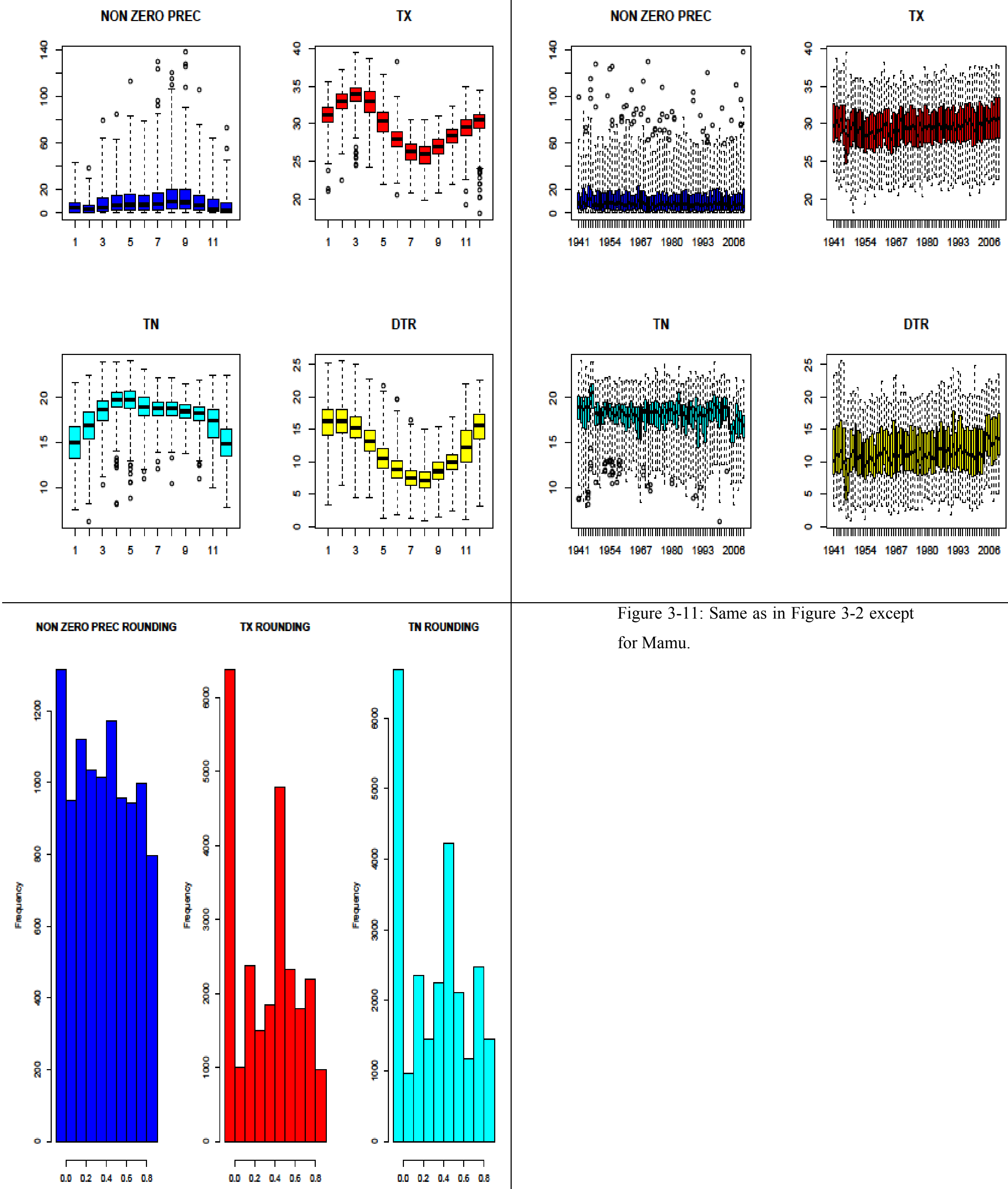
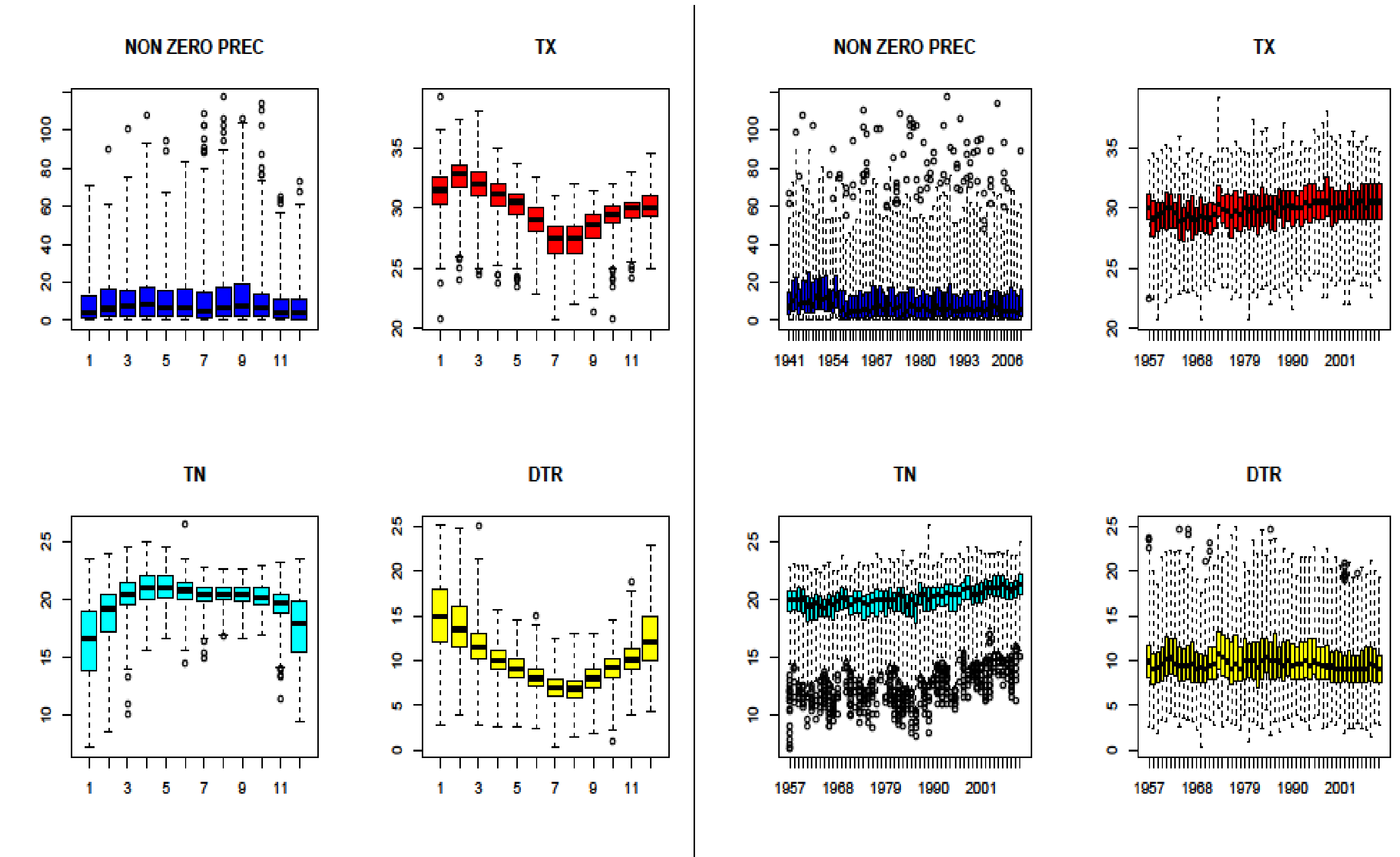


Figure 3-11: Same as in Figure 3-2 except for Mamu.



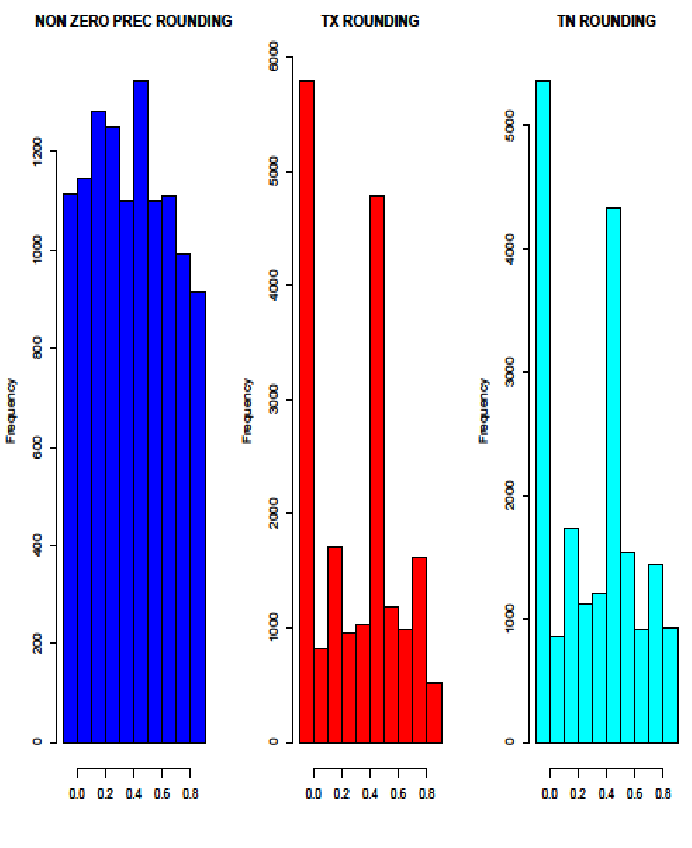


Figure 3-12: Same as in Figure 3-2 except for N'Zerekore.

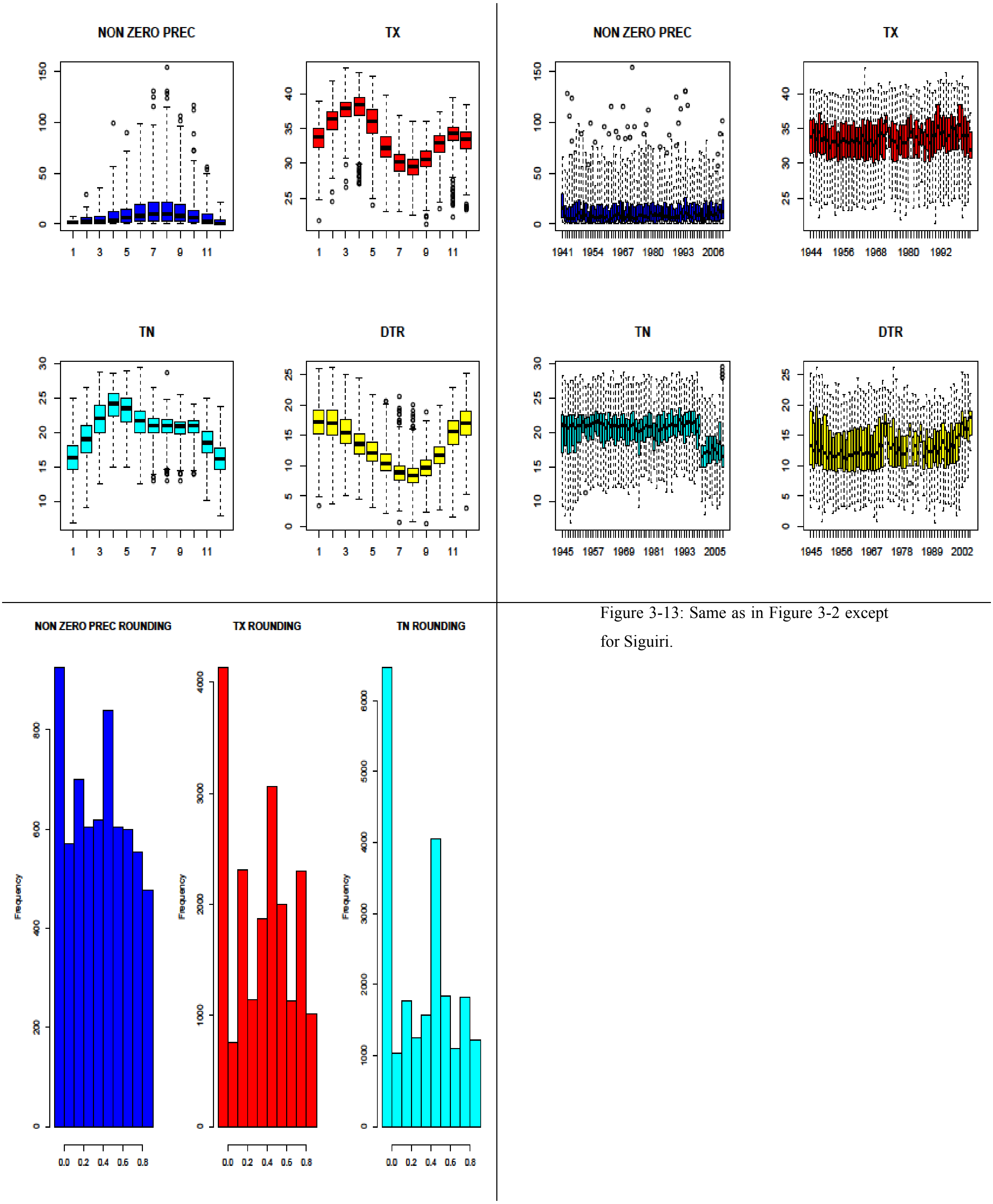


Figure 3-13: Same as in Figure 3-2 except for Siguiri.

The dataset analyzed in this work has been homogenized using HOMER (Homogenization method in R). HOMER is the fruit of the COST-HOME action and contains different state-of-the-art approaches for detection and adjustment of monthly climate data. The daily temperature series have been adjusted by interpolating Homer monthly factors to the daily data following Vincent et al. (2002) method. In this regards a self produce R package implementing this method has been used to ensure the homogeneity of daily dataset. For precipitation, two breaks points have been detected one in Conakry (1941-1961) with amplitude of -12 % and one in Kindia (1941-1970) with amplitude of -10 %. These results are identical to those of Aguilar et al. (2013). Therefore, we used homogenized daily precipitation dataset from Aguilar et al. (2013).

HOMER is a new monthly and annual temperature and precipitation homogenization method (Mestre et al., 2013). Homer provides a fast QC facility through CLIMATOL R package (Guijarro, 2011). Change points are detected using a pairwise univariate detection procedure (Caussinus and Mestre 2004) applied on the difference series between the candidate and its neighbors. This preliminary procedure is completed with a joint detection process originally developed and used by biostatisticians (Picard et al., 2011). The optimum number of break point is estimated using a penalty factor.
A two factor model is then applied to produce a preliminary homogenized dataset. This procedure is repeated until the network is homogeneous. The homogeneity of the network is evaluated via time series plots. Table 3-3 summarizes breaks detected.

Figures 3-14 and 3-15 show pairwise series detection output files for Kindia precipitation series before and after correction compared to its corresponding neighboring stations precipitation series. Pairwise comparison of corrected series is characteristic of a good homogenization. Series comparison is shorted according to the increasing values of the noise standard deviation.
The homogenization effect on Kindia precipitation data are shown in Figures 3-16. Upper panel shows the raw data and lower panel show the corrected series. Trends are more salient after homogenization process.

Figures 3-17 and 3-18 show pairwise series detection output files for Conakry Tx series before and after correction compared to its corresponding neighboring stations Tx series.

Figures 3-19 shows the effect of the homogenization on Conakry Tx data. Upper panel shows the raw data and lower panel show the corrected data. Similarly, Figures 3-20 and 3-21 show pairwise series detection output files for Conakry Tn series before and after correction compared to its corresponding neighboring stations Tn series. Figures 3-22 shows the effect of the homogenization on Conakry Tn data. Upper panel shows the raw data and lower panel show the corrected data.

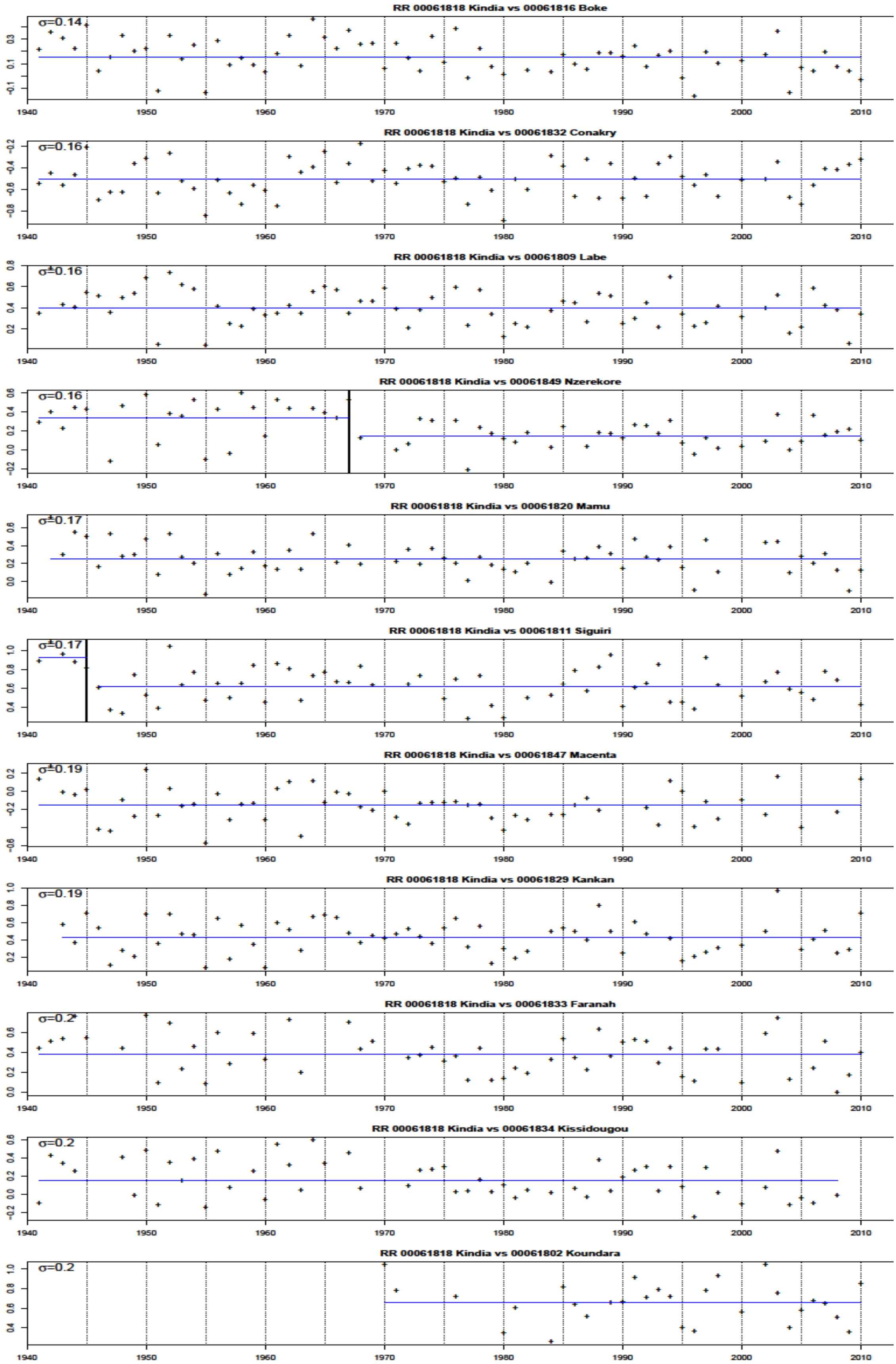


Figure 3-14: Kindia pairwise detection plot for precipitation compared to its neighbors

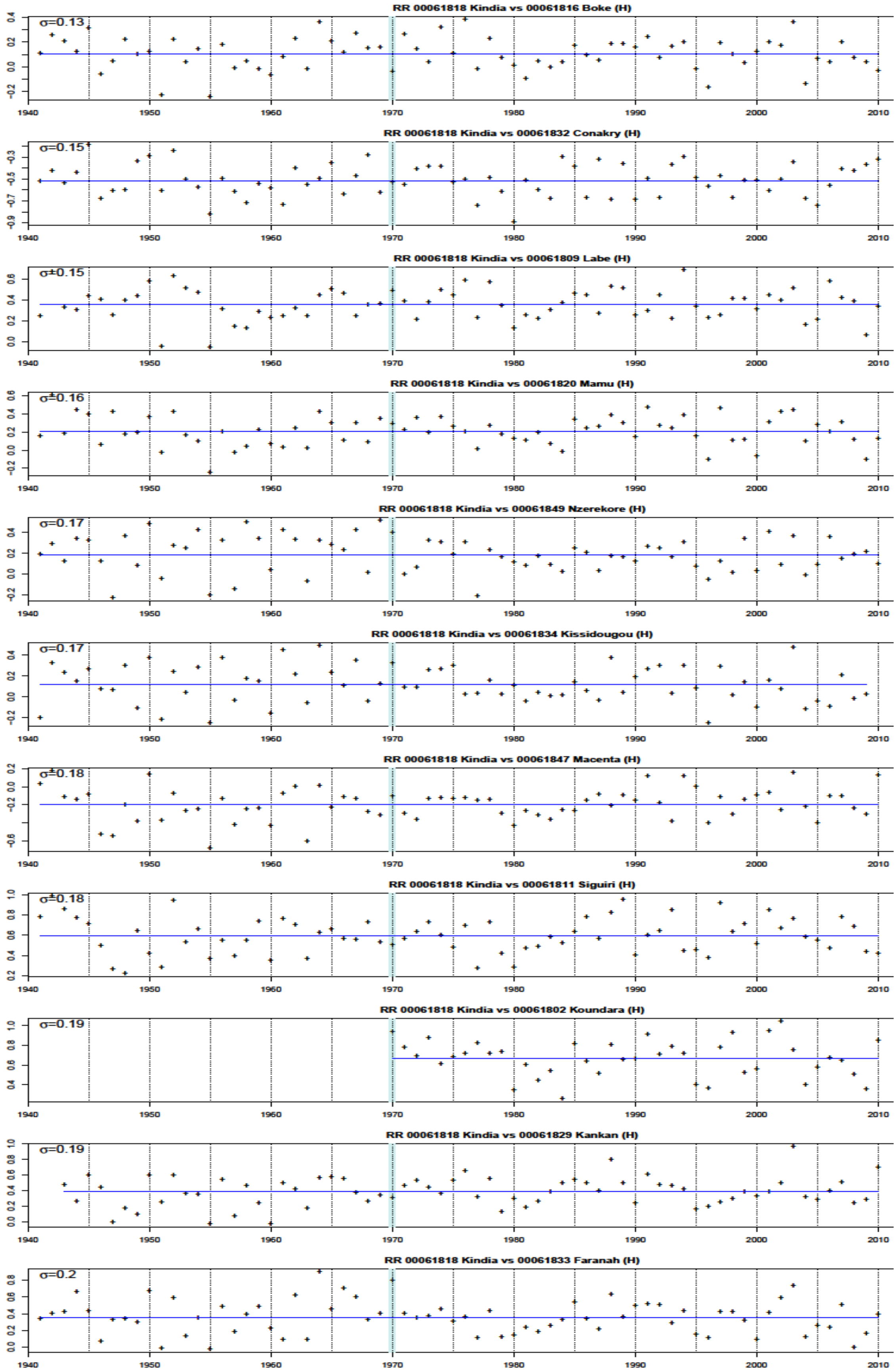


Figure 3-15: Kindia corrected precipitation compared to its corrected neighbors

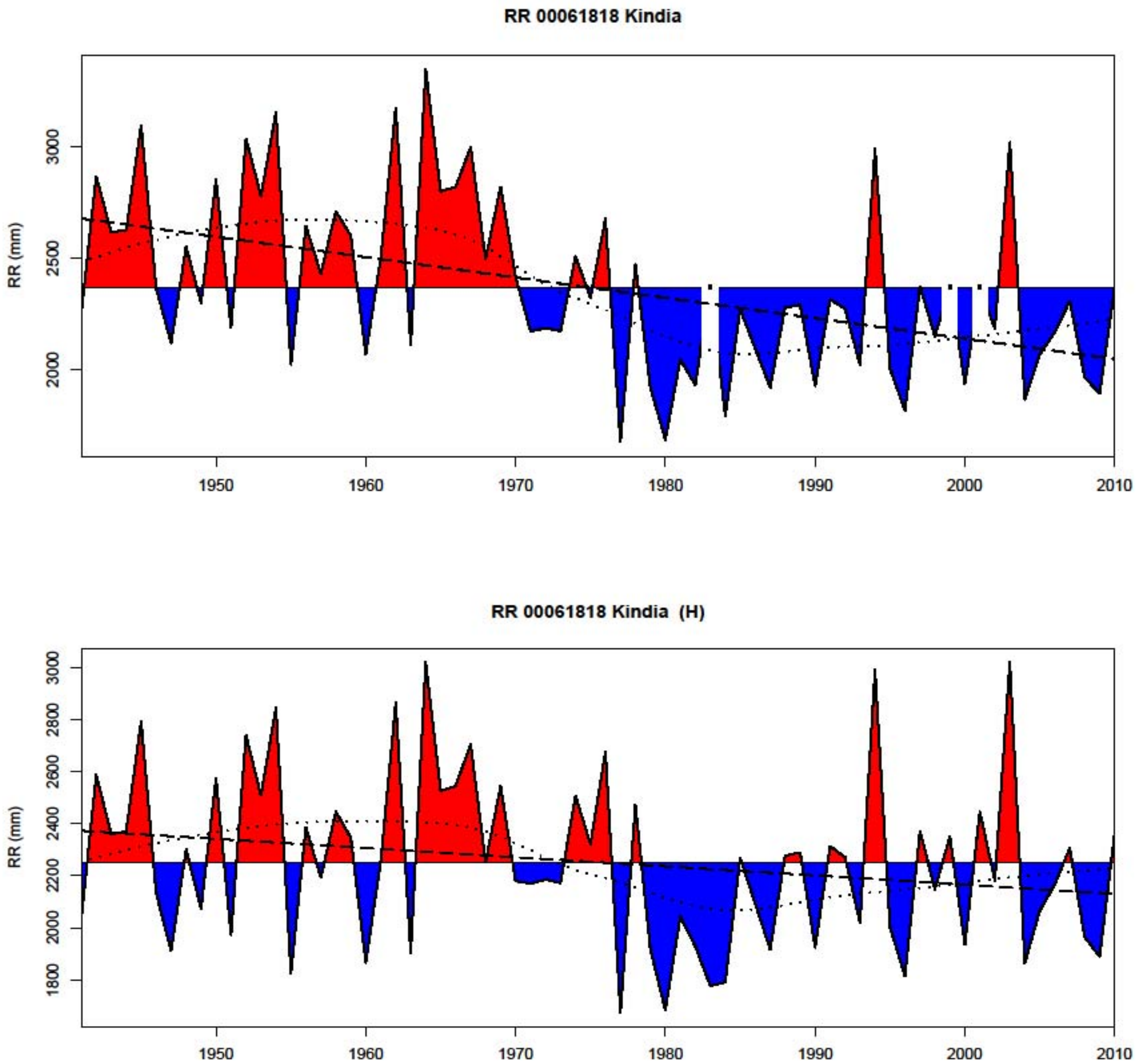


Figure 3-16: Kindia precipitation data (upper panel) and precipitation corrected data (lower panel)

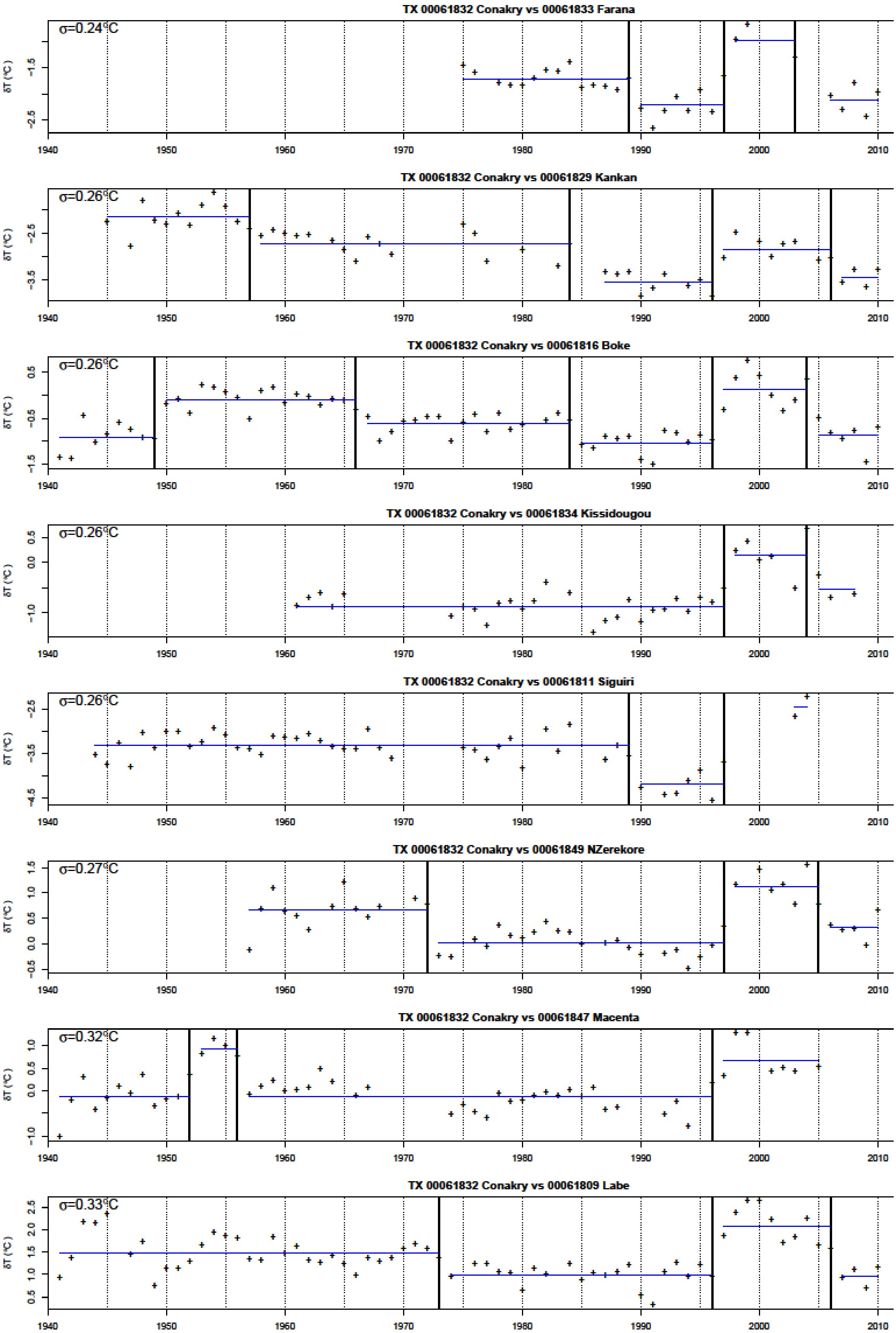


Figure 3-17: Conakry pairwise detection plot for Tx data compared to its neighbors

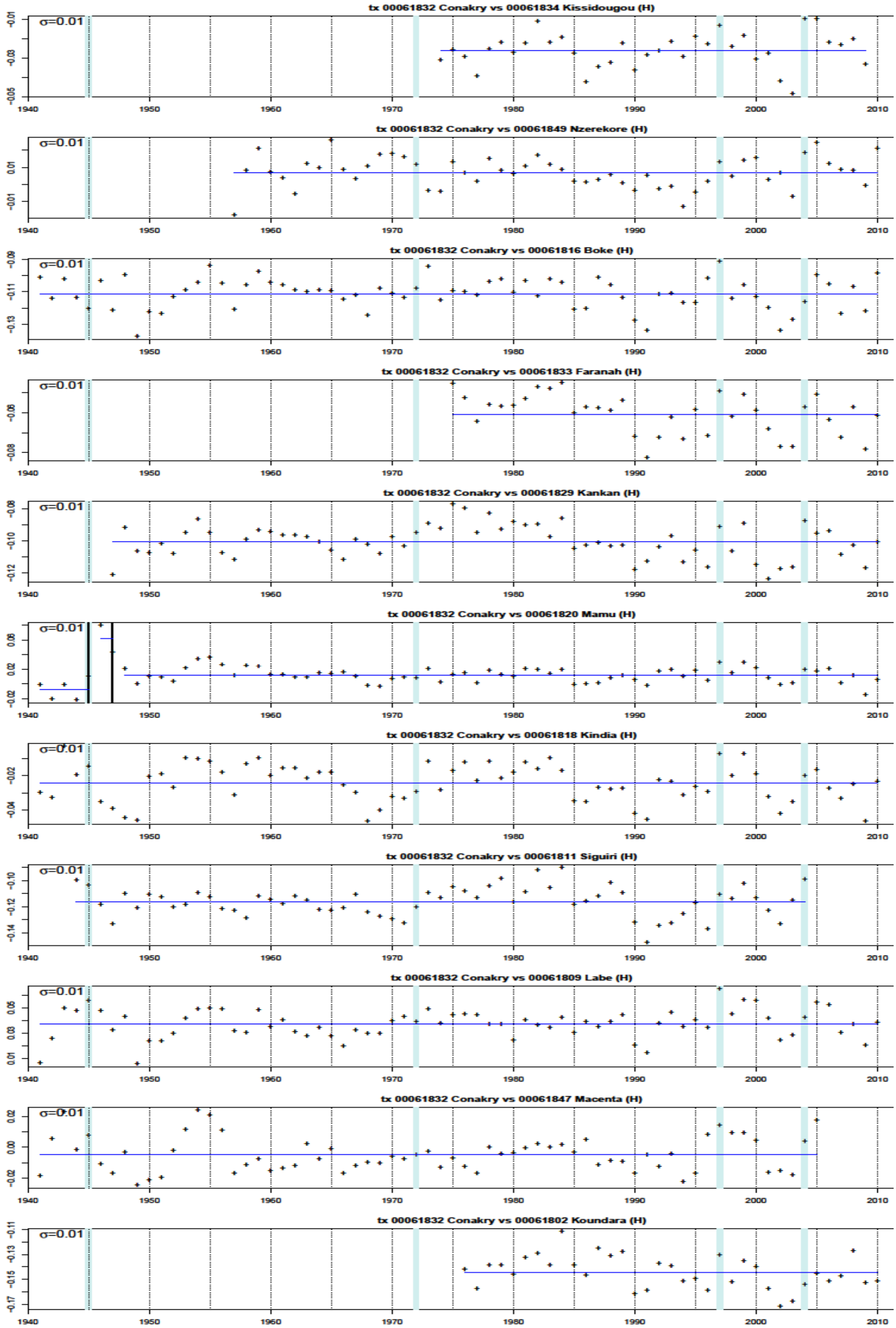


Figure 3-18: Conakry corrected Tx data compared to its neighbors

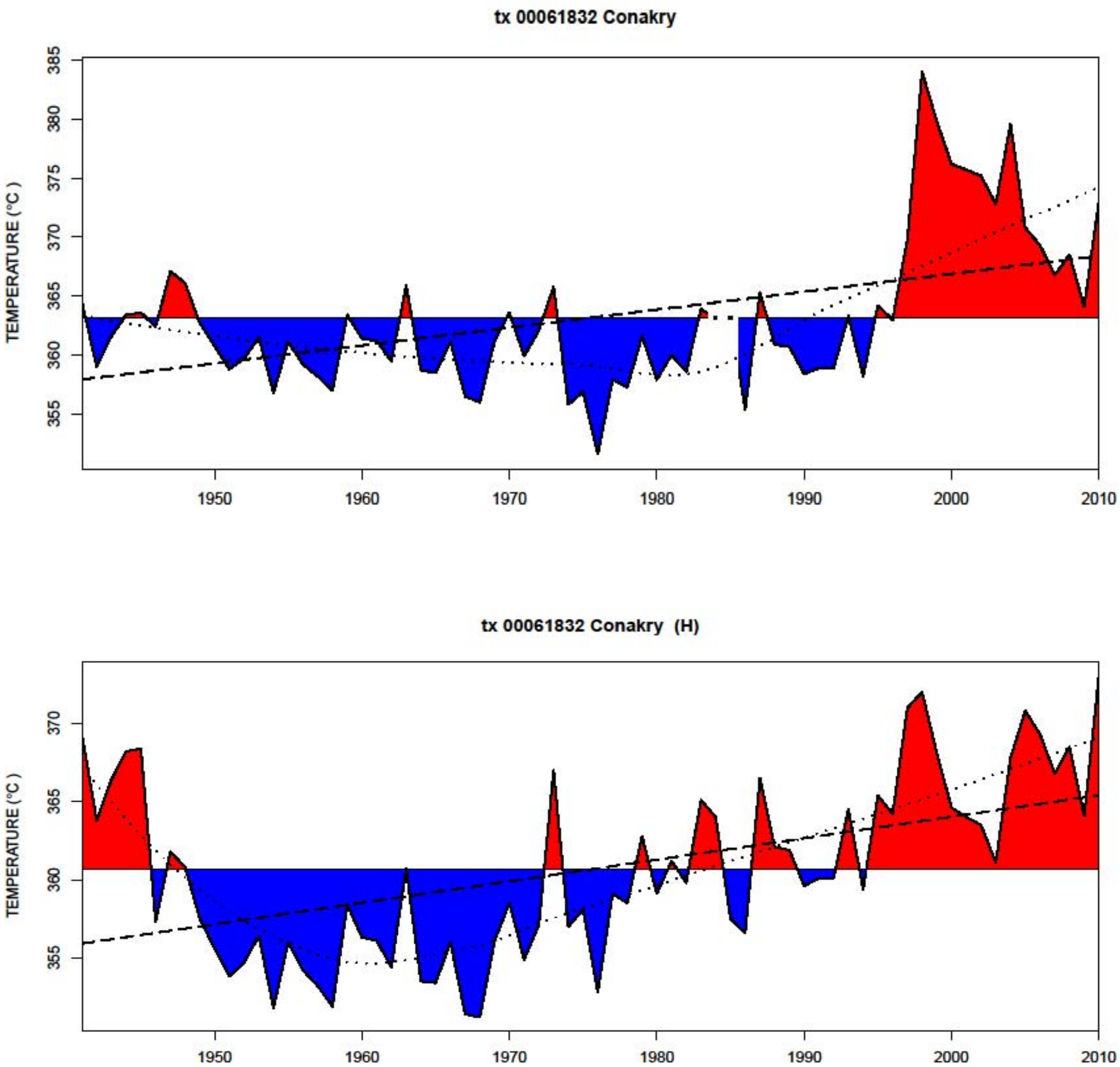


Figure 3-19: Conakry Tx data (upper panel) and Tx corrected data (lower panel)

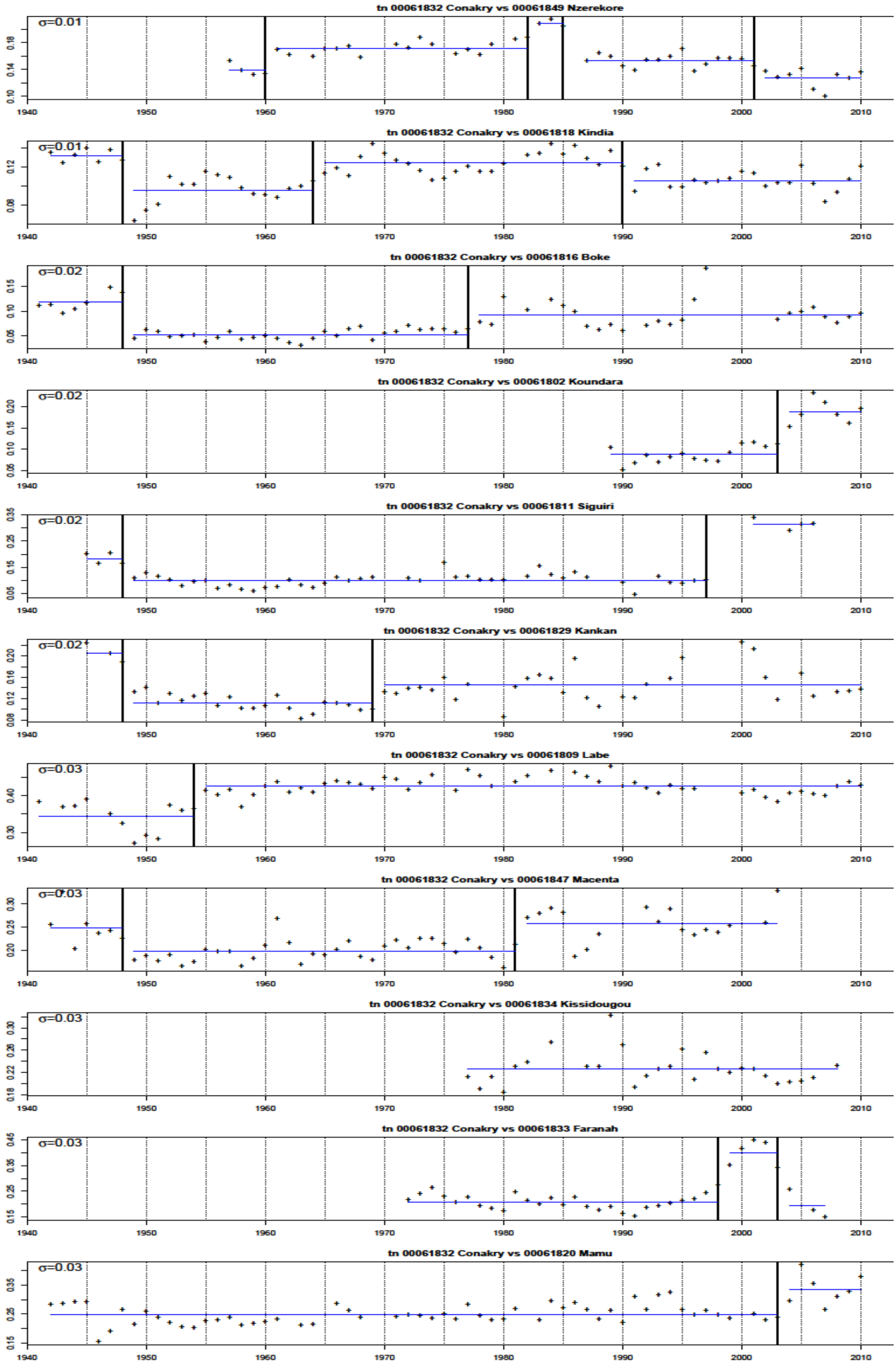


Figure 3-20: Conakry pairwise detection plot for Tn data compared to its neighbors

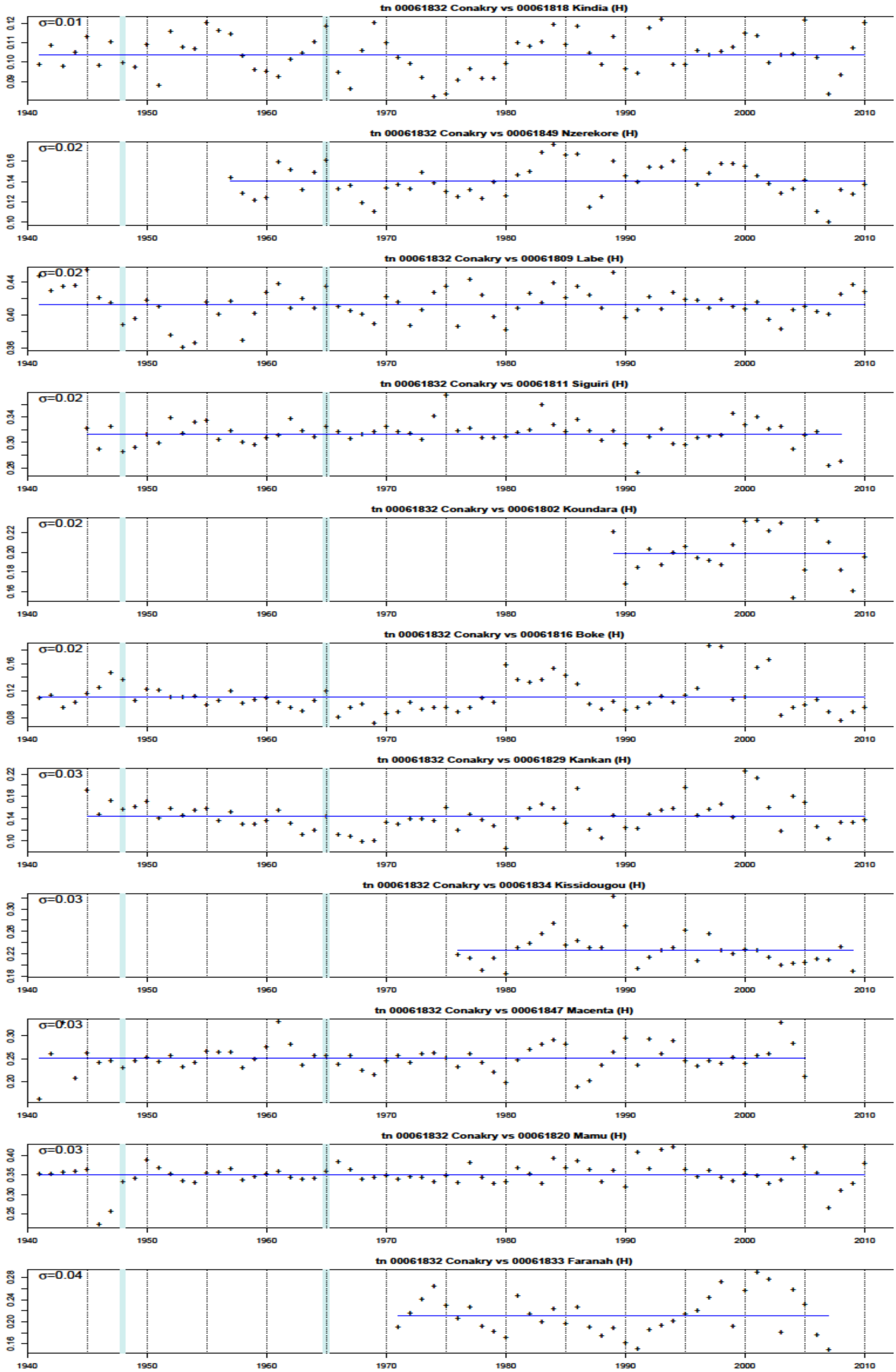


Figure 3-21: Conakry corrected Tn data compared to its corrected neighbors

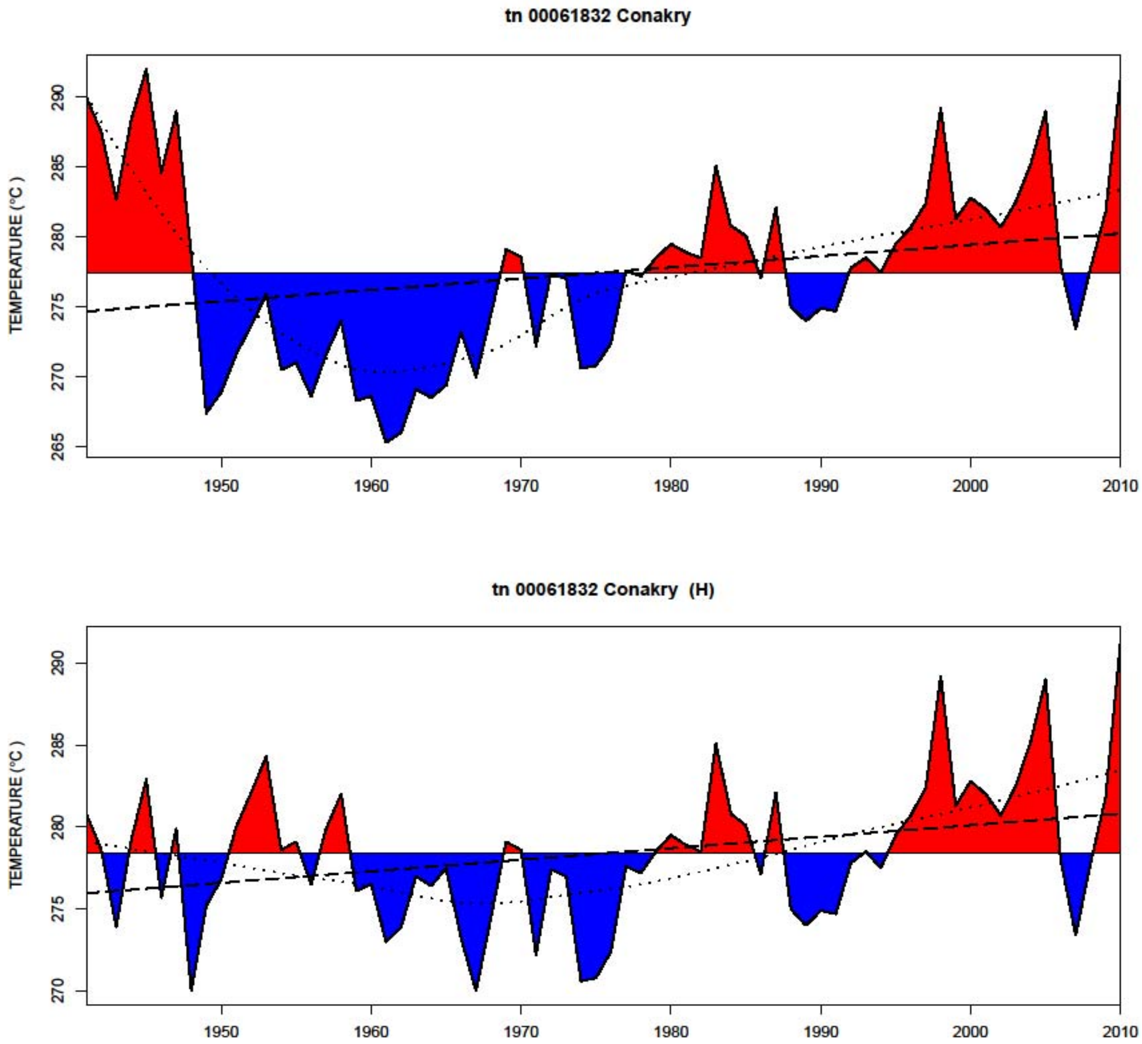


Figure 3-22: Conakry Tn data (upper panel) and Tn corrected data (lower panel)

Table 3-3: Summary of detected breaks by Homer in monthly data

Station Name	WMO Code	Year of breaks detected in	
		Precipitation	Temperatures
Boke	61816		1945, 1986, 1995
Conakry	61832	1961	1945, 1948, 1965, 1972, 1997, 2004
Faranah	61833		1998, 2003
Kankan	61829		1957
Kindia	61818	1970	1950, 1990
Kissidougou	61834		
Koundara	61802		2003
Labe	61809		1945, 1951, 1991
Macenta	61847		1981
Mamu	61820		1947, 2004
N'Zerekore	61849		1988
Siguiri	61811		1951, 1999

The synoptic presented in Figure 3-23 gives an overview of the methodology applied in this study. Using RClimDex requires a specific format, after formatting the daily data into the required RClimDex format a first execution of RClimDex identify aberrant values, for example a negative precipitation, temperature Tn greater than temperature Tx. Similarly, duplicated, missing or invalid dates are also identified. During this step, repetitive consecutive daily values over three days are also localized.

This first step of quality control ends with the update of daily data taking into account the detected anomalies. The next step is to identify the truncated values, jump and outliers by running RClimDex ExtraQC. The values identified as outliers are then analyzed by comparing them with those of neighboring stations or those of previous and/or following days from the same station. Then a subjective decision is made to validate or disqualify by setting it to missing the suspicious value.

The quality controlled daily data and metadata are required to be set on monthly Homer format. A first pairwise detection followed by joint detection are performed on quality controlled data. The detected breaks are then corrected. Then, recursively (usually in two to three repeats) automatic pairwise detection followed by a joint detection are performed on the previously corrected data and newly detected breaks are then corrected. The monthly data homogenization process ends with the monthly changes assessing process. Homer resulting monthly changes files are then used to homogenize the quality controlled daily dataset. The daily homogenized dataset are then used to compute ETCCDI and ET-CRSCI indices using ClimPact after a quick QC to consider data overshooting during the process of monthly data homogenization. From the resulting indices, seasonal indices, as defined in chapter 4, are calculated and the nationwide averages are calculated according to Jones et al. (1996) by applying Osborn et al. (1997) variance stabilization. Finally, results analyses have been done by plotting indices time series and mapping trends.

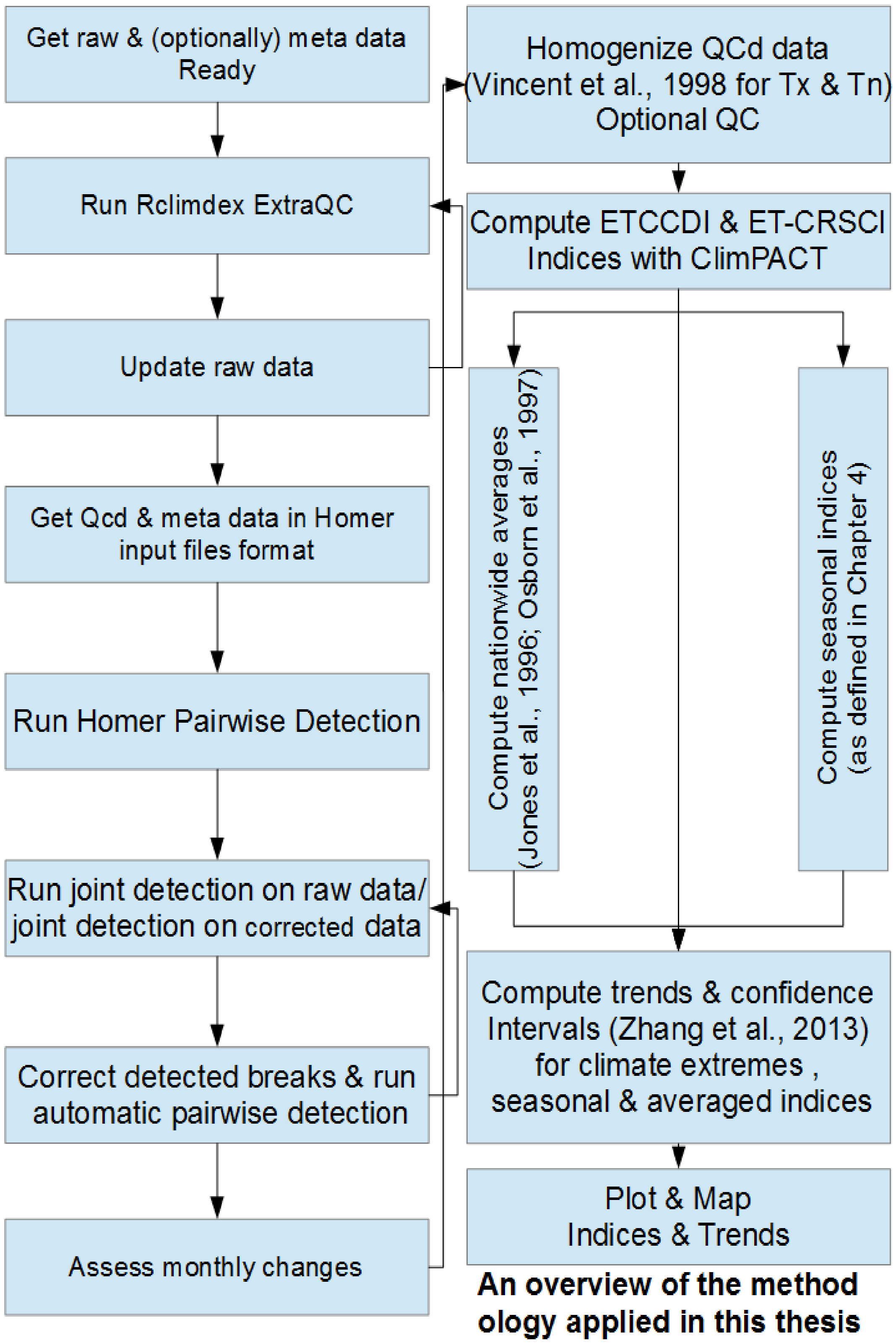


Figure 3-23: Synoptic diagram of the methodology applied in this thesis

3.2. CLIMATE INDICES

The climate is usually described in terms of basic variables such as temperature and precipitation. Furthermore, usually mean values and seasonal variations are given. Typical climate indices are based on yearly, seasonal or monthly means or sums. However, the climate is represented not only by mean values and seasonal variations, but extreme events are also its integral part. Short-lived extreme events are local phenomenon or they have small area extent, while extreme events of a persistent nature typically cover larger regions. An extreme weather or climate event is defined as the occurrence of a weather or climate variable above or below certain threshold values, near the upper or lower ends tails of the range of the observed values of the variable. Some climate extremes (e.g., droughts, floods) may be the result of an accumulation of weather or climate events that are, individually, not extreme themselves, though their accumulation is extreme. As well, weather or climate events, even if they are not extreme in a statistical sense, can still lead to extreme conditions or impacts, either by crossing critical thresholds in social, ecological, or physical systems, or by occurring simultaneously with other events. A weather system such as a tropical cyclone can have an extreme impact, depending on where and when it approaches landfall, even if the specific cyclone is not extreme relative to other tropical cyclones. Conversely, not all extreme events necessarily lead to serious impacts (IPCC, 2012).

There is general agreement that changes in the frequency or intensity of extreme weather and climate events have profound impacts on society and the environment (Karl et al., 1999). Therefore a workshop on indices and indicators for climate extremes was held in Asheville, North Carolina, 3–6 June 1997, to encourage the development of data set analysis techniques in the characterization of the long-term change and variability of extreme climatic events. The main goal was to create indices, which help to examine whether extreme events are becoming even more extreme, even more frequent or more variable, or just the opposite, their frequency and magnitude do not show unfavorable tendencies.

Nicholls and Murray, (1999) and Folland et al. (1999) addressed the needs for such indices, the availability of temperature and precipitation data from countries around the globe, and efforts that should be made to integrate these data in a common data base for international use and assessment of c1imate extremes. They identified a number of indices and indicators of temperature and precipitation extremes, which should be applied consistently to available global data. They also made recommendations regarding aggregation of these indices into indicators of extremes on large spatial scales, on the development of comprehensive data sets to enhance globally-consistent analysis, and on methods for quality control and the removal of inhomogeneities in data for monitoring temperatures and precipitation extremes. The objective was to encourage the development of data sets and analysis techniques, to establish whether such extreme events are becoming more extreme or variable (Karl et al., 1999).

Easterling and Kates (1995) provide a discussion of the attributes of climate indices. One key attribute is that indices should be well defined and another is that they should give warning if trends likely to have societal impact if they were to persist. Other desirable characteristics of indices for monitoring climate extremes include:

- A good signal-to-noise ratio for the detection of a trend or a change from one period to another. Signal refers to the size of the trend or change being estimated; noise refers to the real physical noise in the atmospheric system and not to non-physical measurement error.
- Relevance to economic activity and other aspects of human society and ecological systems.
- Sensitivity to likely anthropogenically-induced or natural variations in climate.
- It should usually be possible to define them also for continental to global scale analyses, although not necessarily for using them everywhere.
- They should be calculable from available or potentially available observational and model data.

Since then climate change indices have been widely used for analyzing global and regional changes in extremes in observational records e.g., Frich et al. (2002); Peterson et al. (2002); Kiktev et al. (2003); Vincent et al. (2011); Zhang et al. (2005b); Alexander et al. (2006); Haylock et al. (2006); Klein Tank et al. (2006); New et al. (2006); Aguilar et al. (2009); Caesar et al. (2011) to name few of studies. Climate change indices have also been used in climate modeling (Terando et al., 2012), in climate simulation (Dulière et al., 2013), in climate model evaluation (Sillmann and Roeckner (2008); Sillmann et al., 2013a), in climate projections (Rajczak et al., 2013; Sillmann et al., 2013b).

In the WMO guidelines in the analysis of extremes in a changing climate (Klein Tank et al., 2009), the usefulness of these indices is further pointed out: "Projected changes in the indices are indicative of future climate change in extremes. By using the same definitions of extremes and analyzing the data in a standardized way, it is possible to compare results from different places and to obtain coherent pictures of change around the world."

3.2.1 EXPERT TEAM ON CLIMATE CHANGE DETECTION AND INDICES

Internationally coordinated work has been conducted by ETCCDI (Expert Team on Climate Change Detection and Indices) <http://www.clivar.org/organization/etccdi/etccdi.php>); Karl et al. (1999), Petersen et al. (2001). Within this working group 27 Core Indices have been developed. A special software tool has also been produced for standardized calculation of those indices (RClimDex, http://etccdi.pacificclimate.org/software.shtml). The indices proposed by the European Climate Assessment & Dataset (ECA&D) correspond to a large extent with the ETCCDI indices. These indices are designed to be independent on climatic zone. Tables 3 -4 and 3-5 show the list and short definition of ETCCDI and ET-CRSCI indices used in this study.

These indices facilitate the investigation of observed and projected changes, particularly in temperature and precipitation extremes. ETCCDI indices in general describe moderate extreme events with a re-occurrence time of one year or less (Sillmann et al., 2013a), forming a balance between data availability and robustness of changes (Zhang et al., 2011) while ET-CRSCI are sectors specifics.

ETCCDI and ET-CRSCI indices are based on daily minimum and maximum of near surface temperature and daily precipitation amounts. Detailed information on the indices can be found in Alexander et al. (2006), Klein Tank et al. (2009), Im et al., 2011), and Zhang et al. (2011) and on WMO and the ETCCDI website.

While most of ETCCDI indices are defined on an annual basis (Sillmann et al., 2013b), a few are also available as monthly statistics or as continuous counts over the total data record and are specified as such in the description below.

3.2.1.1. Temperature Indices

(a) Absolute Indices

The minimum of Tn (TNn) and maximum of Tx (TXx) represent the coldest or hottest day of a year, season, or month, respectively. The annual temperature extremes are used in several studies to express the extreme temperature range, ETR , Alexander et al. (2006); Tebaldi et al. (2006) and to project future changes in 20 year return values of annual temperature extremes (Donat et al., 2013). TNx and TXn are included in this group and also known as general climate indices.

(b) Threshold Indices

Summer days (SU) and tropical nights (TR) count the days when Tx and Tn is above 25 ºC or above 20 ºC, respectively. These indices are often useful for climate impact studies. Changes in summer days, for instance, can be relevant for health and engineering applications (Terando et al., 2012). Tropical nights usually occur in combination with extended periods of heat, particularly in extra-tropical regions, and have been suggested to be problematic for human health (Weisskopf et al., 2002; Patz et al., 2005).

(c) Percentile Indices

The percentile indices are the exceedance rates (in %) above or below thresholds based on the annual cycle of the percentiles calculated for a 5 day sliding window centered on each calendar day in the base period, which is by definition 1961–1990. The calculation of the percentile thresholds in the base period includes a bootstrap re-sampling method (Zhang et al., 2005) to avoid inhomogeneities at the beginning and end of the base period. Usually in climate analysis, we consider cold nights and days (TN10P and TX10P, respectively) and warm nights and days (TN90P and TX90P, respectively), which describe the threshold exceedance rate of days where Tn or Tx is below the 10th or above the 90th percentile, respectively.

(d) Duration Indices

The warm and cold spells duration indices, WSDI (Warm Spells Duration Index) and CSDI (Cold Spells Duration Index) are based on the percentile thresholds calculated from the base period 1961–1990 as described above and according to WMO recommendations. WSDI and CSDI count the number of days in a year when Tx is above the 90th percentile for six consecutive days or longer, or when Tn is below the 10th percentile for six consecutive days or longer, respectively. The advantage of using a percentile-based threshold instead of an absolute value threshold is that warm or cold spells can be captured for a wide variety of climatological conditions (e.g., tropics versus northern latitudes) as pointed out by Radinović and Ćurić (2012). However, Orlowsky and Seneviratne (2012) found that this index is difficult to interpret in comparison with other heat wave indices.

3.2.1.2. Precipitation Indices

(a) Absolute indices

The maximum 5 day precipitation index (Rx5day) describes the monthly or annual maximum of 5 day precipitation accumulations. This index is often used to describe changes in potential flood risks as heavy rain conditions over several consecutive days can contribute to flood conditions (Frich et al., 2002). Absolute indices include Rx1day and Rx2day indices.

(b) Threshold indices

The heavy precipitation days index (R10mm) counts the number of days with more than 10 mm of precipitation. This index is associated with the wet part of the precipitation distribution but does not generally describe extreme precipitation. Very wet days (R95p) describe the annual precipitation amount (in mm) accumulated on days when daily precipitation is greater than the 95th percentile threshold of the wet-day precipitation (PR>1 mm) distribution derived from the base period, by definition, 1961–1990. As this index is based on a percentile threshold, it takes into account the respective precipitation climatology of different regions. This group also includes R20mm, R25mm and R99P indices.

(c) Duration indices

The consecutive dry-day index (CDD) represents the length of the longest period of consecutive dry days, e.g.: days with PR<1 mm, in a year ending in that year. If a dry spell does not end in a particular year and spans a period longer than one year; as may happen in very dry regions, then CDD is not reported for that year and the accumulated dry days are carried forward to the year when the spell ends. This definition avoids the splitting of dry spells in regions where the dry season extends over the year boundary, in contrast to other studies such as Tebaldi et al. (2006) that use a CDD definition where dry spells are always terminated at the year's end. CDD is the only ETCCDI index that describes the lower tail of the precipitation distribution and is often referred to as a drought indicator. As drought is a complex phenomenon depending on various other factors besides lack of precipitation, CDD can only provide an indication for meteorological drought and should be interpreted in combination with other precipitation indices, Tebaldi et al. (2006); Orlowsky and Seneviratne, (2012) or drought indices, Cardona et al. (2012).

(d) Intensity and total rainfall

Two indices that do not fall in one of the categories outlined above are the PRCPTOT (total wet-day precipitation) index and the SDII index. PRCPTOT describes the total annual amount of precipitation on wet days defined as days with more than 1 mm of precipitation. SDII describes the daily precipitation amount averaged over all wet days in a year.

Over the last two decades, the analysis of ETCCDI indices has become increasingly important due to the recognition of their significant impacts on society and natural systems IPCC, (2012a). Since the late 1990s, many efforts have been made to assess changes in spatial and temporal patterns of extreme events using observational climate data through ETCCDI indices. Analyses of long term climatic characteristics of extreme events, including their intensity, duration and frequency are needed for developing mitigation and adaptation plans. From 1998 to nowadays, ETCCDI indices have been extensively used in monitoring and analysis of extreme climate event both at regional and global scales. Among the numerous studies done in recent decades using ETCCDI indices to monitor and analyze extreme climate events can be cited as an example, Peterson et al. (2002) covered the Caribbean region, Zhang et al. (2005b) targeted at middle east, Aguilar et al. (2009) covered central and western Africa, Brown et al. (2010) covered the northeastern United States and also a near-global to global scale we have the study conducted by Folland et al. (2001), Alexander et al. (2006) assessed global extremes in temperature and precipitation, Morak et al. (2013), Donat et al. (2013) assessed Northern Africa climate. ETCCDI indices have been also widely used in climate change projections both at global and regional scale (Kirtman et al., 2013).

As an addition to the core set of ETCCDI indices, RClimDex also includes an approach to the computation of the rainy season determination. Wet season onset date, retreat date, and its duration are determined using the criteria proposed by Wang and LinHo (2002) utilizing only observed precipitation data. Based on the locally averaged climatological mean daily precipitation, which is the difference between the climatological daily precipitation and the driest month mean precipitation, the onset (retreat) date is defined as the date when the relative precipitation first exceeds (last drops below) a locally defined lowest rainfall intensity in base period used in the calculation of the indices, and the duration is define as their difference.

Table 3-4: List and definition of ETCCDI indices used in this thesis

Element	Index	Description	Definition	Unit
Maximum of daily temperature	TxMean	Annual maximum temperature	Annual mean of Tx; Tx is the daily temperature maximum	°C
	SU25	Summer days	Annual count of days when Tx > 25°C	days
	TX90P	Warm days	Percentage of days when Tx > 90th percentile	%
	TX10P	Cold days	Percentage of days when Tx < 10th percentile	%
	TXx	Warmest day	Annual highest value of Tx	°C
	TXn	Coldest day	Annual lowest value of Tx	°C
Minimum of daily temperature	TnMean	Annual minimum temperature	Annual mean of Tn; Tn is the daily temperature minimum	°C
	TR20	Tropical nights	Annual count of days when Tn > 20°C	days
	TN90P	Warm nights	Percentage of days when Tn > 90th percentile	%
	TN10P	Cold nights	Percentage of days when Tn < 10th percentile	%
	TNx	Warmest night	Annual highest value of Tn	°C
	TNn	Coldest night	Annual lowest value of Tn	°C
Both Tx and Tn daily temperature	DTR	Diurnal temperature range	Annual mean of difference between Tx and Tn	°C
Daily precipitation	PRCPTOT	Annual precipitation	Annual total precipitation when RR>=1 mm; RR is daily precipitation	mm
	Rx1day	Maximum 1 day RR	Annual highest daily precipitation	mm
	Rx5day	Maximum 5 days RR	Annual highest 5 consecutive days precipitation	mm
	R95P	Very wet days	Annual total precipitation when RR>95th percentile	mm
	R95pTOT	Contribution from very wet days	annual percentage of RR>95th percentile/PRCPTOT	%
	R99P	Extremely wet days	Annual total precipitation when RR>99th percentile	mm
	R99pTOT	Contribution from extremely wet days	annual percentage of RR>99th percentile/PRCPTOT	%
	SDII	Simple daily intensity index	Annual precipitation divided by number of wet days	mm/day
	CDD	Consecutive dry days	Maximum number of consecutive dry days	days
	CWD	Consecutive wet days	Maximum number of consecutive wet days	days
	R10mm	Number of heavy precipitation days	Annual count of days when RR >= 10 mm	days
	R20mm	Number of very heavy precipitation days	Annual count of days when RR >= 20 mm	days
	R25mm	Number of extremely heavy precipitation days	Annual count of days when RR >= 25 mm	days
Wet season	Onset	Wet season onset	See section 3.2.1.2	Julian
	Retreat	Wet season retreat		days
	Length	Wet season length		days

Table 3-5: List and definition of ET-CRSCI indices used in this thesis

Element	Index	Description	Definition	Unit
Drought Indices	SPI	12 months SPI	See section 3.2.2.1	SPI
	SPEI	12 months SPEI		SPEI
Heat Waves	CDDcold	Cooling Degree Days	Annual sum of (Tm-Tb); Tb is a user defined threshold; Tm>Tb and Tm is the daily mean	ºC
	HWA	Heat wave amplitude	Hottest day of the hottest summer heat wave	ºC
	HWF	Heat wave frequency	Yearly sum of participating heat wave days	days
	WSDIn	Warm Spell Duration Indicator	Annual count of days with at least n consecutives days when Tx>90th percentile	days
	CSDIn	Cold Spell Duration Indicator	Annual count of days with at least n consecutives days when Tn<10th percentile	days
Temperature	TX50P	Above average days	Percentage of days where TX>50th percentile	%
Precipitation	Rx2day	Maximum 2 days RR	Annual highest 2 consecutive days precipitation	mm

3.2.2 EXPERT TEAM ON CLIMATE RISK AND SECTOR SPECIFIC INDICES

One drawback of ETCCDI indices is that only few of them are specifically sector-relevant e.g frost days for agricultural applications. Thus additional and more sector-specific indices are need. With the advent of the GFCS (Global Framework for Climate Services) and the intent for GFCS to provide climate information and services to meet user requirements, new work is now underway to identify the sector-applications of the ETCCDI indices and associated software. In addition, in cooperation with WMO and Sector experts in agricultural meteorology, water resources and health, the new ET-CRSCI (Expert Team on Climate Risk and Sector-Specific Climate Indices) is working to identify and evaluate additional sector specific indices, both single- and multi-variable types, to define both simple and complex climate risks of interest to user groups.

ET-CRSCI met in Tarragona, Spain 13-15 July 2011 to discuss the use of climate indices in sector applications. The dialogue took place in cooperation with experts from health, agriculture and water sectors, particularly focusing on heat waves and droughts at this first stage of expanding the set of indices. Also collaborating in this exercise was the WMO CCl (Commission for Climatology) ETCCDI, which has developed the software, RClimDex, for the calculation of important climate indices based on Tx, Tn and RR. This new team has since added indices recommended by the sector experts to the set of indices in RClimDex and has produced a new software package ClimPACT. ClimPACT includes the SPI (Standardized Precipitation Index), proposed by McKee et al. (1993), and accepted by the World Meteorological Organization as the reference drought index for more effective drought monitoring and climate risk management (Mark et al., 2012), and the SPEI (Standardized Precipitation Evapotranspiration Index), proposed by Vicente-Serrano et al. (2011).

The Workshop on Sector-Specific Climate Indices which took place 10-14 June 2013, Guayaquil, Ecuador launched the ClimPACT software, which is used here to calculate this new set of indices.

In the following section we provide drought definition followed by an overview of some drought indices.

3.2.2.1 Drought Indices

A drought can be defined from different perspectives, depending on the stakeholders involved. The scientific literature commonly distinguishes meteorological drought, which refers to a deficit of precipitation, soil moisture drought often called agricultural drought, which refers to a deficit of soil moisture, and hydrological drought, which refers to negative anomalies in stream flow, lake, and/or groundwater levels (Heim 2002).
For soil moisture or hydrological droughts, the main drivers are reduced precipitation and/or increased evapotranspiration. Although the role of deficits in precipitation is generally considered more prominently in the literature, several drought indicators also explicitly or indirectly consider effects of evapotranspiration. In the context of climate projections, analyses suggest that changes in simulated soil moisture drought are mostly driven by changes in precipitation, with increased evapotranspiration from higher vapor pressure deficit (often linked to increased temperature) and available radiation modulating some of the changes (Orlowsky and Seneviratne, 2012).

The indices of the ET-CRSCI touch upon different sectors, but we will discuss here those related to drought and heat waves. Because of the complex definition of droughts, and the lack of soil moisture observations, several indices have been developed to characterize meteorological, soil moisture, and hydrological drought (Vicente-Serrano, 2010; Dai, 2011a).

A widely used index is the SPI (McKee et al., 1993; Lloyd-Hughes and Saunders, 2002, Vicente-Serrano, 2010), which consists of fitting and transforming a long-term precipitation record into a normal distribution that has zero mean and unit standard deviation. SPI values of -0.5 to -1 correspond to mild droughts, -1 to -1.5 to moderate droughts, -1.5 to -2 to severe droughts, and below -2 to extreme droughts. Similarly, values from 0 to 2 correspond to mildly wet to severely wet conditions, and values above 2 to extremely wet conditions (Lloyd-Hughes and Saunders, 2002). SPI can be computed over several time scales and thus indirectly considers effects of accumulating precipitation deficits, which are critical for soil moisture and hydrological droughts.

SPI is given by

Equation 3-1
$$SPI = \frac{R(i) - \overline{R}}{\delta}$$

Where $R(i)$ is monthly precipitation at a given station, $\overline{R}$ and δ precipitation mean and standard deviation

Another index commonly used in the analysis of climate is the CDD (Consecutive Dry Days) index, which considers the maximum consecutive number of days without rain or below a given threshold, within a considered period (Frich et al., 2002; Alexander et al., 2006; Tebaldi et al., 2006). The major drawback of SPI and CDD indices is that they are only based on precipitation and do not take into account the temperature in the context of global warming. Therefore more appropriate indices are needed.

Some indices reflect both precipitation and estimates of actual or potential evapotranspiration, in some cases also accounting for some temporal accumulation of the forcings or persistence of the drought anomalies. These include the PDSI (Palmer Drought Severity Index) introduced by Palmer, (1965), which measures the departure of moisture balance from normal conditions using a simple water balance model (Dai, 2011a), as well as other indices such as the PPEA (Precipitation Potential Evaporation Anomaly), based on the cumulative difference between precipitation and PET (Potential Evapotranspiration) used in Burke and Brown (2008) and the SPEI (Standardized Precipitation Evapotranspiration Index), which considers cumulated anomalies of precipitation and potential evapotranspiration described in Vicente-Serrano et al. (2010). However, the PDSI lacks the multi-scalar character essential for both assessing drought in relation to different hydrological systems and differentiating among different drought types.The SPEI is a new drought index based on precipitation and temperature data, and it has the advantage of combining multi-scalar character with the capacity to include the effects of temperature variability on drought assessment. The SPEI combines the sensitivity of PDSI to changes in evaporation demand (caused by temperature fluctuations and trends). This new index is particularly suited to detecting, monitoring, and exploring the consequences of global warming on drought conditions.

The procedure to calculate SPEI index is detailed in Vicente-Serrano et al. (2010) and involves a climatic water balance, the accumulation of deficit/surplus at different time scales, and adjustment to a log-logistic probability distribution. Mathematically, the SPEI is similar to the standardized precipitation index (SPI), but it includes the role of temperature.

The first step in the long procedure of calculating SPEI is to estimate the month i PET.

Equation 3-2 $$PET_i = 16K_i\left(\frac{10T_i}{I}\right)^m$$

Where T_i is the monthly i mean temperature, K_i is a correction factor depending on the observing station latitude and the number of days given in month i, m is a coefficient depending on I and I is a heat index defined as the sum of twelve monthly index and is given by the following equation

Equation 3-3 $$I = \sum_{n=1}^{12}\left(\frac{T_i}{5}\right)^{1.514}$$

The second step is to compute the water balance for each month i

Equation 3-4 $$D_i = R_i - PET_i$$

The next step is the normalization of D_i into a log-logistic probability distribution. More details are given by Vicente-Serrano et al. (2010).

And finally SPEI is given by

Equation 3-5 $$SPEI = W - \frac{C_0 + C_1W + C_2W^2}{1 + f_1W + f_2W^2 + f_3W^3}$$

Where

Equation 3-6 $$W = \sqrt{-2\ln(P)}$$ When $P \leq 0.5$

Equation 3-7 $$W = \sqrt{-2\ln(1-P)}$$ When $P > 0.5$

P is the probability of exceeding a determined D_i. If P>0.5 then P is replace by 1-P and the sign of resultant SPEI is reversed. C0=2.515517, C1=0.802853, C2=0.010328, f1=1.432788, f2=0.189269 and f3=0.001308.

SPI and SPEI can be calculated for different time scales, but in the remainder of this thesis, SPI and SPEI refer to twelve months SPI and twelve months SPEI.

Following McKee et al. (1993) and Guttman (1999), a "drought" takes place when the indicator is "constantly negative and more negative than −1 for at least 1 month before it turns back to positive values". For each event, duration stands for the number of months from the first month where the indicator becomes lower than −1 to the last month with a negative value before the indicator turns back positive. Intensity stands for the number of months in which the drought indicator is lower than −1.

3.2.2.2 Heat wave indices

Heat waves also referred as extreme heat event is a period, of at least three consecutive days (Pezza et al. 2012) of abnormally hot weather. Heat waves and warm spells have various and in some cases overlapping definitions. ETCCDI indices, either by themselves or combined, have been used for heat wave purposes (SU25, TR20 and WSDI) (Avila et al 2012). While useful in their own right, many of these indices may not be representing many or even all aspects of heat waves appropriately (Perkins et al. 2013). Thus, the ETCCDI indices that measure extreme temperature only consider one aspect of a heat wave each, either event duration (WSDI) or frequency of days that may be, but are not necessarily, part of a heat waves (CDD, SU25, TR20, TX90P, and TN90P). Furthermore, some ETCCDI indices are based on absolute thresholds (SU25 and TR20), which are not always suitable (Perkins et al. 2013). When considering the impacts of heat waves, which are of course, sector-specific (human health, wildlife, physical environment, ecosystems, agriculture, transport, bushfire-wildfire management, and electricity), it is imperative to know how an index measures the events, as employing the wrong index for a specific purpose could result in incorrect information, resulting in poor adaptation and mitigation planning (Perkins et al. 2013). Because of the range of groups and sectors affected by heat waves it is, of course, nearly impossible to obtain a single index that is appropriate across each group and that can be calculated from readily available climatological data. It is possible, however, to define a set of metrics that can be readily calculated from climatological data and provide information on various aspects of heat waves. Such methods have great potential to be useful to many different sectors affected by heat waves, as well as being applicable to a broad range of climates (Perkins et al. 2013). To address this issue Perkins et al. (2013) investigated a range of heat waves related indices in terms of their feasibility across varying climates and extreme temperature indices defined in the scientist literature to determine a set of widely applicable heat wave definitions and corresponding methodologies.

Perkins et al. (2013) grouped the indices into aspects and definitions, where an aspect represents a certain characteristic of a heat wave: the frequency, the duration, the magnitude, the number of events and the sum of participating heat waves days and; a definition refers to how the heat wave is obtained from the daily data. The three heat wave definitions are: Tx90pct, Tn90pct and EHF (Excess Heat Factor). The threshold for Tx90pct and Tn90pct indices are the calendar day of 90th percentile of Tx and Tn respectively; and EHF is based on Tm as defined by Nairn et al. (2009) (Perkins et al., 2013).

Let Txij, Tnij and Tmij be the Tx, Tn and Tm (Temperature daily mean) on day i in period j respectively. Calculate Txib90p, Tnib90p and Tmib90p as the calendar day 90th percentile of Tx, Tn, and Tm for a five-day window centered on each calendar day in the base period b (WMO recommendation is 1961-1990).

Based on the three indices, if a heat wave conditions persist for at least three days, that is the threshold is exceeded for three or more consecutive days then a heat wave occurs.

4. THE CLIMATE OF GUINEA

The West African country of Guinea extends from the Atlantic Ocean eastward through four regions: the lower land region of Lower Guinea that forms part of Guinean forest savanna mosaic eco-region; the mountainous Middle Guinea in the central region of the country; the north-eastern savannah region of Upper Guinea; and the south-eastern rainforests of Forest Guinea. Twenty two West African rivers have their origin in Guinea's mountains, including Niger, Senegal, Gambia, Cavally and Manoh Rivers. Although the country possesses major mineral and hydropower resources, including almost the half of the world's bauxite reserves and an annual mean rainfall ranging from 1,100 mm to 3,600 mm, nearly half of Guinea's 10,628,972 million inhabitants live below the poverty line. Agriculture continues to be the dominant livelihood activity in the country, providing employment for 76 per cent of the labor force. The country is also experiencing a number of environmental concerns, including the slow degradation of natural resources, unsustainable agricultural practice, bushfires, and uncontrolled exploitation of the forest and wildlife resources (Guinea, 2007). Large areas of agricultural land are currently abandoned due to soil salinization and acidification. These economic and environmental factors affect Guinea's resilience and increase the likelihood of climate variability and climate change affecting local livelihoods and country's overall long-term national development (UNDP, 2009; INS , 2014).

Guinea's current climate varies from being tropical along its coastal region and within much of its interior to being drier with greater variations in temperature in the sahelian Upper Guinea. Climate projections for Guinea are uncertain but suggest that Middle and Upper Guinea will see significant warming by 2100; varying from an increase of 0.3 ºC to 4.8 ºC, and that temperatures will also rise but to a lesser extent in Lower Guinea and Forest Guinea regions, 0.2 ºC to 3.9C (Guinea, 2007). Significant decreases are also possible; projections suggest that rainfall could decrease by 35 per cent 2050 and by 40 per cent by 2100; along with greater rainfall variability and risk of floods, droughts, storms and negative impact on surface and groundwater resources. Climate change-induced sea level rise of anywhere from 15cm to 78cm could also affect Guinea's coastal areas. This combination of changes is expected to negatively affect Guinea's key economic sectors. Socio-economic groups judged to be most at risk include farmers, gardeners, stockbreeders, fishermen, fish smokers, salt producers, traders, transporters, hunters, brick manufacturers, and operator of mines and quarries (Guinea, 2007).

Based on analysis completed through its Initial National Communication and its National Adaptation Program of Action, Guinea has identified the following vulnerable sectors.

(a) Agriculture: Climate change is projected to cause infrastructure destruction, saline intrusion, shortages in potable water and the loss of agricultural land and/or decreased yield. Of particular concern is rice cultivation in Lower Guinea, which represents approximately 42 percent of the region agricultural production.

(b) Water resources: The flow of water in river and stream is expected to undergo a significant reduction, especially in northern regions. For example, flow in the Niger River is expected to reduced by anywhere from 16 to 54 per cent. Impact on potable water resources, including salt-water intrusion, might cause proliferation of waterborne diseases.

(c) Forests: It is expected that current vegetation native to specific regions of the country will shift their location. Mangrove forests, which play a fundamental role in maintaining an environmental equilibrium in the coastal zones, are one of the resources most vulnerable to the impact of climate change.

(d) Coastal regions: Guinea's fisheries sector is likely to be significantly affected as the productivity of marketable species is likely to be reduced. Moreover, the smoking of fish, and activity that is extremely dependent on the mangrove forests, will be reduced.

Unfortunately, the capacity of Guinea to respond to these projected impacts is hampered by a number of factors, including: the low financial capacity of most households, which affects the adaptive capacity of communities; the need to adapt measures or practices to local conditions and the insufficient capacity to implement those measures; lack of technical support from government experts; low institutional and financial capacity of the decentralized administration; lack of community retention of best practices and lessons learned from previous initiatives; and the poor condition of infrastructure due to poor maintenance and low investment. A lack of meteorological information has also been cited as an obstacle to adaptation (UNDP, 2009).

In the following sections, we first describe the normal climate and its evolution for each of the 12 stations included in the dataset. The normal climate is described by the use of climograph and the identification of the correspondent Köppen Type. Cumulative precipitation normal values are provided comparing two different non overlapping periods. The first period goes from 1941 to 1970 and the second one goes from 1971 to 2010. Later on, we provide information on the trends for the annual and seasonal values. Temperature seasons are DJF (December January February), MAM (March April May), JJA (June July August), SON (September October November) and precipitation seasons are wet season which goes from May to October and dry which start in November and ends the following year April. Finally trends on the climate indices of the ET-CCDI and the ET-CRSCI are provided. Trends and their significance are facilitated for different periods using the Sen Slope indicator (Shahid et al., 2011) implemented by Zhang et al. (2013) in the ZYP R package. The 1 % and 5 % level of statistical significance have been used.

4.1 BOKE

Boke prefecture is located between latitudes 10° 27’ 52’’and 11º 40’ 42’’North and longitudes 13° 45’ 28’’ and 15° 5’ 10’’ West. Boke station, like all stations of Guinea, is named after the city that houses it. In this prefecture there are many rivers, lowland, plains, valleys and uplands. The river system is regular over the year. Boke prefecture is bounded on the north by the Republic of Guinea Bissau, on the west by the Atlantic Ocean and the Republic of Guinea Bissau, south by Boffa prefecture and the Atlantic Ocean and east by Telimele prefecture. Boke covers an area of 11,124 km2 and in 2014 has a resident population of 449,405 inhabitants.

4.1.1 Climograph and Cumulative Precipitation

Figure 4-1a shows Boke climograph. The rainy season lasts from May to November with the maximum rainfall in August. Boke has Aw tropical savanna climate type. Boke receives on average 2018.9 mm per year from which 486.8 mm falls in August. Throughout the year, the temperature is relatively high with monthly averages between 25 degrees and 30 degrees Celsius. The dry season lasts from December to April and is characterized by the onset of the eastern hot and dry wind. Figure 4-1b shows cumulated precipitation in Boke over two non overlapping periods 1941-1970 and 1971-2010. The difference in % between the cumulative rainfall during 1941-1970 and 1971-2010 is shown in this and subsequent cumulative rainfall graphs as deficit/excess. Over the period 1971-2010, averaged cumulated precipitation is 27.75 % bellow 1941-1970 cumulative precipitation over Boke prefecture. This suggests that 1971-2010 period is significantly drier compared to 1941-1970 period.

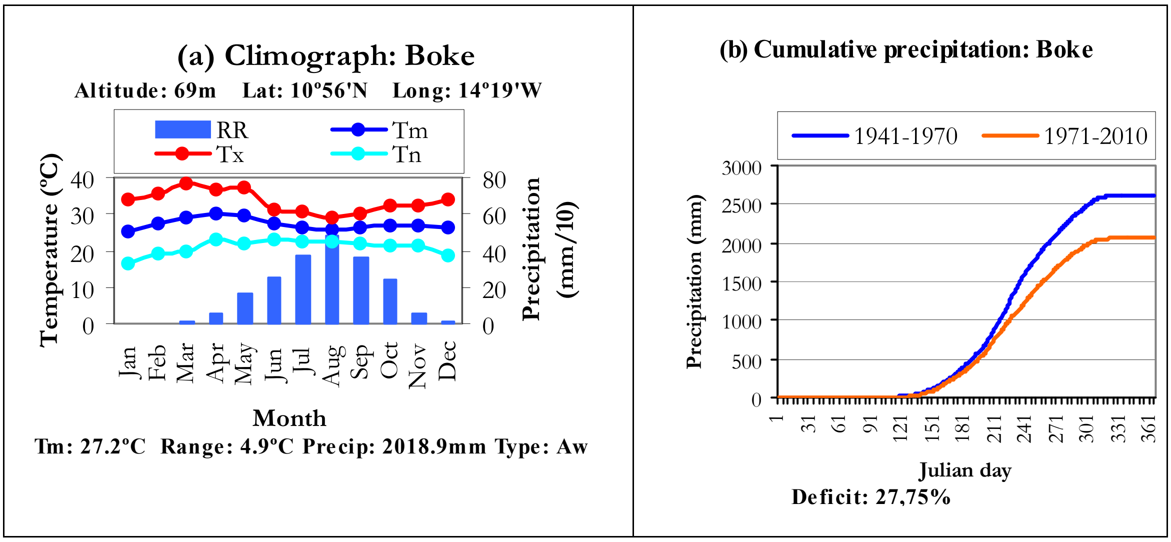


Figure 4-1: Boke cumulative precipitation (right panel) and climograph (left panel) depict the annual cycle of temperature and rainfall for Boke; RR, Tm, Tx and Tn stand for monthly mean precipitation, monthly mean, maximum and minimum of daily temperatures respectively. Climographs comprises, at the very top, the station name and geographical position, at the bottom are indicated the temperature yearly mean and monthly range in degrees Celsius, followed by the yearly mean cumulated precipitation and the Köppen climate type. In the figures, temperatures in degrees Celsius (left axis) are represented by a line graph, while precipitation totals (right axis) are represented by bar graphs. The cumulative rainfall graph shows the climatic means for 1941-1970 and 1971-2010 periods.

4.1.2 Annual results

Figure 4-2 shows anomalies of annual Tx mean (Figure 4-2a), annual Tn mean (Figure 4-2b) and annual total precipitation (Figure 4-2c). Trends, significance level and confidence intervals for these annual time series are also shown in Table 4-1. In this and subsequent sections recent period refers to 1971-2010 and former period refers to 1941-2010. The annual average of Tx and the annual average of Tn show significant upwards trends over the recent and 1961-2010 periods. Trends in annual Tx mean (0.207 ºC/decade;

significant at 1 %) and in annual Tn mean (0.267 ºC/decade; significant at 1 %) over the recent period are consistent with trends observed at the global mean temperature as documented by AR5 (Hartmann et al., 2013). These trends concurs with those found for WA by Barry et al. (2014) and findings at NWA (nationwide average) given in Table 4-15 later in this chapter. Annual Tn shows a sharp increase from mid 1980 to early 2000 followed by a slight cooling lasting up to mid 2000 and since then annual Tn started new warming. Trends in annual Tx and Tn are inherited form previous periods. In contrast to the trend changes observed in annual Tx and annual Tn, annual total precipitation trend shows changes from significant drying climate trend to non-significant wetting conditions trend from former period to recent period as indicated in Table 4-1. Trend in annual total precipitation over the recent period (0.196 mm/decade, non-significant) is in consistent with changes towards wetter conditions found for WA as reported by Barry et al. (2014) but contrasts with Aguilar et al. (2009) findings although the periods of studies are slightly different. Apart from the fact that the study periods are not exactly the same, this difference can be explained by the quality control and homogenization processes applied to raw data.

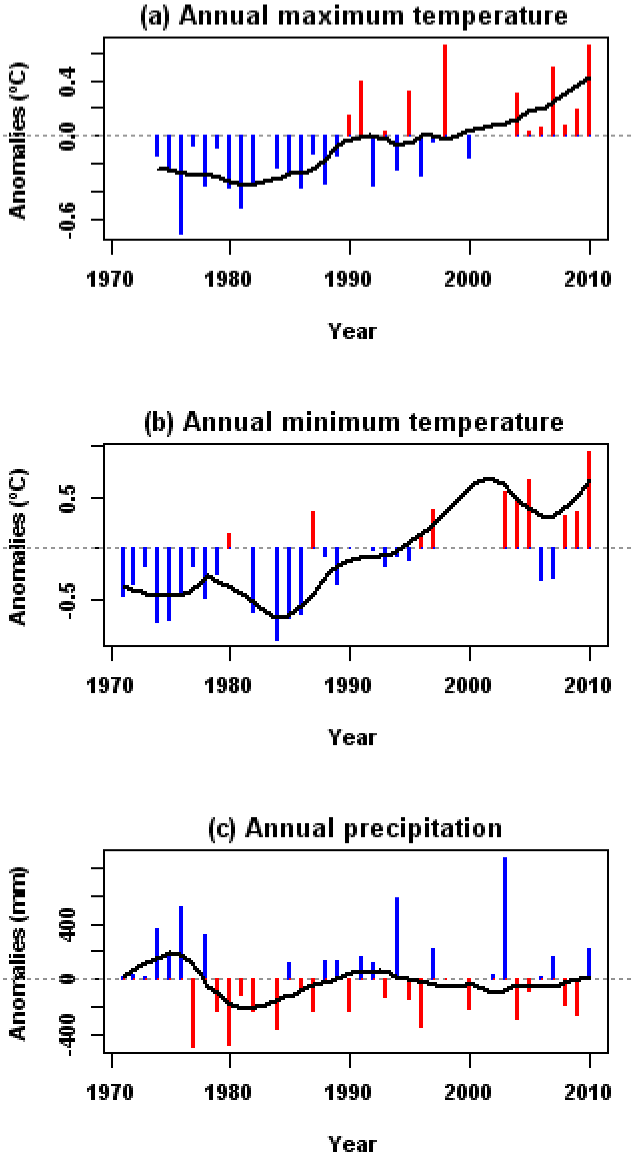


Figure 4-2: Boke anomalies of mean annual Tx (a), anomalies of mean annual Tn (b) and anomalies of total annual precipitation (c). On the graph, colored-bars represent annual anomalies, red for drying (precipitation) or warming (temperature) and blue for wetting (precipitation) or cooling (temperature) and the black smooth curve is generated from LOESS (local Regression) filter applied to the annual anomalies

Table 4-1: Decadal trends in annual, seasonal and climate indices for Boke.

Series/Indices	1941-2010	1961-2010	1971-2010
TxMean	0.065|-0.009:0.134	**0.149|0.097:0.207**	**0.207|0.133:0.247**
TnMean	0.091|0:0.17	**0.179|0.069:0.285**	**0.267|0.109:0.425**
PRCPTOT	**-97.466|-138.978:-55.916**	**-113.925|-197.897:-34.928**	0.196|-79.946:73.143
Tx DJF	0.044|-0.017:0.103	*0.098|0.011:0.215*	*0.193|0.044:0.337*
Tx MAM	-0.01|-0.084:0.078	0.103|-0.01:0.228	0.194|-0.007:0.348
Tx JJA	0.055|-0.037:0.153	**0.187|0.067:0.286**	**0.2|0.067:0.34**
Tx SON	**0.138|0.068:0.198**	**0.232|0.179:0.29**	**0.241|0.168:0.324**
Tn DJF	0.129|-0.053:0.309	*0.322|0.014:0.57*	*0.533|0.116:0.928*
Tn MAM	*0.116|0.008:0.221*	*0.28|0.061:0.445*	*0.333|0.054:0.603*
Tn JJA	*0.078|0.016:0.146*	0.09|-0.045:0.214	0.09|-0.102:0.292
Tn SON	0.033|-0.022:0.082	0.066|-0.01:0.145	0.116|-0.001:0.253
DRY	**-13.154|-19.461:-6.896**	*-8.538|-16.85:-0.872*	-3.275|-15.27:5.286
WET	**-84.731|-131.57:-45.025**	*-103.38|-194.324:-7.044*	1.171|-73.952:89.625
TN10P	-0.58|-1.37:0.206	-1.132|-2.358:0.039	*-1.707|-3.647:-0.239*
TN90P	**0.946|0.338:1.596**	**1.851|1.023:2.828**	**2.486|1.111:3.784**
TX10P	*-0.882|-1.525:-0.23*	**-1.856|-2.504:-1.261**	**-2.105|-2.939:-1.337**
TX90P	0.25|-0.425:0.901	**1.321|0.576:2.108**	**2.051|0.862:3.42**
TNn	*0.228|0.011:0.446*	0.168|-0.212:0.489	0.114|-0.608:0.63
TNx	*0.13|0.018:0.261*	**0.294|0.117:0.464**	*0.273|0.044:0.486*
TXn	0.094|-0.02:0.196	*0.25|0.067:0.417*	*0.333|0.048:0.618*
TXx	0.065|-0.022:0.133	*0.247|0.059:0.456*	**0.324|0.048:0.628**
DTR	-0.064|-0.178:0.055	-0.069|-0.164:0.033	-0.145|-0.25:0.035
SU25	0.187|0:0.476	**0.625|0:1.111**	*0.923|0:1.579*
TR20	1.744|-2.379:5.576	*6.425|0.786:12.287*	**12.065|3.795:18.188**
RX1day	*-4.094|-7.04:-1.167*	*-6.214|-10.425:-1.276*	-6.932|-12.64:0.214
RX5day	*-9.458|-16.585:-2.6*	*-14.238|-26.679:-1.7*	-1.757|-17.75:11.95
SDII	-0.264|-0.517:0.038	*-0.57|-1.03:-0.052*	0.047|-0.619:0.688
R10mm	**-2.635|-3.638:-1.56**	*-2.164|-4.181:-0.509*	0.000|-1.667:2
R20mm	**-1.615|-2.704:-0.605**	*-2.229|-4.091:-0.581*	-0.1|-2.199:2.518
R25mm	**-1.416|-2.357:-0.559**	*-1.956|-3.477:-0.352*	0.000|-1.538:1.667
R95p	**-40.294|-69.673:-16.188**	**-59.2|-115.107:-18.647**	-28.648|-90.375:28.2
R95pTOT	-0.002|-0.013:0.01	-0.005|-0.027:0.02	0.009|-0.03:0.043
R99p	*-9.938|-33:0*	-23.489|-65.557:0	-4.958|-47.85:0
R99pTOT	0|-0.007:0.004	-0.002|-0.015:0.006	-0.001|-0.013:0.013
Onset	0.206|-1.277:1.739	0.845|-1.6:3.953	0.000|-3.529:4.444
Retreat	*-1.264|-2.69:-0.228*	0.000|-1.6:1.429	0.000|-3.103:1.786
Length	-1.446|-3.333:0.6	-1.07|-5:2.432	-0.69|-6.667:4.286
TX50P	2.107|-0.322:4.255	**5.079|3.208:6.824**	**7.084|5.562:8.719**
CDDcold	16.724|-0.472:34.897	**51.378|27.213:79.005**	**88.359|51.653:123.317**
WSDI2	0.000|-1.25:0.952	*1.647|0:3.529*	2.183|0:5
CSDI2	*-2.07|-3.754:-0.19*	*-2.822|-5.309:-0.206*	**-4.535|-7.734:-1.338**
CTN90pct HWA	0.154|-0.688:0.682	0.154|-0.688:0.682	-0.188|-1.75:0.667
CTN90pct HWF	*0.000|0:1.667*	*0.000|0:1.667*	0.577|0:4.783
CTX90pct HWA	NA	NA	NA
CTX90pct HWF	NA	0.000|0:0.8	NA
RX2day	-4.029|-8.862:1.222	-7.293|-15.88:1.188	-1.521|-12.062:11
CWD	*-1.064|-2.069:0*	-0.633|-2.233:0.65	0.455|-0.588:1.714
CDD	**5.451|1.703:8.694**	-1.053|-6:4.348	-0.646|-8.462:8.056
SPEI	**-0.024|-0.032:-0.016**	**-0.034|-0.045:-0.023**	-0.009|-0.024:0.007
SPI	**-0.015|-0.022:-0.008**	**-0.018|-0.03:-0.005**	0.005|-0.008:0.018

In this and subsequent tables trends are separated from confidence intervals by the vertical bar; confidence intervals lower and upper limits are separated by the colon; statistically significant trends at 1 % level are face bold and significant trends at 5 % are in italic and finally NA stands for not available.

4.1.3 Seasonal results

Investigating changes in season time series will provide a more detailed picture of the timing of significant changes in annual time series. Trends in seasonal Tx and Tn are shown in Table 4-1. Over the recent period, both the seasonal Tx and seasonal Tn show significant warming patterns in all seasons except Tn JJA, Tn SON and Tx MAM seasons where mean Tn shows statistically non-significant warming trends. Like the annual Tn mean and the annual Tx mean time series, seasonal trends seem to be inherited from former periods except for mean Tx MAM where a changing trend from cooling to warming though non-significant has been observed. Therefore, warming patterns previously detected in annual Tx are largely explained by warming in Tx DJF, Tx JJA and Tx SON seasons while those observed in annual Tn originate from warming in Tn DJF and Tn MAM seasons. It worth noting that changes magnitudes increase as we move to the recent period.

Unlike seasonal temperatures trends patterns, precipitation seasons (wet and dry) are similar to annual precipitation patterns and do not show any significant trends during the recent period. On the contrary, significant patterns of drying weather observed over the former period become muted in the recent or switch to non-significant wetting trends as it is the case for wet season precipitation time series as indicated in Table 4-1.

4.1.4 Percentile-based and other temperature indices

From the significant changes in annual and seasonal Tx mean and Tn mean it results noticeable changes in the frequency of extreme temperature events. Figure 4-3 shows the annual time series of TN10P (Figure 4-3a), TX10P (figure 4-3b), TN90P (Figure 4-3c) and TX90P (Figure 4-3d). Trends and significance level of TN10P, TX10P, TN90P and TX90P climate indices are summarized in Table 4-1.

Trend in TN10P (-1.707 %/decade; significant at 5 %) and trend in TX10P (-2.105 %/decade; significant at 1 %) suggest that the frequency of cold nights and the frequency of the cold days have significantly decreased in Boke over the recent period. Converting percentage to nights and days these correspond to a decrease of 6.2 cold nights per decade and a decrease of 7.7 cold days per decade. Likewise, trend in TN90P (2.486 %/decade;

significant at 1 %) and trend in TX90P (2.051 %/decade; significant at 1 %) suggest that the frequency of warm nights and the frequency of the warm days have significantly increased in Boke over the recent period. Converting percentage to nights and days these correspond to an increase of 9.1 warm nights per decade and an increase of 7.5 warm days per decade. Similar trends patterns in percentile-based temperature indices are seen over the former and 1961-2010 periods. Additionally, trends in days above average (TX50P) show significant warming patterns (7.084 %/decade; significant at 1 %) over the recent period. Converting percentage to days these correspond to an increase of 25.9 days above average per decade. These consistent patterns of warming are supported by warming patterns reported by Hartmann et al. (2013) at global level. These results also agree with those found by Aguilar et al. (2009) and Barry et al. (2014).

The smoothed curves in Figure 4-3 suggest that changes rate in extremes temperature has accelerated since 1980s for TX10P, TN90P and TX90p and since mid 1980s for TN10P. By and large since mid 1990s the frequency of cold nights and the frequency of cold days are bellow 1981-2010 record average and the frequency of warm nights and the frequency of warm days are above 1981-2010 record average. The strongest changes are observed in TN90P. These warming patterns can also be seen in general climate trends extracted from TNn, TNx, TXn and TXx (see Table 4-1).

Other temperature related indices include TR20 and SU25. Over the recent period tropical nights (12.065 day/decade; significant at 1 %) and summer days (0.923 day/decade; significant at 5 %) indices show significant patterns of warming. These two indices show significant warming trends over the period1961-2010 as well. An increase in both tropical nights and summer days reflects an overall warming trend for the region of Boke.

We can add some more insights to the evolution of temperature by considering additional ET-CRSCI indices, such as CDDcold, WSDI and CSDI indices. Trends and significance level in these indices are given in Table 4-1. CDDcold index expresses the theoretical need for houses cooling for example. Trend in this last index indicates that there is significant growing needs (88.359 ºC/decade; significant at 1 %) for cooling in Boke over the recent period. Finally cold spells (-4.535 day/decade; significant at 1 %) and warm spells (2.183 day/decade; significant at 5 %) indices suggest changes towards warming conditions over the recent period in Boke as indicated in Table 4-1. Significant warming trends in CSDI and quasi stationary or significant warming trends in WSDI are seen over the former and 1961-2010 periods.

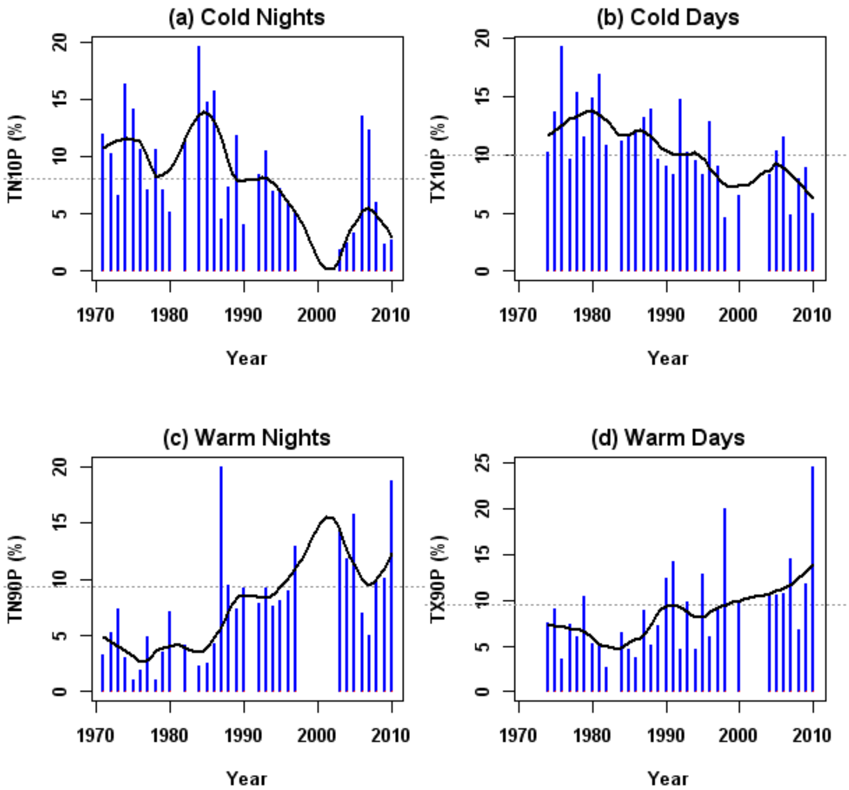


Figure 4-3: Boke indices changes in cold nights (a), cold days (b), warm nights (c) and warm days (d) over the last four decades. The horizontal dotted line is the 1981-2010 of record average. The black smoothed curve is generated from LOESS filter applied to the annual time series

4.1.5 Precipitation intensity index

Figure 4-4 shows Boke SDII index. SDII trend and significance level as well as the confidence intervals are given in Table 4-1. SDII shows very little changes over 1971-2010 in Boke region. During the 1980s drought period, SDII roughly decreased but since 1990s SDII oscillates around the 1981-2010 average. Changes towards non-significant wetting climate are observed in SDII trend when we move from former period (-0.264 mm/day/decade; non-significant) to the recent (0.047 mm/day/decade; non-significant) as indicated in Table 4-1. Over the period 1961-2010 daily intensity shows significant decreases.

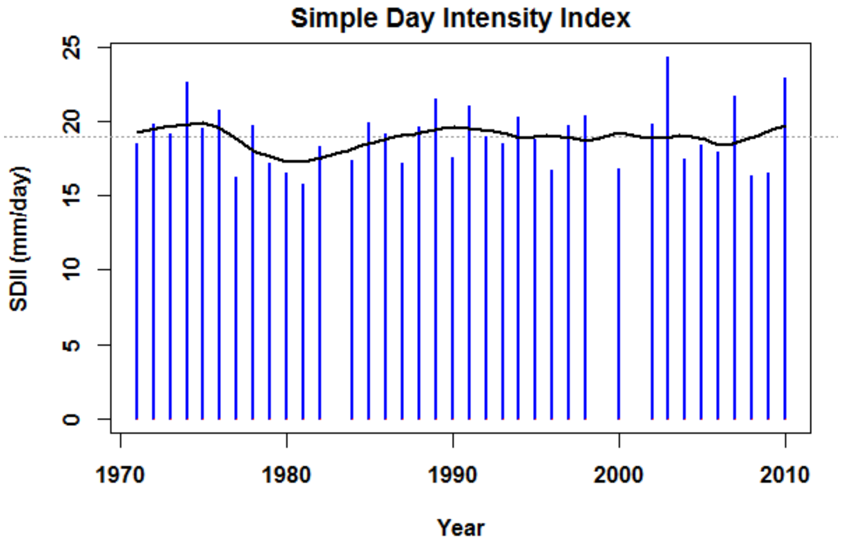


Figure 4-4: Same as in Figure 4-3 except for SDII index

4.1.6 Precipitation percentile indices

Trends and confidence intervals in very and extremely wet days (R95P and R99P) and their respective proportion (R95pTOT and R99pTOT) are given in Table 4-1. None of them shows statistically significant trend over the recent period. Over former period and over 1961-2010 period, R95P show significant drying trend patterns while R99P show significant decreasing over the former period and non-significant over the 1961-2010 period. Figure 4-5 shows R95P index annual time series and the trend suggests that the annual amount of precipitation contributing on days exceeding the 95th percentile has decreased (-28.648 mm/decade; non-significant) over the recent period in Boke, but this change is statistically non-significant. Mid 1970s and early 1990s correspond to years with maximum very wet days precipitation. Over the recent period, Boke trend in R95P index contradicts both findings at NWA (Table 4-15) and those for WA from Barry et al. (2014) but it is consistent with Aguilar et al. (2009) results.

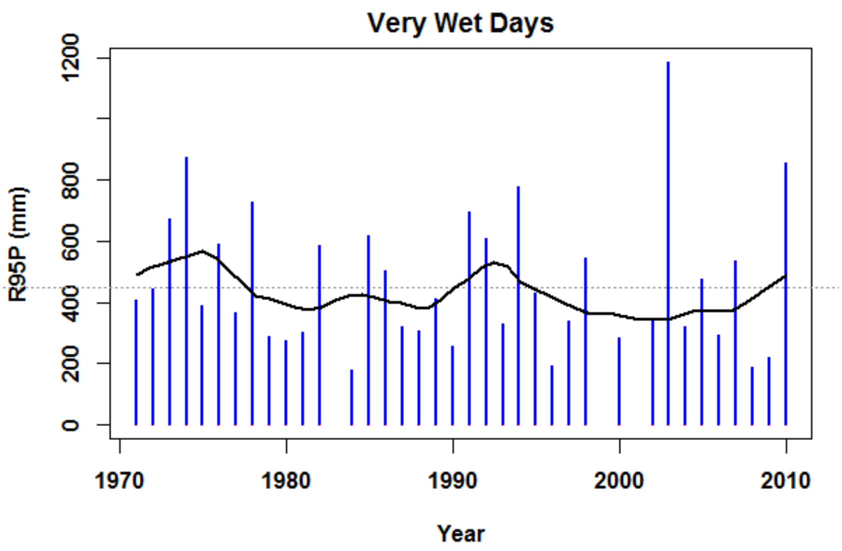


Figure 4-5: Same as in Figure 4-3 except for R95P index

4.1.7 Absolute and other precipitation indices

Table 4-1 shows trends in indices of maximum event intensity Rx1day, Rx2day and Rx5day. Both exhibit very similar patterns in sign although trends in Rx2day are never significant over the study period in Boke while trends in Rx1day (-4.094 mm/decade; significant at 5 %) and Rx5day (-9.458 mm/decade; significant at 5 %) show significant drying conditions over the former period. Over 1961-2010 period Rx1day (-6.214 mm/decade; significant at 5 %) and Rx5day (-14.238 mm/decade; significant at 5 %) show significant changes towards drying climate. Figure 4-6 shows Rx2day index annual time series. Rx2day index shows non-significant decreasing trend (-1.521 mm/decade; non-significant) over the recent period. Similar patterns are observed over the former and 1961-2010 periods.

Other precipitation indices deserving attention are heavy (R10mm), very heavy (R20mm) and extremely heavy events (R25mm) both show nearly stationary trends over the recent period. On the contrary, over the former and 1961-2010 periods both show significant changes towards drying conditions.

Wet spells have increased (0.455 day/decade; non-significant) in Boke over the recent period, but the trend is statistically non-significant as indicated in Table 4-1. These trend patterns are supported by results from Barry et al. (2014) but it contrasts with findings from Aguilar et al. (2009). Contrariwise CWD index shows changes towards significant drying conditions over the former period and non-significant drying conditions over the period 1961-2010.

Trends, significance levels and confidence intervals in wet season onset, retreat and length indices are given in Table 4-1. Boke shows quasi stationary onset and retreat dates over the recent period leading to a non-significant shortened season. Over the former period, Boke shows non-significant delayed onset and significant early retreat leading to a non-significant shortened season, similar trend patterns are seen over the 1961-2010 period with quasi stationary retreat date.

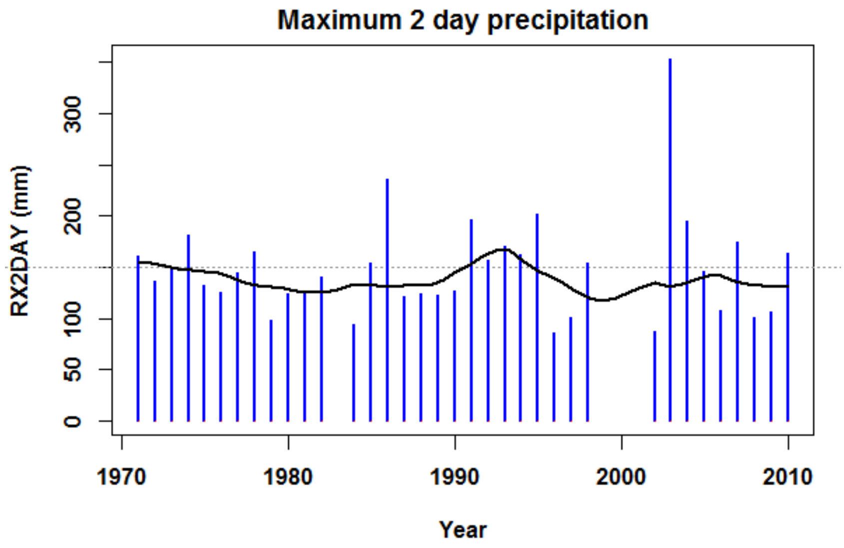


Figure 4-6: Same as in Figure 4-3 except for Rx2day index

4.1.8 Drought indices

Table 4-1 shows trends and significance level in SPEI, SPI and CDD indices. SPI and SPEI show similar and significant decreasing patterns over the former and 1961-2010 periods and opposite non-significant trends over the recent period. It appears that changes magnitude in SPEI trends are twice larger than those observed in SPI trends. This is probably due to the fact that SPEI enables identification of different drought types and impacts in the context of global warming. Figure 4-7 shows SPEI monthly time series anomalies. Over the recent period, droughts have been very frequent in Boke. The worst droughts occurred in 1981, 1983, 1985 and 2009. Less intense but longer lasting droughts have also been observed late 1980s, in 1993 and in 2004.

Dry spells have decreased (-0.646 day/decade; non-significant) in Boke over the recent period, similar trends are seen over the period 1961-2010 contrasting with Aguilar et al. (2009) though the trend is statistically non-significant. CDD trend patterns over the recent period are supported by results from Barry et al. (2014). Over the former period CDD shows significant increasing pattern.

Finally, Table 4-1 shows ET-CRSCI calendar day 90th percentile of Tx (CTX90pct) and Tn (CTN90pct) heat waves amplitude and frequency. Boke is characterized by quasi stationary trends in Tn heat waves frequency over the former and 1961-2010 periods and statistically non-significant trends over the recent one. Tn related heat waves amplitude exhibits non-significant decrease (-0.188 ºC/decade; non-significant) over the recent period and non-significant increase over the former and 1961-2010 periods, suggesting more frequent Tn related heat waves with less amplitude though trends are non-significant over the recent period.

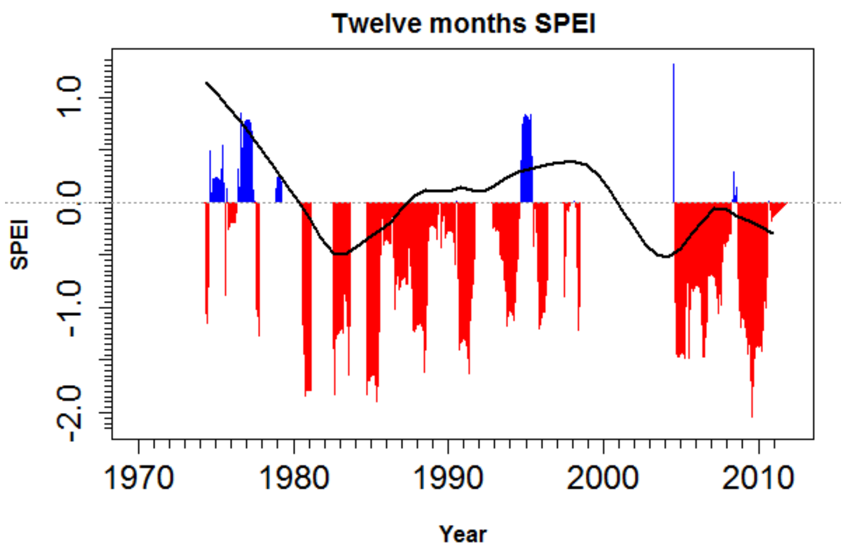


Figure 4-7: Same as in Figure 4-2 except for SPEI index

4.2 CONAKRY

Conakry is a peninsula located between latitudes 9° 30' 2" and 9° 35' 42" North and longitudes 13° 38’ 8’’ and 13° 43’ 10’’ West. Conakry is bounded on the north by Dubreka and Coyah prefecture, on the west and south by the Atlantic Ocean and east by

Coyah and Forecariah prefecture. Conakry covers an area of 450 km2 and in 2014 has a resident population of 1,667,864 inhabitants.

4.2.1 Climograph and Cumulative Precipitation

Coastal, busy and congested urban area, Conakry is very hot all year long with persistent humidity close to 100 % for several consecutives days; Conakry has a typical Am tropical monsoon climate. Figure 4-8a shows Conakry climograph. Although the temperatures don't vary too much over the year, April and May are known as the hottest months of the year with an average of 31.5 °C and the period of wet season onset as well. August is the coolest with an average of 25.3 degrees Celsius. From mid July to mid August the maximum daily temperature decreases, mainly because of high cloud cover. The variation of the average monthly temperatures is only 3.1°C, which is an extremely low range, while that of the mean diurnal range is 7.1°C. Heavily under influence of the western monsoon, Conakry receives on average 3784.7 mm of rainfall per year. Conakry's dry season lasts from December to April. July and August are normally the wettest months with an average of over 1100 millimeters of rainfall. The stormiest months of the year with greatest risk of severe thunderstorms and lightning are June and September. Figure 4-8b shows Conakry cumulative precipitation. This figure suggests that the cumulative rainfall over the period 1941-1970 is above 1971-2010 averaged cumulated precipitation. The period 1971-2010 is 17.51 % drier than the 1941-1970 period.

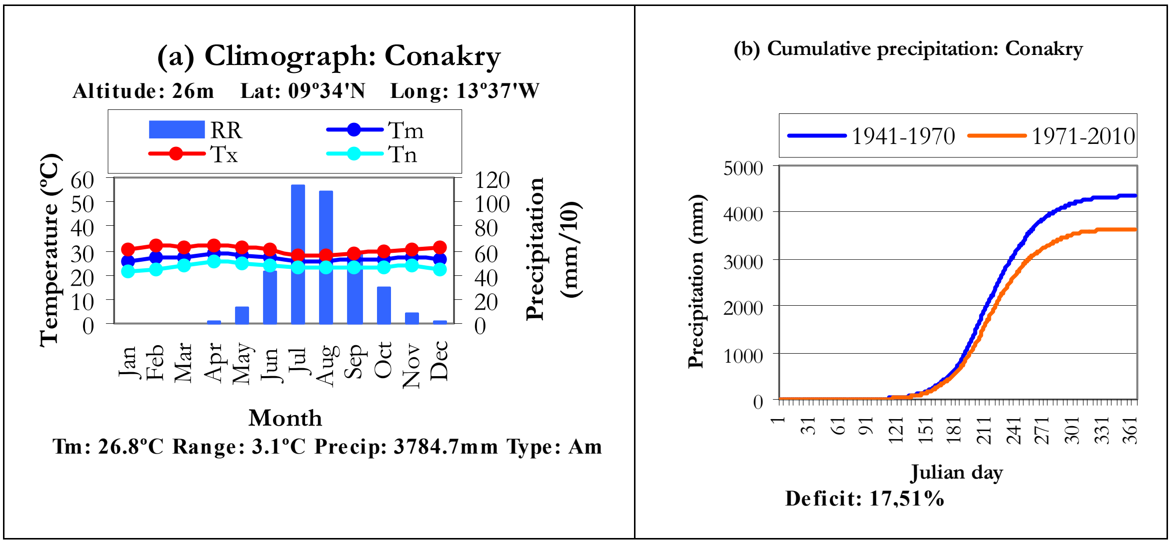


Figure 4-8: Same as in Figure 4-1 except for Conakry.

4.2.2 Annual results

Figure 4-9 shows anomalies of annual Tx mean (Figure 4-9a), annual Tn mean (Figure 4-9b) and annual total precipitation (Figure 4-9c). Trends, significance level and confidence intervals for these annual time series are also shown in Table 4-2. The annual average of Tx and Tn show significant upwards trends during the last four decades. Over the recent period, trend patterns in Tx (0.236 ºC/decade; significant at 1 %) and in Tn (0.286 ºC/decade; significant at 1 %) are supported by observed trend in the global mean temperature as documented by AR5 (Hartmann et al., 2013). Trends in Tx mean and Tn mean also agree with Aguilar et al. (2009) regional results and concur with WA findings from Barry et al. (2014). The fastest increase during the last four decades initiates in 1990s in both Tn mean and Tx mean and since mid 1990s Tn mean and Tx mean remain above 1981-2010 average. Trends in Tx mean and Tn mean are inherited form previous periods specially for Tn mean with which statistically significant warming has always been observed.

In contrast to the consistent trend and higher amplitude of changes observed in Tx mean and Tn mean, annual total precipitation shows a mixed trend that changes from significant drying trend (-154.633 mm/decade; significant at 1 %) from former period to non-significant drying trend (-27.034 mm/decade; non-significant) to recent period. Trend in annual total precipitation contradicts findings for WA as documented by Barry et al. (2014) and shows opposite sign compare to NWA over the recent period (see Table 4-15 later in this chapter). Annual total precipitation trend patterns are supported by results from Aguilar et al. (2009).

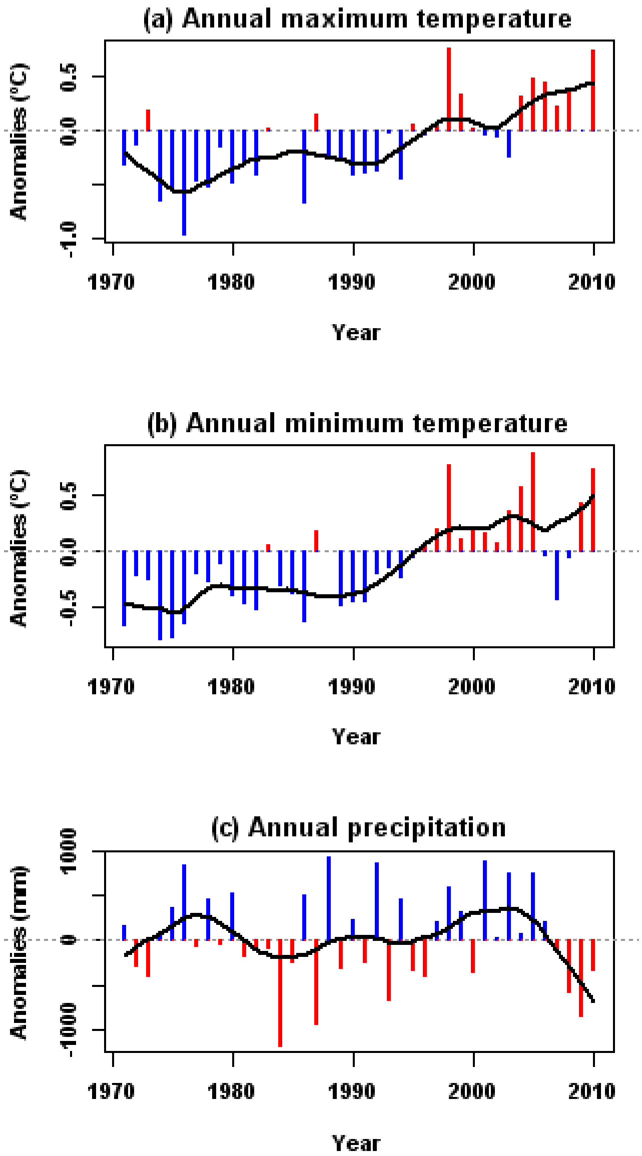


Figure 4-9: Same as in Figure 4-2 except for Conakry

Table 4-2: Decadal trends in annual, seasonal and climate indices for Conakry

Series/Indices	1941-2010	1961-2010	1971-2010
TxMean	0.057|-0.016:0.141	**0.156|0.075:0.239**	**0.236|0.126:0.33**
TnMean	**0.104|0.032:0.169**	**0.211|0.109:0.305**	**0.286|0.134:0.404**
PRCPTOT	**-154.633|-215.064:-89.117**	-126.872|-238.286:11.5	-27.034|-184.429:128
Tx DJF	0.038|-0.061:0.141	*0.182|0.012:0.354*	**0.345|0.165:0.505**
Tx MAM	0.026|-0.064:0.117	0.096|-0.007:0.21	**0.196|0.061:0.327**
Tx JJA	0.07|-0.028:0.164	*0.145|0.032:0.255*	**0.262|0.104:0.409**
Tx SON	**0.108|0.028:0.18**	**0.201|0.112:0.27**	**0.167|0.044:0.305**
Tn DJF	0.101|-0.05:0.251	**0.303|0.105:0.475**	**0.463|0.24:0.699**
Tn MAM	**0.149|0.089:0.207**	**0.257|0.167:0.353**	**0.291|0.151:0.431**
Tn JJA	**0.094|0.044:0.133**	**0.114|0.04:0.179**	*0.14|0.027:0.25*
Tn SON	0.02|-0.031:0.073	*0.116|0.031:0.192*	0.118|-0.015:0.221
DRY	*-13.084|-22.716:-3.392*	-4.062|-17.386:9.991	6.12|-11.62:26.89
WET	**-148.852|-208.677:-79.818**	-119.087|-233.905:13.115	-40.05|-184.1:129.6
TN10P	**-1.063|-1.935:-0.303**	**-2.005|-3.126:-0.904**	*-2.3|-3.657:-0.735*
TN90P	**1.119|0.297:1.994**	**2.54|1.394:3.866**	**3.784|2.274:5.538**
TX10P	-0.9|-1.682:0.002	**-2.116|-3.199:-1.178**	**-2.965|-4.221:-1.544**
TX90P	0.942|-0.221:2.041	**2.298|1.014:3.464**	**3.254|1.838:5.527**
TNn	*0.163|0.024:0.297*	*0.228|0.05:0.402*	**0.378|0.129:0.606**
TNx	**0.097|0.026:0.154**	*0.128|0:0.233*	**0.178|0.05:0.305**
TXn	**0.196|0.11:0.283**	**0.277|0.146:0.41**	**0.423|0.27:0.567**
TXx	*0.11|0.021:0.175*	0.105|-0.043:0.25	0.136|-0.062:0.344
DTR	-0.002|-0.092:0.075	-0.046|-0.127:0.023	-0.033|-0.159:0.087
SU25	**0.574|0.182:0.97**	**0.648|0.13:1.382**	**1.044|0.284:2.028**
TR20	0.333|-1.145:1.938	0.816|-1.396:3.48	2.381|-1.111:6.227
RX1day	-2.4|-9.022:4.054	-3.208|-14.214:6.84	-1.094|-16.375:12.538
RX5day	*-11.505|-19.84:-1.907*	-7.414|-21.207:11.333	-1.56|-19.519:27.5
SDII	**-0.687|-1.168:-0.209**	-0.667|-1.423:0.087	-0.377|-1.427:0.81
R10mm	**-2.821|-3.83:-1.891**	*-2|-3.939:0*	0.000|-2.8:2
R20mm	**-2.242|-3.174:-1.319**	*-1.786|-3.438:0*	-0.742|-2.727:1.333
R25mm	**-2.312|-3.189:-1.385**	-1.111|-2.609:0.37	-0.144|-2.375:1.972
R95p	-51.102|-101.816:7.773	-61.105|-135:39.833	-16.039|-124.571:98.704
R95pTOT	-0.001|-0.023:0.016	0.004|-0.017:0.024	0.007|-0.02:0.035
R99p	-4.571|-46.775:0	0.000|-53.067:9.059	0.000|-45.467:60.75
R99pTOT	0.000|-0.007:0.006	0.005|-0.003:0.017	*0.013|0.002:0.032*
Onset	*0.967|0.002:2.107*	0.584|-1.553:2.664	1.415|-1.84:4.512
Retreat	-1.442|-3.456:0.556	-0.227|-4.061:3.836	0.794|-4.76:6.401
Length	*-2.869|-5.421:-0.09*	-1.005|-5.968:3.629	-0.306|-8.004:6.622
TX50P	2.508|-0.329:5.4	**5.518|3.05:8.469**	**8.698|4.959:11.789**
CDDcold	*24.981|4.861:46.145*	**59.119|28.873:88.818**	**87.892|46.842:128.33**
WSDI2	0.658|-1.329:3.054	**3.862|1.872:6.482**	**5.994|3.333:9.783**
CSDI2	**-2.859|-5.125:-0.658**	**-4.549|-7.525:-2.166**	**-5.059|-8.777:-2.105**
CTN90pct HWA	0.095|-0.069:0.5	0.000|-0.286:0.429	0.000|-0.3:1
CTN90pct HWF	NA	NA	NA
CTX90pct HWA	0.281|-0.322:1.063	-0.125|-0.467:0.278	0.000|-0.56:0.5
CTX90pct HWF	0.508|-2.541:1.743	0.000|-0.667:1	0.000|-1.034:2.273
RX2day	-5.722|-13.034:2.45	-7.3|-19.25:6.535	-0.573|-17:17.917
CWD	*-1.053|-2.143:0*	-0.256|-2.083:1.6	0.000|-2.8:2.632
CDD	-0.286|-5.161:3.958	-4.677|-12.11:3.504	-7.247|-18.182:3.077
SPEI	**-0.017|-0.025:-0.009**	*-0.014|-0.026:-0.002*	-0.004|-0.019:0.01
SPI	**-0.018|-0.024:-0.011**	*-0.012|-0.023:-0.001*	0|-0.014:0.013

4.2.3 Seasonal results

Conakry trends in seasonal Tx and Tn are shown in Table 4-2. Both the seasonal mean Tx and seasonal mean Tn show significant warming patterns in all seasons except for Tn SON season where Tn SON shows statistically non-significant warming trends. Recent seasonal trends seem to be inherited from previous periods. Warming patterns previously observed in annual Tn mean are the results of all seasons warming specially Tn DJF, Tn MAM and Tn JJA while those observed in annual Tx mean may have their explanation in a combined warming of all seasons.

Wet season precipitation index shows similar trend patterns to those of annual precipitation and seems to be the main driver of annual precipitation trend. It is worth noting that significant drying dry season trend (-13.084 mm/decade; significant at 5 %) over the former period turns to non-significant wetting trend (6.12 mm/decade; non-significant) over the recent period while significant drying wet season trend (-148.852 mm/decade; significant at 1 %) over the former period becomes muted (-40.05 mm/decade; non-significant) over the recent period as indicate in Table 4-2. Over the period 1961-2010 both dry and season show non-significant changes towards drier climate.

4.2.4 Percentile-based and other temperature indices

Figure 4-10 shows the annual time series of TN10P (Figure 4-10a), TX10P (Figure 4-10b), TN90P (Figure 4-10c) and TX90P (Figure 4-10d). Trends, significance level and confidence intervals of percentile-based indices climate indices are summarized in Table 4-2.

Trends in TN10P (-2.300 %/decade; significant at 5 %) and trends in TX10P (-2.965 %/decade; significant at 1 %) show significant decreases of the frequency of the cold nights and the frequency of the cold days in Conakry over the recent period. Converting these trends into nights and days these correspond to a decrease of 8.4 cold nights per decade and a decrease of 10.8 cold days per decade. Additionally, trends in TN90P (3.784 %/decade; significant at 1 %) and trends in TX90P (3.254 %/decade; significant at 1 %) also indicate significant increases of the frequency of the warm nights and the frequency of the warm days over the recent period. Converting these trends into nights and days these correspond to an increase of 13.8 warm nights per decade and an increase of 11.9 warm days per decade. This is an indication of warming climate. These trends patterns are supported by those reported by Hartmann et al. (2013); they also agree with those found for WA as documented by Barry et al. (2014) and Aguilar et al. (2009).

Overall, cooling tails remains bellow 1981-2010 average since mid 1990s and warming tails remain above 1981-2010 average since mid 1990s. Accordingly, days above average (TX50P) index is consistent with warming pattern (8.698 %/decade; significant at 1 %) as indicated in Table 4-2. Specifically, this represents an increase of 31.7 days above average temperature per decade over the recent period in Conakry. Furthermore, general climate indices concur with warming patterns.

Other temperature related indices of interest are TR20 and SU25. Tropical nights (2.381 day/decade, non-significant) and summer days (1.044 day/decade, significant at 1 %) exhibit changes towards warming climate (Table 4-2). Over the former and 1961-2010 periods, summer days and tropical nights show identical trends to those they exhibit over the recent period. These results concur with the finding in AR4 where it is reported that a large majority of global land areas had experienced decreases in indices of cold extremes and increases in indices of warm extremes, since the middle of the 20th century, consistent with warming of the climate (Hartmann et al., 2013).

Other temperature related indices worth analyzing are ET-CRSCI indices. Trends and significance level in CDDcold, WSDI and CSDI indices are given in Table 4-2. Trend in CDDcold index (87.892 ºC/decade, significant at 1 %) implies growing needs for cooling in Conakry over the recent period. Cold spells (-5.059 day/decade, significant at 1 %) and warm spells (5.994 day/decade, significant at 1 %) indices also show significant changes towards warming conditions over the recent period. Similarly, cold spells show significant warming patterns over the former and 1961-2010 periods while warm spells show significant warming patterns over the former period and non-significant warming trend over the period 1961-2010.

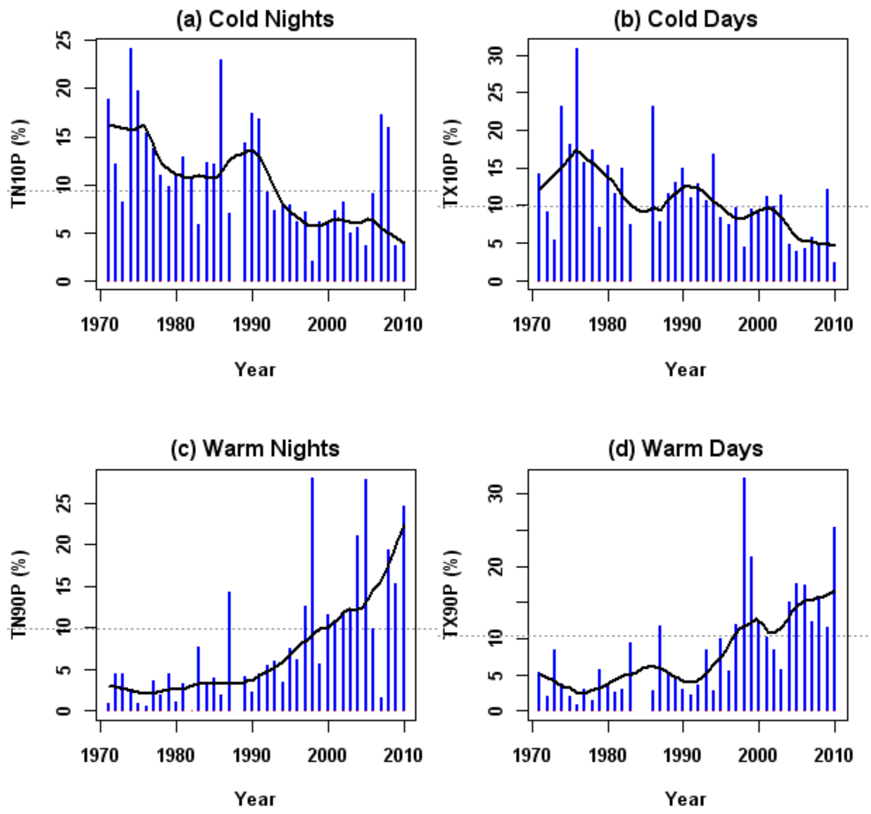


Figure 4-10: Same as in Figure 4-3 except for Conakry

4.2.5 Precipitation intensity index

Conakry SDII index annual time series is presented in Figure 4-11. SDII trend and significance level as well as the confidence intervals are given in Table 4-2. SDII shows non-significant changes towards drier conditions over the recent period and over 1961-2010 period in Conakry. Simple day precipitation index for Conakry is relatively high and since 1970s it oscillates around the 1981-2010 average which is roughly 28 mm/day. This trend patterns is supported by findings from Aguilar et al. (2009) but contrasts with those from Barry et al. (2014). Daily intensity shows significant decreasing trend over the former period.

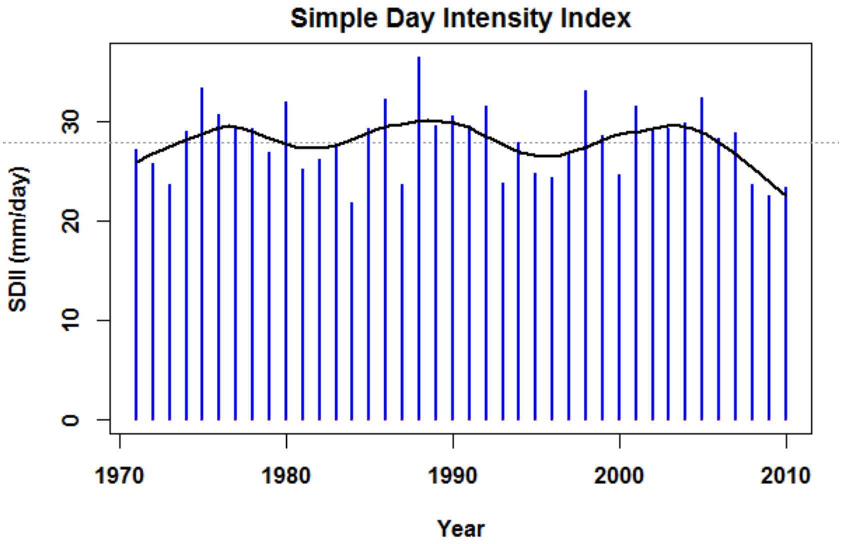


Figure 4-11: Same as in Figure 4-4 except for Conakry

4.2.6 Precipitation percentile indices

Trends and confidence intervals in very and extremely wet days (R95P and R99P) and their respective proportion (R95pTOT and R99pTOT) are given in Table 4-2. Except R99pTOT (0.013 %/decade; significant at 5 %), none of precipitation percentile indices show statistically significant trend over the study period. Figure 4-12 shows R95P index annual time series.

Over the recent period, there is decreasing trend (-16.039 mm/decade; non-significant) in Conakry R95P index indicating that the annual amount of precipitation on days exceeding the 95th percentile has decreased and there is increasing trend (0.007 %/decade; non-significant) in R95pTOT index indicating that the contributed proportion on days exceeding the 95th percentile have increased, but trends are statistically non-significant as indicated in Table 4-2. Contrariwise, contribution from extremely wet day has significantly increased during 1971-2010 period though the magnitude is very small. Over the former and 1961-2010 period very and extremely wet day show non-significant drying conditions while their show near stationary trends.

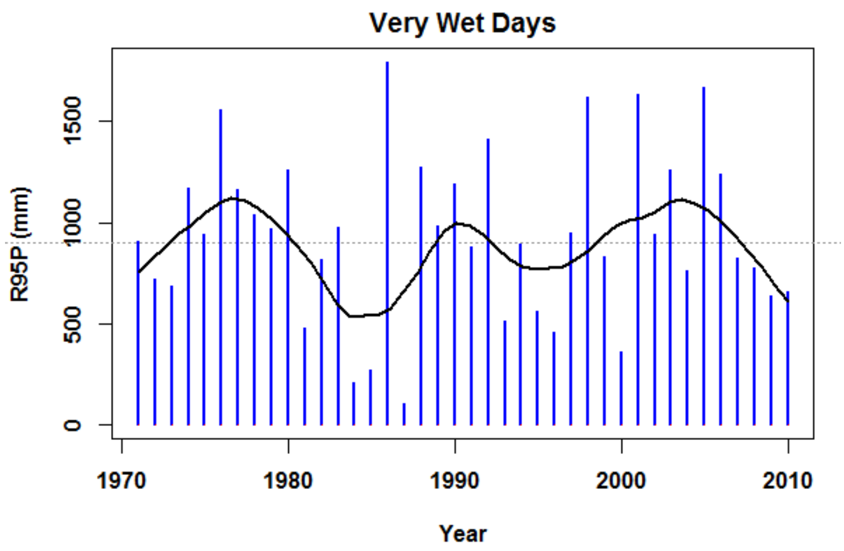


Figure 4-12: Same as in Figure 4-5 except for Conakry

4.2.7 Absolute and other precipitation indices

Trends in absolute precipitation indices Rx1day, Rx2day and Rx5day are shown in Table 4-2. Both indices exhibit very similar patterns of drying conditions although trends are non-significant over both periods except Rx5day (-11.505 mm/decade; significant at 5 %) over the former period. Figure 4-13 shows Rx2day index. Over 1971-2010, Rx2day index oscillates around 1981-2010 average.

In Conakry former period and 1961-2010 period are wetter than the recent period. Thus trends in heavy precipitation days (R10mm, R20mm, R25mm) starting in the early periods show significant drying patterns while those starting in the recent period or the 1961-2010 period show less drying conditions patterns (Table 4-2).

The CWD as a measure of the longest wet spells in a year is near stationary in Conakry over the recent period and tends to drier conditions (-1.053 day/decade; significant at 5 %) when trend starts in the former period as indicated in Table 4-2. Over the 1961-2010 period Conakry shows non-significant decreasing wet spells.
Trends, significance levels and confidence intervals in wet season onset, retreat and length indices are given in Table 4-2. Over the recent period Conakry shows non-significant delayed onset and retreat leading to a non-significant shortened season. Contrariwise former period shows significant onset delay (0.967 day/decade; significant at 5 %) and

non-significant early retreat leading to a significant shorter (-2.869 day/decade; significant at 5 %) wet season. Similar, non-significant trends patterns are observed over the 1961-2010 period.

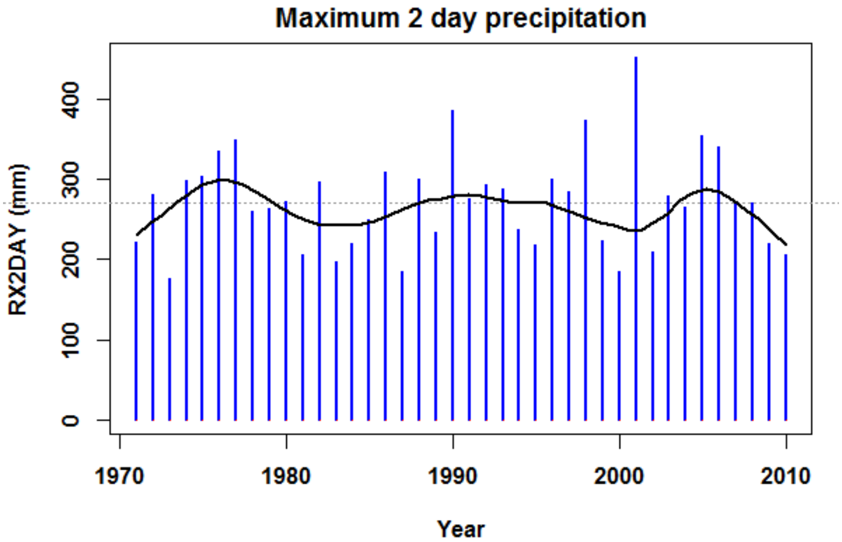


Figure 4-13: Same as in Figure 4-6 except for Conakry

4.2.8 Drought indices

Trends and significance levels in SPEI, SPI and CDD indices are shown in Table 4-2. SPI and SPEI show similar significant patterns of drying trends over the former and 1961-2010 periods and quasi stationary trends over the recent period. Figure 4-14 shows SPEI monthly time series anomalies. Over the recent period, droughts have been very frequent in Conakry. The worst droughts occurred in 1975, 1993 and 1995. Less intense but longer lasting droughts have also been observed early 1980s, early 1990s, early 2000s, in 2008 and early 2010s. Conakry CDD index, the measure of the length of the longest dry spells in a year tends towards wetter conditions (-7.247 day/decade; non-significant) although statistically non-significant over the recent period. Likewise, over the former and 1961-2010 periods Conakry show non-significant decreasing in dry spells. This result contradicts WA regional results from Dai et al. (2013) and Sheffield et al. (2012) where high confidence in increases in CDD have been reported (Hartmann et al., 2013).

Conakry HWA (hottest day of hottest yearly event) and HWF (total heat wave days) indices are characterized by quasi stationary trends over the recent period (Table 4-2).

Over the former period Conakry shows non-significant increase in Tx related heat waves amplitude and frequency and non-significant increase in Tn related heat waves amplitude. Over the period 1961-2010 Conakry shows quasi stationary Tn related heat waves amplitude and quasi stationary Tx related heat waves frequency, and non-significant decrease in Tx related heat waves amplitude.

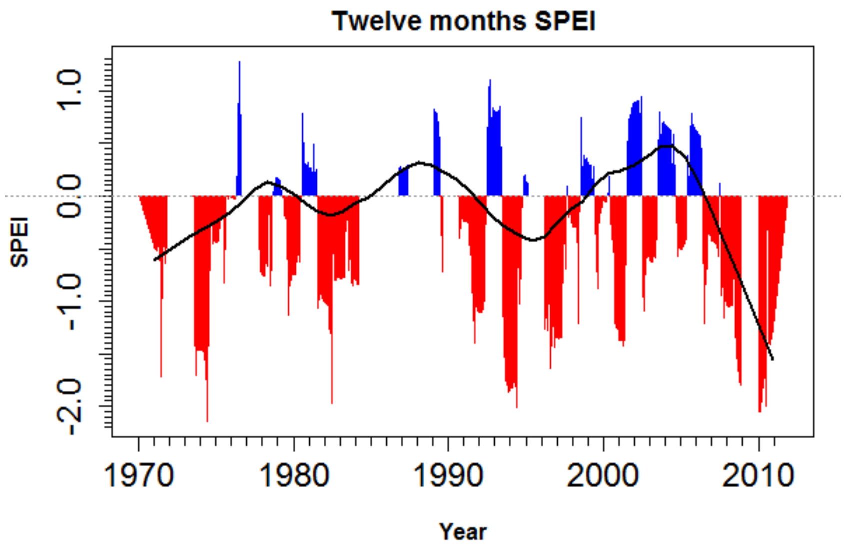


Figure 4-14: Same as in Figure 4-7 except for Conakry

4.3 FARANAH

Faranah is located between latitudes 9° 2’ 58’’and 10° 40’ 14’’ North and longitudes 10° 7’ 3’’ and 9° 5’ 7’’st. Faranah is situated on a relatively low and monotonous plateau, bowing slightly to the northeast. The Niger, the main river in West Africa is rooted in this prefecture. Faranah is bounded on the north by Dabola and Kouroussa prefecture, on the west by that of Mamu and the Republic of Sierra Leone, south by the Republic of Sierra Leone and Gueckedou and east by Kissidougou and Kouroussa. Faranah covers an area of 12,966 km2 and in 2014 has a resident population of 280,511 inhabitants.

4.3.1 Climograph and Cumulative Precipitation

Faranah climate is fairly hot at 26 degrees Celsius of mean temperature with a relatively high diurnal range of 12.8 degrees Celsius and a range of average monthly temperatures of 7.3 degrees Celsius. Figure 4-15a shows Faranah climograph. March and April are the warmest months with a mean temperature of 29.4 °C and December the coolest month with a mean temperature of 22.4 °C. Yearly, Faranah receives 1577.9 millimeters of rainfall. The driest weather is in January with only 3.2 mm monthly total rainfall on average, while the wettest weather is in August when 312 mm rain falls on average. Faranah belongs to Aw climate type. Figure 4-15b shows Faranah cumulative precipitation. Observed cumulative rainfall suggests that 1941-1970 rainfall is 5.70 % bellow 1971-2010 average, indicating that the period 1971-2010 is wetter than 1941-1970 over the territory of Faranah.

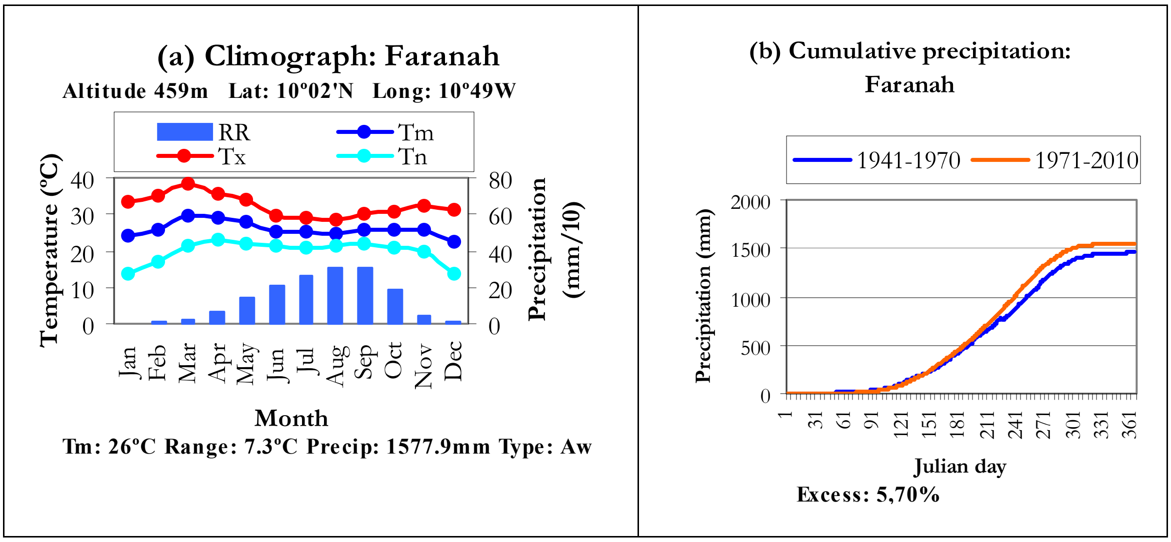


Figure 4-15: Same as in Figure 4-1 except for Faranah.

4.3.2 Annual results

Figure 4-16 shows anomalies of annual Tx mean (Figure 4-16a), annual Tn mean (Figure 4-16b) and annual total precipitation (Figure 4-16c). Trends, significance level and confidence intervals for these annual time series are also shown in Table 4-3.

Figure 4-16a and 4-16b illustrate a general increase in Tx mean and Tn mean from 1970s to mid 1990s, then a steady increasing trend in Tx mean and Tn mean begins in the mid 1990s. In early 2000s both Tx mean and Tn mean initiate relatively short cooling trend lasting up to mid 2000 and since then Tx mean and Tn mean are characterized by an upward trend. Overall, since mid 1990s Tn mean and Tx mean tend to remain over 1971-2010 record average.

Both the Tx mean (0.255 ºC/decade; significant at 1 %) and Tn mean (0.285 ºC/decade; significant at 1 %) show significant warming trends during the recent period. Trend in Tx mean is similar to that observed in the global mean temperature as documented by AR5 (Hartmann et al., 2013) and trend in Tn is similar to that observed in the global mean temperature as documented by AR5 (Hartmann et al., 2013). In contrast to the consistent changes observed in Tx mean and Tn mean, trend in annual total precipitation is characterized by one dry period (1982-1992) corresponding to the well known drought period and two wet periods, the one before 1982 and the one after 1992. Overall annual precipitation shows statistically non-significant drying trend in Faranah.

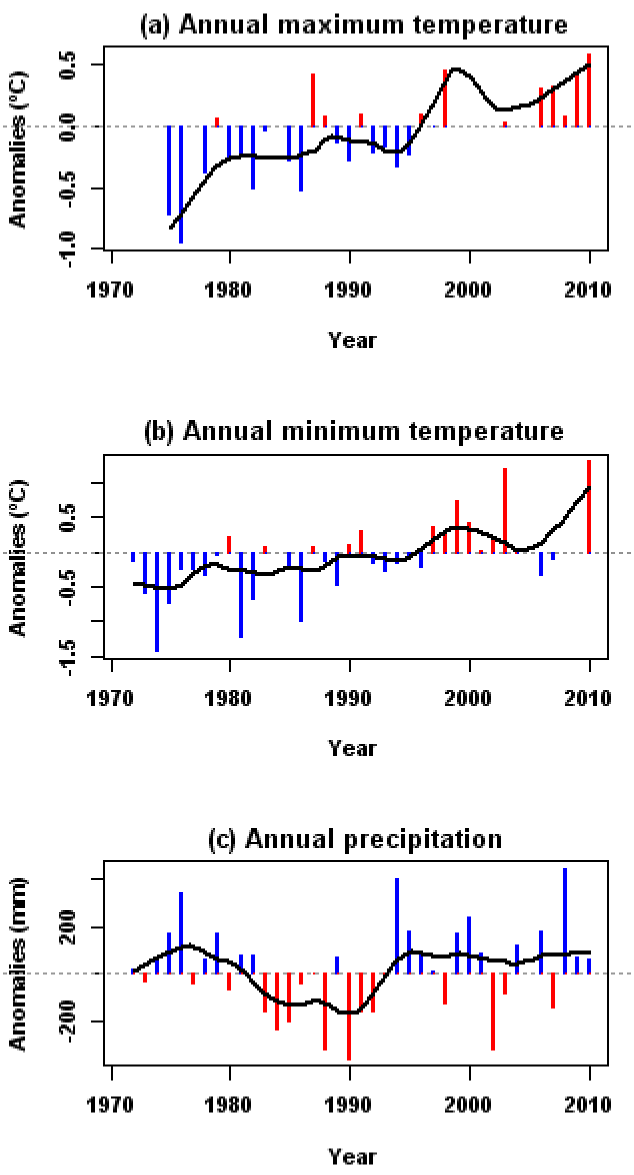


Figure 4-16: Same as in Figure 4-2 except for Faranah

Table 4-3: Decadal trends in annual, seasonal and climate indices for Faranah

Series/Indices	1941-2010	1961-2010	1971-2010
TxMean	NA	NA	**0.255|0.091:0.397**
TnMean	NA	NA	**0.285|0.124:0.483**
PRCPTOT	-35.29|-72.437:2.613	-25.699|-77.299:38.632	-3.109|-63.21:74.296
Tx DJF	NA	NA	0.096|-0.102:0.293
Tx MAM	NA	NA	0.176|-0.067:0.431
Tx JJA	NA	NA	*0.192|0.03:0.317*
Tx SON	NA	NA	**0.15|0.055:0.3**
Tn DJF	NA	NA	0.436|-0.105:0.999
Tn MAM	NA	NA	**0.328|0.122:0.535**
Tn JJA	NA	NA	**0.235|0.12:0.344**
Tn SON	NA	NA	0.1|-0.095:0.3
DRY	**-19.771|-32.337:-6.123**	-10.139|-24.531:2.254	*-18.464|-35.333:-0.692*
WET	-2.445|-24.029:21.978	5.572|-36.984:43.793	14.282|-42.858:72.611
TN10P	NA	NA	*-1.58|-3.191:-0.214*
TN90P	NA	NA	**3.374|1.074:6.383**
TX10P	NA	NA	**-2.583|-3.903:-1.152**
TX90P	NA	NA	**3.818|0.903:6.416**
TNn	NA	NA	**0.779|0.345:1.222**
TNx	NA	NA	**0.22|0.077:0.385**
TXn	NA	NA	0.143|-0.273:0.522
TXx	NA	NA	*-0.308|-0.593:-0.043*
DTR	NA	NA	0.07|-0.274:0.349
SU25	NA	NA	0.000|-1.677:1.667
TR20	NA	NA	*8.301|1.348:16.076*
RX1day	-1|-3.917:1.607	-2.955|-8.425:3.517	-3.136|-9.421:5.413
RX5day	-3.747|-8.403:1.89	-6.405|-17.351:5.638	-0.977|-14.425:13.334
SDII	*-0.976|-1.752:-0.227*	-0.28|-1.867:0.875	0.19|-0.25:0.708
R10mm	-0.756|-2.111:0.265	0.338|-1.407:2.041	0.505|-1.632:2.552
R20mm	*-1.273|-2.308:-0.292*	-0.898|-3.138:1.342	0.199|-1.771:2.21
R25mm	*-1.062|-1.829:-0.203*	-0.895|-2.837:0.966	-0.008|-2.044:1.995
R95P	-20.732|-41.93:3.161	-18.133|-46.267:15.15	9.692|-26.647:40.821
R95pTOT	0.006|-0.02:0.024	0.002|-0.023:0.022	0.017|-0.007:0.034
R99P	-9.023|-28.755:1.3	-3|-37:0	-0.273|-33.087:4.467
R99pTOT	0.003|-0.011:0.018	-0.009|-0.024:0.001	-0.004|-0.017:0.01
Onset	-0.371|-3.333:2.045	-1.429|-5.6:2.5	-1.034|-6.667:4.643
Retreat	-1.484|-3.443:0.373	0.857|-1.111:3.333	1.403|-2.146:6.315
Length	-0.177|-3.774:3.077	3.077|-1.429:6.429	3.333|-2.083:7.714
TX50P	NA	NA	**6.187|1.822:10.482**
CDDcold	NA	NA	71.802|-131.661:283.446
WSDI2	NA	NA	*13.306|2.56:24.261*
CSDI2	NA	NA	*-6.482|-11.694:-1.085*
CTN90pct HWA	NA	NA	0.000|-1.375:0.826
CTN90pct HWF	NA	NA	0.000|-3.333:3.333
CTX90pct HWA	NA	NA	-0.662|-3.45:1.667
CTX90pct HWF	NA	NA	NA
RX2day	-2.296|-6.515:1.599	-2.429|-10.407:5.809	-1.986|-11.744:7.379
CWD	0.243|-0.113:0.6	-0.362|-1.048:0.356	-0.313|-0.988:0.411
CDD	3|-1.224:7.083	1.176|-6.875:8.846	3.75|-5.714:12.353
SPEI	NA	NA	-0.025|-0.071:0.021
SPI	-0.008|-0.019:0.003	0.000|-0.016:0.017	0.001|-0.023:0.025

4.3.3 Seasonal results

The seasonal changes in Tx and Tn over the recent period reflect warming (Table 4-3). However, warming has not occurred consistently for Tx and Tn for all seasons. Changes in DJF are statistically non-significant for both Tx and Tn, and those in Tx MAM and Tn SON are also non-significant. These results suggest that increases previously observed in Tx mean are originated from warming in Tx JJA and Tx SON seasons while increases previously observed in Tn mean are mainly originated from warming in Tn MAM and Tn JJA.

4.3.4 Percentile-based and other temperature indices

Figure 4-17 shows Faranah percentile-based temperature indices of TN10P (Figure 4-17a), TX10P (figure 4-17b), TN90P (Figure 4-17c) and TX90P (Figure 4-17d). Over the recent period trends shows significant patterns of warming in warm nights index (3.374 %/decade; significant at 1 %) and significant patterns of warming in warm days index (3.818 %/decade; significant at 1 %). Compared to trends in TN90P and TX90P observed at global level, Faranah warm nights and warm days indices remain consistent and below average as documented from Hartmann et al. (2013). Converting these trends into days these correspond to an increase of 12.3 warm nights per decade and increase of 13.9 warm days per decade over the recent period.

Similarly, over the recent period Faranah trends in cold nights (-1.580 %/decade; significant at 5 %) and cold days (-2.583 %/decade; significant at 1 %) are consistent and belong to average compared to global observed trends documented by Hartmann et al. (2013). Converting these trends into days these correspond to a decrease of 5.8 cold nights per decade and a decrease of 9.4 cold days per decade. The largest increases in warm nights and warn days occurred in mid 1990s.

Over 1971-2010 Faranah shows a significant increase in TX50P (6.187 %/decade; significant at 1 %), converting percentage into days these correspond to an increase of 22.6 days above average per decade over the recent period (Table 4-3).

Other fixed threshold temperature based indices are SU25 and TR20. Their impacts are easy to understand and to evaluate. Over 1971-2010, Faranah has experienced significant increases in TR20 (8.301 day/decade; significant at 5 %) and quasi stationary in SU25.

Faranah general climate indices are presented in Table 4-3. Generally, the increasing trends in TNn are compatible with decreasing trends in TN10P because the former index is in absolute temperature units while the latter reports frequency of days below a fixed threshold (New et al. 2006). Faranah trends given in Table 4-3 concur with this general literature. The coldest night temperature (0.779 ºC/decade; significant at 1 %) and the warmest night temperature (0.220 ºC/decade; significant at 1 %) indices show significant warming trends over the recent period. The coldest day temperature shows non-significant warming trend and the warmest day temperature shows significant cooling pattern over the recent period; as a result, DTR exhibits non-significant increasing trend.

CSDI and WSDI trends are indicated in Table 4-3. Cold spells (-6.482 day/decade, significant at 5 %) and warm spells (13.306 day/decade, significant at 5 %) suggest significant warming patterns over the recent period. Likewise, trend in CDDcold (71.802 ºC/decade; non-significant) indicates changes towards warming climate though statistically non-significant; the substantial need for cooling expressed by this index is real.

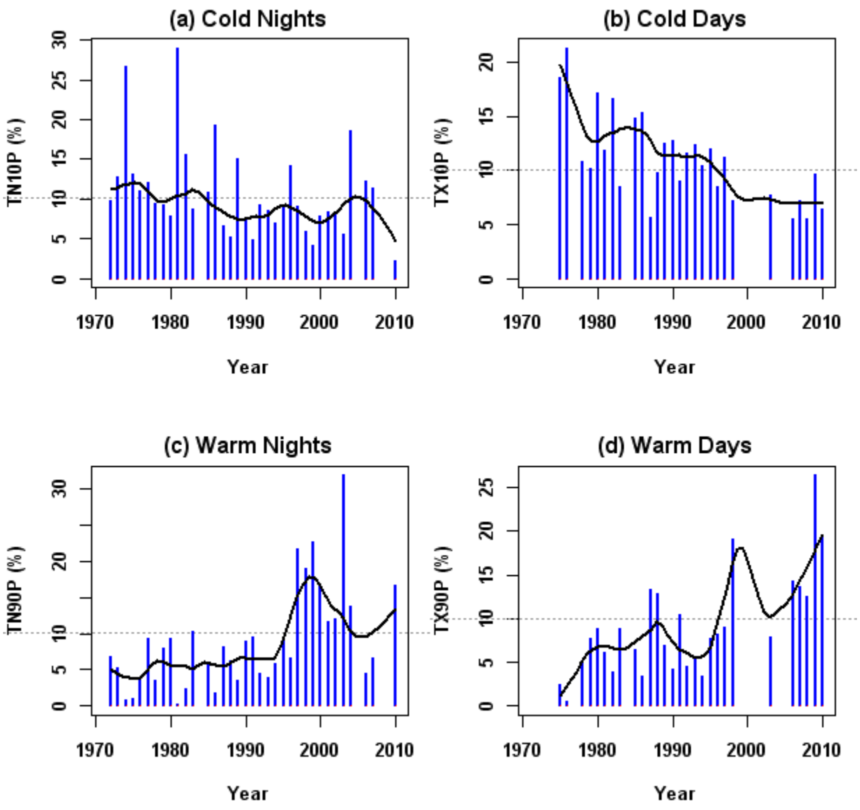


Figure 4-17: Same as in Figure 4-3 except for Faranah

4.3.5 Precipitation intensity index

Figure 4-18 illustrates SDII index annual time series. The SDII index shows an increasing trend at the rate of 0.19 mm/day per decade over the recent period, but this trend is statistically non-significant. Over 1971-2010, SDII index oscillates around 15 mm/day the 1981-2010 average record for Faranah. The highest increase in SDII trend occurred in mid 1990s. Trend in this index becomes muted as we move from former period (-0.976 mm/day/decade; significant at 5 %) to recent period (0.19 mm/day/decade; non-significant) with sign changes. SDII trend over the recent period is supported by WA findings from Barry et al. (2014) but contradicts Aguilar et al (2009) results. Daily intensity shows significant decreasing trend over the former period and non-significant decreasing trend over the period 1961-2010.

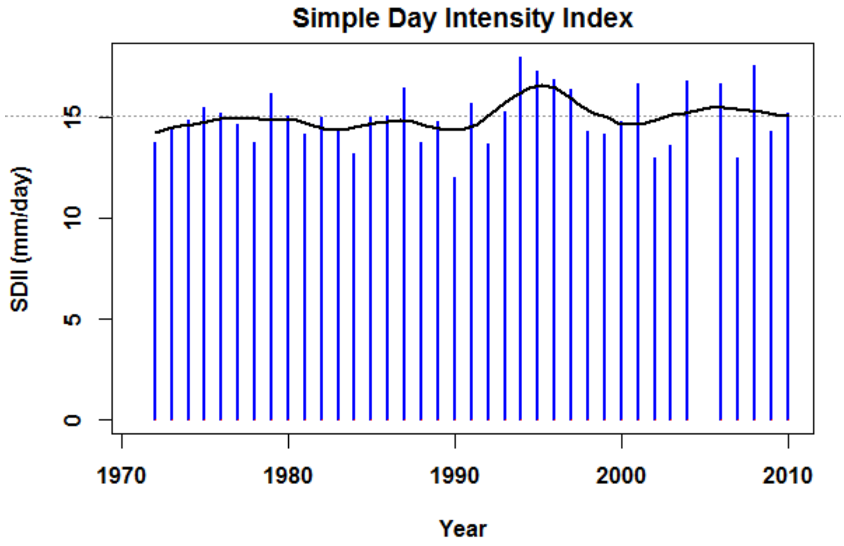


Figure 4-18: Same as in Figure 4-4 except for Faranah

4.3.6 Precipitation percentile indices

Trends and confidence intervals in very and extremely wet days (R95P and R99P) and their respective contribution (R95pTOT and R99pTOT) are shows in Table 4-3. There are increasing trends in Faranah in R95P (Figure 4-19) and R95pTOT indices indicating that the annual amount of precipitation on days exceeding the 95th percentile and their contributed proportion have increased, but changes are overall statistically non-significant over the recent period. There are decreasing trends in Faranah R99P and R99pTOT indices indicating that the annual amount of precipitation on days exceeding the 99th percentile and their contributed proportion have decreased, but again these trends are overall statistically non-significant over the recent period (Table 4-3). Over the former and over the 1961-2010 periods R95P and R99P indices show non-significant decreasing trends.

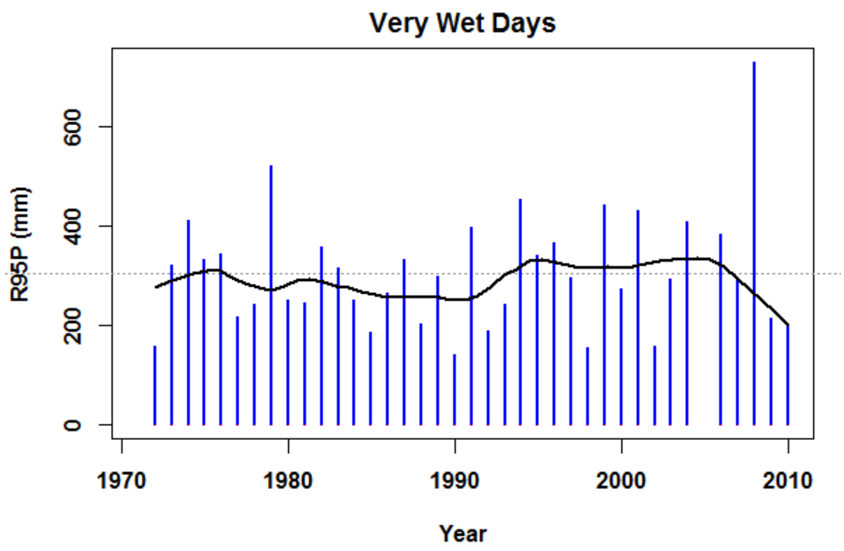


Figure 4-19: Same as in Figure 4-5 except for Faranah

4.3.7 Absolute and other precipitation indices

Trends and confidence intervals in absolute precipitation indices Rx1day, Rx2day and Rx5day are shown in Table 4-3. The patterns of trends for Rx1day, Rx2day and Rx5day are very similar to PRCPTOT trends pattern. These indices do not show significant trend over the study period. Figure 4-20 shows the annual time series for Rx2day index. Over 1971-2010, Rx2day index oscillates around 100 mm, the 1981-2010 record average. Trend in Rx2day (-1.986 mm/decade; non-significant) suggests non-significant changes towards drying conditions over the recent period. Identical trends are seen over the former period and over the period 1961-2010.

Similarly over the recent period CWD index does not show much change and tends to drier weather though statistically non-significant (Table 4-3). The patterns of trends for the frequency of extremely heavy precipitation R25mm are very similar to those of PRCPTOT and tend towards drier conditions while those for heavy and very heavy precipitation show mixed patterns including changes in sign from former period to recent period though changes are statistically non-significant.

Trends, significance levels and confidence intervals in wet season onset, retreat and length indices are given in Table 4-3. Faranah shows non-significant early onset (-1.034 day/decade; non-significant) and late retreat (1.403 day/decade; non-significant) suggesting a longer (3.333 day/decade, non-significant) wet season, but trends are non-significant over the recent period. Identical trend patterns are observed over the 1961-2010 period. Likewise non-significant early onset and retreat are seen over the former period, leading to a non-significant shortened wet season length.

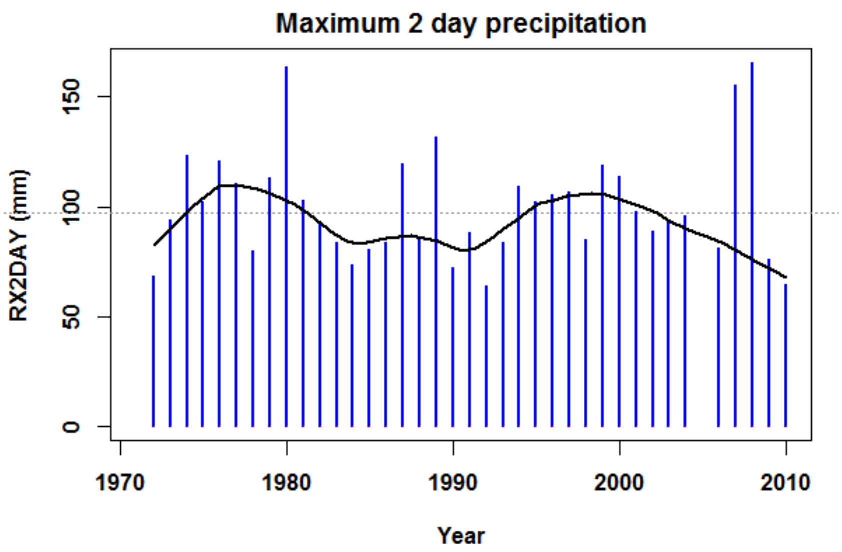


Figure 4-20: Same as in Figure 4-6 except for Faranah

4.3.8 Drought indices

Trends and significance levels in SPEI, SPI and CDD indices are shown in Table 4-3. SPI and SPEI show non-significant and opposite trend over the recent period. Figure 4-21 shows SPEI monthly time series anomalies in Faranah. Over 1971-2010, droughts have been observed late 1980s and early 1990s though 2003 and 2007 droughts are also significant in magnitude with shorter duration.

CDD index shows increasing non-significant trend indicating increases of dry spells over all periods. Results in CDD index concur with Dai et al. (2013) and Sheffield et al. (2012) where high confidence in increases in CDD have been reported (Hartmann et al., 2013) although the CDD index in Faranah does not show statistically significant change, the magnitude (3.750 day/decade; non-significant) is relatively important over the recent period. CDD trend patterns are supported by Aguilar et al. (2009) findings.

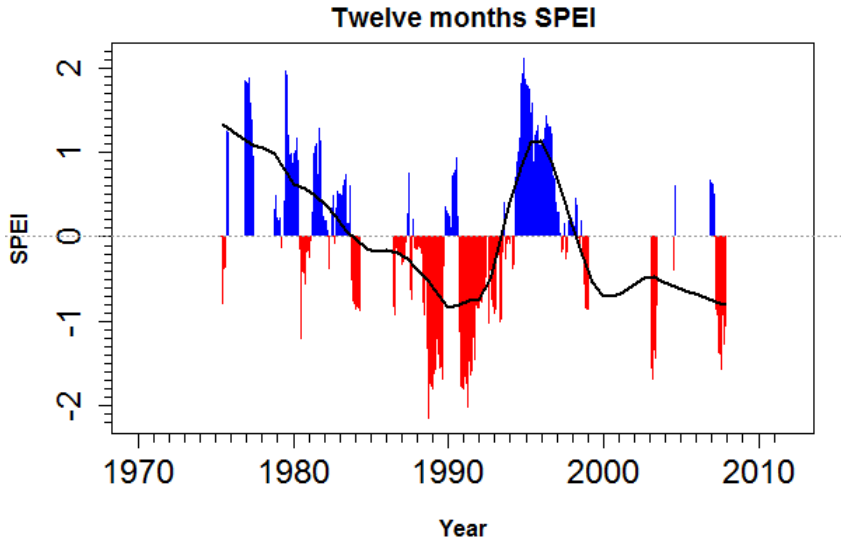


Figure 4-21: Same as in Figure 4-7 except for Faranah

4.4 KANKAN

Kankan is located between latitudes 9° 19’21’’ and 10° 44’ 15’’ North and longitudes 8° 4’ 6’’ and 9° 57’ 21’’ West. South of Kankan, the altitude varies between 650 and 700 m, some points exceeding 800 m. The drainage system consists of the Niger River and its tributaries (Mafu, Niandan Milo Sankarani Banie, and Tinkisso). Kankan is bounded on the north by Mandiana, Siguiri and Kouroussa prefecture, on the west by that of Kouroussa, south by Kereouane, Kissidougou and Beyla and east by the Republic of Côte d'Ivoire and Mandiana prefecture. Kankan covers an area of 119,750 km2 and in 2014 has a resident population of 472,112 inhabitants.

4.4.1 Climograph and Cumulative Precipitation

Capital of the sahelian Upper Guinea, Kankan has a great daily temperature range reaching 19.4°C in January due to the northeastern harmattan. Figure 4-22a shows Kankan climograph. March, the warmest month, is very hot with a mean temperature of 30.6°C, while December, the coldest month, is still fairly hot, with an average of 23.6C. The variation of average monthly temperatures is 7°C, whereas the range of daily mean temperatures is 13.3°C. The annual mean temperature is 26.9 ºC. Kankan receives 1533.5 mm rainfall per year on average. The driest weather is in December when an average of

2.6 mm of rain falls, while the wettest weather is in August when an average of 350 mm of rain falls. Kankan belongs to Aw Köppen climate type. Figure 4-22b shows Kankan cumulative precipitation. Over the period 1971-2010 annual cumulative precipitation is 23.93 % bellow that of 1941-1970.

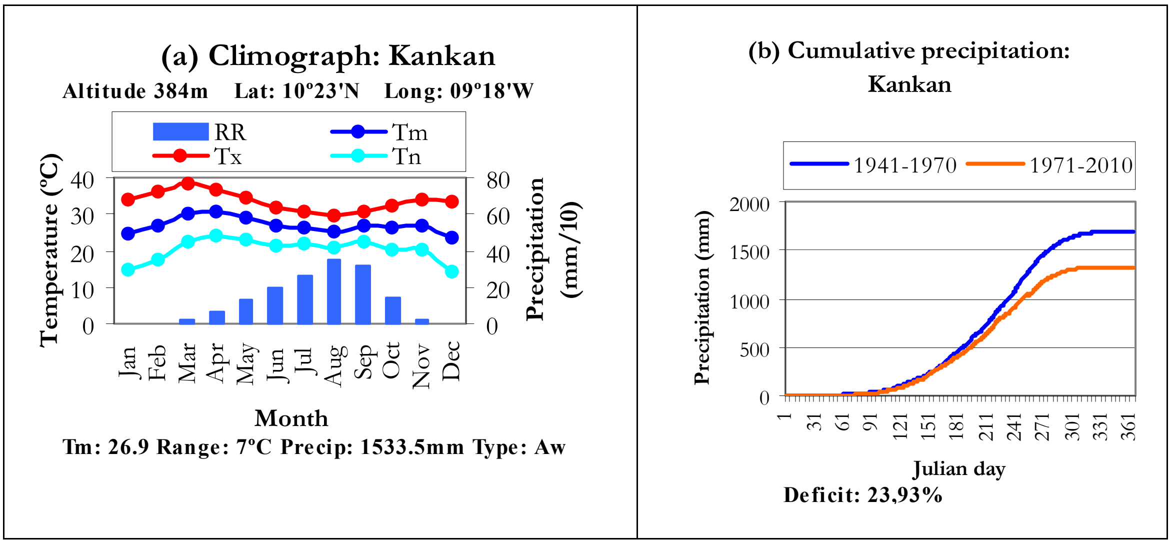


Figure 4-22: Same as in Figure 4-1 except for Kankan.

4.4.2 Annual results

Figure 4-23 shows time series of anomalies of Tx mean (Figure 4-23a), Tn mean (Figure 4-23b) and annual total precipitation (Figure 4-23c). Trends, significance level and confidence intervals for these annual time series anomalies are also shown in Table 4-4. Figures 4-23a and 4-23b illustrate Tx mean and Tn mean annual time series. Both Tx mean and Tn mean exhibit significant warming patterns in Kankan during the recent period. These trends patterns are similar to those observed in the global mean temperature as documented by AR5 (Hartmann et al., 2013). The fastest increase in Tx mean initiated in mid 1970s and since mid 1990s Tx mean remains above 1981-2010 average. Table 4-4 suggests that warming trends are stronger during the recent period than in the former periods. Trends in Tx mean over the recent period are inherited form former period. Warming trends are seen over the former and over the 1961-2010 periods in Tx (significant at 1 %) and Tn indices.

In contrast to the consistent and fairly linear increasing trend observed in Tx mean and Tn mean, annual total precipitation trend shows changes from significant drying trend from the former period (-66.333 mm/decade; significant at 1 %) to non-significant wetting trend (0.989 mm/decade; non-significant) to the recent period as indicated in Table 4-4. In Kankan the former period is wetter than the recent period, thus precipitation related indices starting in the early period show drying trends while those starting in the recent period show non-significant wetting trends (Figure 4-23c). Over the period 1961-2010 Kankan shows non-significant drying trend.

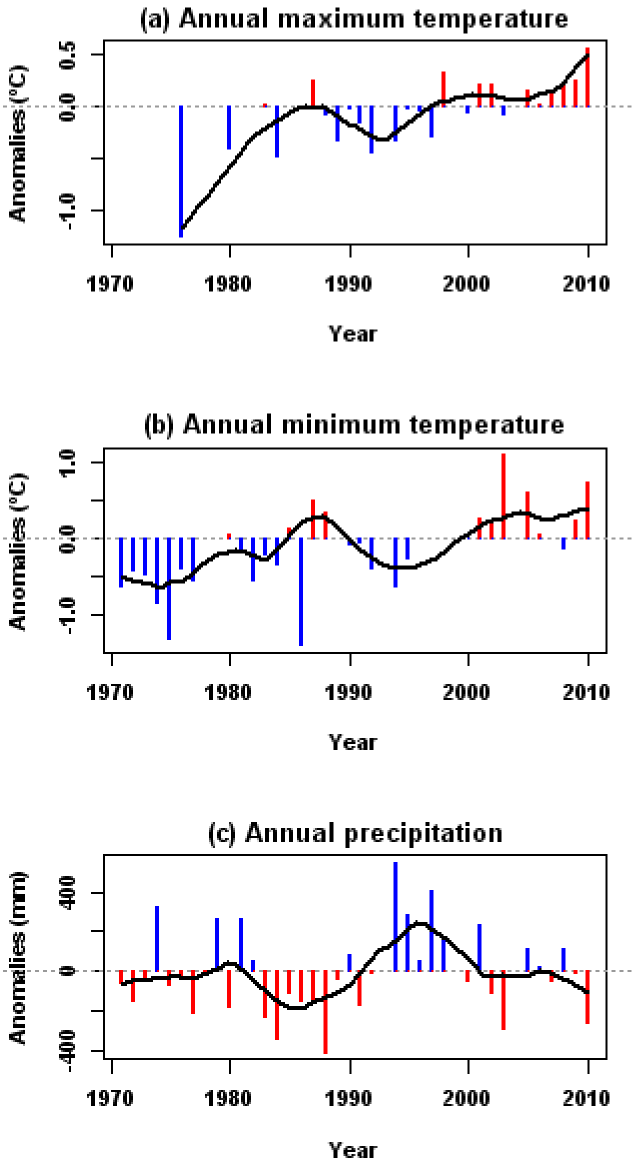


Figure 4-23: Same as in Figure 4-2 except for Kankan

Table 4-4: Decadal trends in annual, seasonal and climate indices for Kankan

Series/Indices	1941-2010	1961-2010	1971-2010
TxMean	**0.112|0.045:0.169**	**0.184|0.108:0.245**	**0.271|0.135:0.38**
TnMean	0.087|-0.006:0.178	*0.14|0.017:0.261*	**0.297|0.172:0.459**
PRCPTOT	**-66.333|-105.525:-26.021**	-57.245|-137.177:4.961	0.989|-88.694:82.046
Tx DJF	0.027|-0.048:0.102	0.091|-0.035:0.244	*0.224|0.035:0.404*
Tx MAM	0.089|0:0.177	*0.141|0.002:0.28*	0.239|-0.014:0.478
Tx JJA	**0.108|0.042:0.173**	**0.145|0.056:0.233**	**0.24|0.079:0.391**
Tx SON	**0.109|0.04:0.171**	**0.167|0.086:0.274**	*0.164|0.026:0.359*
Tn DJF	0.178|-0.001:0.348	*0.313|0.034:0.572*	**0.536|0.166:0.924**
Tn MAM	0.07|-0.024:0.154	*0.154|0.018:0.277*	0.213|-0.02:0.414
Tn JJA	**0.108|0.056:0.157**	*0.108|0.032:0.209*	**0.226|0.092:0.359**
Tn SON	-0.056|-0.138:0.018	0.008|-0.116:0.114	0.106|-0.034:0.256
DRY	**-11.393|-19.442:-3.278**	*-11.055|-22.235:-0.145*	-7.941|-21.727:7.5
WET	**-43.62|-74.378:-16.67**	-31.581|-85.493:16.755	20.313|-50.018:86.345
TN10P	-0.504|-1.195:0.372	-0.778|-2.02:0.501	**-2.238|-4.148:-1.047**
TN90P	0.776|-0.867:2.226	1.68|-0.596:3.687	2.994|-0.684:7.017
TX10P	**-0.725|-1.086:-0.324**	**-1.386|-1.905:-0.79**	**-2.118|-2.871:-1.144**
TX90P	**1.388|0.328:2.249**	**1.998|0.749:3.17**	*3.347|0.113:6.888*
TNn	0.048|-0.143:0.229	0.054|-0.2:0.3	0.2|-0.167:0.652
TNx	**0.223|0.095:0.386**	**0.312|0.093:0.549**	*0.474|0.086:0.888*
TXn	-0.112|-0.273:0.04	-0.034|-0.333:0.222	0.157|-0.5:0.75
TXx	0.000|-0.111:0.103	-0.075|-0.263:0.098	-0.067|-0.333:0.294
DTR	-0.046|-0.195:0.111	0.033|-0.163:0.128	-0.032|-0.538:0.094
SU25	-0.328|-1.059:0.286	-0.628|-2.358:0.4	*-2.187|-5.131:-0.314*
TR20	-0.021|-3.648:4.087	0.298|-6.193:6.004	*7.876|1.504:14.174*
RX1day	-2.951|-6.611:0.512	-1.8|-6.767:3.143	2.068|-4.45:8.649
RX5day	*-6.342|-12.5:-1.545*	-5.286|-14:2.778	-3.287|-15.389:10.24
SDII	-0.116|-0.415:0.176	-0.01|-0.508:0.495	0.214|-0.388:1.046
R10mm	-1.031|-2.223:0.088	-1.14|-3.164:0.548	0.214|-2.251:2.788
R20mm	*-0.988|-1.824:-0.277*	-0.858|-2.427:0.443	0.714|-0.645:2.308
R25mm	*-1.042|-1.816:-0.262*	0.000|-1.379:0.833	0.667|-0.667:2
R95p	*-24.121|-43.125:-4.947*	-16.46|-47.17:15.274	9.882|-36.119:58.46
R95pTOT	-0.009|-0.022:0.005	0.006|-0.022:0.03	-0.041|-0.133:0.017
R99p	0.000|-22.943:0	0.000|-3.826:0	0.000|0:26.519
R99pTOT	-0.009|-0.019:0	-0.001|-0.011:0.011	-0.005|-0.03:0.014
Onset	0.351|-2:2.941	1.606|-2.222:5.806	2|-4.444:8.333
Retreat	-1.165|-3.229:0.679	-0.533|-3.75:1.765	2|-1.379:5.263
Length	-2.222|-5.758:0.87	-2.5|-7.222:2.222	-0.625|-8.182:6.667
TX50P	**3.653|2.081:5.502**	**4.363|2.588:6.018**	**5.615|2.417:9.267**
CDDcold	25.884|-14.371:68.323	44.512|-51.484:164.225	135.897|-110.952:422.066
WSDI2	*2.149|0.073:5.298*	*4.681|0.819:8.014*	9.199|0:21.869
CSDI2	*-2.361|-4.094:-0.016*	*-3.096|-5.637:-0.039*	**-5.605|-10.099:-2.215**
CTN90pct HWA	NA	NA	NA
CTN90pct HWF	0.357|-0.204:1.552	1.5|0:3.077	2|0:5.238
CTX90pct HWA	-0.013|-0.757:1.721	NA	NA
CTX90pct HWF	0.000|0:0.484	0.000|-0.833:0.75	0.000|0:1.579
RX2day	*-5.147|-9.607:-1.003*	-3.776|-10.556:2.383	5.075|-3.545:13.742
CWD	0.000|-0.476:0	0.000|-0.476:0.476	0.000|-0.417:0.87
CDD	*4.607|0.317:8.996*	-1.667|-7.727:3	-1.296|-11.281:7.543
SPEI	**-0.026|-0.038:-0.013**	*-0.022|-0.043:-0.002*	0.023|-0.002:0.047
SPI	**-0.023|-0.033:-0.012**	*-0.017|-0.034:-0.001*	0.006|-0.014:0.025

4.4.3 Seasonal results

Trends and confidence intervals in seasonal Tx and seasonal Tn in Kankan are shown in Table 4-4. Both the seasonal Tx and Tn show warming trends in all seasons, tough some are statistically non-significant over the recent and over the 1961-2010 periods. Warming trends are also seen over the former period, except for Tn SON. Overall trends results suggest that the warming observed in Tx mean is mostly due to more warming in Tx DJF, Tx JJA and Tx SON and warming observed in Tn mean is mostly due to warming in Tn DJF and Tn JJA over the recent period. The seasonal Tx and the seasonal Tn both show noticeable warming trends over the recent period than over the former and 1961-2010 periods, suggesting an accelerated warming during the recent period.

Trends and confidence intervals in wet season and dry season are indicated in Table 4-4. Both seasons show similar patterns to those shown by annual total precipitation over the former and 1961-2010 periods. Statistically significant drying dry season trend (-11.393 mm/decade; significant at 1 %) over the former period turns to non-significant drying trend (-7.941 mm/decade; non-significant) over the recent period in Kankan. Similarly, significant drying wet season trend (-43.620 mm/decade; significant at 1 %) over the former period switches to non-significant wetting trend (20.313 mm/decade; non-significant) over the recent period in Kankan. Both wet and dry season show non-significant drying changes over the period 1961-2010 over Kankan territory.

4.4.4 Percentile-based and other temperature indices

Figure 4-24 shows Kankan percentile-based temperature indices of TN10P (Figure 4-24a), TX10P (figure 4-24b), TN90P (Figure 4-24c) and TX90P (Figure 4-24d). Trends, significance level and confidence intervals are given in Table 4-4. Figure 4-24 suggests changes towards warming trends. Trends in TN10P (-2.238 %/decade; significant at 1 %) and in TX10P (-2.118 %/decade; significant at 1 %) suggest significant decreases of the frequency of the cold nights and the frequency of the cold days in Kankan over the recent period. Converting these trends into nights and days these correspond to a decrease of 8.2 cold nights per decade and a decrease of 7.7 cold days per decade. TN10P shows similar non-significant warming trends and TX10P show identical warming trends over the former period and over the period 1961-2010.

Trends in TN90P (2.994 %/decade; non-significant) and in TX90P (3.347 %/decade; significant at 5 %) also indicate increases of the frequency of the warm nights and the frequency of the warm days over the recent period. Converting these trends into nights and days these correspond to an increase of 10.9 warm nights per decade and an increase of 12.2 warm days per decade. TN90P shows similar non-significant warming trends and TX90P show identical warming trends over the former period and over the period 1961-2010.

This is an indication of warming climate. Consequently, in Kankan the days above average temperature TX50P shows significant increasing trend over the former and over the recent (5.615 %/decade; significant at 1 %) periods. This trend converted into days corresponds to an increase of 20.5 days above average temperature per decade over the recent period. Days above average show identical trends pattern over the former and 1961-2010 periods. These trends patterns are supported by those reported by Hartmann et al. (2013); they also agree with those found for WA as documented by Barry et al. (2014) and Aguilar et al. (2009).

Other temperature based indices of interest are SU25 and TR20. Over 1971-2010, Kankan has experienced significant increases (7.876 day/decade; significant at 5 %) in TR20 and significant decreases (-2.187 day/decade; significant at 5 %) in SU25 over the recent period. Summer days show non-significant decreases over the former and over the 1961-2010 periods. Tropical nights show non-significant changes from decreasing to increasing trends from the former period to the period 1961-2010. Trend patterns in TR20 coincide with those found for WA by Barry et al. (2014) and NWA average given later in Table 4-15. Interestingly, summer day index shows significant decreasing patterns in Kankan over the last four decades.

General climate indices are presented in Table 4-4. Results suggest increasing temperatures of the coldest nights (0.200 ºC/decade, non-significant), increasing temperatures of the coldest days (0.16 ºC/decade, non-significant), increasing temperature of the hottest nights (0.474 ºC/decade, significant at 5 %) and decreasing temperature of the hottest days (-0.067 ºC/decade, non-significant). Hottest nights show significant pattern of increasing temperature over the former and over the 1961-2010 periods. Consequently, the DTR index shows non-significant decreasing trend (-0.032 ºC/decade) over the recent period.

Over 1971-2010 period, Kankan has experienced non-significant increase of warm spells (9.199 day/decade; non-significant) and significant decrease of cold spells (-5.6 day/decade; significant at 1 %). Significant warming patterns are seen over the former period and over the period 1961-2010 in both warm and cold spells, consistent with changes towards warming climate.

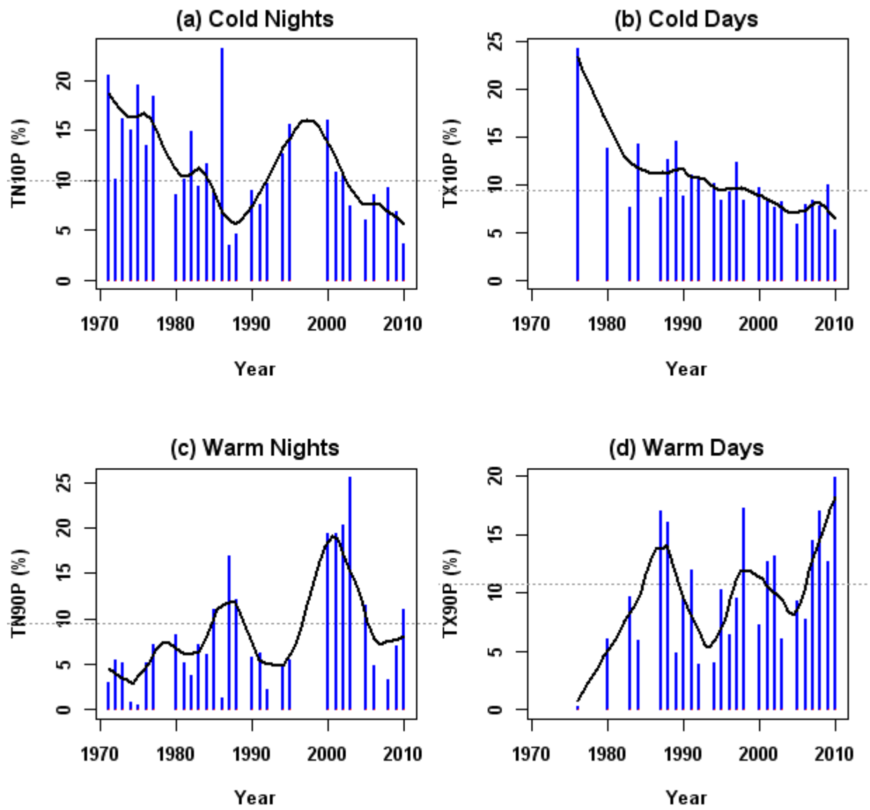


Figure 4-24: Same as in Figure 4-3 except for Kankan

4.4.5 Precipitation intensity index

Figure 4-25 shows annual time series for Kankan SDII index. Trend, significance level and confidence intervals for this index are given in Table 4-4. SDII shows four periods of significant changes: a wet period ending early 1980s followed by a dry period lasting up to early 1990s, the period from early 1990s to mid 1990s is also characterized by significant wet conditions and finally since mid 1990s SDII tends toward less intense precipitation day. Over the recent period daily intensity trend (0.2 mm/day/decade, non-significant) concurs with WA average observed by Barry et al (2014) but contrasts with regional results from Aguilar et al. (2009). Non-significant decreasing trends are seen over the former and over 1961-2010 periods in SDII index.

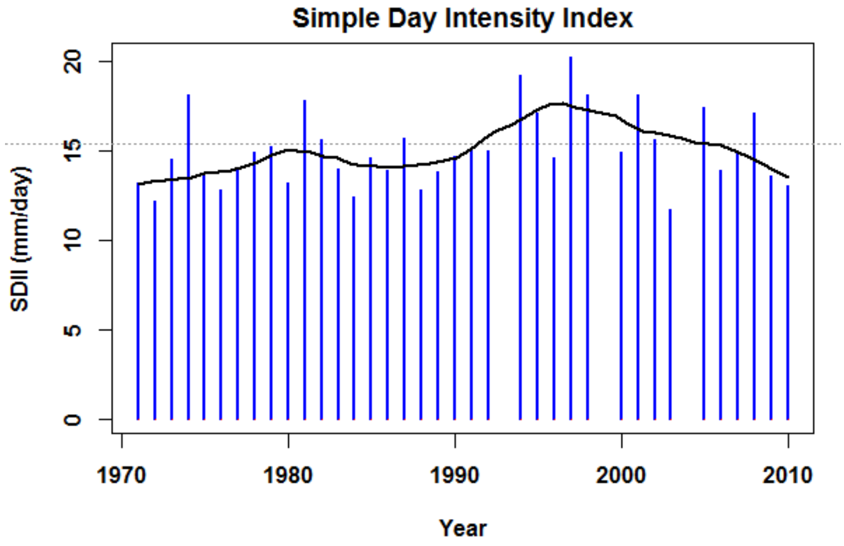


Figure 4-25: Same as in Figure 4-4 except for Kankan

4.4.6 Precipitation percentile indices

Trends and confidence intervals in very and extremely wet days (R95P and R99P) and their respective proportion (R95pTOT and R99pTOT) are shows in Table 4-4. Over the recent period there is no significant change in these precipitation-derived indices. Trends starting in the former periods are quasi stationary except for R95P (Figure 4-26) where significant drying trend (-24.121 mm/decade, significant at 5 %) turns to non-significant wetting trend (9.882 mm/decade, non-significant) from former to recent period. Figure 4-26 suggests that R95P index initiated a downward trend in mid 1990s. R95P trend patterns are supported by WA findings from Barry et al. (2014) but in disagreement with those from Aguilar et al. (2009).

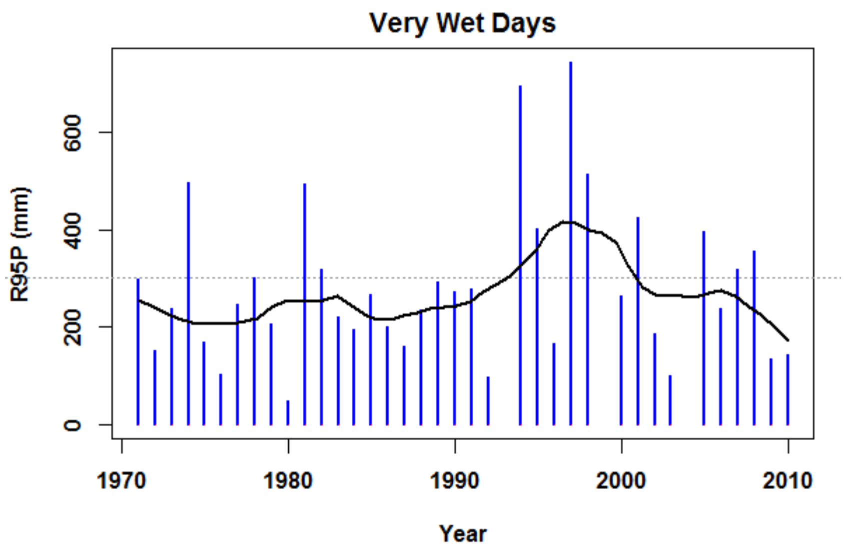


Figure 4-26: Same as in Figure 4-5 except for Kankan

4.4.7 Absolute and other precipitation indices

Trends and confidence intervals in absolute precipitation indices Rx1day, Rx2day and Rx5day are shown in Table 4-4. Trends patterns in Rx1day and Rx2day indices are very similar to those in PRCPTOT index where drying trend turns to wetting trend though statistically non-significant. Figure 4-27 illustrates Rx2day index annual time series. Over the recent period, RX2day shows increasing trend, suggesting that maximum 2 day precipitation has increased in Kankan, but this increase is statistically non-significant. Two days precipitation show significant decreases over the former period and non-significant decreases overt the period 1961-2010. One day and five days precipitation show similar trends over the same periods.

Wet spells index does show little change and remains quasi stationary over all periods.

Changes in heavy, very heavy and extremely heavy precipitation days show non-significant wetting trends over the recent period and show drying trend patterns including significant changes (R20mm and R25mm) over the former period and non-significant drying or quasi stationary trends over the period 1961-2010. Trends in R10mm and R20mm over the recent period concur with those found for WA from Barry et al. (2014) and contradict those at regional level documented by Aguilar et al. (2009).

Trends, significance levels and confidence intervals in wet season onset, retreat and length indices are given in Table 4-4. Kankan shows non-significant delayed onset and retreat leading to a non-significant shortened wet season over the recent period. Over the former period and over the period 1961-2010 non-significant delayed onset and non-significant early retreat leading to a non-significant shortened wet season length are observed.

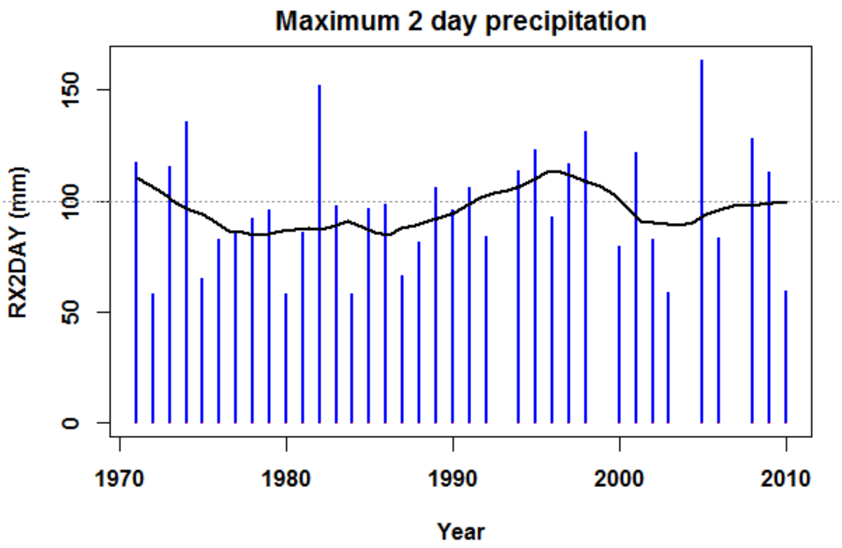


Figure 4-27: Same as in Figure 4-6 except for Kankan

4.4.8 Drought indices

Trends, significance levels and confidence intervals in SPEI, SPI and CDD indices are given in Table 4-4. SPI and SPEI show very similar and significant (at 1 % level) drying patterns over the former period and significant (at 5 % level) drying patterns over the period 1961-2010. These patterns change to non-significant wetting conditions over the recent period. Figure 4-28 illustrates changes in SPEI monthly time series anomalies. Despite the high number of missing data droughts have been extremely frequent in Kankan over 1971-2010. Longer lasting droughts have been seen in 1983, in 1987 and 2003.

In Kankan dry spells suggest changes towards wetter weather though trends are non-significant over the recent period. Over the former period changes tend towards significant increase of dry spells (4.607 day/decade; significant at 5 %). Over the recent period, dry spells trends patterns (-1.296 day/decade; non-significant) concur with findings for WA from Barry et al. (2014) but contrast with those from Aguilar et al. (2009). Note that heat waves indices are either stationary or non-significant.

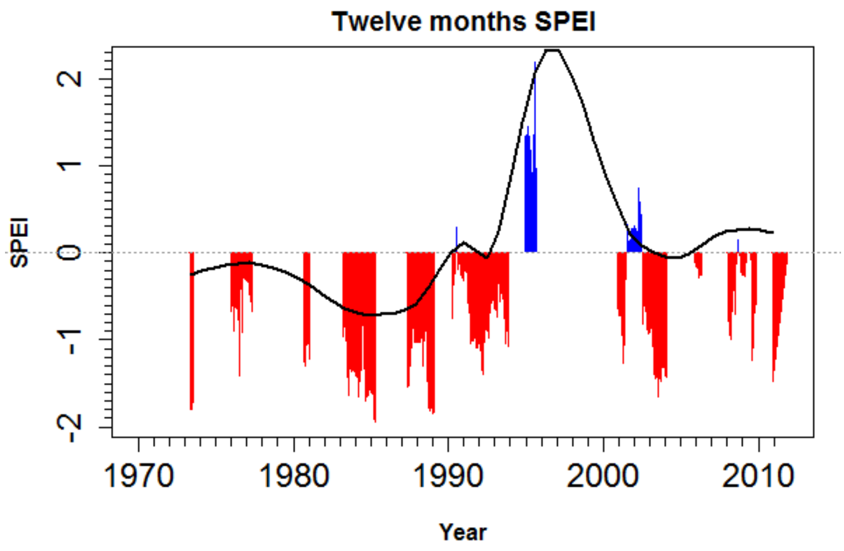


Figure 4-28: Same as in Figure 4-7 except for Kankan

4.5 KINDIA

Kindia is located between latitudes 9° 35' 4'' and 10° 37' 8'' North and longitudes 12° 6' 23'' and 13° 17' 26''West. In Kindia we notice swampy plains expanding towards the north. Kindia is low-lying area and is sometimes flooded. However, it contains some mountains: Gangan (1,116 m), Benna (1,124 m), Kakoulima (1,011 m). The river system is very dense. Kindia is bounded on the north by Dalaba, Pita and Telimele prefecture, to the east by Mamu prefecture, south by prefecture of Forecariah and the Republic of Sierra Leone and west by Coyah and Dubreka prefecture. Kindia covers an area of 9,648 km2 and in 2014 has a resident population of 438,315 inhabitants.

4.5.1 Climograph and Cumulative Precipitation

Kindia has a tropical savanna climate. Figure 4-29a shows Kindia climograph. Kindia is fairly hot with 25.8 °C annual mean temperature. Mean monthly temperatures have a range of 5.6 °C. The mean daily temperature varies during the year and peaks in March with 36.4 ºC. August is the coolest month although its average temperature 23 degrees Celsius is still fairly warm. The annual rainfall of Kindia is 2254.4 mm on average. The dry season lasts from December to April; January is the driest month with 0.3 mm rainfall on average. The wet season lasts from May to November. August is the wettest month accounting for 596.2 mm of rainfall on average. Figure 4-29b shows Kindia cumulative precipitation. The average cumulative rainfall for 1941-1970 over Kindia territory is 11.09 % above of the 1971-2010 average cumulative.

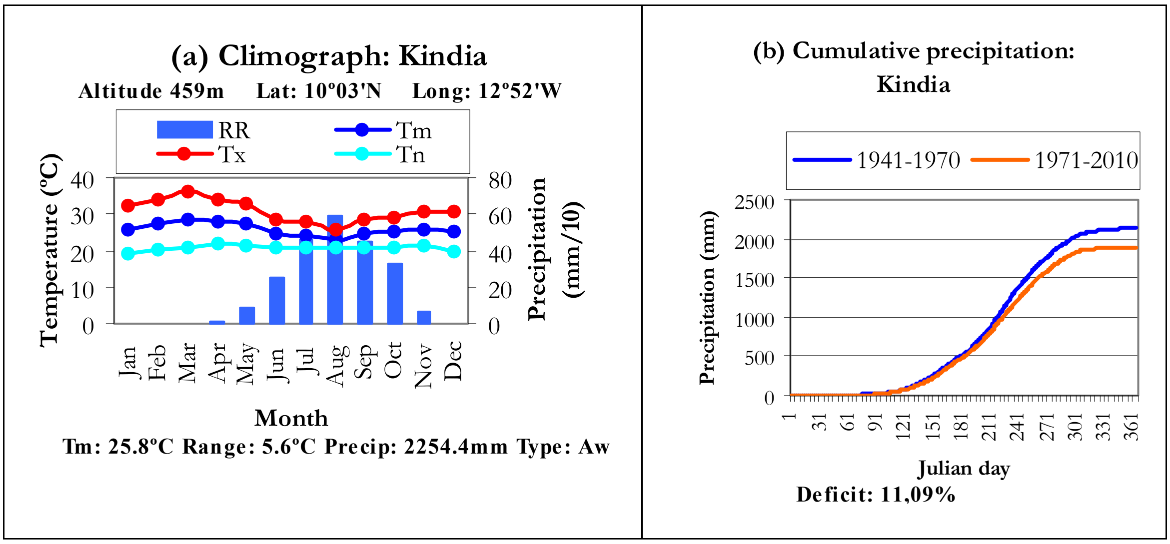


Figure 4-29: Same as in Figure 4-1 except for Kindia.

4.5.2 Annual results

Figure 4-30 shows time series of anomalies of Tx mean (Figure 4-30a), Tn mean (Figure 4-30b) and annual total precipitation (Figure 4-30c). Trends, significance level and confidence intervals for these annual time series anomalies are also shown in Table 4-5. Figures 4-30a and 4-30b suggest warming in Tx mean and Tn mean in Kindia during the recent period. Trends in annual Tx mean (0.206 ºC/decade; significant at 1 %) and in annual Tn mean (0.207 ºC/decade; significant at 1 %) over the recent period are consistent with trends observed at the global mean temperature as documented by AR5 (Hartmann et al., 2013). Significant pattern of warming are seen over the former period and over the period 1961-2010. Figures 4-30a and 4-30b suggest that since mid 1990s, anomalies much above-average Tx mean and Tn mean remain high or have continued to increase. Increases in frequency of much above-average Tx mean and Tn mean are consistent with characteristics of a warming climate.

The fastest increase in Tn mean initiated in late 1980s and since mid 1990s Tn mean remains above 1981-2010 average. Changes in Tx mean are nearly linear over the recent period. Both trends in Tx mean Tn mean are inherited from former period and from the period 1961-2010.

In contrast to trends in Tx mean and Tn mean, there are non-significant increasing trends for annual precipitation in Kindia. Trends become muted as they turned from significant pattern of drying weather (-38.055 mm/decade; significant at 5 %) to non-significant pattern of wetting weather (53.800 mm/decade; non-significant) from former period to the recent one. Results over 1971-2010 coincide with findings for WA from Barry et al. (2014) but contradicts findings from Becker et al. (2013) for tropical areas as stated in Hartmann et al. (2013) although the periods are not the same. Over the period 1961-2010 Kindia shows non-significant decreasing annual total precipitation.

In Kindia, former and 1961-2010 periods are wetter than the recent one, thus indices starting in the early period show significant drying trend and those starting in the recent period show wetting trends.

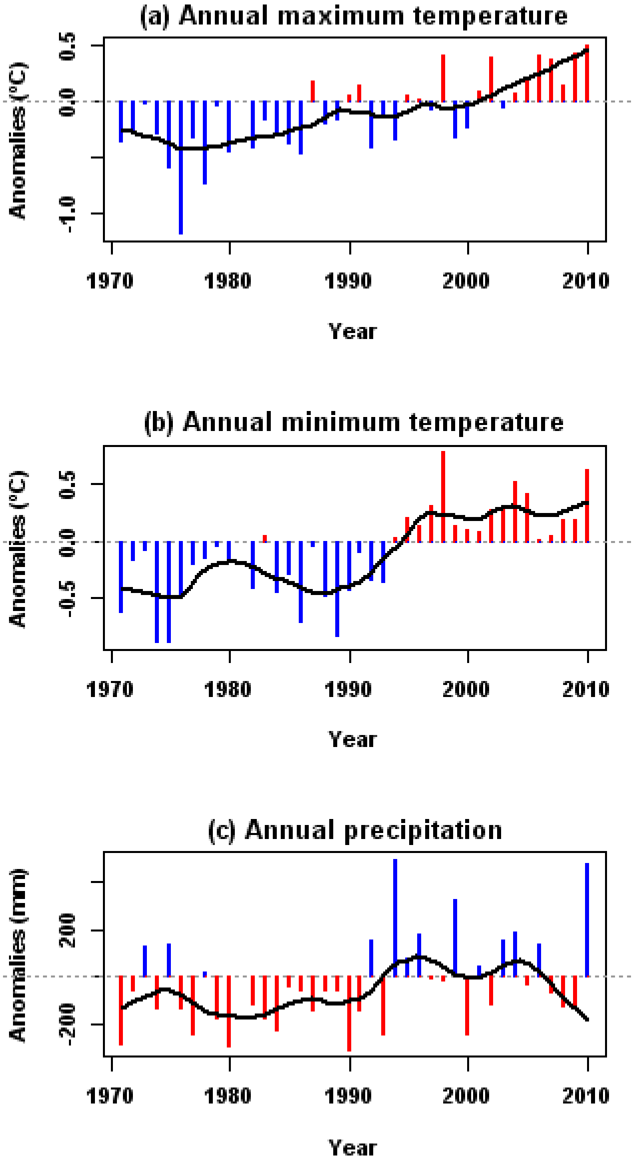


Figure 4-30: Same as in Figure 4-2 except for Kindia

Table 4-5: Decadal trends in annual, seasonal and climate indices for Kindia

Series/Indices	1941-2010	1961-2010	1971-2010
TxMean	*0.082|0.022:0.138*	**0.14|0.08:0.2**	**0.206|0.136:0.29**
TnMean	**0.103|0.039:0.162**	**0.186|0.12:0.264**	**0.207|0.085:0.364**
PRCPTOT	*-38.055|-70.686:-2.534*	-11.463|-54.4:29.75	*53.8|2.222:105.833*
Tx DJF	0.038|-0.021:0.103	0.08|-0.03:0.222	**0.224|0.098:0.358**
Tx MAM	0.015|-0.064:0.103	0.089|-0.014:0.192	**0.213|0.061:0.345**
Tx JJA	0.06|-0.013:0.123	**0.147|0.055:0.233**	**0.191|0.079:0.316**
Tx SON	**0.137|0.049:0.216**	**0.256|0.17:0.342**	**0.275|0.137:0.389**
Tn DJF	0.104|-0.025:0.241	**0.274|0.125:0.44**	**0.394|0.201:0.658**
Tn MAM	**0.151|0.117:0.196**	**0.222|0.168:0.295**	**0.206|0.115:0.321**
Tn JJA	**0.087|0.051:0.13**	**0.128|0.062:0.187**	**0.144|0.036:0.234**
Tn SON	0.034|-0.015:0.081	**0.098|0.022:0.17**	0.097|-0.01:0.23
DRY	*-10.259|-17.964:-1.581*	0.25|-11.622:14.444	8.418|-9.29:29.036
WET	-24.159|-51.404:3.452	-18.415|-58.257:23.238	42.231|-13.25:87.654
TN10P	**-1.576|-2.386:-0.539**	**-2.805|-4.057:-1.748**	**-2.964|-5.625:-1.431**
TN90P	**1.017|0.412:1.729**	**1.987|0.965:3.224**	*2.129|0.435:3.803*
TX10P	**-1.085|-1.742:-0.351**	**-1.507|-2.126:-0.839**	**-1.881|-2.906:-1.159**
TX90P	0.866|-0.163:1.884	*1.873|0.358:3.756*	**3.697|1.773:5.649**
TNn	0.084|-0.127:0.259	0.294|-0.023:0.609	0.336|-0.145:0.797
TNx	**0.091|0.025:0.16**	**0.182|0.076:0.281**	0.136|0:0.301
TXn	0.098|-0.015:0.2	0.111|-0.079:0.273	0.111|-0.143:0.353
TXx	0.078|-0.019:0.167	*0.176|0.035:0.301*	**0.318|0.194:0.441**
DTR	-0.033|-0.112:0.045	-0.06|-0.149:0.034	-0.018|-0.173:0.155
SU25	**2.509|1.558:3.353**	**2.788|1.5:3.738**	*2.555|0.554:4.179*
TR20	*7.218|0.702:13.987*	**14.258|7.398:22.275**	**17.001|5.928:30.409**
RX1day	0.328|-1.744:2.64	-0.321|-3.25:3.25	-0.6|-5.444:3.95
RX5day	-0.283|-6.279:4.815	1.72|-6.094:6.878	5|-2.25:12.292
SDII	0.071|-0.083:0.222	0.19|-0.105:0.419	0.24|-0.167:0.6
R10mm	-1.17|-2.514:0.032	0.06|-1.815:1.689	1.681|-0.652:3.972
R20mm	-0.495|-1.219:0.202	-0.481|-1.518:0.5	1|0:2.174
R25mm	-0.323|-0.889:0.159	0.29|-0.476:1.2	**1.389|0.37:2.5**
R95p	-0.522|-16.442:16.404	8.221|-15.971:30.75	13.222|-17:52.125
R95pTOT	0.000|-0.008:0.009	0.007|-0.007:0.017	0.005|-0.021:0.024
R99p	-0.1|-15.766:1.4	-0.952|-23.067:4.439	-1.4|-34.792:5.2
R99pTOT	0.000|-0.006:0.003	0.002|-0.004:0.007	-0.001|-0.015:0.006
Onset	0.000|-2.093:2.105	1.744|-2.249:5.282	2.435|-3.299:7.961
Retreat	*-1.407|-2.836:-0.124*	-0.658|-2.474:1.689	0.000|-2.5:2.857
Length	-2.471|-4.884:0.525	-3.015|-6.789:1.906	-3.498|-8.633:2.545
TX50P	**3.28|1.348:5.048**	**5.825|3.682:7.496**	**7.906|6.027:9.936**
CDDcold	**33.886|16.627:50.706**	**61.781|39.054:85.386**	**85.154|48.547:113.622**
WSDI2	1.121|-0.739:3.011	2.503|-0.196:5.768	**6.117|1.894:10.245**
CSDI2	**-4.014|-5.753:-2.071**	**-5.753|-8.641:-3.753**	**-4.128|-10.661:-1.514**
CTN90pct HWA	*0.306|0.1:0.5*	NA	0.249|4.524:4.524
CTN90pct HWF	0.227|0:1.053	0.000|-1.429:1.667	0.000|-1.429:1.667
CTX90pct HWA	-0.306|-0.984:0.158	-1.036|-2.179:0.143	-0.41|-2.583:0.833
CTX90pct HWF	0.000|-0.714:0.8	0.8|0:2.5	1.716|0:3.636
RX2day	0.556|-2.636:3.944	1.307|-4.083:6.526	4.316|-2.6:12.217
CWD	-0.412|-1.25:0.444	0.357|-1.111:1.714	1.429|0:3.529
CDD	3.882|-1.126:8.625	0.062|-7.613:7.853	-8.831|-17.049:2.647
SPEI	-0.011|-0.024:0.001	-0.001|-0.016:0.014	*0.023|0.003:0.043*
SPI	*-0.011|-0.021:-0.002*	0.001|-0.012:0.014	**0.023|0.008:0.039**

4.5.3 Seasonal results

Table 4-5 shows trends and confidence intervals in seasonal Tx and seasonal Tn in Kindia. Over the recent period both Tx and Tn show significant warming trends in all seasons except Tn SON. Thus previously observed warnings in annual Tx mean and annual Tn mean are the result of a combined warming of all seasons over the recent period. Kindia shows warming in all Tx and Tn seasons, though some are non-significant over the former period and over the period 1961-2010.
Wet season and dry season trends and confidence intervals are indicated in Table 4-5. Changes previously observed in annual total precipitation are well explained by wet season trends. Trend in dry season index switches from significant drying weather to non-significant wetting weather from the former period to the recent one. Similarly trend in wet season index switches from non-significant drying weather to non-significant wetting weather. These changes are consistent with those of annual total precipitation.

4.5.4 Percentile-based and other temperature indices

Figure 4-31 shows Kindia percentile-based temperature indices of TN10P (Figure 4-31a), TX10P (figure 4-31b), TN90P (Figure 4-31c) and TX90P (Figure 4-31d). Trends, significance level and confidence intervals are given in Table 4-5. Figure 4-31 suggests changes towards warming trends. Figure 4-31a indicates decreasing trend in the frequency of cold nights (-2.964 %/decade; significant at 1 %) over the recent period, consistent with global observed trends documented by Hartmann et al. (2013). These trend patterns are also consistent with WA warming trend observed by Barry et al. (2014). Figure 4-31b also suggests decreases in the frequency of cold days (-1.881 %/decade; significant at 1 %) over the recent period, this result is also in agreement with the observed trends at global level documented by Hartmann et al. (2013). Figures 4-31c and 4-31d also illustrate increases in the frequency of warm nights (2.129 %/decade; significant at 5 %) and in the frequency of warm days (3.697 %/decade; significant at 1 %) over the recent period, in agreement with global trends patterns for TN90P and TX90P from Hartmann et al. (2013) and consistent with findings for WA for TN90P and TX90P from Barry et al. (2014).

Converting these trends into days these correspond to a decrease of 10.8 cold nights per decade, a decrease of 6.9 cold days per decade, an increase with low confidence, of 7.8 warm nights and an increase of 13.5 warm days per decade. As a consequence of this warming, the frequency of days above average has significantly increased (7.906 %/decade; significant at 1 %) over 1971-2010. This trend converted into days corresponds to an increase of 28.9 day above average temperature per decade. Identical warming patterns are seen in TX50P over the former period and over the 1961-2010 one.

Both summer days and tropical nights have significantly increased in Kindia over both periods, consistent with findings for WA from Barry et al. (2014) and suggest changes towards warming climate.

Trends in general climate indices also suggest warming in Kindia. There is increased in the temperature of the coldest nights (0.336 ºC/decade; non-significant), increased in the temperature of the coldest days (0.111 ºC/decade; non-significant), increased in the temperature of the warmest nights (0.136 ºC/decade; non-significant) and increased in the temperature of the warmest days (0.318 ºC/decade; significant at 1 %). Similar patterns of warming are seen over the former period and over the period 1961-201. As a result the DTR trend is negative and statistically non-significant over all periods.

WSDI has also persistently increased over time though changes are only significant (6.117 day/decade; significant at 1 %) over the recent period. CSDI has also significantly decreased over all periods in Kindia and over the recent (-4.128 day/decade; significant at 1 %) one. Trends in warm spells and cold spells suggest warming climate in Kindia. CDDcold has significantly and continuously increased over all periods and over the recent period (85.154 ºC/decade; significant at 1 %) stressing the need for cooling.

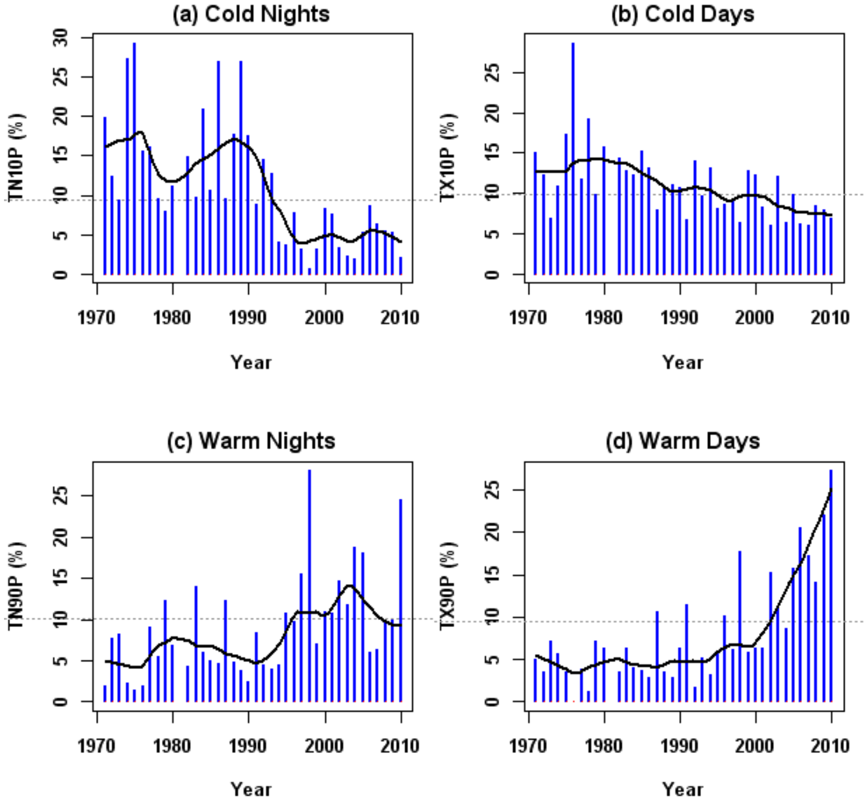


Figure 4-31: Same as in Figure 4-3 except for Kindia

4.5.5 Precipitation intensity index

Figure 4-32 shows the annual time series for SDII. SDII shows an increasing trend (0.24 mm/day/decade; non-significant) indicating that the daily intensity has increased but this trend is statistically non-significant over the recent period, contrasting with Aguilar et al (2009) findings but in agreement with WA results from Barry et al. (2014). Kindia is characterized by a fairly constant daily intensity oscillating around 15 mm/day, the 1981-2010 record average. Identical trends are seen over the former period and over the period 1961-2010.

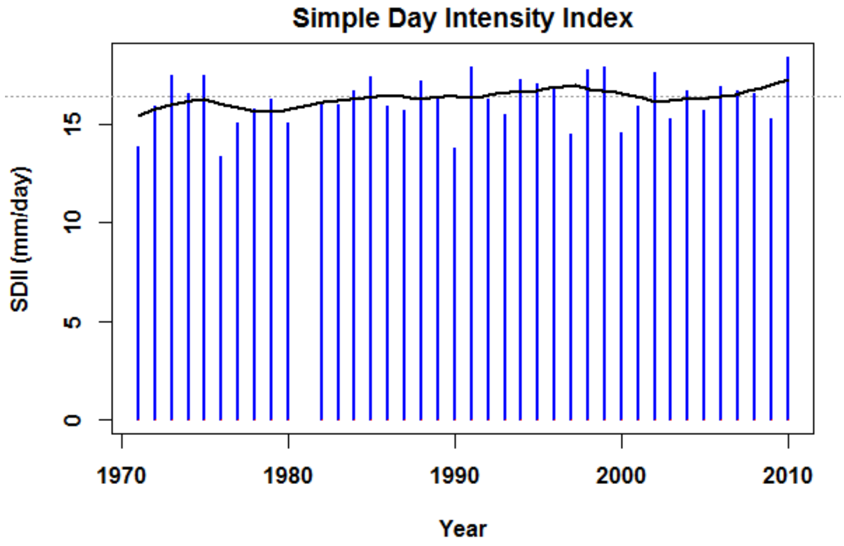


Figure 4-32: Same as in Figure 4-4 except for Kindia

4.5.6 Precipitation percentile indices

Trends and confidence intervals in very and extremely wet days (R95P and R99P) and their respective contribution to annual total precipitation (R95pTOT and R99pTOT) are given in Table 4-5. R95P (13.222 mm/decade; non-significant) and R95pTOT (0.005 %/decade; non-significant) tend towards wetter weather indicating that the annual total precipitation on days exceeding the long-term 95th percentile and their contribution to annual total precipitation have increased over the recent period, but trends are non-significant. Contrariwise, R99P (-1.400 mm/decade; non-significant) and R99pTOT (-0.00 1 %/decade; non-significant) tend towards drier weather over the recent period suggesting that the annual total precipitation on days exceeding the long-term 99th percentile and their contribution to annual total precipitation have decreased over the recent period, but trends are non-significant. Figure 4-33 shows R95P index annual time series. Except some years R95P index remains near or above 400 mm, Kindia 1981-2010 record average.

Trends in R95P index concur with findings for WA from Barry et al. (2014) but contradict results from Aguilar et al. (2009) while trends in R99P index contradict findings for WA from Barry et al. (2014) but in agreement with Aguilar et al. (2009)

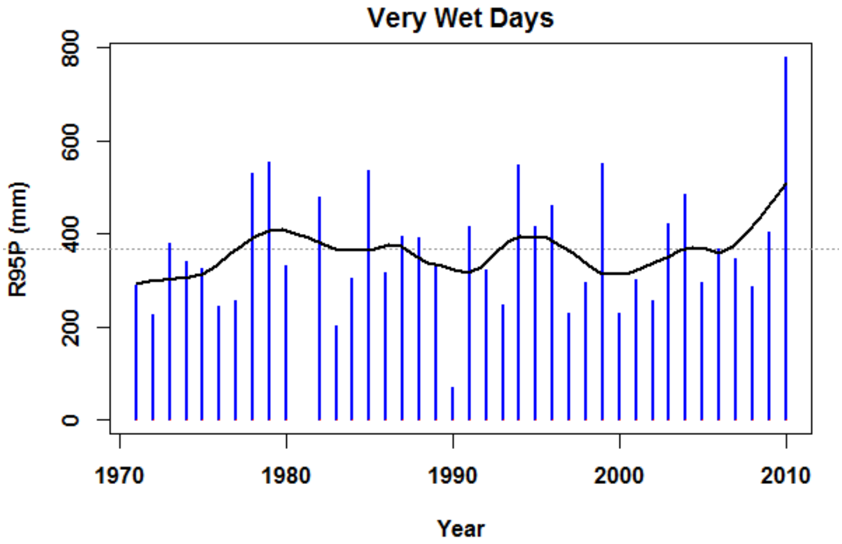


Figure 4-33: Same as in Figure 4-5 except for Kindia

4.5.7 Absolute and other precipitation indices

Trends in absolute precipitation indices Rx1day, Rx2day and Rx5day are shown in Table 4-5. Changes in Rx1day suggest trends towards dry weather while those observed in Rx2day and Rx5day denote trends towards wetter conditions over the recent period.

Compared with regional studies, Rx1day (-0.600 mm/decade; non-significant) trend contradicts that of WA from Barry et al. (2014) but in agreement with Aguilar et al (2019) while Rx5day (5.000 mm/decade; non-significant) trend concurs with that of WA reported by Barry et al. (2014) but in disagreement with Aguilar et al. (2009). These indices do not show significant patterns of changes.

Figure 4-34 shows the annual time series for Rx2day index. Trend in Rx2day (4.316 mm/decade; non-significant) suggests non-significant changes towards wetting conditions over the recent period in Kindia. Similar trends are seen over the former period and over the period 1961-2010. Likewise, over the recent period the frequency of heavy precipitation (1.681 day/decade, non-significant), the frequency of very heavy precipitation (1.000 day/decade, non-significant) and the frequency of extremely heavy precipitation (1.389 day/decade, significant at 1 %) exhibit changes towards wetter weather. Heavy and extremely heavy precipitation show changes from non-significant drying conditions over the former period to non-significant wetting conditions over the period 1961-2010 while very heavy precipitation days shows non-significant drying conditions over both former and 1961-2010 periods.

Wet spells show increasing trend (1.429 day/decade; non-significant), suggesting changes towards wetter conditions in Kindia over the recent period but these changes are non-significant in concordance with WA results from Barry et al. (2014) but contradicts those from Aguilar et al. (2009). Wet spells show changes from non-significant drying conditions (-0.412 day/decade; non-significant) over the former period to non-significant wetting conditions (0.357 day/decade; non-significant) over the period 1961-2010.
Trends, significance levels and confidence intervals in wet season onset, retreat and length indices are given in Table 4-5. Over the recent period, Kindia shows delayed onset and quasi stationary retreat dates leading to a shorter (-3.498 day/decade; non-significant) rainy season, but these trends are non-significant. Over the former period, quasi stationary onset dates and significant early retreats are seen leading to a non-significant shorter rainy season. Over the period 1961-2010 non-significant delayed onset and non-significant early retreat leading to a non-significant shortened wet season length are observed.

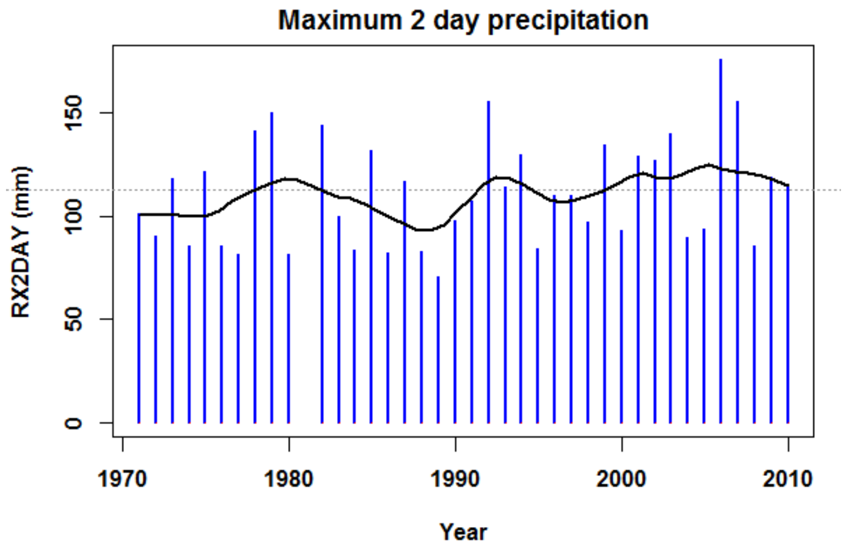


Figure 4-34: Same as in Figure 4-6 except for Kindia

4.5.8 Drought indices

Trends and significance levels in SPEI, SPI and CDD indices are shown in Table 4-5. Both SPI (0.023 spi/decade; significant at 1 %) and SPEI (0.023 spei/decade; significant at
5 %) indices show significant increasing trend over the recent period. Figure 4-35 shows SPEI monthly time series anomalies in Kindia over the period 1971-2010. Over recent period long lasting successive dry periods ending in 1995 are followed by a relatively wet period going from 1995 to 2008. Worst droughts have been observed in 1972, 1991, 1993 and 2002. Over the recent period dry spells suggest changes towards wetter weather though trends are non-significant, consistent with WA patterns from Barry et al. (2014) but in disagreement with NWA findings (Table 4-15 later in this chapter) and findings from Aguilar et al. (2009). Contrariwise over the former period and over the period 1961-2010 changes tend towards non-significant increase of dry spells.

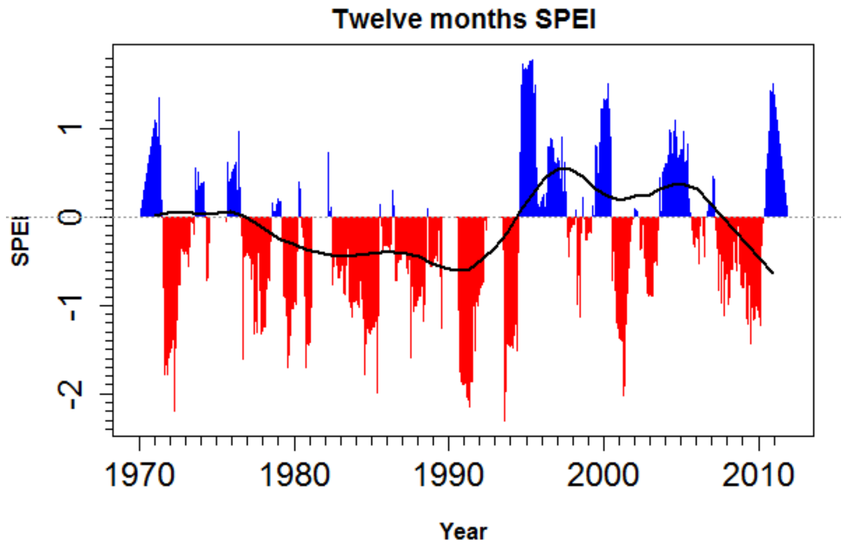


Figure 4-35: Same as in Figure 4-7 except for Kindia

4.6 KISSIDOUGOU

Kissidougou is located between latitudes 8° 50’ 51’ and 9° 42’ 59’’ North and longitudes 9° 12’ 39’’ and 10° 30’ 13’’ West. Kissidougou is characterized by the presence of gently sloping hills (600-650 m). These hills are separated by depressions of varying size, where we meet the lowlands and alluvial plains along rivers. The river system is very dense and regular over the year. The prefecture is bounded on the north by Kankan and Kouroussa prefecture, on the west by that of Faranah, south by Gueckedou and Macenta and east by Kankan and Kereouane prefecture. Kissidougou covers an area of 8,300 km2 and in 2014 has a resident population of 283,609 inhabitants.

4.6.1 Climograph and Cumulative Precipitation

Figure 4-36a shows Kissidougou climograph. Kissidougou has a tropical monsoonal climate with a relatively dry season and a heavy monsoon in the rest of year. The annual mean temperature in Kissidougou is 24.9 ºC and the mean monthly temperatures varies very little 3.9 ºC only. Contrariwise, the diurnal range varies along the year and reaches a peak of 18.7 ºC in February. The hottest month is March with 26.1 ºC on average, while the coolest month is January with an average of 22.9 ºC. Kissidougou receives on average 2000 mm rainfall per year. The driest weather is in January with only 10 mm rainfall, while the wettest month is September with 353.3 mm rainfall on average. Figure 4-36b shows Kissidougou cumulative precipitation. The average cumulative rainfall during 1941-1970 is above the 1971-2010 average; but the deficit is not larger than 3.50 %.

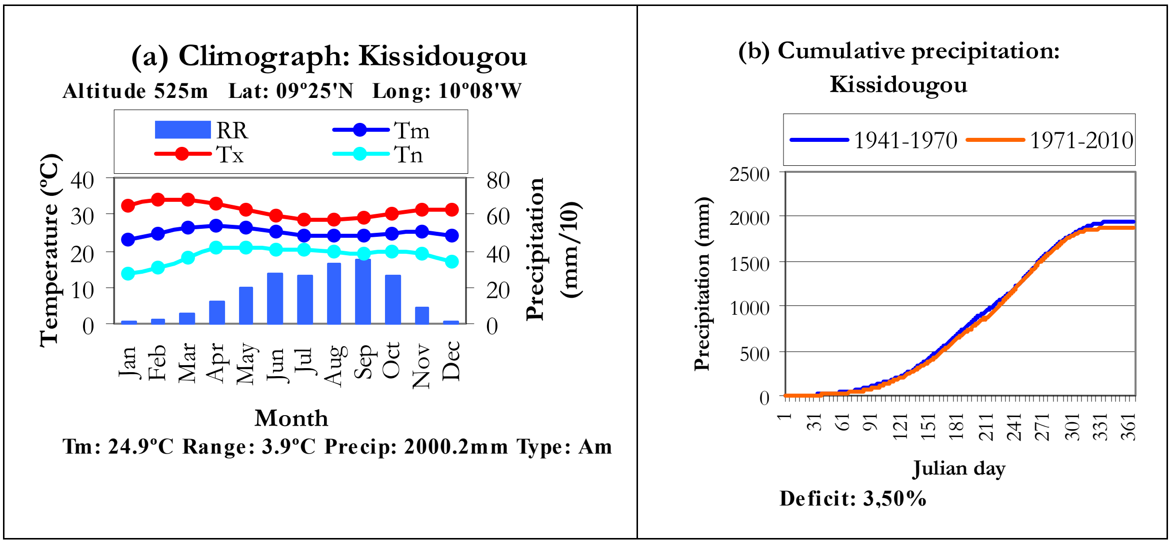


Figure 4-36: Same as in Figure 4-1 except for Kissidougou.

4.6.2 Annual results

Figure 4-37 shows time series of anomalies of Tx mean (Figure 4-37a), Tn mean (Figure 4-37b) and annual total precipitation (Figure 4-37c). Trends, significance level and confidence intervals for these anomalies time series are also shown in Table 4-6. Figures 4-37a and 4-37b suggest warming in Tx mean and Tn mean in Kissidougou over the last four decades. Trend in Tx mean (0.216 ºC/decade, significant at 1 %) and trend in Tn mean (0.250 ºC/decade, non-significant) over the recent period concur with the findings at global level as documented by AR5 (Hartmann et al., 2013).

Figure 4-37c shows annual total precipitation time series in Kissidougou during the recent period. Annual total precipitation shows a mixed trend that changes from drying trend (-12.748 mm/decade; non-significant) over the former period to non-significant wetting trend (84.333 mm/decade; non-significant) over the recent period (Table 4-6). Trend in annual total precipitation coincides with findings for WA documented by Barry et al. (2014) but contradicts tropical areas results documented in Becker et al. (2013) and those from Aguilar et al. (2009).

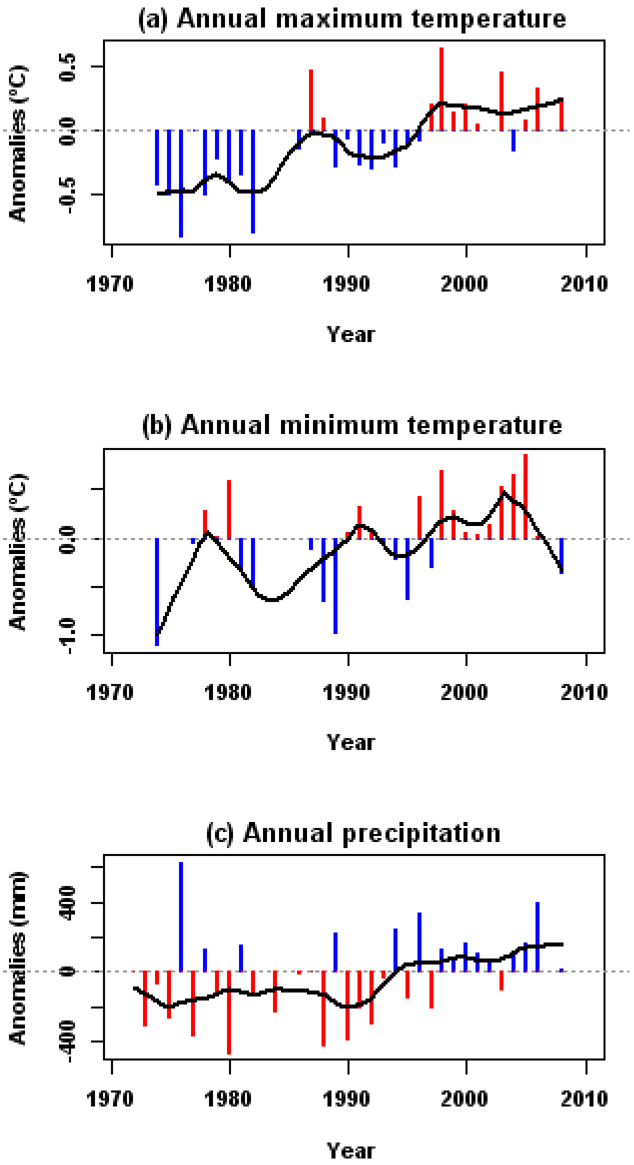


Figure 4-37: Same as in Figure 4-2 except for Kissidougou

Table 4-6: Decadal trends in annual, seasonal and climate indices for Kissidougou

Series/Indices	1941-2010	1961-2010	1971-2010
TxMean	NA	NA	**0.216|0.099:0.341**
TnMean	NA	NA	0.25|-0.084:0.555
PRCPTOT	-12.748|-52.333:31.244	49.172|-19:106.812	*84.333|8.421:162.167*
Tx DJF	NA	NA	**0.247|0.084:0.374**
Tx MAM	NA	NA	0.153|-0.066:0.36
Tx JJA	NA	NA	**0.224|0.101:0.313**
Tx SON	NA	NA	**0.227|0.082:0.393**
Tn DJF	NA	NA	0.371|-0.272:1.201
Tn MAM	NA	NA	0.216|-0.012:0.367
Tn JJA	NA	NA	0.118|-0.005:0.233
Tn SON	NA	NA	0.181|-0.025:0.393
DRY	**-23.254|-38.135:-4.943**	-6.409|-36.125:24.069	-6.263|-47.294:31.485
WET	14.69|-16.96:42.781	23.789|-27.244:70.5	59.786|-11.211:124.613
TN10P	NA	NA	-2.117|-4.465:0.185
TN90P	NA	NA	**3.177|1.785:4.829**
TX10P	NA	NA	**-2.345|-3.183:-1.381**
TX90P	NA	NA	1.928|-0.623:4.416
TNn	NA	NA	0.098|-1.323:1.589
TNx	NA	NA	0.044|-0.188:0.333
TXn	NA	NA	0.067|-0.443:0.528
TXx	NA	NA	0.222|-0.077:0.529
DTR	NA	NA	0.122|-0.314:0.499
SU25	NA	NA	0.52|-1.022:2.441
TR20	NA	NA	**22.271|7.517:36.298**
RX1day	-1.04|-4.439:2.304	3.147|-3.266:9.326	3.82|-4.419:12.319
RX5day	-0.604|-5.711:3.387	5.208|-4.204:15.627	9.634|-1.593:23.727
SDII	-0.098|-0.402:0.163	*0.4|0.1:0.775*	**0.645|0.2:1.091**
R10mm	-0.513|-1.667:0.69	0.295|-1.622:2.5	1.667|-0.909:4.615
R20mm	-0.44|-1.343:0.556	1.357|0:2.5	*2.174|0:4.242*
R25mm	-0.444|-1.316:0.323	0.76|-0.588:2.273	1.25|-0.667:3
R95p	-0.835|-24:23.87	34.378|-9:68.444	54.933|-0.857:124.75
R95pTOT	0.004|-0.009:0.013	0.003|-0.026:0.023	0.003|-0.044:0.038
R99p	0.000|-15.604:2	2.113|0:32.514	2.455|0:48.12
R99pTOT	0|-0.006:0.004	0.003|-0.005:0.013	0.001|-0.021:0.014
Onset	0.385|-2.745:3.158	0.000|-4.286:5.484	3.819|-3.939:10
Retreat	*-2.61|-4.805:-0.698*	-1.507|-4.617:2.312	-0.718|-4.576:3.839
Length	-2.727|-5.385:0.476	-1.07|-7.46:6.249	-2.973|-9.998:8.07
TX50P	NA	NA	**7.649|4.513:10.699**
CDDcold	NA	NA	**83.248|29.305:168.133**
WSDI2	NA	NA	3.096|-1.153:6.739
CSDI2	NA	NA	-4.997|-9.862:0.832
CTN90pct HWA	NA	NA	1.871|-0.5:4
CTN90pct HWF	NA	NA	-0.313|-0.835:0
CTX90pct HWA	NA	NA	NA
CTX90pct HWF	NA	NA	NA
RX2day	*-4.133|-8.484:-0.1*	0.251|-4.667:5.5	2.667|-4.667:10.909
CWD	0.212|-0.244:0.724	-0.102|-1.166:0.834	0.000|-0.714:1.111
CDD	3.703|-0.233:7.75	0.532|-7.308:7.692	3.462|-6.786:13.75
SPEI	NA	NA	0.03|-0.002:0.063
SPI	-0.005|-0.018:0.007	0.002|-0.018:0.022	0.017|-0.006:0.041

4.6.3 Seasonal results

Seasonal trends in Tx and Tn (Table 4-6) exhibit changes towards warming conditions in Kissidougou over the recent period although only few (Tx DJF, Tx JJA and Tx SON) are significant. Previously observed warming trends in Tx mean seem to be inherited from warming in Tx DJF, Tx JJA and Tx SON seasonal warming.

Trends, significance level and confidence intervals in dry and wet season precipitation indices are given in Table 4-6. Dry season precipitation index shows decreasing trend over all periods, and this trend (-23.254 mm/decade; significant at 1 %) is significant over the former period. On the contrary, wet season precipitation index shows non-significant increasing over all periods.

4.6.4 Percentile-based and other temperature indices

Figure 4-38 shows Kissidougou percentile-based temperature indices of TN10P (Figure 4-38a), TX10P (figure 4-38b), TN90P (Figure 4-38c) and TX90P (Figure 4-38d) and their respective significance level and confidence intervals are given in Table 4-6. Trends in TN10P (-2.117 %/decade; non-significant) and in TX10P (-2.345 %/decade; significant at 1 %) suggest decreases of the frequency of the cold nights and significant decreases of the frequency of the cold days in Kissidougou over the recent period. Converting these trends into nights and days these correspond to a decrease of 7.2 cold nights per decade and a decrease of 8.6 cold days per decade. Trends in TN90P (3.177 %/decade; significant at 1 %) and in TX90P (1.928 %/decade; non-significant) also indicate significant increases of the frequency of the warm nights and non-significant increases of the frequency of the warm days over the recent period. Converting these trends into nights and days these correspond to an increase of 11.6 warm nights per decade and an increase of 7 warm days per decade. This is an indication of warming climate. Accordingly, days above average (TX50P) index is consistent with warming pattern (7.649 %/decade; significant at 1 %). Converting this trend into days this corresponds to an increase of 27.9 days above average per decade over the recent period in Kissidougou.

These trends patterns are supported by those reported by Hartmann et al. (2013); they also agree with those found for WA as documented by Barry et al. (2014) and Aguilar et al. (2009).

Similarly, both SU25 and TR20 show warming trends in Kissidougou over the study period although trend in SU25 is statistically non-significant. This result coincides with Hartmann et al. (2013), where it is reported that nighttime temperature over land has increased by about twice the rate of the daytime temperature during the past 50 years. Trends patterns in TR20 and SU25 also concur with findings for WA from Barry et al. (2009).

All trends in general climate indices also suggest warming in Kissidougou though none of them shows statistically significant changes (Table 4-6). As a result the DTR shows non-significant increasing trend over the recent period.
Warm spells (3.096 day/decade, non-significant) and cold spells (-4.997 day/decade, non-significant) exhibit warming trends over the recent period in Kissidougou. Consequently, the need for cooling index shows significant increasing (83.248 ºC/decade; significant at 1 %) trend.

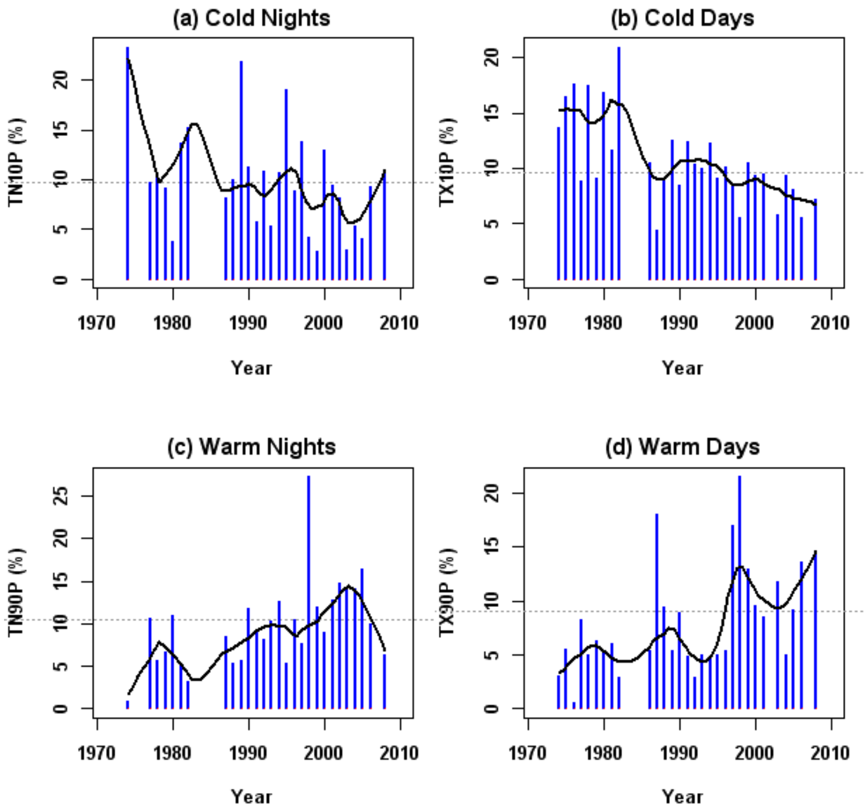


Figure 4-38: Same as in Figure 4-3 except for Kissidougou

4.6.5 Precipitation intensity index

Figure 4-39 illustrates changes in SDII annual time series. Trend, significance level and the confidence intervals for this index are given in Table 4-6. Over the recent period there have been significant changes (0.645 mm/day/decade; significant at 1 %) towards wetter weather in SDII index. The highest increase in SDII index initiates in early 1990s. Trend patterns in daily intensity index are consistent with wetter weather over both recent and over the 1961-2010 periods, in agreement with WA findings by Barry et al. (2014) but contradict regional results from Aguilar et al. (2009).

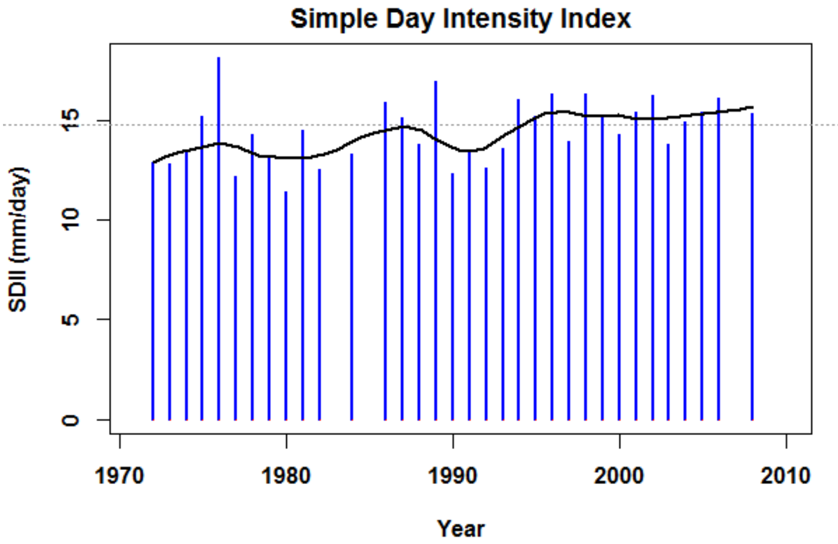


Figure 4-39: Same as in Figure 4-4 except for Kissidougou

4.6.6 Precipitation percentile indices

Trends and confidence intervals in very and extremely wet days (R95P and R99P) and their respective proportion (R95pTOT and R99pTOT) are given in Table 4-6. The two percentile exceedence indices, R95P and R99P, show similar patterns of trends to those of PRCPTOT over the study periods, though there are no statistically significant changes. The two indices of the proportion of total precipitation from extremes, R95pTOT and R99pTOT, also show similar patterns of trends to those of PRCPTOT over the study period though there are no significant changes. Trends in R95P and R95pTOT suggest larger annual number of days with intense precipitation and larger fraction of annual precipitation due to events exceeding 95th percentile. Trends in R99P and R99pTOT suggest larger annual number of days with very intense precipitation and larger fraction of annual precipitation due to events exceeding 99th percentile.

Figure 4-40 illustrates R95P index annual time series. Noticeable increases of the annual total precipitation on days exceeding the long-term 95th percentile are seen in mid 1980s and mid 1990s.

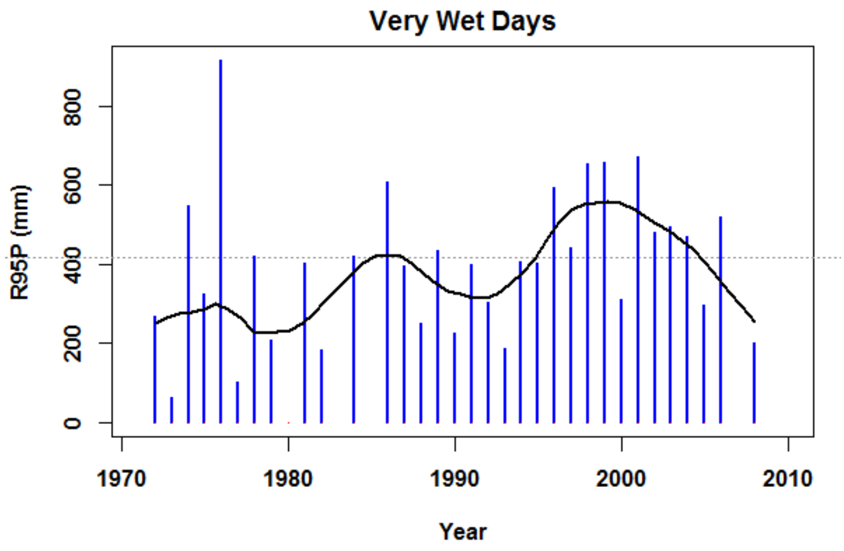


Figure 4-40: Same as in Figure 4-5 except for Kissidougou

4.6.7 Absolute and other precipitation indices

Trends in absolute precipitation indices Rx1day, Rx2day and Rx5day are shown in Table 4-6. Both indices exhibit trends pattern very similar to that of PRCPTOT over all periods. Trends in Rx1day (3.820 mm/decade; non-significant), Rx2day (2.667 mm/decade; non-significant) and Rx5day (9.634 mm/decade; non-significant) indices suggest changes towards wetter climate though there is no statistically significant trend over the recent period. Drying trends over the former period switch to wetting trends over the recent periods. Figure 4-41 shows the annual time series for Rx2day index.

Wet spells show quasi stationary trend over the recent period. Over the former period and over the 1961-2010 period wet spells show non-significant opposite trends (Table 4-6).

Trends, significance levels and confidence intervals in wet season onset, retreat and length indices are given in Table 4-6. Over the recent period Kissidougou shows non-significant delayed onset and early cessation leading to shorter wet (-2.973 day/decade, non-significant) season. Similarly, over the period 1961-2010 Kissidougou shows quasi stationary onset dates and non-significant early retreat dates leading to non-significant shorter wet season. Finally, over the former period, Kissidougou shows non-significant delayed onset dates and non-significant early retreat dates leading to non-significant shortened wet season.

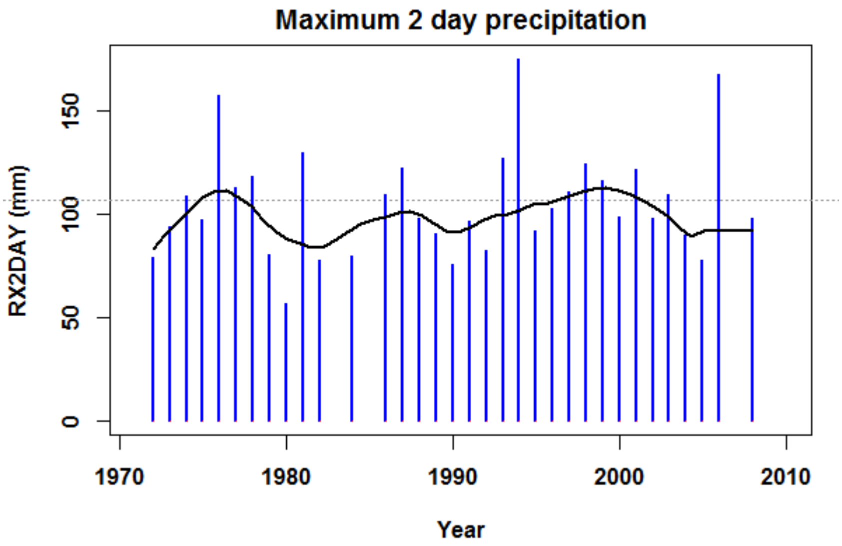


Figure 4-41: Same as in Figure 4-6 except for Kissidougou

4.6.8 Drought indices

Trends, significance levels and confidence intervals in drought indices SPEI, SPI and CDD indices are shown in Table 4-6. SPI and SPEI show similar trend patterns over the recent period. Recent trends in SPI index suggest changes towards wetter climate. SPI shows non-significant drying trend over the former period and non-significant wetting trend over the period 1961-2010.

Dry spells exhibits statistically non-significant changes towards drier weather over all periods, contradicting WA results from Barry et al. (2014) but concurring with findings by Dai et al. (2013) and Sheffield et al. (2012) where high confidence in increases in CDD have been reported (Hartmann et al., 2013).

Kissidougou is characterized by non-significant increases in the Tn related heat waves amplitude (1.871 ºC/decade; non-significant) and non-significant decreases (-0.31 day/decade; non-significant) in the Tn related heat waves frequency over the recent period.

Figure 4-42 shows SPEI monthly time series anomalies. Over the recent period, droughts have been sparsely frequent in Kissidougou. The worst drought occurred in 1980 followed by a long-lasting in 1991. Shorter and less intense droughts have also been observed in 1978, in 1998 and 2002.

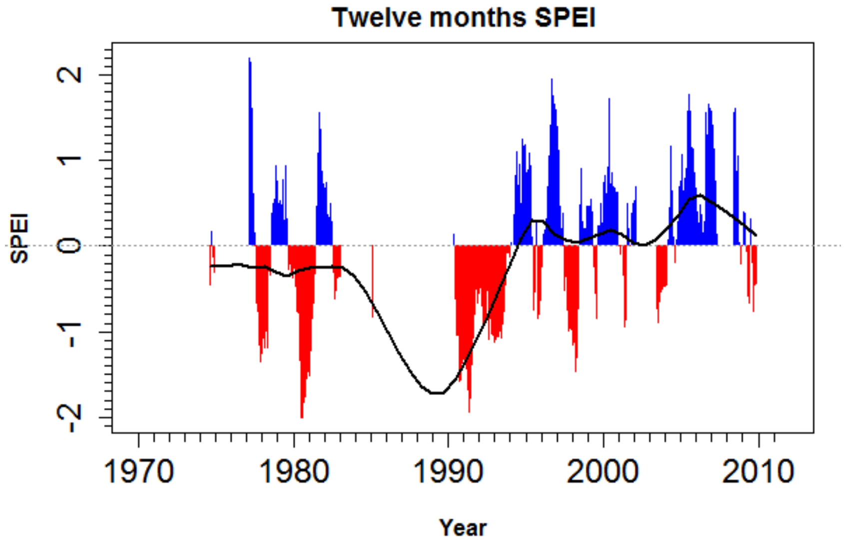


Figure 4-42: Same as in Figure 4-7 except for Kissidougou

4.7 KOUNDARA

Koundara is located between latitudes 12° 1’ 59’’ and 12° 40’ 34’’ North and longitudes 12° 34’ 16’ and 13° 42’ 32’’ West. Koundara is characterized by a flat area of low altitude less than 400 m with large, sandy plains. Koundara is bounded on the north by the Republic of Senegal, to the east by Mali prefecture, south by prefecture of Gaoual and west by the Republic of Guinea Bissau. Koundara covers an area of 5,238 km2 and in 2014 has a resident population of 130,205 inhabitants.

4.7.1 Climograph and Cumulative Precipitation

Koundara has monsoon climate with pronounced dry and wet seasons. Figure 4-43a shows Koundara climograph. Throughout the year, the mean monthly temperature does not drop below 23 °C. The average annual temperature in Koundara is as high as 27.6 ºC. The mean monthly temperatures range is 8.4 ºC, while the diurnal range is 16 ºC reaching its peak of 22.4 ºC in February. January is known as the coolest months with a mean monthly temperature of 25 ºC. The warmest month is April with 32.2 ºC on average. Koundara receives 1117.2 mm rainfall per year on average. The driest month is January when no precipitation falls at all, while the wettest month is August with 323 mm of rainfall. Figure 4-43b shows the average cumulative precipitation.

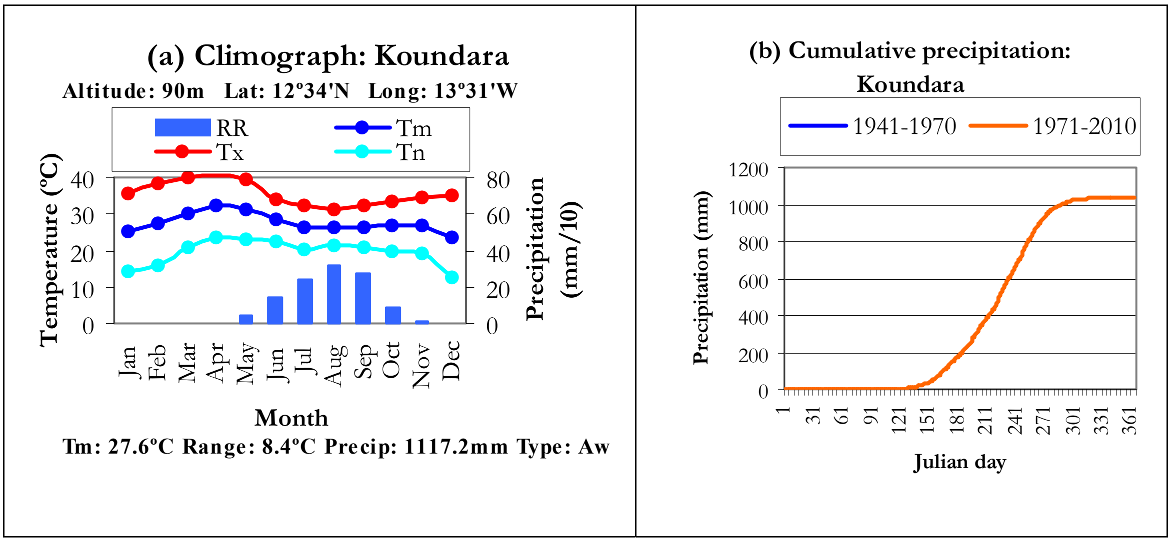


Figure 4-43: Same as in Figure 4-1 except for Koundara.

4.7.2 Annual results

Figure 4-44 shows anomalies of annual Tx mean (Figure 4-44a), annual Tn mean (Figure 4-44b) and annual total precipitation (Figure 4-44c). Trends, significance level and confidence intervals for these annual time series are also shown in Table 4-7.

Figure 4-44a and 4-44b illustrate a general warming trend in Koundara. This warming initiated early 1990s for Tn mean and ten years later in early 2000s for Tx mean. A salient feature of this region warming is that Tx mean increases faster than Tn mean.

Over the recent period, trend in Tx mean (0.350 ºC/decade; significant at 1 %) and in Tn mean (0.213 ºC/decade; non-significant) concur with WA findings from Barry et al. (2014) and those found at global level as documented by AR5 (Hartmann et al., 2013). Annual total precipitation is characterized by a non significant decreasing trend of -0.273 mm/decade, consistent with findings by Aguilar et al. (2009) but in contradiction with the results from Barry et al. (2014). It worth noting that annual total precipitation trend patterns contrast with those at NWA level (Table 4-15 later in this chapter). Wet season precipitation index shows a significant increasing trend whereas dry season precipitation index shows a non-significant decreasing trend.

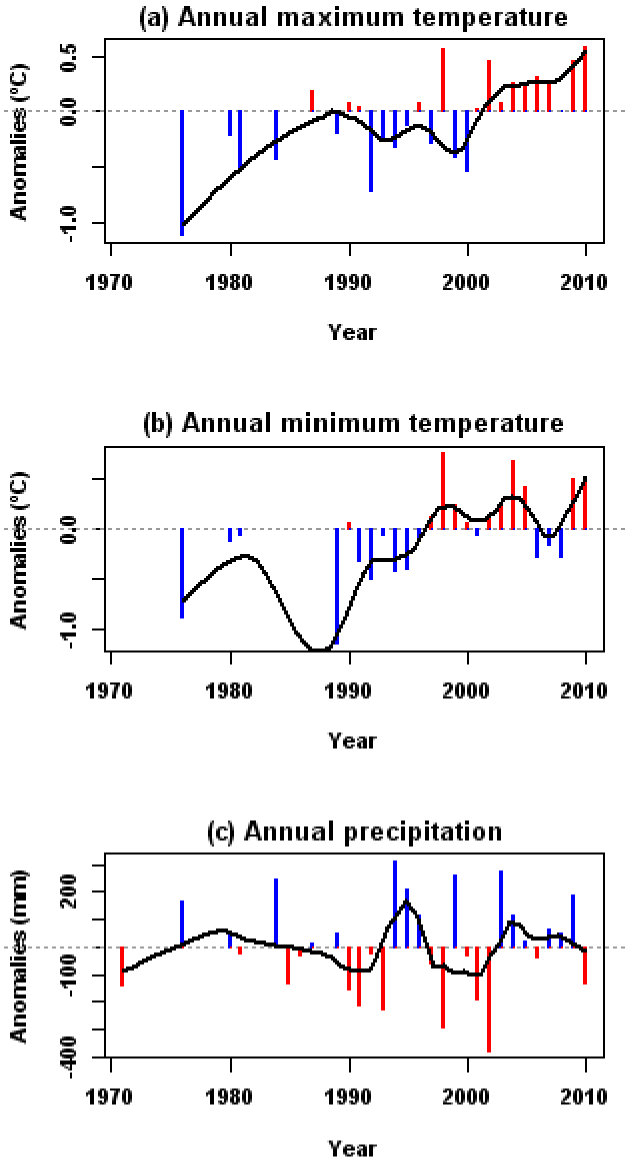


Figure 4-44: Same as in Figure 4-2 except for Koundara

Table 4-7: Decadal trends in annual, seasonal and climate indices for Koundara

Series/Indices	1941-2010	1961-2010	1971-2010
TxMean	NA	NA	**0.35|0.15:0.548**
TnMean	NA	NA	0.213|-0.075:0.552
PRCPTOT	NA	NA	-0.273|-74.182:74
Tx DJF	NA	NA	**0.362|0.186:0.575**
Tx MAM	NA	NA	*0.19|0.042:0.392*
Tx JJA	NA	NA	*0.209|0.01:0.377*
Tx SON	NA	NA	**0.319|0.148:0.466**
Tn DJF	NA	NA	0.386|-0.179:0.954
Tn MAM	NA	NA	*0.396|0.057:0.7*
Tn JJA	NA	NA	0.105|-0.113:0.317
Tn SON	NA	NA	0.1|-0.1:0.314
DRY	NA	NA	-0.067|-2:0.571
WET	NA	NA	*68.868|4.86:130.495*
TN10P	NA	NA	-1.41|-4.487:1.226
TN90P	NA	NA	2.384|-0.389:5.896
TX10P	NA	NA	**-2.345|-3.737:-1.024**
TX90P	NA	NA	**4.911|1.134:8.207**
TNn	NA	NA	0.387|-0.099:0.983
TNx	NA	NA	0.000|-0.429:0.462
TXn	NA	NA	0.664|-0.159:1.261
TXx	NA	NA	0.25|-0.048:0.583
DTR	NA	NA	0.21|-0.143:0.509
SU25	NA	NA	**1|0:1.667**
TR20	NA	NA	4.607|-10.344:22.528
RX1day	NA	NA	-0.538|-7.188:7.333
RX5day	NA	NA	0.545|-16.222:16.5
SDII	NA	NA	-0.5|-1.357:0.375
R10mm	NA	NA	0.000|-1.852:2.069
R20mm	NA	NA	0.000|-1.667:1.538
R25mm	NA	NA	0.357|-1.053:1.667
R95p	NA	NA	-1.471|-50.2:41.75
R95pTOT	NA	NA	-0.043|-0.252:0.113
R99p	NA	NA	2.928|-30.023:44.048
R99pTOT	NA	NA	-0.013|-0.027:0.002
Onset	NA	NA	1.315|-2.105:4.8
Retreat	NA	NA	2.158|-2.308:5.333
Length	NA	NA	0.4|-6.562:5.789
TX50P	NA	NA	**9.835|4.359:15.523**
CDDcold	NA	NA	*102.528|28.43:176.397*
WSDI2	NA	NA	*7.904|0.874:13.464*
CSDI2	NA	NA	-2.271|-7.411:2.38
CTN90pct HWA	NA	NA	0.000|-0.875:0.9
CTN90pct HWF	NA	NA	0.000|-4:1.667
CTX90pct HWA	NA	NA	-0.077|-3:2.267
CTX90pct HWF	NA	NA	-2.447|-5.518:1.007
RX2day	NA	NA	0.08|-12.4:11.522
CWD	NA	NA	0.625|0:1.2
CDD	NA	NA	-7.277|-25.014:10.483
SPEI	NA	NA	-0.002|-0.042:0.036
SPI	NA	NA	0.007|-0.016:0.029

4.7.3 Seasonal results

Trends and confidence intervals in seasonal Tx and seasonal Tn in Kankan are shown in Table 4-7. Both Tx and Tn show warming trend in all seasons, although Tn DJF, Tn JJA and Tn SON show non-significant trend. Trends results suggest that the warming observed in Tx mean is the result of a combined warming of all season and mostly due to warming in Tx DJF and Tx SON seasons and that observed in Tn is mainly due to Tn MAM warming.

Trends and confidence intervals in wet season and dry season are indicated in Table 4-7. Dry season (-0.067 mm/decade; non-significant) and wet season (68.868 mm/decade; significant at 5 %) show opposite trend patterns.

4.7.4 Percentile-based and other temperature indices

Figure 4-45 shows Koundara percentile-based temperature indices of TN10P (Figure 4-45a), TX10P (figure 4-45b), TN90P (Figure 4-45c) and TX90P (Figure 4-45d). Trends, confidence intervals and significance level are indicated in Table 4-7. Trend in cold nights (-1.410 %/decade, non-significant) and trend in cold days (-2.345 %/decade, significant at 1 %) exhibit changes towards warming climate. Likewise, trend in warm nights (2.384 %/decade, non-significant) and trend in warm days (4.911 %/decade, significant at 1 %) also suggest changes towards warming weather. These results sustain findings at global level documented by Hartmann et al. (2013) and those found at regional level by Aguilar et al. (2009).

Converting these trends into days these correspond to a decrease of 5.1 cold nights per decade, a decrease of 8.6 cold days per decade, an increase of 8.7 warm nights per decade and an increase of 17.9 warm days per decade.

Over the period 1971-2010 the number of days above average temperature exhibits warming trend (9.835 %/decade; significant at 1 %), converting percentage into days these corresponds to an increase of 35.9 days above average per decade in Koundara (Table 4-7). This result is eloquently confirmed by increases in WSDI (7.904 day/decade; significant at 5 %) and decreases in CSDI (-2.273 day/decade, non-significant).

Additionally, the CDDcold index in Koundara has significantly increased (102.528 ºC/decade; significant at 5 %) over the 1971-2010 period.
Other temperature based indices of interest are SU25 and TR20. Over the period 1971-2010, Koundara has experienced significant increases in SU25 (1.000 day/decade; significant at 5 %) and non-significant increases in TR20 (4.607 day/decade; non-significant) index.

Koundara general climate indices (TNn, TNx, TXn and TXx) presented in Table 4-7 also sustain changes towards warmer climate although significant trend has not been detected. This pattern is in agreement with Aguilar et al. (2009) at regional and sub-regional level and Hartmann et al. (2013) at global level.

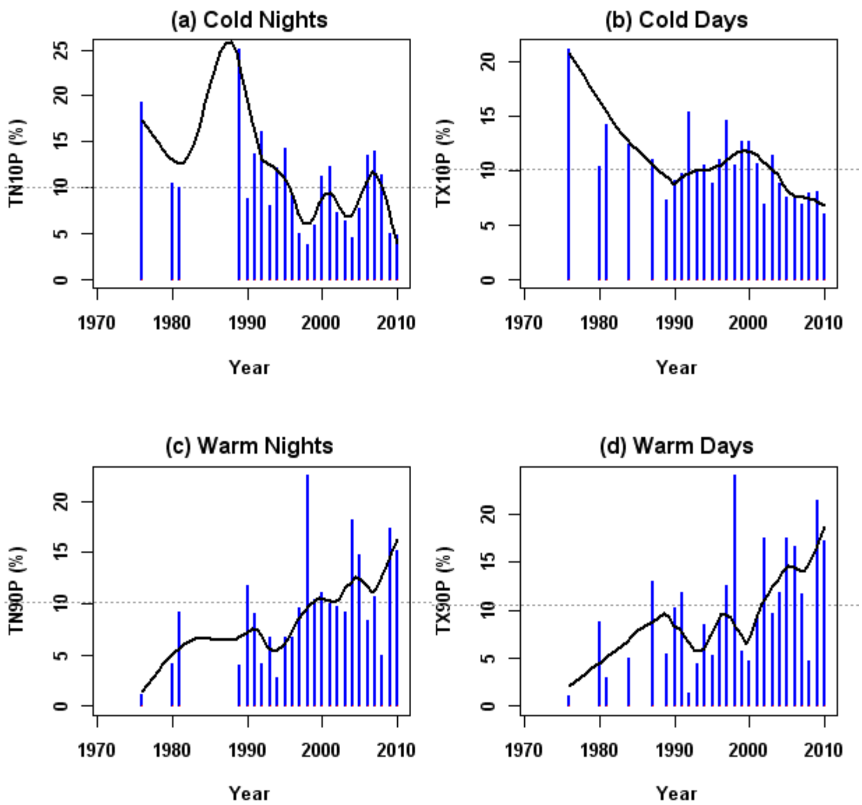


Figure 4-45: Same as in Figure 4-3 except for Koundara

4.7.5 Precipitation intensity index

Figure 4-46 shows the annual time series for SDII for Koundara. Overall, SDII shows a non-significant decreasing trend, consistent with Aguilar et al. (2009) findings but this result contradicts WA average from Barry et al. (2014) and the NWA given in Table 4-15 later in this chapter.

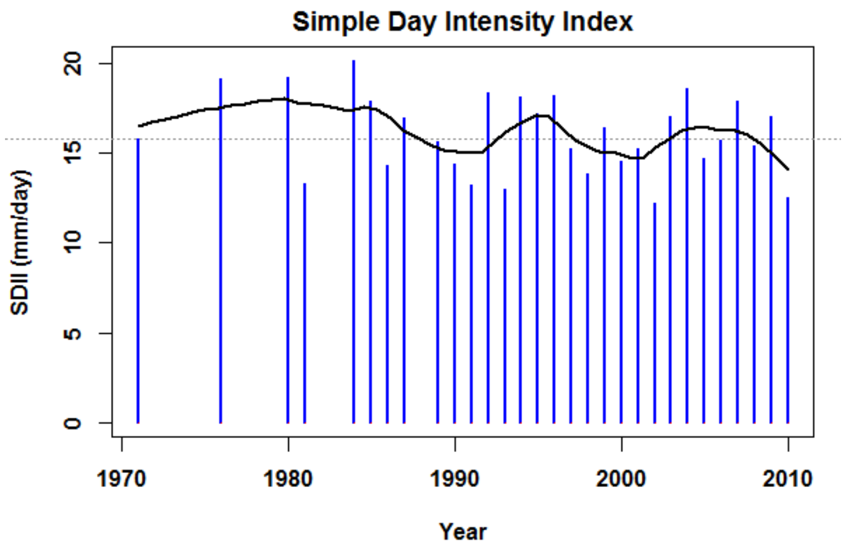


Figure 4-46: Same as in Figure 4-4 except for Koundara

4.7.6 Precipitation percentile indices

Trends and confidence intervals in very and extremely wet days (R95P and R99P) and their respective proportion (R95pTOT and R99pTOT) are given in Table 4-7. Overall, results from these indices sustain changes towards drier climate, except extremely wet days though statistically non-significant. Figure 4-47 suggests that R95P index initiated noticeable downward trend in mid 1990s and reached it lowest value early 2000s. Since then R95P shows sharp increases.

Drying trend observed in R95P (-1.471 mm/decade, non-significant) is consistent with Aguilar et al. (2009) findings while non-significant wetting trends in R99P (2.928 mm/decade) are in disagreement with Aguilar et al. (2009).

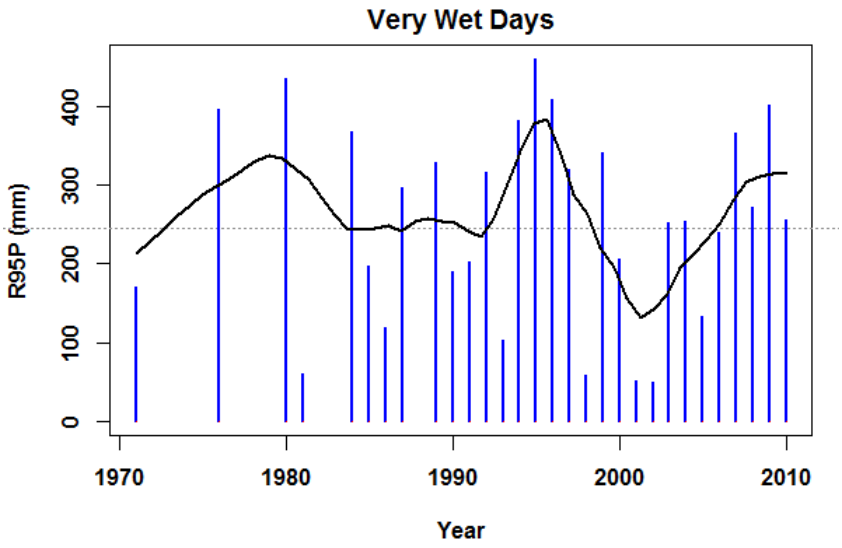


Figure 4-47: Same as in Figure 4-5 except for Koundara

4.7.7 Absolute and other precipitation indices

Trends and confidence intervals in absolute precipitation indices Rx1day, Rx2day and Rx5day are shown in Table 4-7. Figure 4-48 illustrates Rx2day index annual time series. Trends patterns in Rx2day and Rx5day indices sustain wetting conditions while Rx1day suggests changes towards drier climate. CWD index shows non-significant changes towards wet weather over the period 1971-2010, in agreement with findings from Barry et al. (2014) but contradicts Aguilar et al. (2009) results. Changes in R10mm, R20mm, and R25mm remain non-significant or quasi stationary.

Trends, significance levels and confidence intervals in wet season onset, retreat and length indices are given in Table 4-7. Koundara shows non-significant delayed onset (1.315 day/decade; non-significant) and non-significant delayed retreat (2.158 day/decade; non-significant) leading to a non-significant longer wet season.

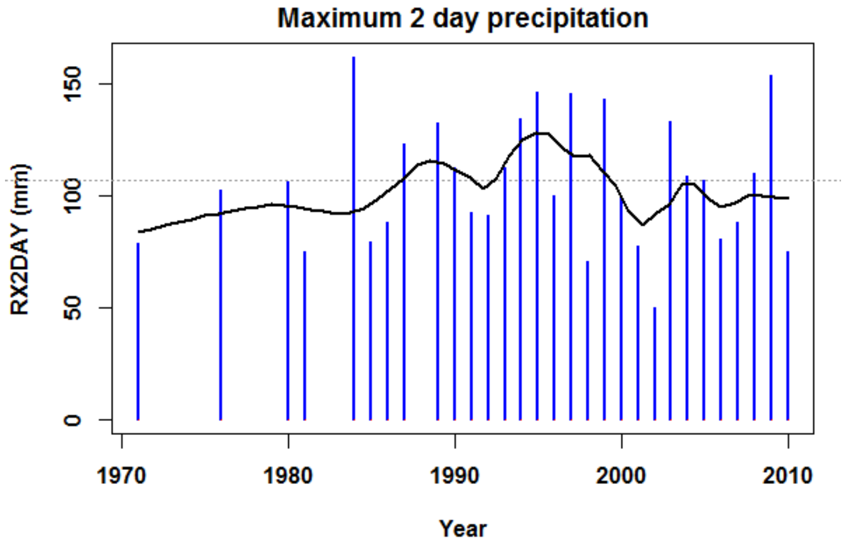


Figure 4-48: Same as in Figure 4-6 except for Koundara

4.7.8 Drought indices

Trends, significance levels and confidence intervals in drought indices SPEI, SPI and CDD indices are shown in Table 4-7. SPEI exhibits non-significant downward trend. On the contrary, SPI exhibits non-significant upward trend. Over the last four decades many periods of severe droughts have been seen in Koundara. Figure 4-49 shows SPEI monthly time series anomalies. Droughts observed in 1991, 1993, 1998 and 2002 are among the most severe. Likewise, CDD index tends towards drier climate though changes are statistically non-significant in Koundara, in opposition with Aguilar et al. (2009) results but in agreement with WA findings from Barry et al. (2014).

There is almost no change in nighttime heat waves frequency and amplitude while daytime heat waves exhibit non-significant decreases in the frequency (-2.447 day/decade; non-significant) and amplitude (-0.077 ºC/decade; non-significant).

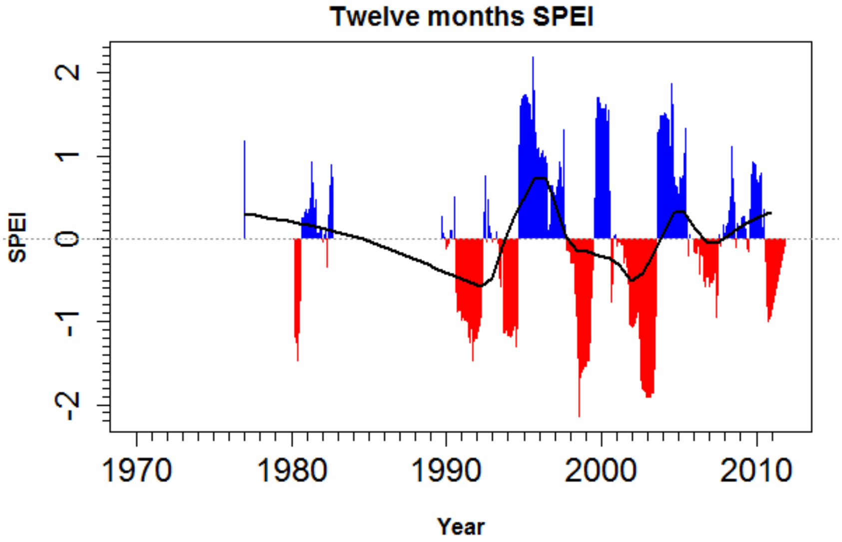


Figure 4-49: Same as in Figure 4-7 except for Koundara

4.8 LABE

Labe is located between latitudes 11° 9' 6'' and 11° 44' 44'' North and longitudes 12° 4' 54'' and 12° 32' 50'' West. Its terrain is mountainous with an average altitude of about 700m. The prefecture is bounded on the north by Mali prefecture, on the west by that of Lelouma, south by Pita and Dalaba and east by Tougue and Koubia. Labe covers an area of 2,242 km2 and in 2014 has a resident population of 318,633 inhabitants.

4.8.1 Climograph and Cumulative Precipitation

Labe is characterized by low temperatures ranging from 8 degrees Celsius to 19 degrees Celsius from December to February. Labe has a tropical savanna climate of Köppen classification (Figure 4-50a). Its wet season lasts six months from May to October. Labe receives 1579.2 mm of rain per year on average. Daily temperature range can be especially large during the dry season, reaching the peak of 21.2 °C on average in January; this period corresponds to the arrival of northern harmattan. Labe is never hot enough; the hottest month is April averaging 26 ºC. Labe mean monthly temperature is 7.4 ºC. August is the wettest month with 360 mm rainfall on average, while January is the driest month with 2 mm. Figure 4-50b the average cumulative precipitation. During 1971-

2010 period average cumulated precipitation is mostly bellow 1941-1970 average cumulated. The deficit is as larger as 8.55 %.

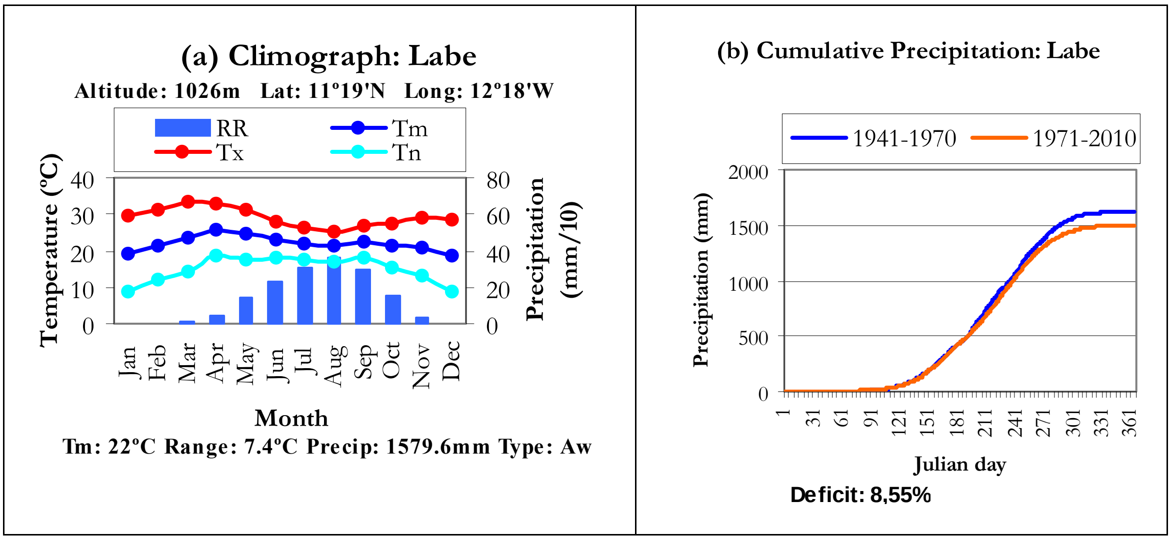


Figure 4-50: Same as in Figure 4-1 except for Labe.

4.8.2 Annual results

Figure 4-51 shows annual anomalies of Tx mean (Figure 4-51a), Tn mean (Figure 4-51b) and total precipitation (Figure 4-51c). Trends, significance level and confidence intervals for these annual time series are given in Table 4-8. Figures 4-51a and 4-51b suggest warnings climate in Labe.

Over the recent period trend in Tx (0.186 ºC/decade; significant at 1 %) and trend in Tn (0.288 ºC/decade; significant at 1 %) are consistent with warming climate. Identical same trend patterns are seen over the former period and over the period 1961-2010 and concur with finding by Barry et al. (2014) for WA and those at global level documented by Hartmann et al. (2013).

Table 4-8 suggests that warming has started in the former period for both Tx mean and Tn mean and accelerated in the recent period; and (Figures 4-51a and 4-51b) since mid 1990s Tx mean and Tn mean remain above average.

In contrast to the temporarily consistent trend changes observed in Tx mean and Tn mean, annual total precipitation trend shows changes from non-significant drying climate towards non-significant wetting climate from former period to the recent period (Table 4-8). Trend in annual total precipitation concurs with findings for WA from Barry et al.

(2014) and show opposite sign compare to results from Aguilar et al. (2014) over the recent period.

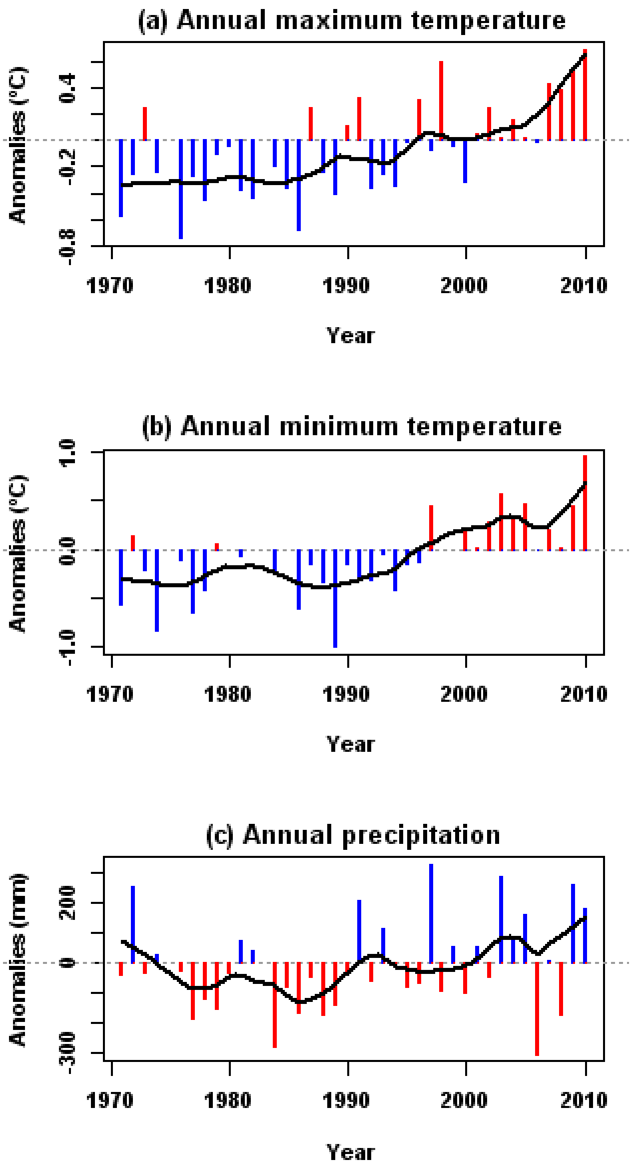


Figure 4-51: Same as in Figure 4-2 except for Labe

Table 4-8: Decadal trends in annual, seasonal and climate indices for Labe

Series/Indices	1941-2010	1961-2010	1971-2010
TxMean	**0.094|0.03:0.154**	**0.13|0.057:0.197**	**0.186|0.075:0.285**
TnMean	*0.097|0.018:0.18*	**0.161|0.087:0.26**	**0.288|0.112:0.427**
PRCPTOT	-17.512|-48.751:10.943	-10.028|-52.215:29.088	32.333|-16.667:77.667
Tx DJF	0.028|-0.03:0.089	0.053|-0.031:0.187	*0.17|0.021:0.35*
Tx MAM	0.042|-0.04:0.118	0.084|-0.021:0.207	*0.197|0.051:0.338*
Tx JJA	*0.087|0.015:0.16*	**0.118|0.051:0.192**	**0.136|0.045:0.227**
Tx SON	**0.112|0.045:0.171**	**0.192|0.12:0.26**	*0.139|0.036:0.256*
Tn DJF	0.119|-0.003:0.23	**0.254|0.073:0.436**	**0.364|0.107:0.605**
Tn MAM	**0.131|0.034:0.228**	**0.256|0.122:0.377**	*0.208|0.021:0.392*
Tn JJA	**0.096|0.048:0.143**	**0.148|0.063:0.215**	**0.188|0.059:0.291**
Tn SON	-0.027|-0.083:0.037	0.004|-0.085:0.1	0.075|-0.047:0.195
DRY	-2.469|-9.926:5.216	-3.538|-14.812:8.714	3.241|-14.167:20.447
WET	-21.398|-48.997:7.231	1.339|-49.818:46.489	31.996|-12.816:77.682
TN10P	*-0.977|-1.929:-0.034*	**-2.424|-3.216:-1.59**	**-3.311|-5.096:-2.14**
TN90P	**0.864|0.231:1.505**	0.814|-0.036:1.584	1.128|-0.395:2.919
TX10P	**-0.969|-1.545:-0.378**	**-1.225|-1.8:-0.571**	**-1.585|-2.574:-0.59**
TX90P	*1.167|0.196:2.136*	*1.777|0.213:3.328*	**3.069|0.414:5.473**
TNn	0.207|-0.072:0.453	*0.319|0.023:0.667*	0.312|-0.319:1.039
TNx	0.061|-0.095:0.229	0.021|-0.258:0.313	-0.058|-0.556:0.446
TXn	-0.063|-0.171:0.037	0.000|-0.182:0.143	-0.037|-0.257:0.188
TXx	0.000|-0.074:0.087	0.091|-0.028:0.2	0.167|0:0.312
DTR	-0.004|-0.094:0.098	-0.05|-0.15:0.032	-0.041|-0.196:0.071
SU25	**2.474|0.78:4.118**	**3.653|1.752:5.369**	*3.333|0.526:5.652*
TR20	0.878|0:1.841	0.945|-0.297:2.404	0.126|-2.439:2.549
RX1day	-1.671|-4.116:0.306	-1.092|-4.615:3.371	2.75|-2:7.375
RX5day	-3.15|-6.324:0.428	-2.692|-8.556:2.622	4.571|-2:10.6
SDII	-0.065|-0.251:0.108	-0.077|-0.348:0.143	0.087|-0.286:0.364
R10mm	-0.811|-1.786:0	-0.714|-2.333:0.714	0.000|-2.5:1.786
R20mm	*-0.667|-1.351:0*	-0.87|-2:0	0.000|-1.429:1.579
R25mm	-0.417|-0.952:0	-0.417|-1.25:0.476	0.000|-1:1.429
R95p	-12.253|-35.781:12.855	9.307|-40.486:41.355	42.023|-7.062:78.623
R95pTOT	-0.003|-0.02:0.011	0|-0.016:0.021	0.021|-0.006:0.059
R99p	-3.273|-16.582:1.91	0.000|-18.139:1.042	0.000|0:28.261
R99pTOT	-0.002|-0.008:0.003	-0.002|-0.01:0.006	0.002|-0.011:0.016
Onset	0.18|-1.695:2.221	0.859|-2.817:4.071	-0.978|-5.289:2.674
Retreat	0.000|-1.667:1.818	1.219|-1.65:3.942	*3.638|0:7.586*
Length	0.000|-2.8:2.143	0.333|-3.409:3.913	*4.387|0:8.824*
TX50P	**3.624|1.596:5.714**	**5.372|3.039:7.731**	**6.818|3.294:11.057**
CDDcold	27.5|-2.63:56.714	*50.34|6.391:97.341*	*93.125|6.108:160.877*
WSDI2	*1.915|0.174:4.041*	3.283|-0.274:6.722	*6.132|1.182:12.132*
CSDI2	*-2.752|-5.165:-0.431*	**-6.631|-8.445:-4.731**	**-7.692|-10.389:-4.8**
CTN90pct HWA	0.136|-0.051:0.25	0.27|-0.031:0.556	0.15|-0.455:0.515
CTN90pct HWF	NA	0.000|0:1.852	0.000|-0.811:2.632
CTX90pct HWA	0.05|-0.7:0.667	0.091|-1.476:1.429	1.429|-0.222:3
CTX90pct HWF	-0.769|-1.622:0	0.000|-2.5:0.909	0.667|0:2.308
RX2day	-1.833|-4.083:0.483	-1.323|-5.6:2.818	2.667|-2.688:7.476
CWD	0.000|-0.526:0.294	0.000|-0.5:0.741	0.723|-0.009:1.733
CDD	3.573|-1.613:8.714	0.000|-7.143:7.727	1.25|-10:10.588
SPEI	-0.009|-0.022:0.003	-0.015|-0.031:0.001	0.007|-0.013:0.027
SPI	-0.009|-0.018:0	-0.009|-0.023:0.006	0.014|-0.001:0.028

4.8.3 Seasonal results

Seasonal trend in Tx and Tn are shown in Table 4-8. Both the seasonal Tx and Tn show significant warming in all seasons except for Tn SON where Tn mean shows statistically non-significant warming trend over the recent period. Seasonal trends seem to be inherited from former period except for Tn SON where non-significant cooling during the former periods turns to non-significant warming during over the recent period. Warming patterns over the recent period previously observed in annual Tn mean is the results of Tn DJF, Tn MAM and Tn JJA warming while those previously observed in annual Tx mean are originated from all Tx seasons warming.

Like annual total precipitation, wet season and dry season show non-significant drying trends over the former period and non-significant wetting trends patterns over the recent period. As former period is wetter than the recent period, trend starting in the former period shows changes towards drier climate.

4.8.4 Percentile-based and other temperature indices

Figure 4-52 shows Labe percentile-based temperature indices of TN10P (Figure 4-52a), TX10P (figure 4-52b), TN90P (Figure 4-52c) and TX90P (Figure 4-52d) and their respective trends, significance level and confidence intervals are given in Table 4-8. Figure 4-52 suggests warming trends in all percentile-based temperatures indices.

Over the recent period the decrease of the frequency of cold nights (-3.311 %/decade; significant at 1 %) and the increase of the frequency of warm nights (1.128 %/decade; non-significant) suggest changes towards warming climate. Converting these trends into days and nights these correspond to a decrease of 12.1 cold nights per decade and an increase of 4.1 warm nights per decade. Similar trends are seen over the former period and over the period 1961-2010. Likewise, the significant decreases in the frequency of cold days (-1.585 %/decade; significant at 1 %) and the significant increases in the frequency of warm days (3.069 %/decade; significant at 1 %) suggest changes towards warming climate. Converting these trends into days and nights these correspond to a decrease of 5.8 cold days per decade and an increase of 11.2 warm days per decade. Similar trends are seen over the former period and over the period 1961-2010.

These results are consistent with trends observed at global level as documented by Hartmann et al. (2013) and at regional level from Aguilar et al (2009).
The frequency of days above average also shows warming trend (6.818 %/decade; significant at 1 %) over the recent period. Converting percentage in days this corresponds to an increase of 24.5 days above average temperature per decade. Similar trends are seen over the former period and over the period 1961-2010 in this index.
TR20 (0.126 day/decade, non-significant) and SU25 (3.333 day/decade, significant at 5 %) show warming trends over the recent period. Identical trends are seen over the former period and over the period 1961-2010 in tropical nights and summer days indices.
Additionally general climate indices show increases of the temperature of warmest day and coldest night and; the decreases of the temperature of coldest day and warmest night, though none of them show significant trend over the recent period. The warming patterns in warm spells (6.132 day/decade; significant at 1 %) and in cold spells (-7.692 day/decade; significant at 1 %) suggest also overall warming patterns. Warming patterns are seen over the former period and over the period 1961-2010 in these two indices. Finally CDDcold index exhibits significant increases, expressing the growing needs for cooling over the recent period.

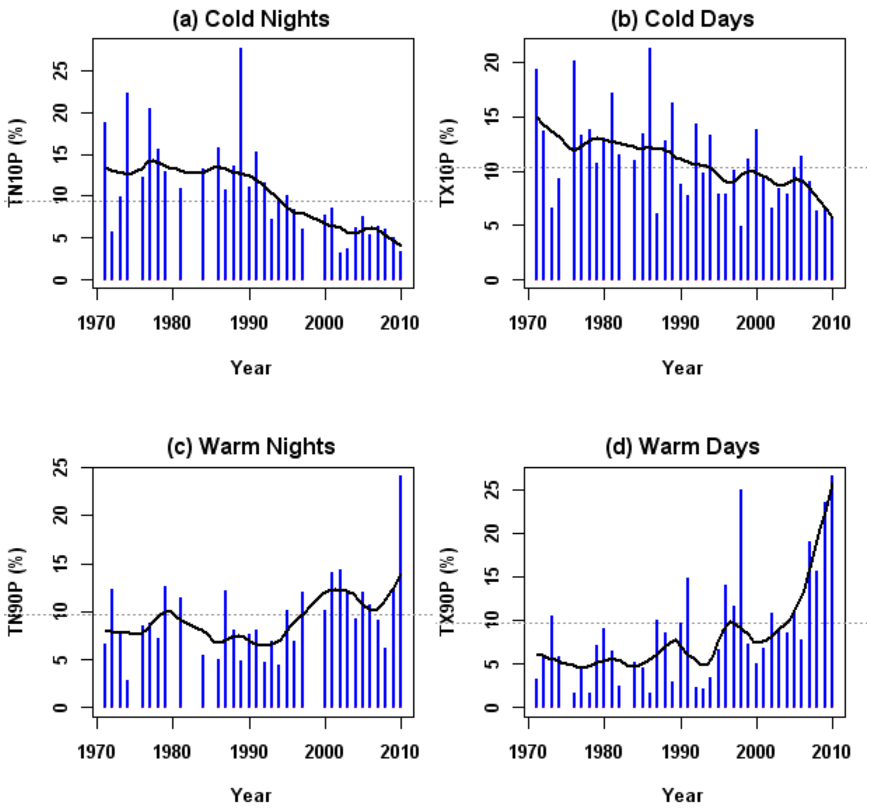


Figure 4-52: Same as in Figure 4-3 except for Labe

4.8.5 Precipitation intensity index

Figure 4-53 shows the annual time series for SDII. Over the recent period, SDII exhibits non-significant increases trend (0.087 mm/day/decade; non-significant) and it is characterized by very low inter-annual variability. SDII in Labe oscillates around 14 mm/day the 1981-2010 average. Trend in SDII index contradicts regional results from Aguilar et al. (2009). Daily intensity shows non-significant decreasing trends over the former period and over the period 1961-2010.

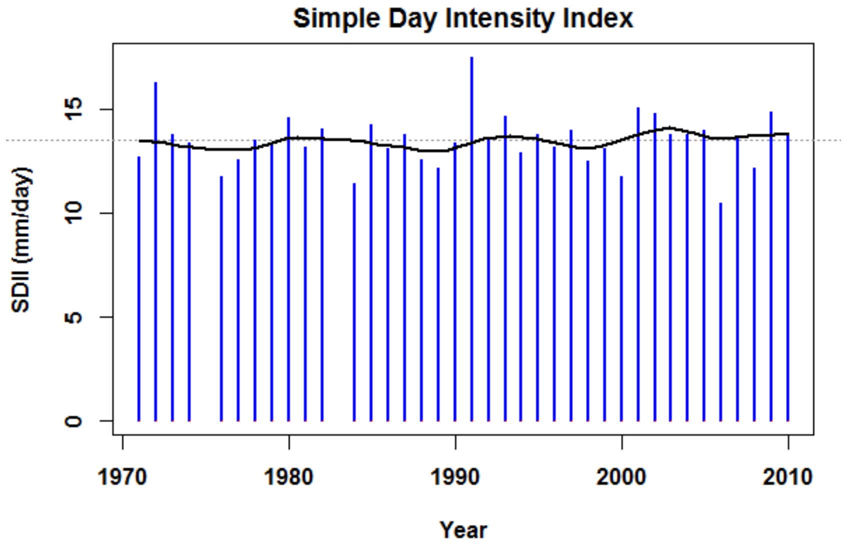


Figure 4-53: Same as in Figure 4-4 except for Labe

4.8.6 Precipitation percentile indices

Trends, significance level and confidence intervals in very and extremely wet days (R95P and R99P) and their respective proportion (R95pTOT and R99pTOT) are given in Table 4-8. Precipitation percentile indices show non-significant trends over both periods. It worth noting that R95P (42.023 mm/decade; non-significant) and R95pTOT (0.021 %/decade; non-significant) tend towards wetter climate over the recent period while R99P and R99pTOT exhibit nearly stationary trend.

Figure 4-54 illustrates the annual time series for R95P index. Figure 4-54 suggests that sharp increases in R95P initiated in mid 1980s and since then for most of years R95P index remains above or near 300 mm, the 1981-2010 average. Trend in R95P index over the recent period concurs with findings for WA from Barry et al. (2014) but contradicts regional averages from Aguilar et al. (2009).

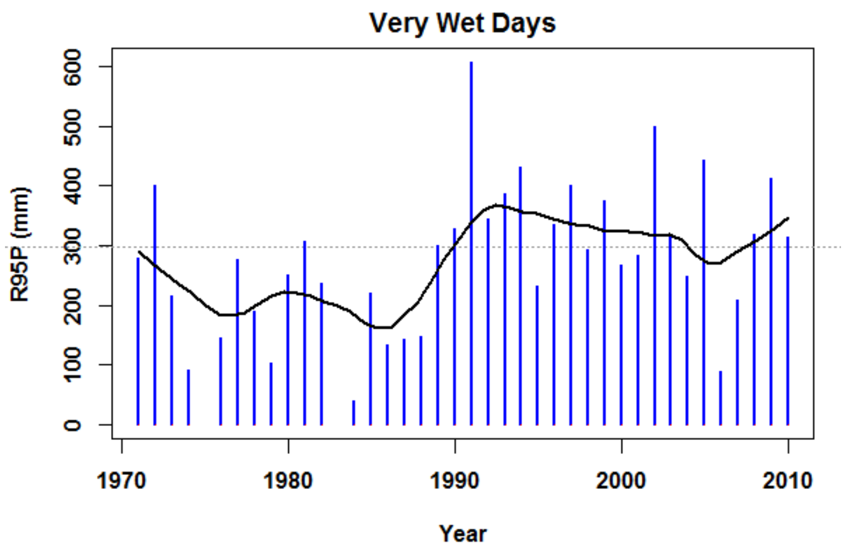


Figure 4-54: Same as in Figure 4-5 except for Labe

4.8.7 Absolute and other precipitation indices

Trends, significance level and confidence intervals in absolute precipitation indices Rx1day, Rx2day and Rx5day are shown in Table 4-8. Both indices exhibit trends patterns very similar to that of PRCPTOT over the recent and former periods. Trends in Rx1day (2.750 mm/decade; non-significant), Rx2day (2.667 mm/decade; non-significant) and Rx5day (4.571 mm/decade; non-significant) indices suggest changes towards wetter climate though there is no statistically significant trend. Figure 4-55 shows Rx2day annual time series. A salient feature common to absolute precipitation indices and annual total precipitation is that they have switched from drying trends to wetting trends form former period to the recent one.

Wet spells show either quasi stationary trends over former and over 1961-2010 one or non-significant increasing trend over the recent period.

Trends, significance levels and confidence intervals in wet season onset, retreat and length indices are given in Table 4-8. Over the recent period, Labe shows non-significant early onset (-0.978 day/decade; non-significant) and significant delayed retreat (3.638 day/decade; significant at 5 %), leading to a significant longer (4.387 day/decade; significant at 5 %) rainy season. Over the former period and over the period 1961-2010 Labe shows non-significant delayed onset and quasi stationary or non-significant delayed retreat leading to quasi stationary or non-significant shortened season length.

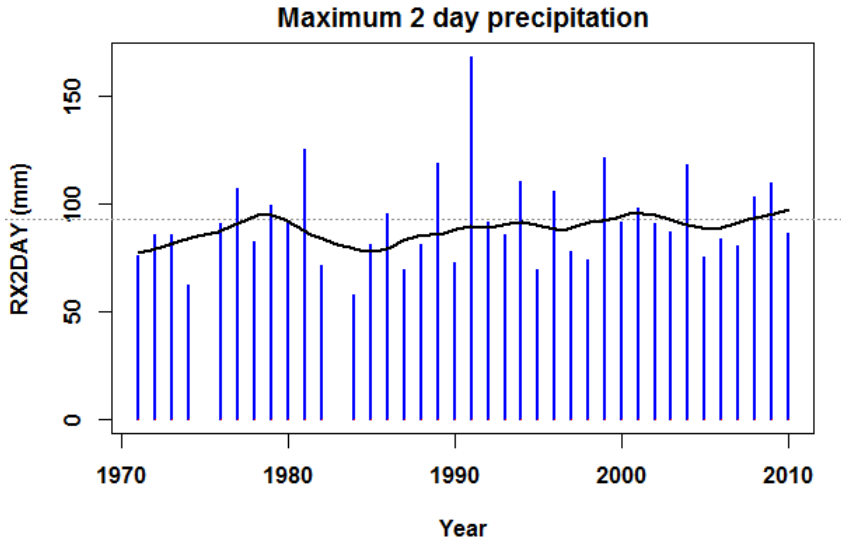


Figure 4-55: Same as in Figure 4-6 except for Labe

4.8.8 Drought indices

Table 4-8 shows trends and significance level as well as the confidence intervals for SPEI, SPI and CDD indices. SPI and SPEI show similar non-significant wetting trends over the recent period and non-significant drying trends over the former period and over the period 1961-2010. Figure 4-56 shows SPEI monthly time series. Over 1971-2010, droughts have been very frequent in Labe. The worst droughts occurred in 1978, 1985, 2007. Less intense but longer lasting droughts have also been observed in early 1970s, in 1987 and in 1989.

The dry spells (1.250 day/decade; non-significant) index tends towards drier climate though statistically non-significant over the recent period. The same patterns are observed over the former period.

Finally, over the recent period, Tn related HWA, Tx related HWA and Tx related HWF exhibit positive non-significant trends stressing the health effects.

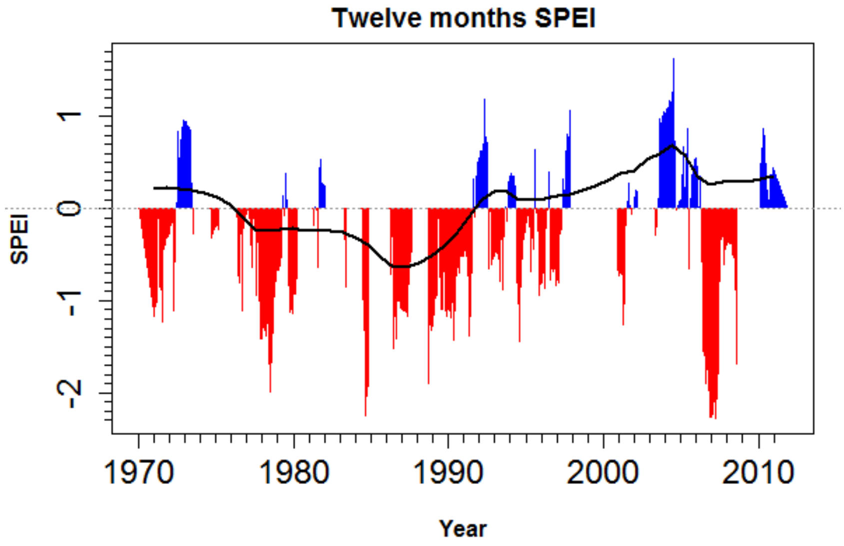


Figure 4-56: Same as in Figure 4-7 except for Labe

4.9 MACENTA

Macenta is located between latitudes 7° 44' 22'' and 8° 22' 6'' North and longitudes 8° 51' 21'' and 9° 55' 54'' West. Low hills (450-500 m) cover the South and the North East of Macenta. Mountainous areas with steep slopes are located in Northwest. The river system is very dense and regular over the year. The prefecture is bounded on the north by Kereouane and Kissidougou prefectures, on the west by Gueckedou and the Republic of Liberia, south by Yomou and the Republic of Liberia and east by Beyla and N'Zerekore prefectures. Macenta covers an area of 7,056 km2 and in 2014 has a resident population of 298,282 inhabitants.

4.9.1 Climograph and Cumulative Precipitation

Macenta is characterized by mild and constant temperatures; high cloud cover and high humidity in most part of the year. Macenta has a tropical monsoonal climate with a short, three months long, dry season and a heavy monsoon in the rest of the year. Figure 4-57a shows Macenta climograph. The mean annual temperature in Macenta is 24.5 °C. The range of mean monthly temperatures is as small as 7.1°C, but the diurnal range is more important, reaching 22.9 ºC in February. Macenta has 2746.3 mm annual rainfall on average. The driest weather is in January when the monthly average rainfall is only 16.5

mm, while the wettest weather is in August when an average of 536.8 mm of rain falls. Figure 4-57b shows the cumulative precipitation. The cumulative rainfall during 1941-1970 is predominantly above 1971-2010 average. A deficit of 17.12 % is observed during the period 1971-2010.

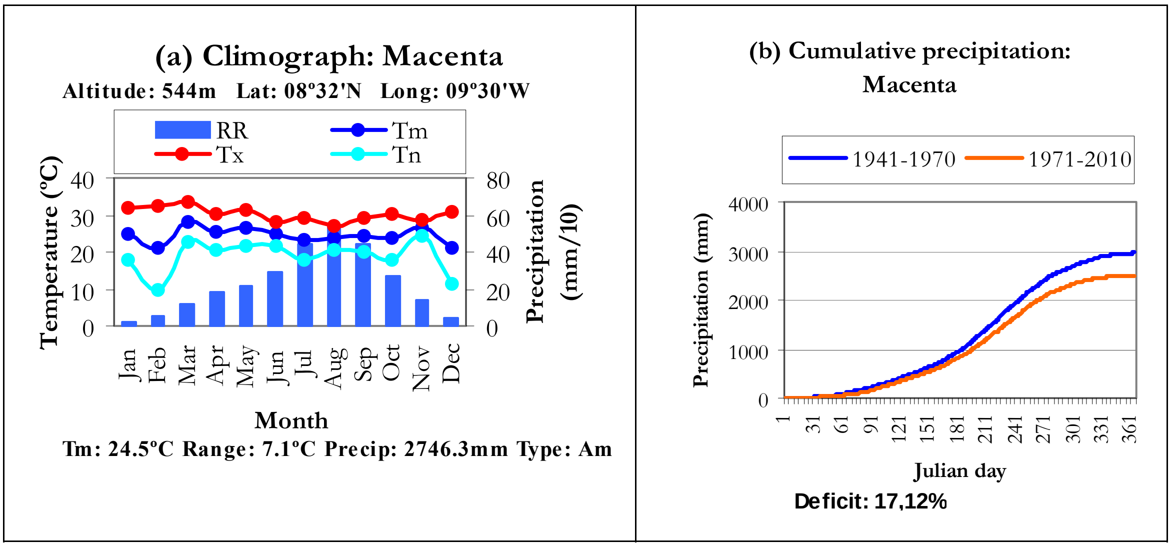


Figure 4-57: Same as in Figure 4-1 except for Macenta.

4.9.2 Annual results

Figure 4-58 shows anomalies of annual Tx mean (Figure 4-58a), annual Tn mean (Figure 4-58b) and annual total precipitation (Figure 4-58c). Trends, significance level and confidence intervals for these annual time series are also shown in Table 4-9. The annual mean of Tx and the annual mean of Tn exhibit changes toward warming climate. Trends in Tx mean (0.223 ºC/decade; significant at 1 %) and in Tn mean (0.359 ºC/decade; significant at 5 %) over the recent period are consistent with warming conditions and concur with those observed at global level as documented by AR5 (Hartmann et al., 2013) and in agreement with those observed at regional level from Aguilar et al. (2009). Overall, since mid 1990s Tx mean and Tn mean tend to remain above 1971-2010 average.

Annual total precipitation trend shows significant changes towards drier climate for all periods except the recent one, consistent with regional findings from Aguilar et al. (2009) but disagrees with the wetter trend found for WA as reported by Barry et al. (2014).

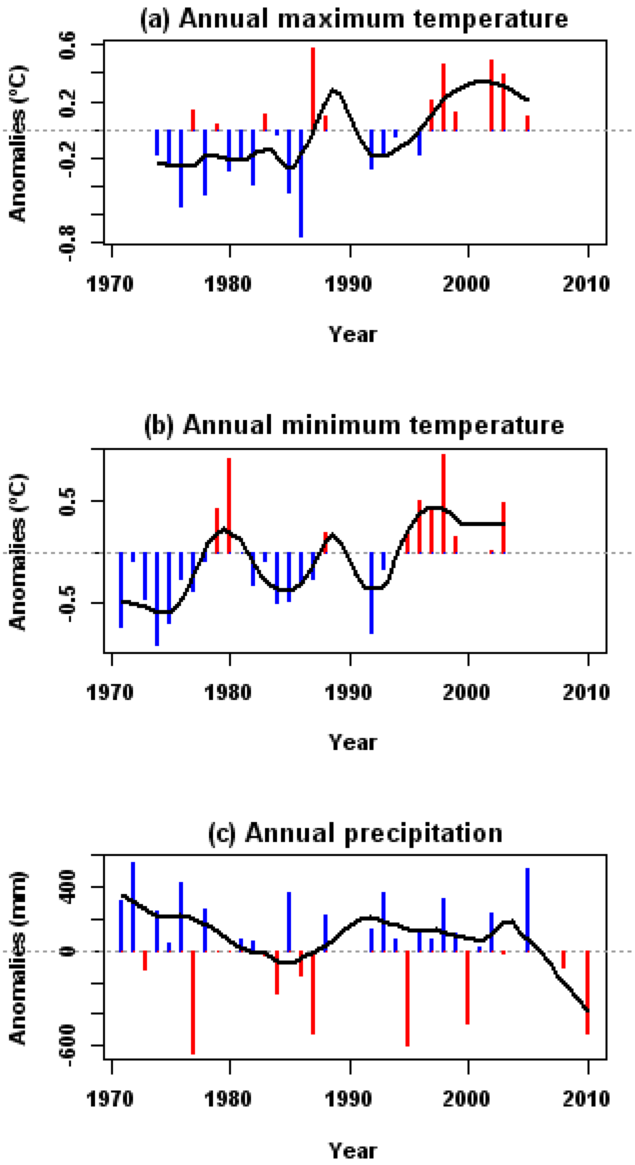


Figure 4-58: Same as in Figure 4-2 except for Macenta

Table 4-9: Decadal trends in annual, seasonal and climate indices for Macenta

Series/Indices	1941-2010	1961-2010	1971-2010
TxMean	-0.01|-0.1:0.079	*0.147|0.041:0.257*	**0.223|0.058:0.365**
TnMean	0.058|-0.045:0.157	0.182|-0.024:0.388	*0.359|0.031:0.71*
PRCPTOT	**-90.178|-162.818:-23.069**	*-97.625|-171.44:-19.233*	-56.024|-162.63:41.692
Tx DJF	0.013|-0.069:0.091	*0.151|0.005:0.325*	**0.252|0.081:0.429**
Tx MAM	0.003|-0.079:0.078	0.055|-0.113:0.17	0.13|-0.158:0.32
Tx JJA	0.019|-0.057:0.09	0.101|-0.026:0.217	0.051|-0.15:0.2
Tx SON	0.026|-0.024:0.09	**0.18|0.071:0.277**	*0.161|0.037:0.298*
Tn DJF	-0.056|-0.264:0.159	0.107|-0.245:0.588	0.461|-0.153:1.066
Tn MAM	**0.174|0.085:0.251**	**0.352|0.265:0.436**	**0.35|0.233:0.487**
Tn JJA	0.074|0:0.144	0.132|-0.009:0.262	0.129|-0.116:0.335
Tn SON	0.004|-0.081:0.089	0.096|-0.086:0.257	0.179|-0.155:0.457
DRY	**-44.653|-67.206:-25.139**	**-48|-88.917:-16.708**	-36.412|-89.333:5.619
WET	*-51.363|-95.782:-10*	*-64.167|-120:-0.68*	-41.415|-117.121:26.3
TN10P	NA	NA	NA
TN90P	NA	NA	NA
TX10P	NA	NA	NA
TX90P	NA	NA	NA
TNn	-0.046|-0.508:0.376	-0.525|-1.405:0.3	-0.087|-1.272:1.105
TNx	0.157|-0.034:0.352	**0.485|0.157:0.8**	0.595|-0.054:0.937
TXn	0.125|0:0.25	0.302|-0.115:0.658	0.000|-0.346:0.25
TXx	-0.02|-0.225:0.207	0.000|-0.286:0.276	0.168|-0.308:0.621
DTR	-0.095|-0.198:0.035	-0.001|-0.249:0.291	-0.03|-0.388:0.4
SU25	0.938|-0.1:1.954	0.581|-1.164:2.727	-0.973|-3.023:1.576
TR20	5.426|-0.225:11.583	**14.53|7.692:23.74**	*18.12|4.629:35.07*
RX1day	-2.233|-5.8:1.615	-2.182|-9.241:4.16	1.708|-9:10.889
RX5day	-1.471|-7.1:5.371	-1.333|-12.176:9.867	1.034|-14.615:17.267
SDII	-0.022|-0.267:0.2	0.071|-0.273:0.4	0.042|-0.364:0.562
R10mm	**-2.496|-3.928:-0.99**	*-2.432|-4.375:-0.476*	-1.369|-5.031:2.161
R20mm	-1.083|-2.443:0.175	*-1.905|-3.333:0*	-1.765|-3.684:0.357
R25mm	**-1.206|-2.176:-0.235**	*-1.25|-2.5:0*	-0.96|-2.581:0.714
R95p	*-40.01|-76.515:-0.987*	-25.03|-79.667:33.28	16.552|-63.704:93.667
R95pTOT	0|-0.012:0.009	0|-0.019:0.016	0.005|-0.019:0.03
R99p	-16.111|-39.054:0	0.000|-35.8:19	0.000|-30.914:59.556
R99pTOT	-0.001|-0.009:0.004	0.004|-0.005:0.015	*0.013|0:0.057*
Onset	*4.58|0.526:8.846*	*7.5|1.429:13.889*	**11.667|4.167:20.435**
Retreat	*-3.341|-6.064:-0.524*	-1.699|-6.324:2.602	2.536|-3.587:7.54
Length	**-10.147|-14.093:-6.279**	**-10.375|-16.026:-3.888**	-11.439|-20.5:0.824
TX50P	NA	NA	NA
CDDcold	NA	NA	NA
WSDI2	NA	NA	NA
CSDI2	NA	NA	NA
CTN90pct HWA	NA	NA	NA
CTN90pct HWF	NA	NA	NA
CTX90pct HWA	NA	NA	NA
CTX90pct HWF	NA	NA	NA
RX2day	-0.714|-4.895:3.407	-1.214|-8.893:6.667	0.871|-10:11.769
CWD	-0.759|-1.695:0.019	-1.145|-2.857:0.769	-0.151|-3.275:2.435
CDD	*3.513|0.2:6.802*	0.833|-4.286:6	0.889|-5.556:8
SPEI	-0.019|-0.039:0.001	*-0.042|-0.08:-0.004*	-0.008|-0.044:0.029
SPI	-0.014|-0.029:0.001	*-0.021|-0.04:-0.003*	-0.009|-0.031:0.012

4.9.3 Seasonal results

Trends in seasonal Tx and Tn are shown in Table 4-9. Both the seasonal Tx and Tn show warming trends in all seasons though only few (Tx DJF, Tx SON and Tn MAM) are statistically significant over the recent period. Warming trends previously observed in Tx are largely explained by warming in Tx DJF and Tx SON seasons while those observed in Tn are mainly due to Tn MAM season warming.

Wet season and dry season show (temporal) consistent changes towards drier climate though the trends become muted over the recent period. Decreases in annual total precipitation are due to decreases in both wet and dry seasons (Table 4-9).

4.9.4 Percentile-based and other temperature indices

General climate indices are presented in Table 4-9. Results suggest increasing temperatures of the hottest night (0.595 ºC/decade, non-significant) and hottest day (0.16 8 ºC/decade, non-significant) over the recent period. Contrariwise, the coldest night temperature displays cooling trends (-0.087 ºC/decade, non-significant) while coldest day temperature exhibit quasi stationary trend over the recent period. Consequently, the DTR trend shows negative non-significant trend over the recent period. TNx and TXx trends patterns concur with findings by Aguilar et al. (2009) while those for TNn and TXn contradict findings by Aguilar et al. (2009).

Tropical nights shows significant increases over the recent period (18.120 day/decade; significant at 5 %) and over the period 1961-2010 (14.53 day/decade; significant at 1 %) and non-significant increases over the former one. Summer days shows non-significant decreases over the recent period or non-significant increases over the period 1961-2010 and over the former one.

4.9.5 Precipitation intensity index

Figure 4-59 shows annual time series for Macenta SDII index. Trends, significance level and the confidence intervals for this index are given in Table 4-9. SDII shows non-significant changes over the study period. SDII index trend pattern (0.042 mm/day/decade, non-significant) over the recent period contradicts regional results from Aguilar et al. (2009) but concurs with those for WA from Barry et al. (2014).

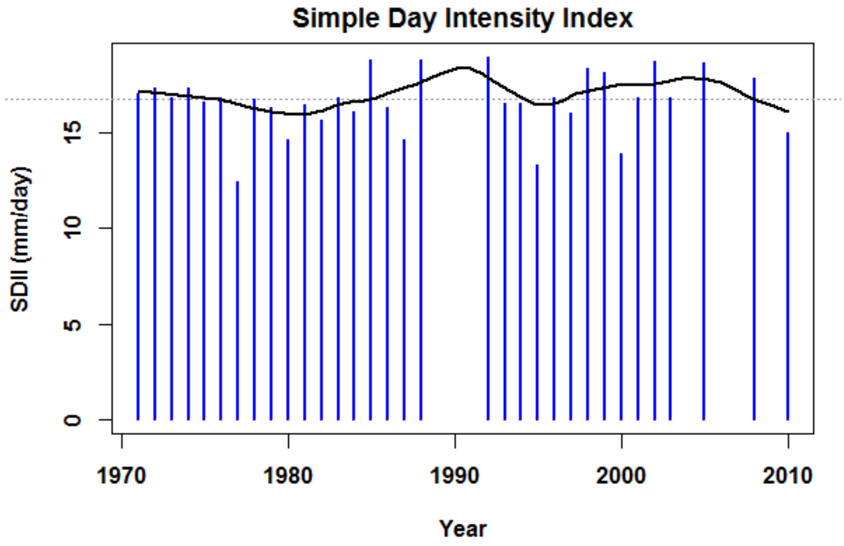


Figure 4-59: Same as in Figure 4-4 except for Macenta

4.9.6 Precipitation percentile indices

Trends, confidence intervals and significance level in very and extremely wet days (R95P and R99P) and their respective proportion (R95pTOT and R99pTOT) to annual precipitation are given in Table 4-9. Except R99pTOT, none of these indices shows statistically significant changes over recent period; and over former period R95P index tends towards drier climate indicating that the contribution of days exceeding the long-term 99th percentile to annual total precipitation has significantly increased.

It worth noting that over the recent period, R95P (16.552 mm/decade; non-significant) and R95pTOT (0.005 %/decade; non-significant) tend towards wetter climate. Figure 4-60 illustrates the annual time series for R95P index. Early 1990s and 2000s are among the wettest years. Trend in precipitation percentile indices contradicts Aguilar et al. (2009) findings.

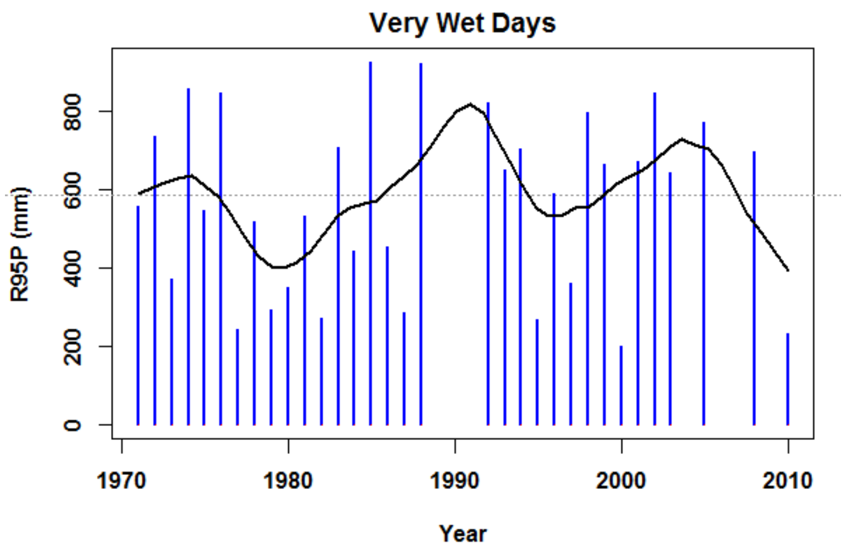


Figure 4-60: Same as in Figure 4-5 except for Macenta

4.9.7 Absolute and other precipitation indices

Trends in absolute precipitation indices Rx1day, Rx2day and Rx5day are shown in Table 4-9. Both indices exhibit similar non-significant drying weather patterns over the former period and over the period 1961-2010 and non-significant wetting weather patterns over the recent period. One common characteristic to these indices is the change from drying trends to wetting trends from older periods to recent and none of them shows statistically significant changes. The recent period wetting pattern contrasts with Aguilar et al. (2009) findings. Figure 4-61 shows annual time series for Rx2day index.

In Macenta former periods are wetter than the recent one. Thus trends in heavy precipitation days (R10mm, R20mm, R25mm) starting in the early period show significant changes towards drier climate while those starting in the recent period show non-significant drying changes, see Table 4-9. This drying pattern concurs with findings from Aguilar et al (2009).

In addition wet spells index shows temporally consistent decreases, though statistically non-significant over all periods: This trend pattern is consistent with Aguilar et al (2009) findings.

Trends, significance levels and confidence intervals in wet season onset, retreat and length indices are given in Table 4-9. Over the recent period, Macenta shows significant delayed onset (11.667 day/decade, significant at 1 %) and non-significant delayed retreat (2.536

day/decade, non-significant) leading to a non-significant (-11.439 day/decade; non-significant) shortened rainy season. Likewise, over the former period, significant delayed onset (4.580 day/decade, significant at 5 %) and significant early retreat (-3.341 day/decade, significant at 5 %) yield a significant shortened (-10.147 day/decade; significant at 1 %) wet season; similar patterns are seen over the period 1961-2010.

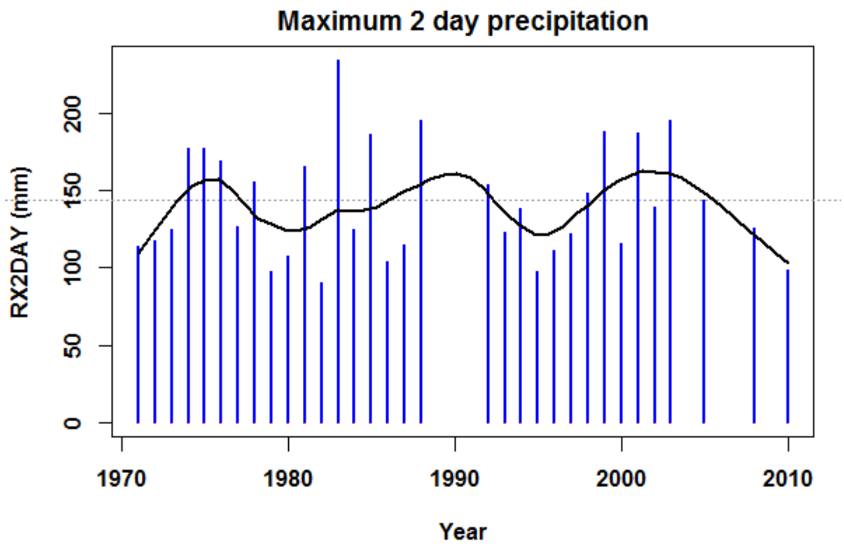


Figure 4-61: Same as in Figure 4-6 except for Macenta

4.9.8 Drought indices

Trends and significance levels in SPEI, SPI and CDD indices are shown in Table 4-9. Both SPI (-0.009 spi/decade; non-significant) and SPEI (-0.008 spei/decade; non-significant) indices show decreasing trends. Similar significant patterns are seen in these indices over the former period and non-significant over the period 1961-2010. Figure 4-62 shows SPEI monthly time series. Over 1971-2010, droughts have been very frequent in Macenta. Extreme droughts have been observed in 1978 and 1988; and severe droughts have been observed in 1980, 1983, 1986 and 1998. In addition dry spells shows non-significant changes towards dry weather over the former and recent periods; and significant drying trends over the period 1961-2010

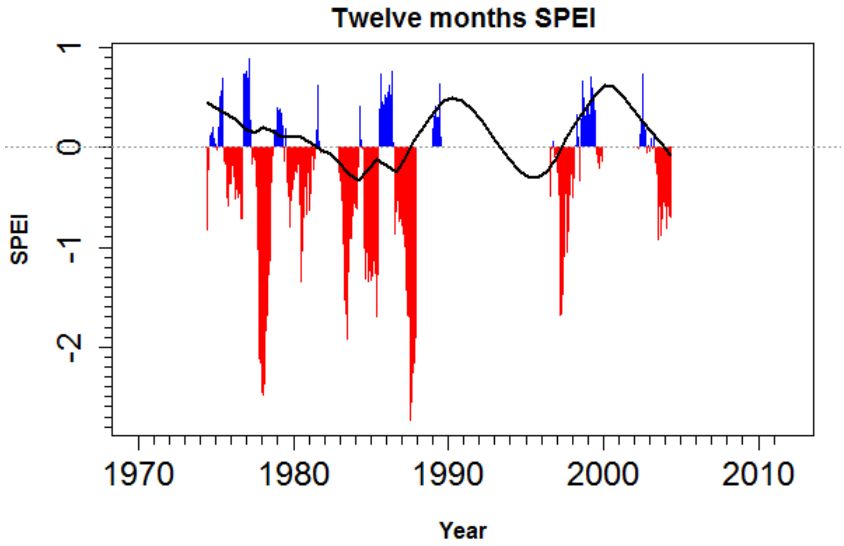


Figure 4-62: Same as in Figure 4-7 except for Macenta

4.10 MAMU

Mamu is located between latitudes 9° 52' 33" and 11° 18' 55" North and longitudes 11° 14'17 " and 12° 26' 4" West, at an altitude between 45 m and 1424 m. The prefecture of Mamu is bounded on the north by the prefectures of Dalaba and Tougue and to the east by the prefectures of Dabola, Dinguiraye and Faranah and south by the Republic of Sierra Leone and to the west by the province of Kindia. Mamu prefecture is located on the southern and south-eastern foothills of the Fouta Djallon and occupies a position of transition between Lower Guinea and continental part of the country. Its terrain is characterized by the alternation between highlands to the west and north-east, and depressions and lowlands to the south and north-central, crisscrossed by tributaries of major rivers like the Konkoure, Bafing and Kaba. Mamu covers an area of 9,108 km2 and in 2014 has a resident population of 318,738 inhabitants.

4.10.1 Climograph and Cumulative Precipitation

Throughout the year heavy fogs can be seen in the series of valleys and ridges in the area. Temperatures don't change much over the year. December and January and are usually the coolest months but there is no much difference from July, Augusts and September' temperatures when the temperature also drops bellow 22 degrees Celsius because of heavy cloud cover. Figure 4-63a shows Mamu climograph. Mamu belongs to Köppen monsoonal climate type. The average annual temperature is 22.9 ºC. The monthly range is as small as 4.7 ºC, whilst the diurnal range is much higher, it is 14.4 ºC on average and reaches 20 ºC in January when the northeastern harmattan blows. April is the hottest month with an average of 26 °C, while August is the coolest month with 21.3 °C. Mamu receives on average 1830.9 mm rainfall annually. The driest month is January with 4 mm, while the wettest month is August with 414 mm of rainfall on average. Figure 4-63b shows the cumulative precipitation. During 1971-2010, averaged cumulated precipitation is bellow 1941-1970 cumulative precipitation over Mamu territory. A deficit of 7.10 % is observed during the period 1971-2010.

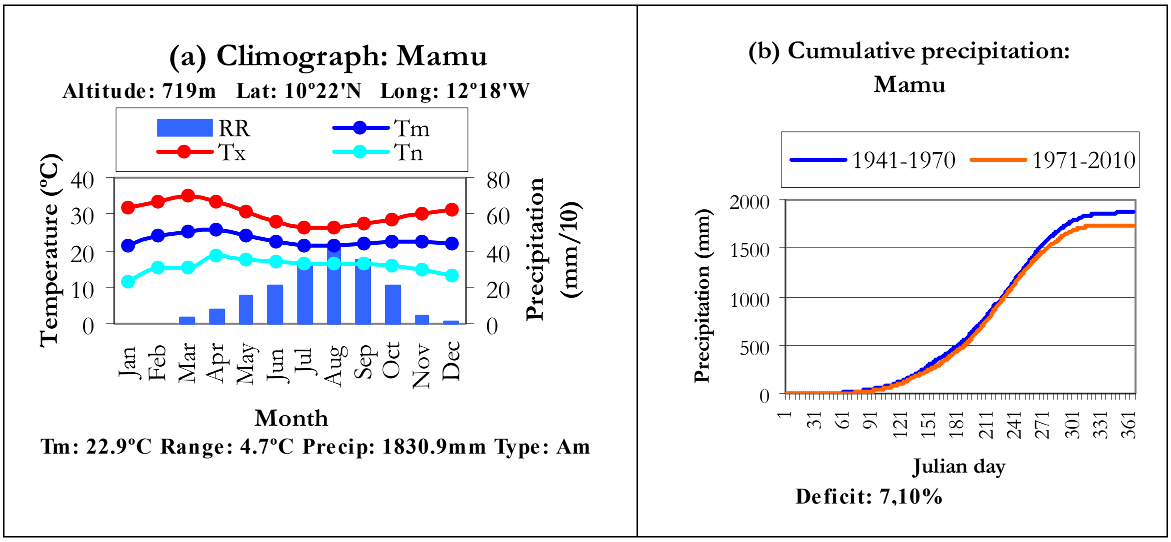


Figure 4-63: Same as in Figure 4-1 except for Mamu.

4.10.2 Annual results

Figure 4-64 shows anomalies of annual Tx mean (Figure 4-64a), annual Tn mean (Figure 4-64b) and annual total precipitation (Figure 4-64c). Trends, significance level and confidence intervals for these annual time series are also shown in Table 4-10. Annual temperature Tx mean (0.205 ºC/decade; significant at 1 %) and Tn mean (0.259 ºC/decade; significant at 1 %) suggest changes towards warming climate over the recent period. Similar patterns of warming are also seen over former and over the period 1961-2010. These patterns are in agreement with warming patterns found by Aguilar et al.

(2009) at regional level and at global level documented by Hartmann et al. (2013). Overall, since mid 1990s annual Tx mean and annual Tn mean tend to remain above 1971-2010 record average.

Annual total precipitation trend exhibits non-significant changes towards drier climate over the former and 1961-2010 periods and non-significant changes towards wetter climate over the recent period. Annual total precipitation pattern of trends over the recent period contradicts regional findings from Aguilar et al. (2009) but concur with those from Barry et al. (2014).

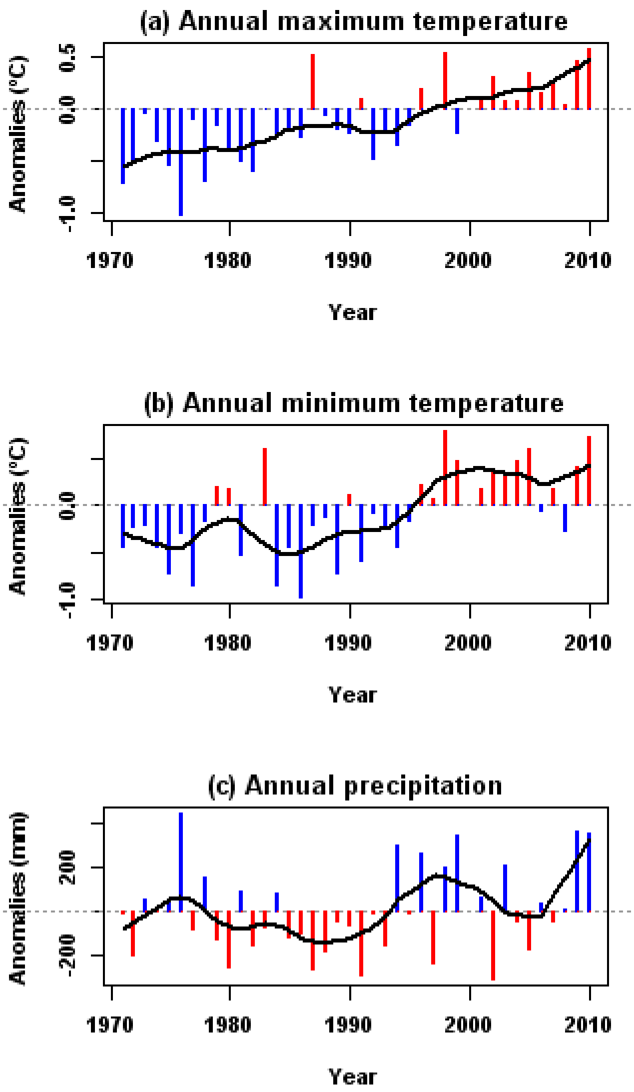


Figure 4-64: Same as in Figure 4-2 except for Mamu

Table 4-10: Decadal trends in annual, seasonal and climate indices for Mamu

Series/Indices	1941-2010	1961-2010	1971-2010
TxMean	**0.134|0.052:0.202**	**0.199|0.142:0.262**	**0.205|0.143:0.278**
TnMean	**0.136|0.051:0.21**	**0.226|0.117:0.35**	**0.259|0.141:0.404**
PRCPTOT	-40.889|-81.562:3.571	-15.684|-78.284:61.036	30.286|-30.906:86.042
Tx DJF	0.063|-0.019:0.139	*0.166|0.015:0.319*	**0.299|0.149:0.462**
Tx MAM	0.054|-0.039:0.148	*0.157|0.016:0.284*	*0.206|0.005:0.385*
Tx JJA	0.044|-0.009:0.1	0.089|0:0.176	**0.141|0.034:0.227**
Tx SON	**0.109|0.038:0.176**	**0.207|0.128:0.286**	**0.197|0.089:0.316**
Tn DJF	0.098|-0.034:0.24	*0.265|0.023:0.502*	*0.396|0.065:0.707*
Tn MAM	**0.123|0.059:0.19**	**0.213|0.115:0.316**	**0.228|0.062:0.337**
Tn JJA	**0.118|0.07:0.157**	**0.144|0.083:0.2**	**0.143|0.062:0.252**
Tn SON	0.012|-0.045:0.074	*0.107|0.012:0.186*	*0.141|0.006:0.25*
DRY	-9.008|-22.821:3.237	-7.395|-21:6.214	-4.519|-22.769:13.333
WET	-36.12|-65.508:5.659	-24.169|-88.941:40.197	12.467|-41.25:75.909
TN10P	*-1.401|-2.328:-0.297*	**-2.284|-3.997:-1.182**	**-2.736|-4.507:-1.513**
TN90P	**1.429|0.754:2.132**	**2.549|1.268:3.823**	**2.985|1.298:4.359**
TX10P	**-1.23|-2.099:-0.496**	**-1.667|-2.369:-1.058**	**-1.66|-2.587:-0.972**
TX90P	**1.242|0.458:2.099**	**2.656|1.806:3.91**	**3.095|2.11:4.271**
TNn	**0.318|0.116:0.509**	*0.514|0.126:0.876*	*0.554|0.12:1.064*
TNx	*0.101|0.006:0.194*	0.069|-0.071:0.242	0.000|-0.269:0.167
TXn	0.000|-0.107:0.102	0.036|-0.168:0.235	0.054|-0.178:0.3
TXx	*0.135|0.001:0.261*	**0.35|0.135:0.554**	**0.366|0.145:0.584**
DTR	-0.03|-0.112:0.069	-0.061|-0.145:0.05	-0.023|-0.1:0.104
SU25	**1.68|0.73:2.701**	**2.083|0.686:3.17**	1.3|-0.316:2.753
TR20	*0.583|0.045:1.178*	0.603|-0.184:1.799	0.27|-0.588:1.786
RX1day	-0.9|-3.419:1.857	-1.954|-5.241:1.571	-0.5|-3.938:4.333
RX5day	-1.192|-5.8:3	-3.877|-9.478:3.28	1.077|-8.036:8
SDII	0.000|-0.189:0.174	0.000|-0.303:0.3	0.182|-0.176:0.545
R10mm	*-1.485|-2.775:-0.203*	-1.429|-2.75:0	0.000|-1.786:1.667
R20mm	-0.763|-1.608:0.093	0.218|-1.611:1.969	1|-0.588:2.5
R25mm	-0.408|-1.087:0.299	0.191|-1.193:1.847	0.667|-0.667:2.083
R95p	-8.04|-31.594:13.778	-11.815|-55.254:27.589	3.036|-48.75:43.833
R95pTOT	0|-0.012:0.01	0.002|-0.029:0.025	0.008|-0.037:0.04
R99p	*-19.852|-36.879:-0.264*	*-33.188|-54.869:-0.658*	-24.139|-46.735:18.377
R99pTOT	-0.011|-0.028:0.01	-0.007|-0.037:0.028	0.01|-0.035:0.05
Onset	0.000|-2.5:2.791	2.183|-2:5.385	1.111|-4.4:5.714
Retreat	-1|-2.333:0.435	-1.087|-3.077:1.429	0.000|-3.214:2.381
Length	-1|-4.167:2.419	-3.445|-8.667:1.667	-1.875|-9.474:4.667
TX50P	**3.885|1.905:5.919**	**6.813|5.187:8.327**	**7.082|5.498:8.707**
CDDcold	**38.611|16.429:60.096**	**78.71|49.777:104.307**	**78.863|52.245:113.537**
WSDI2	*1.713|0.156:3.357*	**4.958|2.255:7.782**	**5.689|3.286:8.571**
CSDI2	*-3.078|-5.114:-0.983*	**-5.083|-8.45:-2.052**	**-5.842|-9.082:-3.556**
CTN90pct HWA	0.222|-0.208:0.5	0.218|-0.375:0.8	0.218|-0.375:0.8
CTN90pct HWF	0.000|-1.053:0	-0.656|-1.538:0	-0.656|-1.538:0
CTX90pct HWA	-0.175|-0.706:0.229	-1|-2.88:0	-1|-3.5:0
CTX90pct HWF	0.000|-0.465:0	0.000|-1.667:0	0.000|-2:0
RX2day	-1.844|-5.386:1.528	-3.222|-10.718:3.86	0.464|-8.382:8.432
CWD	-0.588|-1.477:0.105	*-1.053|-2.5:0*	-0.458|-1.746:0.596
CDD	*5.514|1.29:9.474*	0.312|-7.143:6.923	-1.538|-12.273:7.647
SPEI	-0.01|-0.023:0.002	-0.011|-0.028:0.005	0.006|-0.012:0.024
SPI	-0.009|-0.02:0.002	-0.009|-0.025:0.007	0.011|-0.006:0.027

4.10.3 Seasonal results

Table 4-10 shows calculated trends, significance level and confidence intervals in seasonal Tx and seasonal Tn for Mamu. Both Tx and Tn show significant patterns of warming in all seasons over the recent period. Thus, previously observed warnings in Tx mean and Tn mean are the result of a combined warming in all Tx and Tn seasons. Similar warming patterns are seen over the period 1961-2010 and over former period.

Wet season and dry season trends and confidence intervals are also indicated in Table 4-10. Patterns of trends in dry season precipitation suggest changes towards drier dry season for all periods while those in wet season precipitation suggest changes towards drier wet season over the former period and over the period 1961-2010; and non-significant wetter wet season for the recent period. As a result, the mixed trend patterns in wet season annual precipitation modulate better changes previously observed in annual total precipitation.

4.10.4 Percentile-based and other temperature indices

Figure 4-65 shows Mamu percentile-based temperature indices of TN10P (Figure 4-65a), TX10P (figure 4-65b), TN90P (Figure 4-65c) and TX90P (Figure 4-65d) and their respective significance level and confidence intervals are given in Table 4-10. Figures 4-65 suggests warming climate in all percentile-based temperatures indices.
There have been decreases in the frequency of cold nights (-2.736 %/decade; significant at 1 %) and in the frequency of cold days (-1.660 %/decade, significant at 1 %) over the recent period. Converting these trends into nights and days these correspond to a decrease of 10 cold nights per decade and a decrease of 6.1 cold days per decade.
There have also been significant increases in the frequency of warm nights (2.985 %/decade; significant at 1 %) and in the frequency of warm days (3.095 %/decade; significant at 1 %) over the recent period. Converting these trends into nights and days these correspond to an increase of 10.9 warm nights and an increase of 11.3 warm days per decade. Furthermore Tx50P index shows consistent patterns of warming. Patterns of trend (7.082 %/decade; significant at 1 %) over the recent period correspond to an increase of 25.8 day above average temperature per decade.

These results are consistent with warming patterns observed at global level as documented by Hartmann et al. (2013) and at regional level from Aguilar et al. (2009) study.

Warming trends are also visible in the frequency of tropical nights and the frequency of summer days although statistically non-significant over the recent period.

The patterns of trends of general climate indices are similar to those of these percentile indices and suggest warming climate as well.

Decreasing cold spells (-5.842 day/decade; significant at 1 %) and increasing warm spells (5.689 day/decade; significant at 1 %) over the recent period also suggest changes towards warming climate (Table 4-10). Similarly cooling need index exhibits significant patterns of warming climate over all periods.

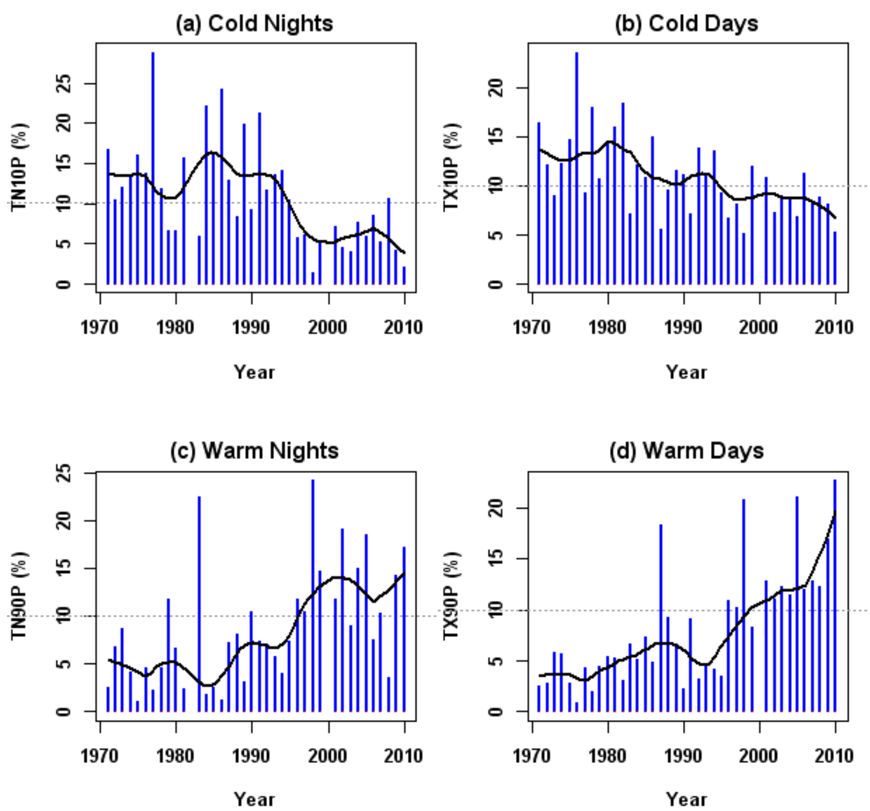


Figure 4-65: Same as in Figure 4-3except for Mamu

4.10.5 Precipitation intensity index

Figure 4-66 shows SDII annual time series. SDII exhibits non-significant increasing trend (0.182 mm/day/decade; non-significant) over the recent period. Mamu SDII is characterized by very low inter-annual variability and oscillates around 14 mm/day the 1981-2010 average. Trends patterns of SDII index over the recent period contrast regional results from Aguilar et al. (2009). It worth noting that SDII has switched from quasi stationary trend to trend towards wetter climate from former period to recent one.

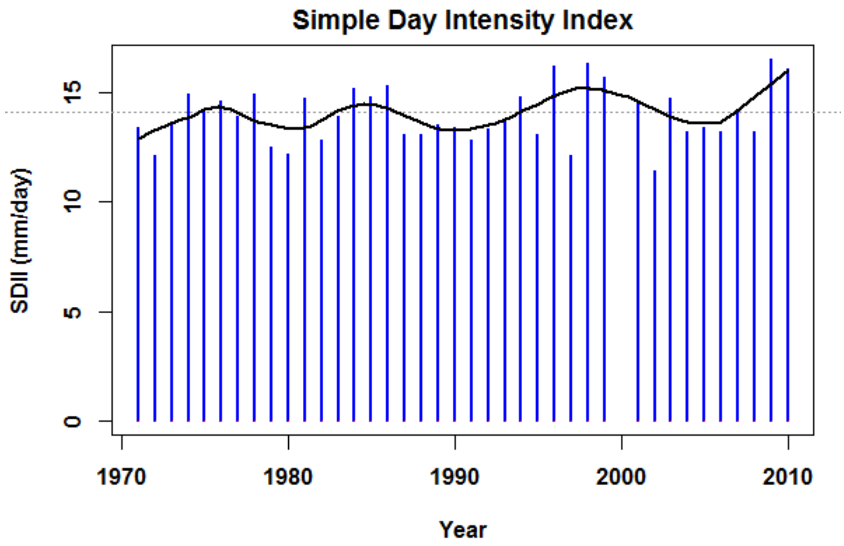


Figure 4-66: Same as in Figure 4-4 except for Mamu

4.10.6 Precipitation percentile indices

Trends and confidence intervals in very and extremely wet days (R95P and R99P) and their respective contribution to annual precipitation (R95pTOT and R99pTOT) are shows in Table 4-10. Over the recent period very wet days and their contribution exhibit non-significant increase. Contrariwise extremely wet days index shows non-significant decreasing trend. Sign changes from former to recent period have been seen in R95P, R99P and R99pTOT indices. Figure 4-67 suggests that R95P index initiated a relatively sharp upward trend in early 1990s. Trend in R95P over the recent period concurs with WA results (28.1 mm/decade) from Barry et al. (2014) but contradicts those from Aguilar et al. (2009).

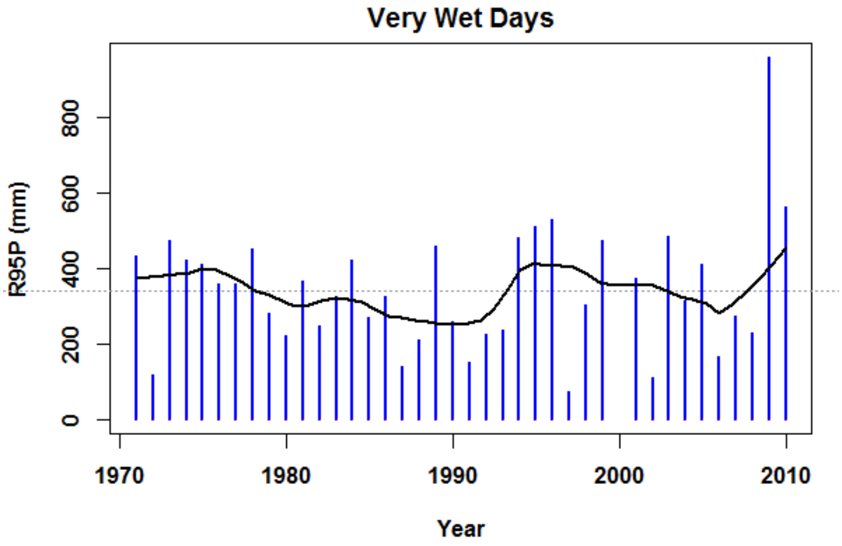


Figure 4-67: Same as in Figure 4-5 except for Mamu

4.10.7 Absolute and other precipitation indices

Table 4-10 shows trends, significance level and confidence intervals in absolute precipitation indices Rx1day, Rx2day and Rx5day. Trends patterns in Rx2day and Rx5day indices sustain changes towards wetter conditions while Rx1day consistently suggests changes towards drier climate over the recent period. Non-significant decreasing trends in these indices are seen over former period and over the period 1961-2010. Figure 4-68 illustrates the annual time series for Rx2day index.

Overall wet spells exhibit changes towards drier weather, in disagreement with findings from Barry et al. (2014) but concurs Aguilar et al. (2009) results.

Very heavy and extremely heavy precipitation days suggest non-significant changes towards wet weather while heavy precipitation day shows quasi stationary trends over the recent period. R20mm and R25 trend patterns contrast with Aguilar et al. (2009) but are in agreement with findings documented by Barry et al. (2014). Over the former period both precipitation days show non-significant drying trends.

Trends, significance levels and confidence intervals in wet season onset, retreat and length indices are given in Table 4-10. Non-significant delayed onset and quasi stationary retreat dates yield non-significant shortened wet season length in Mamu over the recent period. Similarly the former period shows quasi stationary onset dates and non-significant early retreat trend leading to a non-significant shortened season. Identical trend patterns are seen over the period 1961-2010 with non-significant delayed onset.

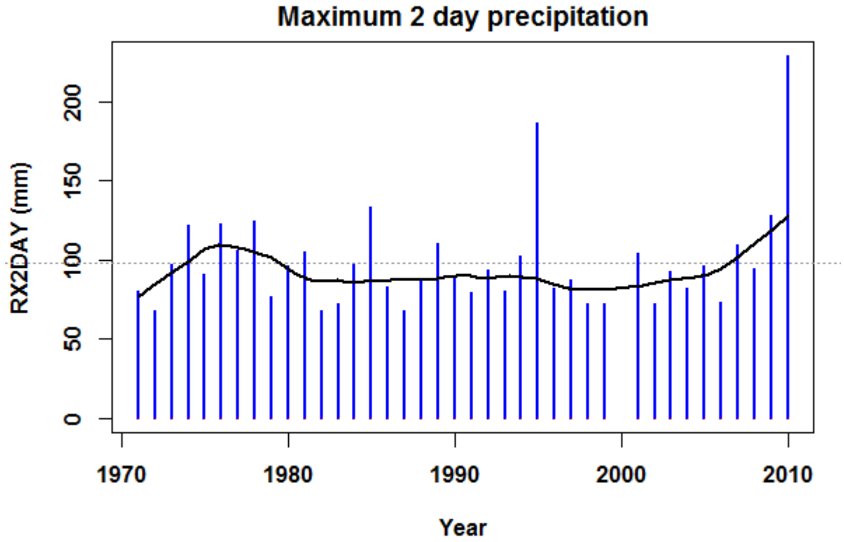


Figure 4-68: Same as in Figure 4-6 except for Mamu

4.10.8 Drought indices

Trends, significance levels and confidence intervals in drought indices SPEI, SPI and CDD are given in Table 4-10. Trends in SPI and SPEI indices suggest changes towards wetter climate over the recent period and changes towards drier climate over former period and over the period 1961-2010 though both trends are statistically non-significant.
Dry spells exhibits significant increasing trend over the former period and non-significant increasing trend over the period 1961-2010 and non-significant decreasing trend over the recent period. Trend over the recent period is in disagreement with regional results from Aguilar et al. (2009) and also contrasts findings by Dai et al. (2013) and Sheffield et al. (2012) where high confidence in increases in CDD has been reported (Hartmann et al., 2013).
Over all periods Tn related heat waves amplitude shows non-significant increasing trends. Likewise over all periods Tx related heat waves amplitude shows non-significant decreasing trends.
Figure 4-69 shows SPEI monthly time series anomalies. Over the recent period, droughts are very common in Mamu. Severe drought occurred in 1980, in 1987, in 1992, in 1998, and in 2002. SPI and SPEI show similar non-significant wetting trends over the recent

period and non-significant decreasing trends over the former period and over the period 1961-2010.

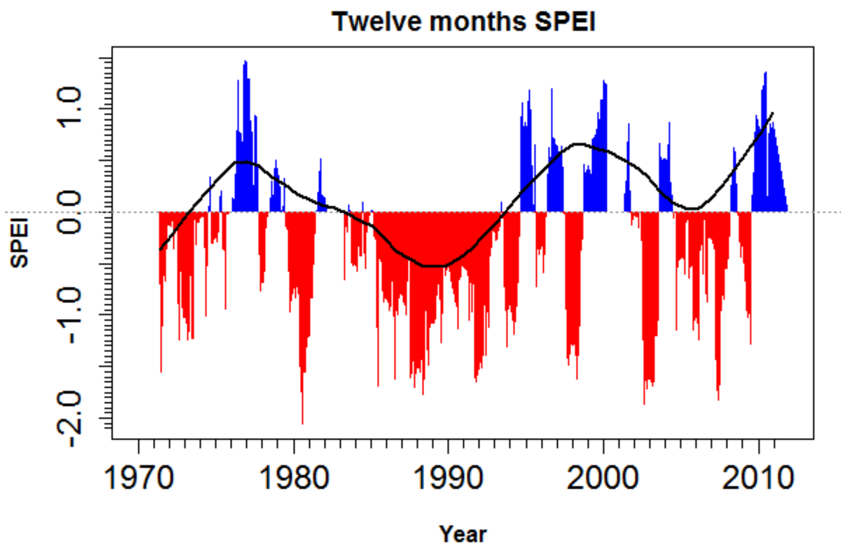


Figure 4-69: Same as in Figure 4-7 except for Macenta

4.11 N'ZEREKORE

N'Zerekore is located between latitudes 7° 33' 30'' and 9° 0' 29'' North and longitudes 8° 27' 27'' and 11° 28' 51'' West. High hills, uplands and plains are found at an altitude between 450 m and 1000 m on the northern N'Zerekore. The river system is very dense and regular over the year in N'Zerekore. The prefecture is bounded on the north by Beyla prefecture, on the west by that of Macenta and Yomou, south by Yomou and the Republic of Côte d'Ivoire and east by Lola prefecture. N'Zerekore covers an area of 3,632 km2 and in 2014 has a resident population of 396,118 inhabitants.

4.11.1 Climograph and Cumulative Precipitation

In N'Zerekore the mean annual temperature is 25.1 °C. The seasonal curve of temperature has two peaks. The first one is 26.8 °C in March when the wet season is about to start and the second one is 25.8 °C in November when the wet season is about to end. Figure 4-70a shows N'Zerekore climograph. The climate of N'Zerekore belongs to Köppen monsoonal climate type. The range of average monthly temperatures is very low (3.1ºC), and the daily temperature range is low as well, it is estimated to be 9 ºC on average. March is the hottest month with 26.8 ºC on average, while December is the coolest month with 23.7 ºC. N'Zerekore is received 1868.3 mm rainfall per year on average. The driest month is January with 14.6 mm rainfall, and the wettest is September when 318.9 mm of rain falls. Figure 4-70b shows the cumulative precipitation; this figure suggests that the two periods are similar though 1941-1970 is 2.68 % wetter.

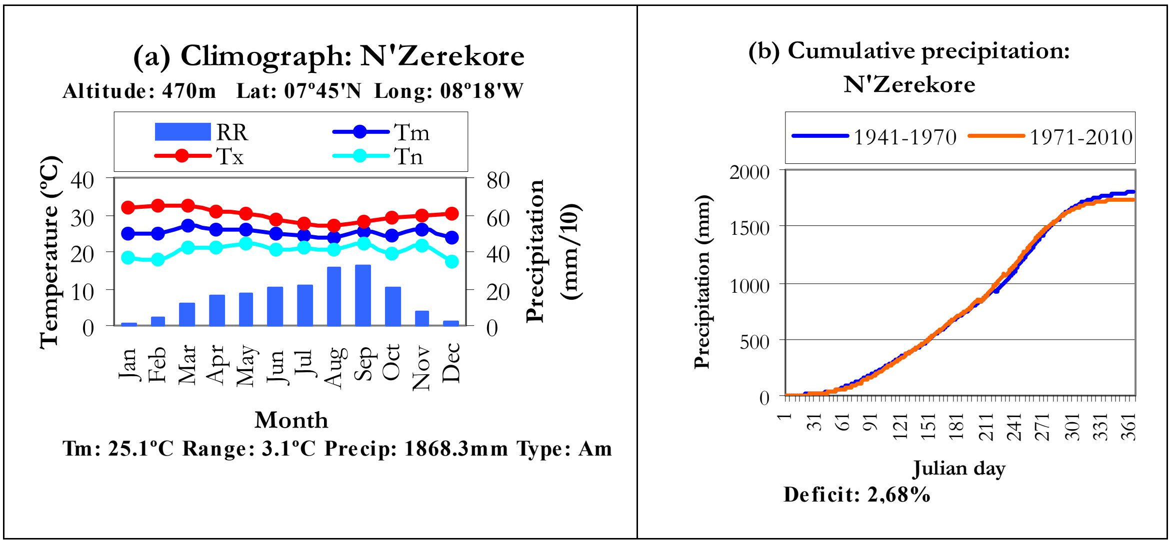


Figure 4-70: Same as in Figure 4-1 except for N'Zerekore.

4.11.2 Annual results

Figure 4-71 shows anomalies of annual Tx mean (Figure 4-71a), annual Tn mean (Figure 4-71b) and annual total precipitation (Figure 4-71c). Trends, significance level and confidence intervals for these annual time series are given in Table 4-11. Figures 4-71a and 4-71b suggest warming patterns for both annual mean of Tx (0.192 ºC/decade; significant at 1 %) and the annual mean of Tn (0.313 ºC/decade; significant at 1 %) over the recent period. Trends patterns observed during the 1961-2010 period are also consistent with warming climate. These patterns concur with those observed at global level as documented in AR5 (Hartmann et al., 2013) and those observed at regional level from Aguilar et al. (2009) though the periods are slightly different. Overall, since mid 1990s Tx mean and Tn mean tend to remain above 1981-2010 average.

Unlike trends patterns for Tx mean and Tn mean, changes in annual total precipitation show non-significant trends towards drier conditions over the former period and the period 1961-2010 and a non-significant trend (24.674 mm/decade; non-significant) towards wetter climate over the recent period. Drying trends are consistent at regional and global level with findings from Aguilar et al. (2009) and Hartmann et al. (20013) respectively.

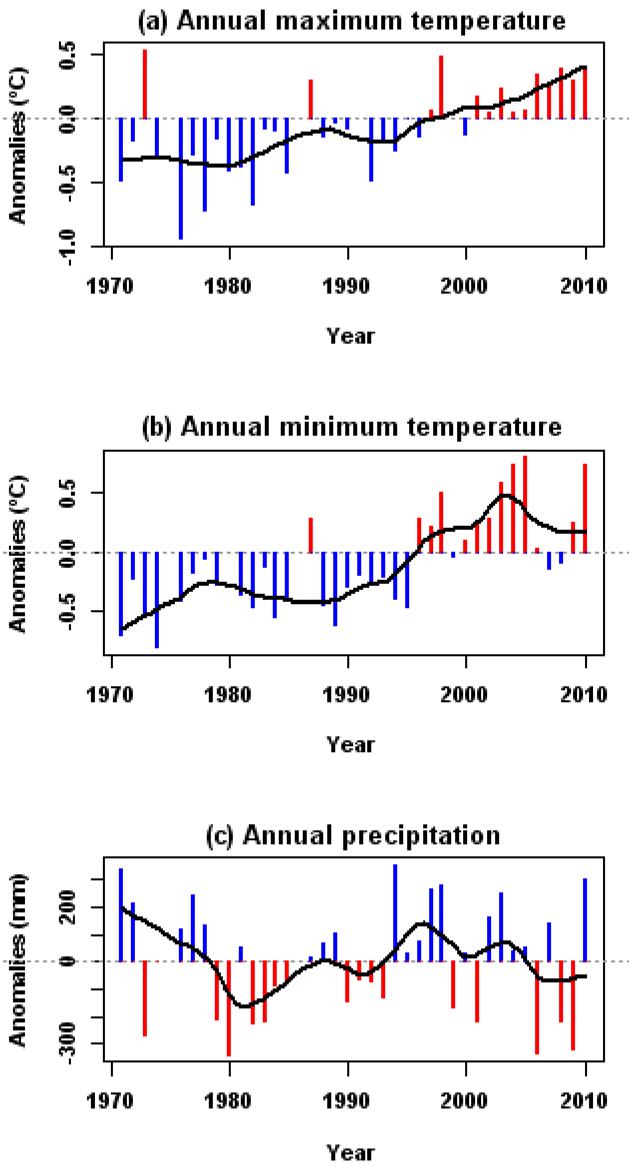


Figure 4-71: Same as in Figure 4-2 except for N'Zerekore

Table 4-11: Decadal trends in annual, seasonal and climate indices for N'Zerekore

Series/Indices	1941-2010	1961-2010	1971-2010
TxMean	NA	**0.186|0.109:0.261**	**0.192|0.127:0.287**
TnMean	NA	**0.259|0.135:0.356**	**0.313|0.135:0.453**
PRCPTOT	-14.176|-44.7:16.703	-17.616|-66.636:33.682	24.674|-55.963:109.145
Tx DJF	NA	*0.147|0.03:0.253*	**0.259|0.138:0.405**
Tx MAM	NA	*0.11|0.008:0.215*	**0.17|0.045:0.282**
Tx JJA	NA	**0.172|0.074:0.242**	**0.211|0.051:0.304**
Tx SON	NA	**0.237|0.115:0.301**	**0.22|0.081:0.301**
Tn DJF	NA	*0.337|0.027:0.615*	**0.547|0.168:0.905**
Tn MAM	NA	**0.303|0.202:0.383**	**0.296|0.151:0.405**
Tn JJA	NA	**0.143|0.095:0.193**	**0.136|0.073:0.205**
Tn SON	NA	*0.078|0.003:0.165*	0.077|-0.078:0.193
DRY	-11.197|-24.894:3.412	-10.75|-31.846:8.364	2.739|-29:27.556
WET	1.456|-24.328:26	0.358|-31.9:39.875	4.214|-36.818:59.862
TN10P	NA	**-3.072|-4.124:-1.985**	**-3.144|-4.287:-1.682**
TN90P	NA	**2.866|1.298:4.469**	**3.382|1.14:5.657**
TX10P	NA	**-1.98|-2.945:-0.708**	**-1.665|-2.852:-0.623**
TX90P	NA	**2.222|1.1:3.572**	**3.219|1.668:4.473**
TNn	NA	**0.505|0.164:0.925**	*0.546|0.03:1.215*
TNx	NA	**0.228|0.064:0.401**	0.124|-0.076:0.363
TXn	NA	0.062|-0.261:0.375	0.041|-0.406:0.457
TXx	NA	0.000|-0.25:0.2	0.06|-0.227:0.308
DTR	NA	-0.101|-0.247:0.046	-0.109|-0.323:0.07
SU25	NA	0.205|-0.707:1.14	0.135|-0.606:1.429
TR20	NA	**17.314|10.334:22.989**	**19.14|10.428:27.719**
RX1day	-0.039|-1.833:2.519	-1.692|-5.278:2.364	-4.361|-9.118:0.222
RX5day	-1.372|-5.655:2.5	-4.85|-13.014:3.956	-6.125|-16.585:5.453
SDII	-0.131|-0.396:0.072	0.000|-0.25:0.188	-0.122|-0.575:0.166
R10mm	-0.556|-1.667:0.385	-0.923|-2.667:0.556	0.000|-2.174:2
R20mm	-0.182|-0.952:0.385	0.000|-1.429:0.714	0.263|-1.111:2
R25mm	0|-0.625:0.5	0.000|-0.833:1.111	0.303|-0.769:1.739
R95p	-4.857|-23.463:14.923	-6.319|-38.426:30.98	-15.276|-60.102:27.532
R95pTOT	-0.002|-0.01:0.009	-0.003|-0.016:0.016	-0.002|-0.021:0.025
R99p	0|-12.667:6.375	-2.407|-31.353:6.438	*-31.617|-59.042:-4.271*
R99pTOT	0.003|-0.001:0.009	0.003|-0.009:0.015	0.003|-0.01:0.017
Onset	-1.111|-5.333:2.857	-1.51|-9.167:5.238	2.061|-7.5:10
Retreat	0.417|-1.463:2.292	0.000|-3.333:4	2.591|-1.456:6.933
Length	2.632|-2.5:7.059	3.548|-4.583:11.667	2.5|-5.909:13.929
TX50P	NA	**6.717|4.43:9.112**	**7.303|5.153:9.811**
CDDcold	NA	**74.936|50.35:99.976**	**87.457|50.936:120.542**
WSDI2	NA	**3.638|1.15:6.003**	**4.936|2.93:7.674**
CSDI2	NA	**-8.534|-10.618:-5.909**	**-7.735|-10.491:-4.901**
CTN90pct HWA	NA	0.729|-3.019:2.546	0.727|-3.005:2.512
CTN90pct HWF	NA	0.172|0:1.818	0.4|0:2.143
CTX90pct HWA	NA	0.087|-0.364:0.588	0.214|-0.364:0.917
CTX90pct HWF	NA	0.000|-1.481:0	0.000|-3.182:0
RX2day	-1.4|-4.789:1.182	-4.977|-9.757:0.45	-6.566|-13.76:1.561
CWD	0.366|-0.062:0.824	0.194|-0.722:1.114	0.709|-0.512:1.894
CDD	**3.732|1.106:6.524**	3.178|-1.822:8.11	3.116|-4.347:9.227
SPEI	NA	-0.002|-0.023:0.019	0.006|-0.02:0.031
SPI	-0.004|-0.015:0.007	-0.005|-0.022:0.012	0.000|-0.021:0.02

4.11.3 Seasonal results

Trends in seasonal Tx and Tn are shown in Table 4-11. Both seasonal Tx and Tn show significant warming patterns in all seasons, except Tn SON. As a result, previously observed warming in Tx mean and Tn mean are due to all season warming.

Wet season shows consistent changes towards wetter climate over all periods though statistically non-significant while dry season trends switch from drying conditions over the former period and over the period 1961-2010 to wetting conditions over the recent period. Consequently previously observed increases in annual total precipitation over the recent period are due to increases in both wet and dry seasons.

4.11.4 Percentile-based and other temperature indices

Figure 4-72 shows N'Zerekore percentile-based temperature indices of TN10P (Figure 4-72a), TX10P (figure 4-72b), TN90P (Figure 4-72c) and TX90P (Figure 4-72d) and their respective trends, significance level and confidence intervals are given in Table 4-11. Figure 4-72 suggests warming climate for percentile-based temperatures indices. Over the recent period, it has been observed significant decreases in the frequency of cold nights (-3.144 %/decade; significant at 1 %) and in the frequency of cold days (-1.665 %/decade; significant at 1 %). Converting these trends into days and nights these correspond to a decrease of 11.5 cold nights per decade and a decrease of 6.1 cold days per decade. Likewise, it has been observed significant increases in the frequency of warm nights (3.382 %/decade; significant at 1 %) and significant increases in the frequency of warm days (3.219 %/decade; significant at 1 %). Converting these trends into days and nights these correspond to an increase of 12.3 warm nights per decade and an increase of 11.7 warm days per decade. Consequently, Tx50P index also exhibits warming trend (7.303 %/decade; significant at 1 %) corresponding to an increase of 26.7 day above average temperature per decade over the recent period. Identical warming patterns are seen over the period 1961-2010 in percentile based temperature indices.

These results are consistent with warming climate and concur with trends observed at global level as documented by Hartmann et al. (2013) and at regional level from Aguilar et al (2009).

Tropical nights (19.140 day/decade; significant at 1 %) and summer days (0.135 day/decade, non-significant) suggest changes towards warming climate over the recent period. Similar trend patterns are seen over the period 1961-2010. Likewise, trend patterns in general climate indices are consistent with warming climate though none of them is statistically significant. This warming signal concurs with trend patterns in WSDI (4.936 day/decade; significant at 1 %) and in CSDI (-7.735 day/decade; significant at 1 %) observed over the recent period. Identical trends pattern are observed in these indices over the period 1961-2010.

Finally, CDDcold exhibits significant increases expressing the growing needs for cooling over the period 1961-2010 and over the recent period.

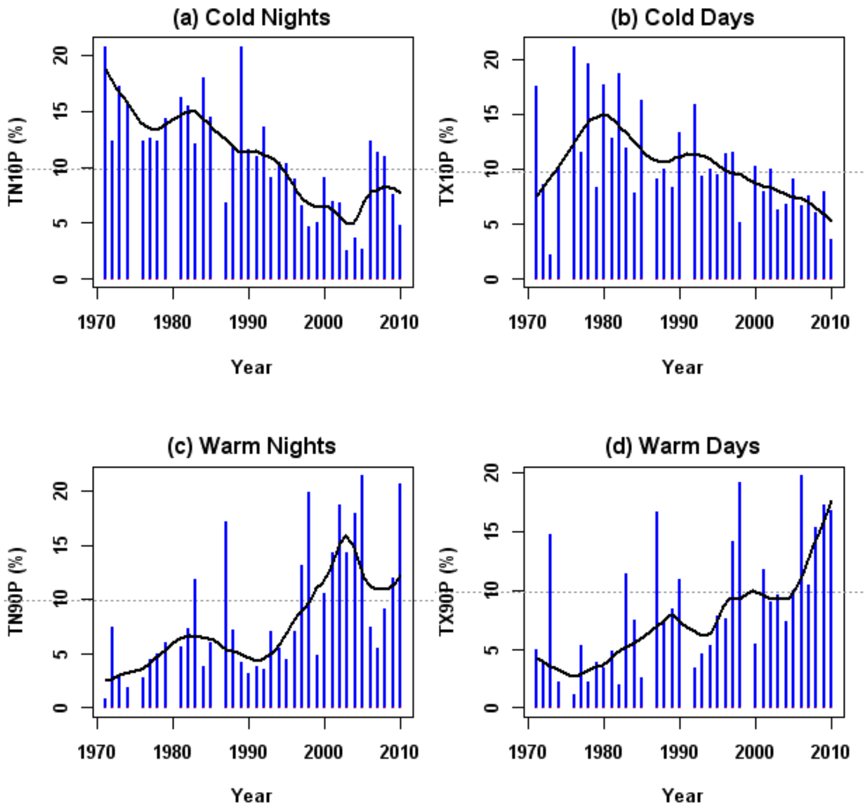


Figure 4-72: Same as in Figure 4-3 except for N'Zerekore

4.11.5 Precipitation intensity index

Figure 4-73 illustrates changes in SDII annual time series. Trend, significance level and the confidence intervals for this index are given in Table 4-11. Over the recent period SDII index shows non-significant changes (-0.122 mm/day/decade; non-significant) towards less daily intensity. Similarly non-significant drying patterns are seen over the former period. Trend patterns of SDII are consistent with regional results from Aguilar et al. (2009) and contradict WA results from Barry et al. (2014).

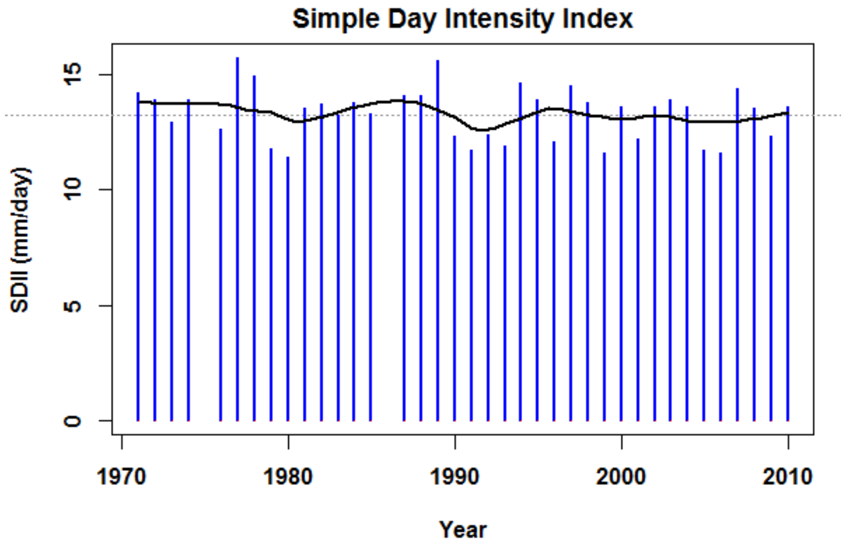


Figure 4-73: Same as in Figure 4-4 except for N'Zerekore

4.11.6 Precipitation percentile indices

Trends and confidence intervals in R95P and R99P and their respective proportion R95pTOT and R99pTOT are given in Table 4-11. Figure 4-74 shows R95P annual time series. Over all periods R95P and R95pTOT show non-significant changes towards drier conditions. Similarly R99pTOT exhibit non-significant trends towards wetter conditions over all periods. Contrariwise, R99P index exhibits changes from quasi stationary trend from the former period to a significant decreases of extremely wet day precipitation over the recent period. These results suggest a tendency towards less frequent very and extremely heavy precipitation day.

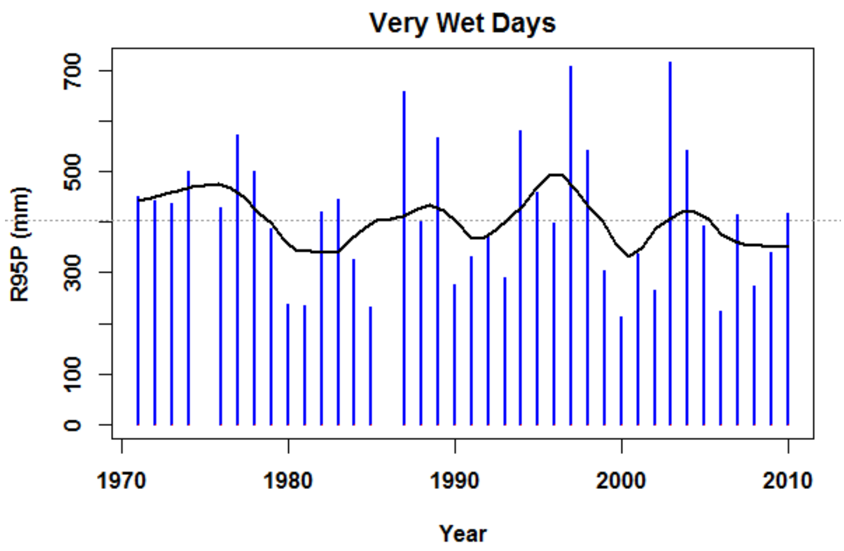


Figure 4-74: Same as in Figure 4-5 except for N'Zerekore

4.11.7 Absolute and other precipitation indices

Table 4-11 shows trends, confidence intervals and significance level for Rx1day, Rx2day and Rx5day indices. Figure 4-75 illustrates Rx2day index annual time series anomalies. Over all periods, both indices show similar non-significant drying trend patterns. Contrariwise, heavy (R10mm), very heavy (R20mm) and extremely heavy events (R25mm) show non-significant trends including a sign change and unclear trends patterns. However, wet spells exhibits non-significant increasing trend over all periods.

The patterns of these absolute trends concur with regional results from Aguilar et al. (2009) and those at global level as documented by Hartmann et al. (2013). Contrariwise, trends in heavy and very heavy precipitation days contrast with those from Aguilar et al. (2009) findings.

Trends, significance levels and confidence intervals in wet season onset, retreat and length indices are given in Table 4-11. Over the recent period, N'Zerekore shows non-significant delayed onset and retreat leading to a non-significant lengthened wet season. Early onset leading to longer wet season are seen over the former period and over the period 1961-2010, but trends are non-significant.

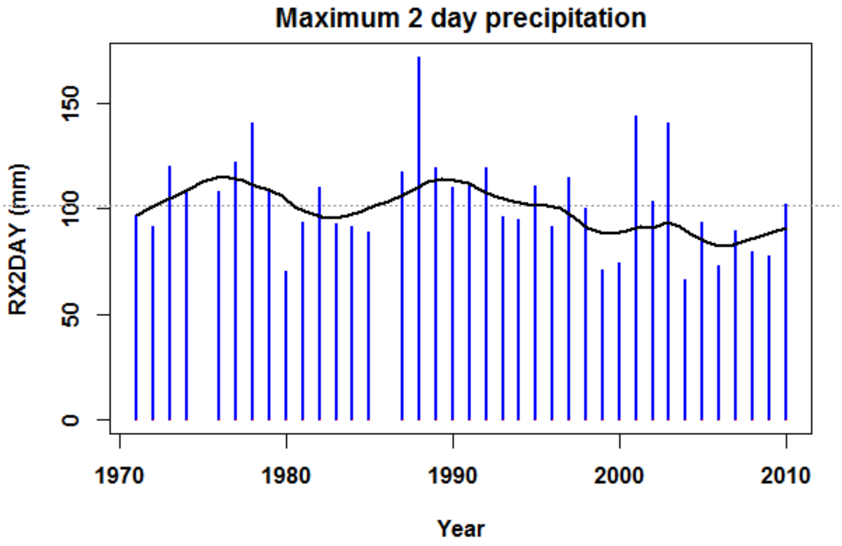


Figure 4-75: Same as in Figure 4-6 except for N'Zerekore

4.11.8 Drought indices

Trends and significance levels in SPEI, SPI and CDD indices are shown in Table 4-11. SPEI shows non-significant increasing trend over the recent period while SPI index exhibits quasi stationary trend. Figure 4-76 shows SPEI monthly time series for N'Zerekore. Over the recent period the major droughts are those observed in 1971, in 1975, in 1983 and 2007. Additionally, longer lasting but less severe droughts are also observed in 1983 and 2008. In accordance with this relatively frequent drought, dry spells index shows non-significant increase trend over the recent period and over the period 1961-2010. Similar significant patterns are seen over the former period.

Heat waves indices suggest warming trends. This warming pattern is supported by the increases of the frequency (0.400 day/decade; non-significant) and the amplitude (0.727 ºC/decade; non-significant) of Tn related drought and the increases of the amplitude (0.214 ºC/decade; non-significant) of Tx related drought.

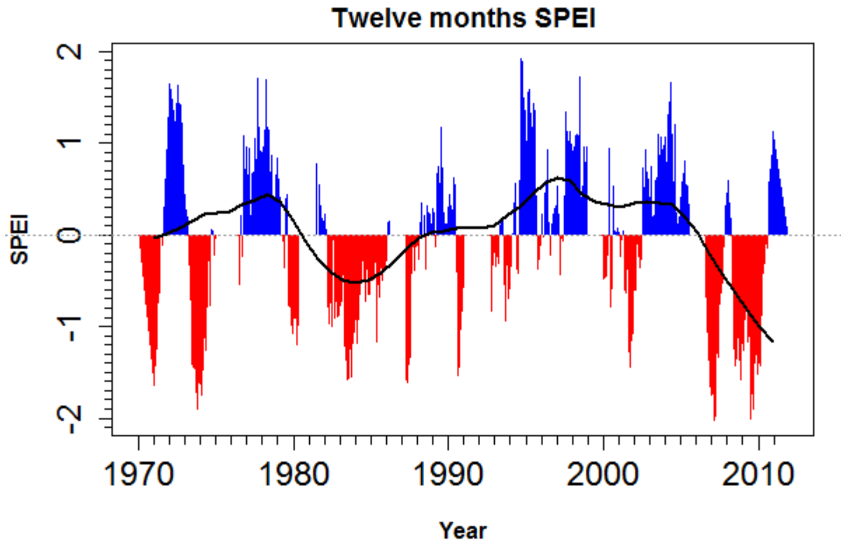


Figure 4-76: Same as in Figure 4-7 except for N'Zerekore

4.12 SIGUIRI

Siguiri is located between latitudes 10° 51' 3'' and 12° 30' 9''North and longitudes 8° 40' 56'' and 10° 10' 8'' West. Siguiri is characterized by an almost flat topography. The river system is very irregular over the year. Siguiri is bounded on the north by the Republic of Mali, on the west by the prefecture of Dinguiraye and Kouroussa, south by Kouroussa, Kankan and Mandiana and east by Mandiana prefecture and the Republic of Mali. Siguiri covers an area of 18,500 km2 and in 2014 has a resident population of 695,449 inhabitants.

4.12.1 Climograph and Cumulative Precipitation

Sahelian part of Upper Guinea, Siguiri is one of the hottest sites in Guinea. In Siguiri, the monthly average temperature is 25.6 °C. According to Köppen climate classification, Siguiri belongs to savanna climate type with a pronounced dry season that lasts six months from November to April and a six months wet season that goes from May to October. Figure 4-77a shows Siguiri climograph. In Siguiri the range of monthly mean temperatures is 8.1 ºC, while the daily temperature range is 16.3 ºC with a peak of 22.6 ºC in January when the dry desert wind, also known as harmattan, blows from the northeast lowering the humidity and causing hot days and cool nights. The hottest month in Siguiri is April when the mean value is as high as 29.7 ºC; while the relatively coolest month is January with mean temperature of 21.6 ºC of mean. Siguiri receives 1250 mm rainfall per year on average. The driest month is January with 0.4 mm and August is the wettest with 335 mm of rain. Figure 4-77b shows the cumulative precipitation. The average cumulative rainfall for 1941-1970 over Siguiri is 13.60 % above that of the period 1971-2010.

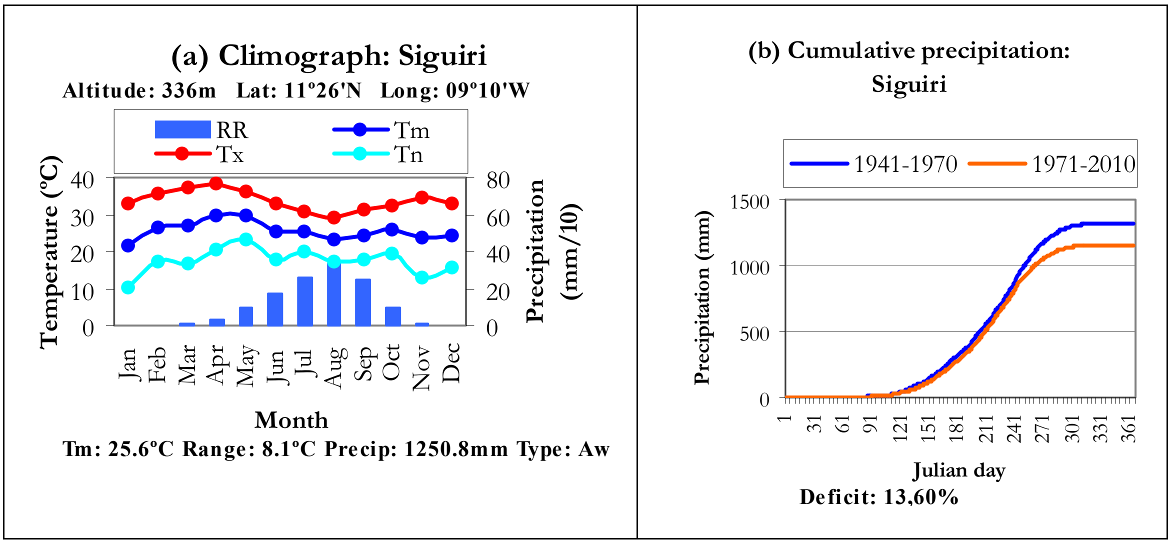


Figure 4-77: Same as in Figure 4-1 except for Siguiri.

4.12.2 Annual results

Figure 4-78 shows anomalies of annual Tx mean (Figure 4-78a), annual Tn mean (Figure 4-78b) and annual total precipitation (Figure 4-78c). Trends, significance level and confidence intervals for these annual time series are indicated in Table 4-12.

Trends in Tx mean (0.132 ºC/decade, non-significant) and in Tn mean (0.265 ºC/decade, significant at 1 %) suggest warming climate in Siguiri over the recent period. Identical trends are seen over the period 1961-2010. These trends are consistent with observed trend in the global mean temperature as documented by AR5 (Hartmann et al., 2013). These warming patterns concur with those found for WA by Barry et al. (2014) and Aguilar et al. (2009) at regional level.

Annual total precipitation trend shows significant changes towards drier conditions over the former period and over the period 1961-2010 but this trend becomes muted in the recent period. These drying patterns concur with results from Aguilar et al. (2009) at regional level and those from Becker et al. (2013) for 30ºS-30ºN latitudinal band (Hartmann et al., 2013) but contrast with findings for WA from Barry et al. (2014).

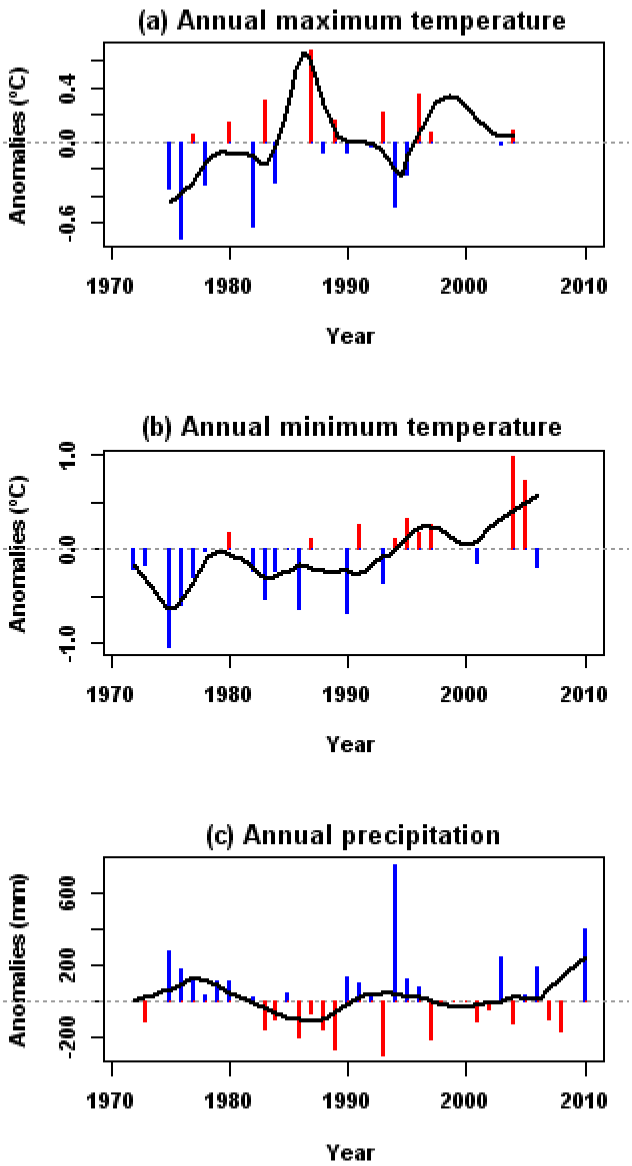


Figure 4-78: Same as in Figure 4-2 except for Siguiri

Table 4-12: Decadal trends in annual, seasonal and climate indices for Siguiri

Series/Indices	1941-2010	1961-2010	1971-2010
TxMean	-0.045|-0.111:0.039	0.08|-0.025:0.186	0.132|-0.06:0.311
TnMean	0.097|-0.011:0.191	**0.208|0.114:0.309**	**0.265|0.118:0.417**
PRCPTOT	**-43.014|-67.794:-13.095**	**-57.502|-94.455:-17.958**	-16.059|-69.967:43.944
Tx DJF	-0.062|-0.193:0.066	-0.102|-0.356:0.144	-0.018|-0.412:0.399
Tx MAM	-0.025|-0.123:0.064	0.058|-0.104:0.217	0.091|-0.186:0.347
Tx JJA	0.04|-0.058:0.131	*0.153|0.026:0.308*	*0.218|0.028:0.473*
Tx SON	0.064|-0.04:0.176	**0.267|0.098:0.403**	0.1|-0.089:0.3
Tn DJF	*0.16|0.021:0.268*	**0.334|0.132:0.533**	*0.348|0.042:0.634*
Tn MAM	**0.14|0.043:0.245**	**0.276|0.095:0.427**	0.188|-0.048:0.458
Tn JJA	**0.111|0.052:0.16**	**0.138|0.064:0.215**	**0.159|0.028:0.277**
Tn SON	0.006|-0.06:0.07	*0.113|0.027:0.222*	**0.225|0.067:0.441**
DRY	*-4.501|-7.934:-0.072*	-5|-10.056:1.667	-1.429|-9.455:6.5
WET	**-34.745|-59.681:-10.669**	*-46.363|-81.8:-6.353*	-27.429|-78.273:26.8
TN10P	NA	NA	NA
TN90P	NA	NA	NA
TX10P	NA	NA	NA
TX90P	NA	NA	NA
TNn	*0.299|0.018:0.549*	0.171|-0.206:0.542	0.138|-0.5:0.769
TNx	**0.259|0.118:0.401**	**0.435|0.116:0.709**	0.384|-0.009:0.799
TXn	0.000|-0.125:0.114	-0.098|-0.294:0.125	-0.232|-0.722:0.211
TXx	0.017|-0.103:0.172	-0.046|-0.333:0.192	-0.2|-0.5:0.25
DTR	-0.084|-0.246:0.057	-0.155|-0.318:0.004	-0.202|-0.54:0.141
SU25	0.000|-0.556:0	-0.426|-1.111:0	0.000|-1.579:1.25
TR20	**4.707|1.786:7.115**	**9.581|4.663:13.125**	**13.613|6.551:18.343**
RX1day	**-3.841|-6.405:-1.114**	**-6.373|-11.213:-2.182**	-5.993|-13.58:1.948
RX5day	**-5.949|-10.137:-1.822**	*-8.525|-15.452:-1.842*	-4.916|-17.111:4.793
SDII	0.077|-0.132:0.324	0.000|-0.333:0.4	0.166|-0.346:0.75
R10mm	-0.515|-1.376:0.409	-1.011|-2.249:0.438	0.476|-0.909:2.222
R20mm	-0.65|-1.376:0.019	-0.769|-1.86:0	0.000|-1.562:1.429
R25mm	-0.289|-1.032:0.372	-0.37|-1.429:0.333	0.000|-1.111:1.333
R95p	*-21.111|-38.276:-3*	-31.09|-57.84:1.583	-11.731|-54.778:42
R95pTOT	-0.006|-0.019:0.009	0.002|-0.022:0.03	0.002|-0.04:0.063
R99p	-6.598|-20.263:0	-19.663|-32.074:0	-25.68|-56.897:0.457
R99pTOT	-0.006|-0.026:0.014	0.003|-0.016:0.04	-0.088|-0.337:0.01
Onset	1.625|-0.667:3.514	1.057|-2.5:5	0.000|-4.5:4.848
Retreat	*-1.559|-3.077:0*	-0.909|-3.333:1.875	-0.69|-4.231:2.5
Length	-2.692|-5.472:0.333	-2|-6.897:3.125	-2.214|-7.5:4.286
TX50P	NA	NA	NA
CDDcold	NA	NA	NA
WSDI2	NA	NA	NA
CSDI2	NA	NA	NA
CTN90pct HWA	NA	NA	NA
CTN90pct HWF	NA	NA	NA
CTX90pct HWA	NA	NA	NA
CTX90pct HWF	NA	NA	NA
RX2day	**-5.831|-9.294:-1.969**	**-10.296|-16.124:-4.398**	-8.23|-17.13:1.314
CWD	*-0.323|-0.588:0*	-0.496|-1.059:0	0.000|-0.769:0
CDD	*4.314|0.191:8.998*	3.101|-4.828:9.5	3.038|-9.474:13.75
SPEI	-0.017|-0.034:0	-0.03|-0.066:0.005	-0.036|-0.166:0.088
SPI	*-0.01|-0.018:-0.001*	**-0.016|-0.028:-0.004**	-0.004|-0.02:0.012

4.12.3 Seasonal results

Trends and confidence intervals in seasonal Tx and seasonal Tn are shown in Table 4-12. Over the recent period both the seasonal Tx and seasonal Tn show warming trends in all seasons except Tx DJF where temporal consistent changes towards cooling conditions have been seen tough trends are statistically non-significant. Increasing nighttime temperature previously observed over recent period is mainly due to Tn DJF, Tn JJA and Tn SON seasonal warming.

Wet season and dry season trends, confidence intervals and significance level are indicated in Table 4-12. Both wet and dry season exhibit temporally consistent changes towards drier climate for all periods. Trends in wet season are significant over the former period and over the period 1961-2010 while trends in dry season are significant over the former period.

4.12.4 Percentile-based and other temperature indices

General climate indices are presented in Table 4-12. Results suggest mixed trend patterns including sign change. Note that very few trends are statistically significant. Over the recent period coldest night temperature (0.138 ºC/decade; non-significant) and the hottest night temperature (0.384 ºC/decade; non-significant) indices show non-significant warming trends. Contrariwise the coldest day temperature (-0.232 ºC/decade; non-significant) and warmest day temperature (-0.2 ºC/decade; non-significant) indices display non-significant cooling trends. Consequently, DTR exhibits non-significant decreasing trend.

Statistically significant patterns of warming climate are associated with the tropical nights over all periods.

4.12.5 Precipitation intensity index

Figure 4-79 shows annual time series for Macenta SDII index. Trends, significance level and the confidence intervals for this index are given in Table 4-12. SDII shows non-significant wetting patterns over all periods contrasting with regional results from Aguilar et al. (2009) but in agreement with those for WA from Barry et al. (2014).

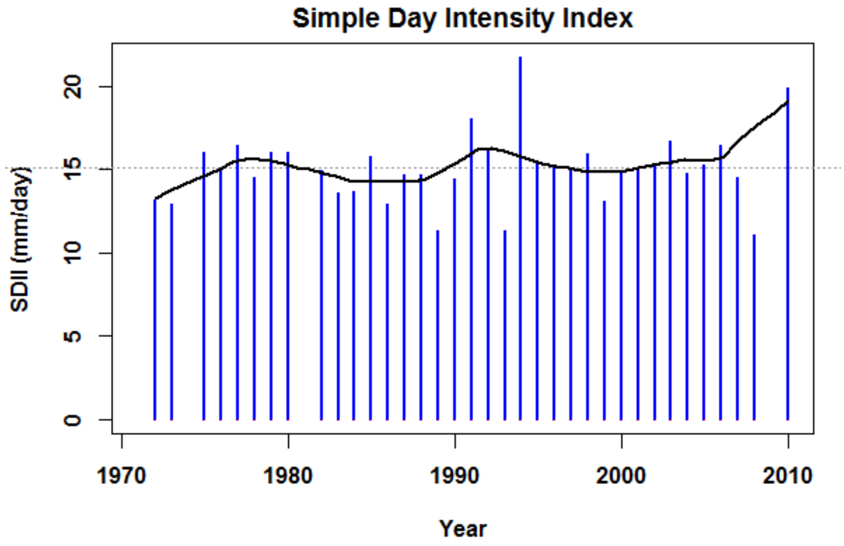


Figure 4-79: Same as in Figure 4-4 except for Siguiri

4.12.6 Precipitation percentile indices

Trends, significance level and confidence intervals for very wet and extremely wet days (R95P and R99P) and their respective contribution (R95pTOT and R99pTOT) to annual total precipitation are given in Table 4-12.

Over all periods very wet and extremely wet days precipitation show a pattern of decreasing trends, though very few are statistically significant (Table 4-12). Likewise very wet days and extremely wet days contribution show alternating sign trend patterns and statistically non-significant. Figure 4-80 illustrates changes for R95P annual time series. At regional level R95P and R99P trend patterns over the recent period concur with Aguilar et al. (2009).

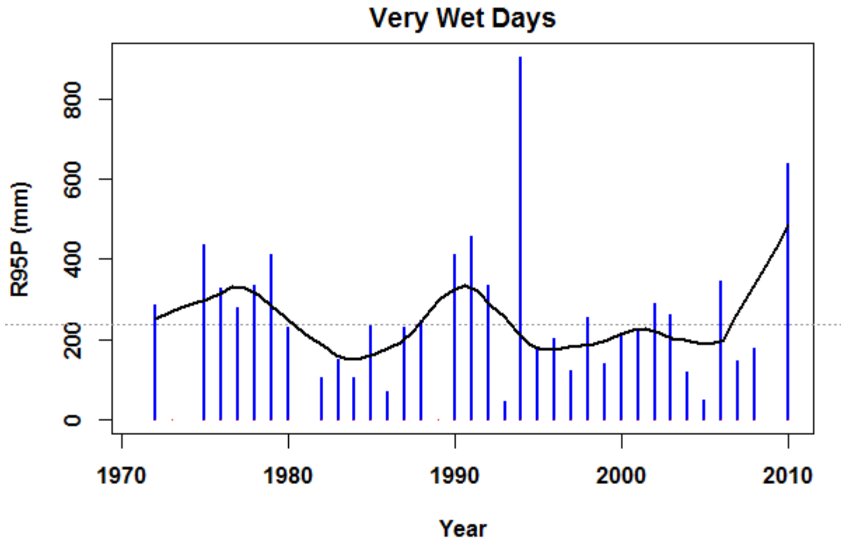


Figure 4-80: Same as in Figure 4-5except for Siguiri

4.12.7 Absolute and other precipitation indices

Trends, significance level and confidence intervals for Rx1day, Rx2day and Rx5day indices are given in Table 4-12. Both indices show decreasing trends patterns over all periods. These patterns are significant over the former period and over the period 1961-2010 and non-significant over the recent period. Figure 4-81 illustrates the annual time series for Rx2day index where noticeable changes are seen in mid 1970s and a steady decline since early 1990s.

Wet spells index shows significant decreasing trend over the former period, non-significant decreasing changes over the period 1961-2010 and; quasi stationary over the recent one. Patterns of drying conditions are in agreement with Aguilar et al. (2009).

Heavy, very heavy and extremely heavy precipitation days show non-significant decreasing trends over the former period and over the period 1961-2010; and quasi stationary or non-significant increasing trends over the recent period (Table 4-12).

Trends, significance levels and confidence intervals in wet season onset, retreat and length indices are given in Table 4-12. Over the recent period Siguiri shows quasi stationary onset date and early retreat date indicating a shorter rainy season, but these trends are non-significant. Similar trends patterns are seen over the former period and over the period 1961-2010 with non-significant delayed onset.

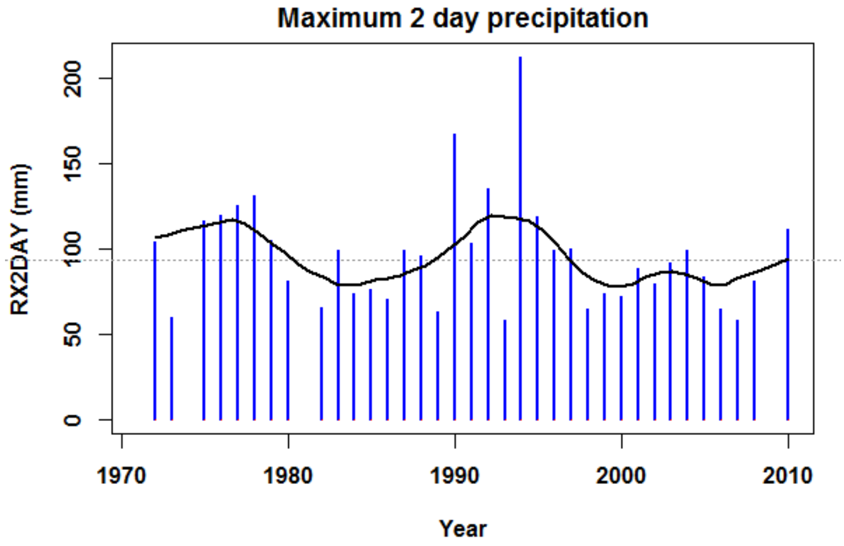


Figure 4-81: Same as in Figure 4-6 except for Siguiri

4.12.8 Drought indices

Trends, significance levels and confidence intervals in drought indices SPEI, SPI and CDD indices are given in Table 4-12.

Over all periods SPI and SPEI show decreasing trends patterns but these patterns are significant over the former period (-0.010 spi/decade; significant at 5 %) and over the period 1961-2010 (-0.016 spi/decade; significant at 1 %) for SPI index.

Figure 4-82 illustrates SPEI monthly time series. Droughts are very frequent in Siguiri over the recent period. Severe drought occurred in 1984 and in 1987 while extremely wet weather has been observed in mid 1990s. Thus, trends in SPEI and SPI suggest changes towards drier climate but trends are statistically non-significant.

Over all periods dry spells index suggests changes towards more frequent dry spells, though changes are significant only over the former period. This trend patter concurs with findings by Dai et al. (2013) and Sheffield et al. (2012) where high confidence in increases in CDD have been reported (Hartmann et al., 2013).

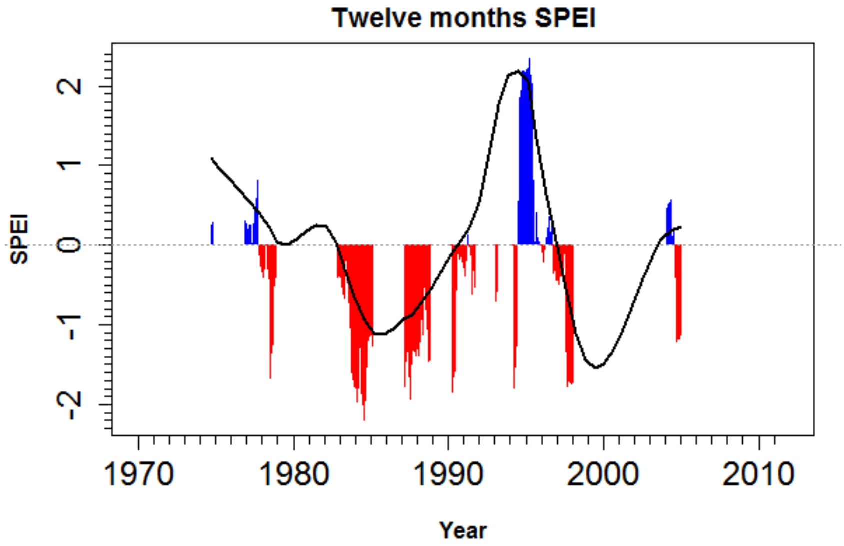


Figure 4-82: Same as in Figure 4-7 except for Siguiri

4.13 REGIONAL SERIES AND EXTREME INDICES

The nationwide average time series for indices were created by averaging station's time series (Jones et al., 1996, Aguilar et al. 2009, Alsarmi and Washington 2011). As the number of available station varies over time, variance stabilization has been applied. (Aguilar et al. 2009). Anomalies were computed relative to 1981-2010 average.

4.13.1 Annual results

Figure 4-83 shows 1971-2010 maps of trends and nationwide averaged annual Tx and Tn mean time series. Trends, significance level and confidence intervals for these indices for 1941-2010, 1961-2010 and 1971-2010 periods are shown in Tables 4-13, 4-14 and 4-15 respectively. Over the recent period annual Tx mean and Tn mean are characterized by a monotonic or nearly monotonic increase trend, see Figure 4-83 upper right panel and lower right panel. Annual Tn mean reveals a sharp rise from mid 1970s to early 1980s followed by a modest cooling that lasts up to the mid 80s, at which time both annual Tx and annual Tn increased, and they have since mid 1990s remained warmer than the 1971-2010 record average. Warming are seen at all stations though some trends are statistically non-significant. The warming trends observed in annual Tx and annual Tn range are spatially coherent in Guinea over the recent period, see Figure 4-83 upper left panel and lower left panel. Over the recent period, the magnitude of changes in Tx mean (0.199 ºC/decade significant at 1 %) is lower than that in Tn mean (0.245 ºC/decade significant at 1 %). Is that allows us to make a first remark; warming has been much stronger in cooler temperature than in the warmer over the recent period despite the cooling period in yearly Tn trend going from early 1980 to mid 1980s. Similar patterns in Tx mean (0.059 ºC/decade significant at 5 %) and in Tn mean (0.081 ºC/decade significant at 1 %) are seen over the former period. Likewise over the 1961-2010 period trends in Tx mean (0.144 ºC/decade significant at 5 %) and Tn mean (0.182 ºC/decade significant at 1 %) exhibit similar patterns of warming.

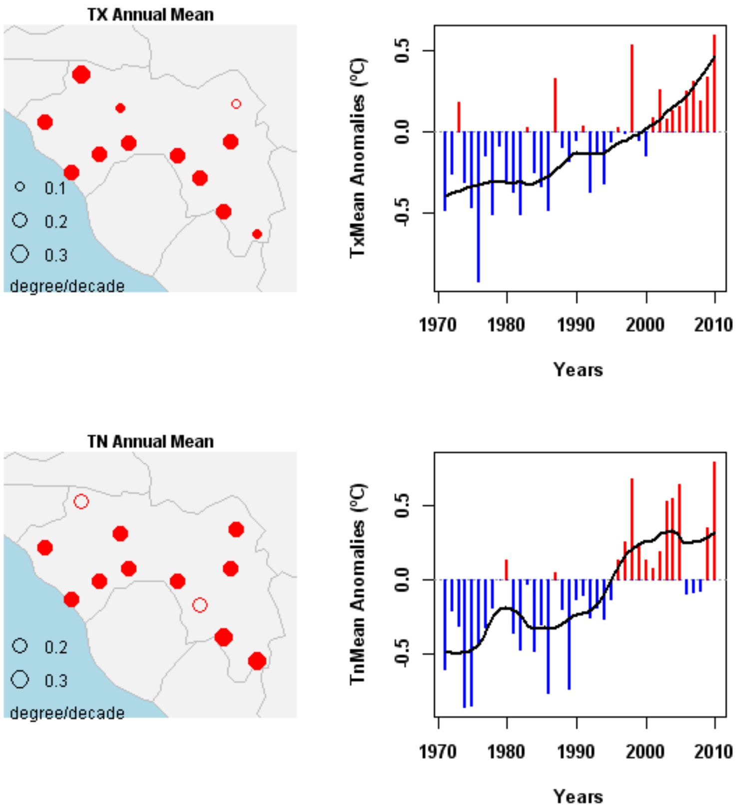


Figure 4-83: Decadal of trends along with a graph of nationwide averaged anomalies for annual Tx (upper panels) and annual Tn (lower panels) over the recent period. In this and subsequent figures filled circles represent statistically significant (at 5 % level) trends; the color indicates the sign of changes. Red/Blue solid circles indicate a statistically significant increase/decrease trend; Red/Blue open circles denote statistically non-significant increase/decrease trend; and the size of the symbol represent the magnitude of changes. On the graph, colored-bars represent annual anomalies (or time series), color coding has been used red for drying (precipitation indices) or warming trends (temperature indices) and blue for wetting (precipitation indices) or cooling (temperature indices) trends and the black smooth curve is generated from a LOESS filter applied to the annual anomalies time series.

Figure 4-84 shows 1971-2010 maps of trend and nationwide annual precipitation averaged time series. The area-average annual precipitation has always varied from decade to decade since 1970s drought, see Figure 4-84 right panel. In this variation, the maximum trend is observed in mid 1990s and the minimum in mid 1980s with a rest period in early 2000s. Over the recent period Kissidougou (84.333 mm/decade; significant at 5 %) and Kindia (53.800 mm/decade; significant at 5 %) show significant increasing trends in annual precipitation while the rest shows either positive (at 5 stations) or negative (at 5 stations) non-significant trends as indicated in Table 4-15. Overall; a less coherence patterns in annual precipitation trend is observed compared to temperatures, see Figure 4-84 left panel. The nationwide average suggests changes towards wetter conditions (19.780 mm/decade; non-significant) but these changes are statistically non-significant over the recent period. Opposite significant trend patterns (-40.115 mm/decade; significant at 1 %) are seen over the former period and non-significant trend patterns (-33.052 mm/decade; non-significant) over 1961-2010 period. The increase over the recent period is not apparent everywhere however, as some regions like Macenta, Siguiri, Faranah, Conakry and Koundara show decreases in annual rainfall, meaning that changes observed in annual precipitation are not uniform.

Trend in nationwide average precipitation over the recent period concurs with findings for WA as documented by Barry et al. (2014) and contrasts with results from Aguilar et al. (2009).

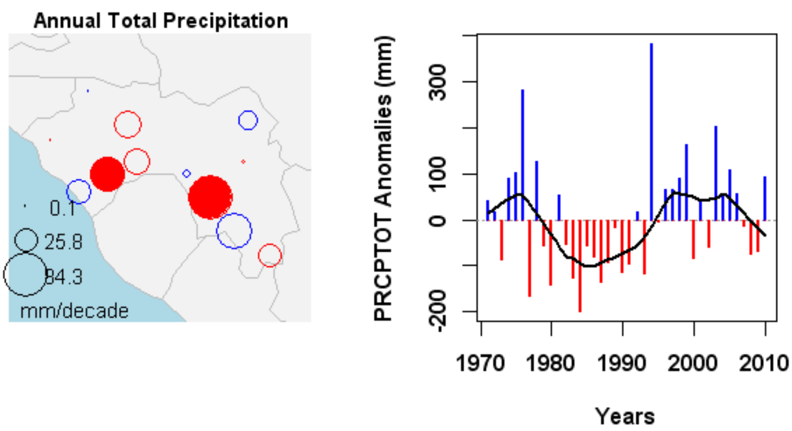


Figure 4-84: Same as in Figure 4-83 except for annual rainfall index

4.13.2 Seasonal results

Additionally to warming patterns shown by nationwide average of annual Tx mean and annual Tn mean, both Tx and Tn show consistent patterns of warming in all seasons over the recent period as indicated in Table 4-15. In this warming process Tn SON is statistically non-significant. Thus, previously observed warnings in the nationwide average of annual Tx mean and annual Tn mean, over the recent period, are the result of a combined warming of all seasons. Similar trends of warming patterns are seen in these indices over the former period and over the period 1961-2010.

Unlike seasonal temperatures, nationwide average of wet season and dry season total precipitation show mixed trend of climate patterns. Changes in dry season total precipitation (-3.810 mm/decade, non-significant) suggest drying climate while changes in wet season total precipitation (15.168 mm/decade, non-significant) suggest wetting climate over the recent period. Significant decreasing trends in dry season and in wet season precipitation are observed over the former period and non-significant drying trends over the period 1961-2010. As former period is wetter than the recent one, trend starting in the former period shows changes towards drier climate. Overall, changes observed in nationwide average of annual precipitation are well explained by those in nationwide average of wet season total precipitation.

4.13.3 Percentile-based and other temperature indices

The percentile-based temperature indices group comprises a set of five extreme climate change indices that indicate percentage of time when an index exceeds a percentile limit depicting a rare climate trends. These indices allow capturing changes in unusually warm or cool weather, even when average-area temperatures are near normal.

Figure 4-85 shows 1971-2010 maps of trends and nationwide averaged of lower tails percentile-based temperature indices. Trends, significance level and confidence intervals for these indices for 1941-2010, 1961-2010 and 1971-2010 periods are given in Tables 4-13, 4-14 and 4-15 respectively. Trend in TN10P (-2.653 %/decade; significant at 1 %) and trend in TX10P (-2.048 %/decade; significant at 1 %) suggest that the frequency of cold nights and the frequency of the cold days have significantly decreased in Guinea over the recent period. Converting percentage to nights and days these correspond to a decrease of

9.7 cold nights per decade and a decrease of 7.5 cold days per decade. Cool days, see Figure 4-85 upper left panel, and cool nights, see Figure 4-85 lower left panel, indices exhibit spatially coherent changes in Guinea over the recent period. Similar trends of warming patterns are seen in these indices over the former period and over the period 1961-2010.

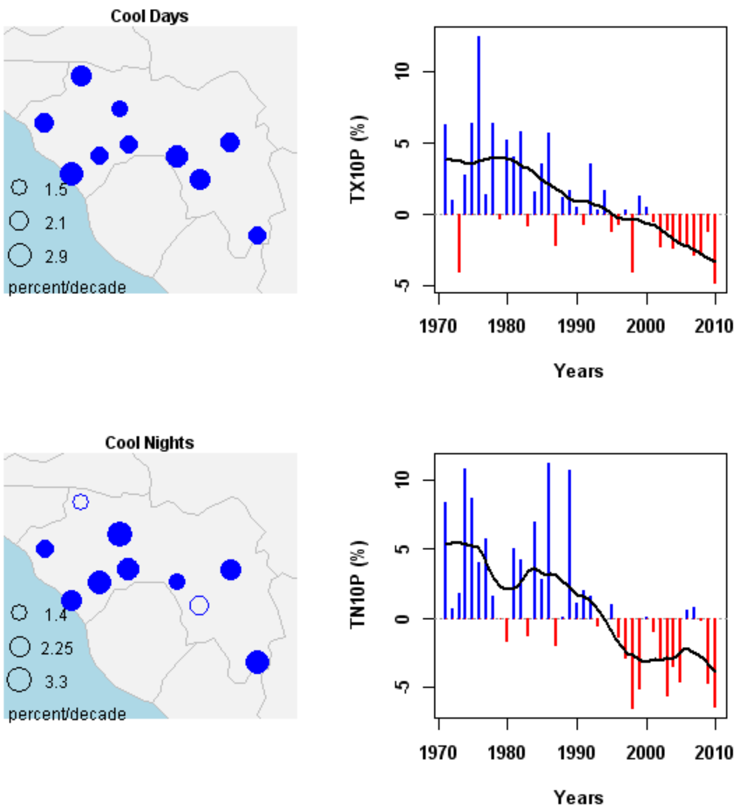


Figure 4-85: Same as in Figure 4-83 except for TX10P and TN10P indices

Figure 4-86 shows 1971-2010 maps of trends and nationwide averaged of upper tails percentile-based temperature indices. Trends, significance level and confidence intervals for these indices for 1941-2010, 1961-2010 and 1971-2010 periods are given in Tables 4-13, 4-14 and 4-15 respectively. Trend in TN90P (2.672 %/decade; significant at 1 %) and trend in TX90P (2.845 %/decade; significant at 1 %) suggest that the frequency of warm nights and the frequency of the warm days have significantly increased in Guinea over the recent period. Converting percentage to nights and days these correspond to an increase of 9.8 warm nights per decade and an increase of 10.4 warm days per decade. Warm days (Figure 4-86 upper left panel) and warm nights (Figure 4-86 lower left panel) indices exhibit spatially coherent changes in Guinea over the recent period. These patterns of warming are supported by warming patterns reported by Hartmann et al. (2013) at global level. These results also agree with those found by Aguilar et al. (2009) and Barry et al. (2014). Similar trends of warming patterns are seen in these indices over the former period and over the period 1961-2010.

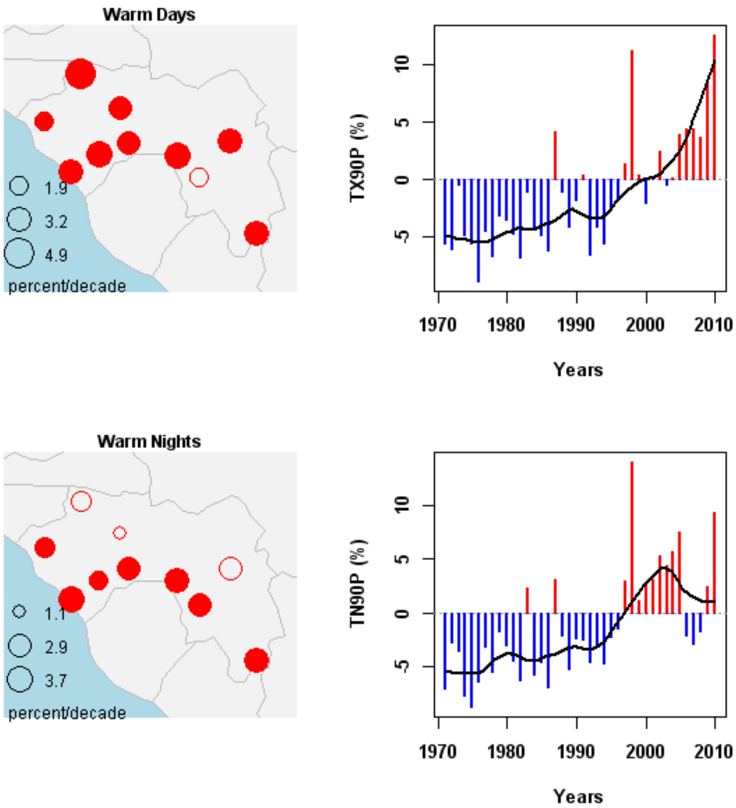


Figure 4-86: Same as in Figure 4-83 except for TX90P and TN90P indices

Further analyzing percentile-based temperature indices; we notice that the rate of change in percentile-base temperature indices has accelerated during the last forty years and especially since mid 1970s. In any case cool extremes indices (TX10P and TN10P) tend to remain bellow 1971-2010 record average and warm extremes indices (TX90P and TN90P) tend to remain above 1971-2010 record average. These results indicate possible warming climate. Furthermore, over the recent period days above average temperature have increased in ten stations among them Boke, Conakry, Faranah, Kankan, Kindia, Kissidougou, Koundara, Labe, Mamu and N'Zerekore show significant patterns leading to a significant increase (7.395 day/decade; significant at 1 %) of the nationwide average of days above average temperature. Converting percentage to days these correspond to an increase of 27 days above average per decade. Similar patterns are seen over the former period and over the periods 1961-2010.

Over the recent period, summer days have increased in ten stations among them Boke, Conakry, Kindia, Koundara and Labe show significant patterns and decreased in two stations among them Kankan shows significant patterns leading to a non-significant increase (4.118 day/decade, non-significant) of the nationwide average of summer days. SU25 shows non-significant decreasing trends (-0.303 day/decade, non-significant) over the former period and non-significant increasing trends (1.201 day/decade, non-significant) over the period 1961-2010. Similarly, over the recent period tropical nights have significantly increased in all stations except Conakry, Koundara, Labe and Mamu leading to a significant increase (9.847 day/decade, significant at 1 %) of the nationwide average of tropical days. Comparable trend patterns (5.659 day/decade, significant at 5 %) are seen over the period 1961-2010.

General climate indices suggest changes towards warming climate. The hottest night temperature has increased in eleven stations among them Boke, Conakry, Faranah and Kankan show significant patterns leading to a significant increase (0.188 ºC/decade, significant at 1 %) of the nationwide average of the hottest night temperature over the recent period. Similar trends are seen over the former period and over the period 1961-2010. Likewise, the hottest day temperature has increased in nine cities among them Boke, Kindia and Mamu show significant patterns and decreased in three cities among them Faranah shows significant patterns over the recent period leading to a significant increase (0.131 ºC/decade, significant at 1 %) of the nationwide average of the hottest day temperature. Comparable trends are observed over the former period (0.016 ºC/decade; non-significant) and over the period 1961-2010 (0.077 ºC/decade; significant at 5 %).

Cold spells duration has decreased in all stations among them Boke, Conakry, Faranah, Kankan, Kindia, Kissidougou, Koundara, Labe, Mamu and N'Zerekore show significant patterns leading to a significant decrease (-6.180 day/decade, significant at 1 %) of the nationwide average of the cold spells duration over the recent period. Similar trends are observed over the former period (-2.984 day/decade; significant at 1 %) and over the period 1961-2010 (-5.416 day/decade; significant at 1 %).

Warm spells duration has increased in all stations among them Conakry, Faranah, Kindia, Koundara, Labe, Mamu and N'Zerekore show significant patterns leading to a significant increase (5.170 day/decade, significant at 1 %) of the nationwide average of the warm spells duration over the recent period. Similar non-significant trends are observed over the former period (0.511 day/decade; non-significant) and significant trends (2.676 day/decade; significant at 1 %) over the period 1961-2010.

The cooling degree days has increased in all stations among them Boke, Conakry, Kindia, Kissidougou, Koundara, Labe, Mamu and N'Zerekore show significant patterns leading to a significant increase (90.238 ºC/decade, significant at 1 %) of the nationwide average of the need for cooling. Similar non-significant trend (13.998 ºC/decade; non-significant) are observed over the former period and significant trend (46.098 ºC/decade; significant at 1 %) over the period 1961-2010.

4.13.4 Precipitation intensity index

Figure 4-87 shows SDII index map of trends and SDII nationwide averaged anomalies. Trends, significance level and confidence intervals for this index for 1941-2010, 1961-2010 and 1971-2010 periods are given in Tables 4-13, 4-14 and 4-15 respectively. Daily intensity has increased (0.136 mm/day/decade, non-significant) in nine stations among them only Kissidougou shows significant patterns and decreased in three other stations with non-significant patterns suggesting that simple day intensity has increased, but this increase is non-significant over the recent period. Figure 4-87 (left panel) shows trends spatial distribution. Decreasing SDII is particularly noticeable during the drought of the 1980s. Significant decreasing trends (-0.182 mm/day/decade; significant at 1 %) are seen in SDII index over the former period and similar non-significant patterns (-0.039 mm/day/decade; non-significant) over the period 1961-2010.

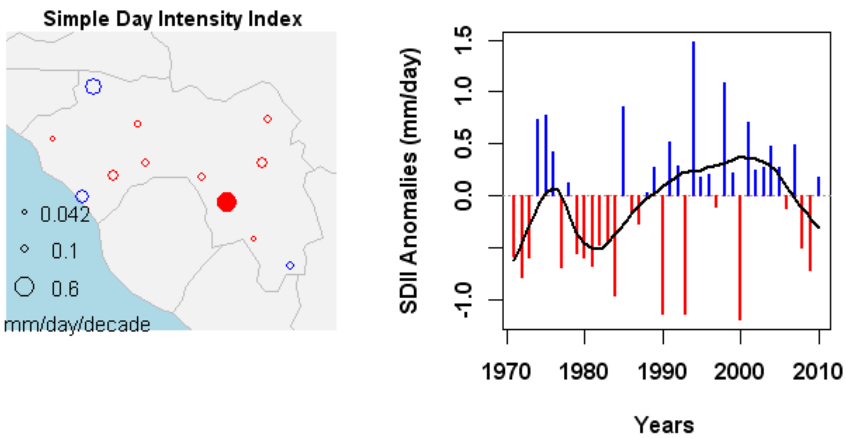


Figure 4-87: Same as in Figure 4-83 except for SDII index

4.13.5 Precipitation percentile indices

This group comprises the two wet-day indices R95P and R99P and their respective contribution to annual precipitation percentile indices R95pTOT and R99pTOT.

Figure 4-88 shows 1971-2010 maps of trends and nationwide averaged of very wet-day precipitation over the recent period. Trends, significance level and confidence intervals for these indices for 1941-2010, 1961-2010 and 1971-2010 periods are given in Tables 4-13, 4-14 and 4-15 respectively.

Over the recent period, very wet days precipitation has increased in seven cities and decrease in five cities with non-significant pattern indicating that the annual total precipitation on days exceeding the long-term 95th percentile has increased (12.068 mm/decade, non-significant), but this increase is non-significant. Figure 4-88 (left panel) shows 1971-2010 trends spatial distribution and Figure 4-88 (right panel) shows the annual time series. Opposite patterns are observed over the former period (-17.022 mm/decade; significant at 1 %) and over the period 1961-2010 (-12.989 mm/decade, non-significant) in R95P index. Likewise, over the recent period the percentage contribution from very wet days to the annual precipitation total has increased in nine stations and has decreased in three station with non-significant trend leading to a non-significant increase (0.001 %/decade; non significant) of contribution from very wet days. Decreasing significant patterns are seen over the former period (-0.005 mm/decade; significant at 1 %) and decreasing non-significant trends (-0.005 mm/decade; non-significant) are observed over the period 1961-2010 in R95pTOT index.

Extremely wet days precipitation has decreased in six cities among them N'Zerekore shows significant pattern and increased in six stations with non-significant pattern suggesting that the annual total precipitation on days exceeding the long-term 99th percentile has decreased (-3.587 mm/decade; non-significant), but this decrease is non-significant over the recent period. Likewise, the percentage contribution from extremely wet days to the annual precipitation total has increased (0.001 %/decade; non-significant) in six stations among them Conakry and Macenta show significant patterns and decreased in six other stations with non-significant trend leading to a non-significant increase of contribution from extremely wet days over the recent period. Decreasing significant patterns are seen over the former period (-0.002 mm/decade; significant at 1 %) and decreasing non-significant trends (-0.001 mm/decade; non-significant) are seen over the period 1961-2010 in R99pTOT index.

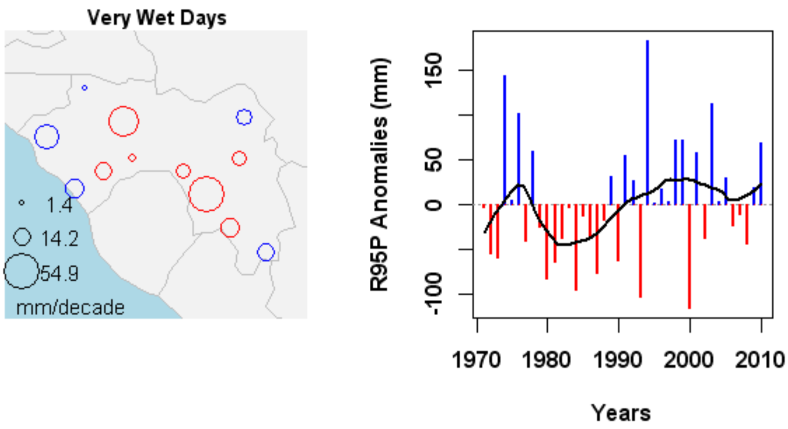


Figure 4-88: Same as in Figure 4-83 except for R95P index

4.13.6 Absolute and other precipitation indices

The absolute precipitation indices group comprises the maximum event intensity indices: Rx1day, Rx2day and Rx5day. Figure 4-89 shows Rx2day index map of trends (left panel) and the nationwide averaged anomalies (right panel) over recent period. Trends, significance level and confidence intervals for these indices for 1941-2010, 1961-2010 and 1971-2010 periods are given in Tables 4-13, 4-14 and 4-15 respectively.

Over the recent period, Rx2day has increased (0.628 mm/decade, non-significant) in seven cities and decreased in five cities with non-significant pattern indicating that the annual maximum 2 days precipitation has increased, but this increase is non-significant. Opposite significant patterns are seen over the former period (-2.664 mm/decade; significant at 1 %) and over the period 1961-2010 (-3.110 mm/decade; significant at 5 %).

Over the recent period Rx1day has decreased (-0.321 mm/decade, non-significant) in eight cities and increased in four cities with non-significant pattern indicating that the annual maximum 1 days precipitation has decreased, but this decrease is non-significant. Similar significant patterns are seen over the former period (-1.738 mm/decade; significant at 1 %) and over the period 1961-2010 (-1.975 mm/decade; significant at 5 %).

Over the recent period Rx5day has increased (1.5 mm/decade, non-significant) in six stations and decreased in six other stations with non-significant pattern suggesting that the annual maximum 5 days precipitation has increased, but this decrease is non-significant. Opposite significant patterns are seen over the former period (-3.879 mm/decade; significant at 1 %) and non-significant patterns over the period 1961-2010 (-3.601 mm/decade; non-significant).

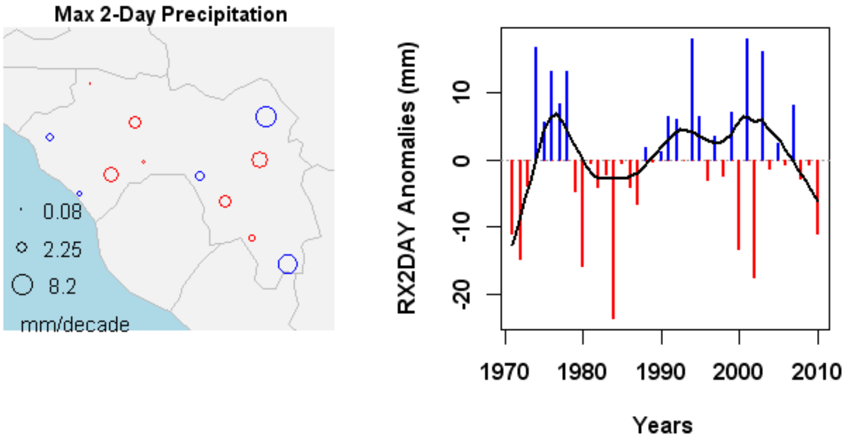


Figure 4-89: Same as in Figure 4-83 except for RX2day index

R10mm has decreased (-0.4day/decade, non-significant) in one city and increased in eleven stations with non-significant pattern suggesting that heavy precipitation days have decreased over the recent period, but this decrease is non-significant. Similar significant patterns are seen over the former period (-1.316 day/decade; significant at 1 %) and non-significant patterns over the period 1961-2010 (-1.210 day/decade; non-significant).

R20mm has decreased (-0.039 day/decade, non-significant) in three cities with non-significant pattern and increased in nine cities among them only Kissidougou shows significant pattern suggesting that very heavy precipitation days have decreased over the recent period, but this decrease is non-significant. Similar significant patterns are seen over the former period (-0.781 day/decade; significant at 1 %) and non-significant patterns over the period 1961-2010 (-0.826 day/decade; non-significant).

R25mm has decreased (-0.008 day/decade, non-significant) in three cities with non-significant pattern and increased in nine other cities among them only Kindia shows significant pattern suggesting that extremely heavy precipitation days have decreased over the recent period, but this decrease is non-significant. Comparable significant patterns are seen over the former period (-0.769 day/decade; significant at 1 %) and non-significant patterns over the period 1961-2010 (-0.772 day/decade; significant at 5 %).

Though statistically non-significant over the recent period, NWA of heavy, very heavy and extremely heavy precipitation days are consistent with drying climate and concur with Aguilar et al. (2009) results.

CWD has decreased (-0.175 day/decade, non-significant) in three cities and increased in nine other cities with non-significant pattern suggesting that the nationwide wet spells length has decreased over the recent period, but this decrease is non-significant. Similar significant patterns are seen over the former period (-0.426 day/decade; significant at 1 %) and over the period 1961-2010 (-0.466 day/decade; significant at 5 %). CWD trend patterns over the recent period concur with findings from Aguilar et al. (2009) at regional level.

Rainy season onset date has delayed in ten cities among them Macenta shows significant trend and decreased in two cities with non-significant pattern suggesting that the nationwide onset date has significantly delayed (2.177 day/decade, significant at 5 %) over the recent period. Similar non-significant patterns are seen over the former period (0.282 day/decade; non-significant) and over the period 1961-2010 (0.578 day/decade; non-significant).

Retreat date has delayed in ten cities among them Labe shows significant trend and decreased in two cities with non-significant pattern indicating that the nationwide retreat date has delayed (1.071 day/decade, non-significant), but this delay is non-significant over the recent period. Significant early retreat patterns are seen over the former period (-1.032 day/decade; significant at 5 %) and non-significant early retreat patterns over the period 1961-2010 (-0.576 day/decade; non-significant).

Season length has decreased in eight stations with non-significant pattern and increased in four cities among them Labe shows significant pattern suggesting that the nationwide season length has decreased (-0.683 day/decade, non-significant), but this decrease is non-significant over the recent period. Similar patterns are seen over the former period (-1.008 day/decade; non-significant) and over the period 1961-2010 (-0.298 day/decade; non-significant).

4.13.7 Drought indices

Figure 4-90 shows SPEI index map of trends (left panel) and the nationwide monthly averaged anomalies (right panel). Trends, significance level and confidence intervals for these indices for 1941-2010, 1961-2010 and 1971-2010 periods are given in Tables 4-13, 4-14 and 4-15 respectively.

Over the recent period, SPEI has increased (0.005 spei/decade, non-significant) in six stations among them Kindia shows significant pattern and decreased in six other cities with non-significant pattern suggesting that the temporal evolution of dry and wet conditions during the last four decades tends towards wetter climate, but this trend is non-significant. Opposite significant patterns are seen over the former period (-0.012 spei/decade; significant at 1 %) and non-significant pattern over the period 1961-2010 (-0.010 spei/decade; non-significant). Overall four wet/dry periods emerge from SPEI indicators: the period prior to 1980 characterized by a fairly wet weather mid 1970s being the wettest period; early 1980s to mid 1990s period which is characterized by a major drought peaking in 1984-85. This drought period is followed by a wetter period that goes from the second half of the 1990s to mid 2000s and finally a new short dry period starting mid 2000s and ending in 2010 is observed.

SPI has increased (0.005 spi/decade, non-significant) in eight stations among them Kindia shows significant pattern and decreased in four station with non-significant pattern suggesting that the temporal evolution of dry and wet conditions over the recent period tends towards wetter climate, but this trend is non-significant. Opposite significant patterns are seen over the former period (-0.011 spi/decade; significant at 1 %) and non-significant pattern over the period 1961-2010 (-0.009 spi/decade; non-significant).

CDD has decreased (1.129 day/decade, non-significant) in six stations and increased in six other stations both with non-significant pattern suggesting that dry spells have increased, but this decrease is non-significant over the recent period. Similar significant patterns are seen over the former period (3.051 day/decade; significant at 5 %) and opposite non-significant trend over 1961-2010 period (-0.402 day/decade; non-significant).

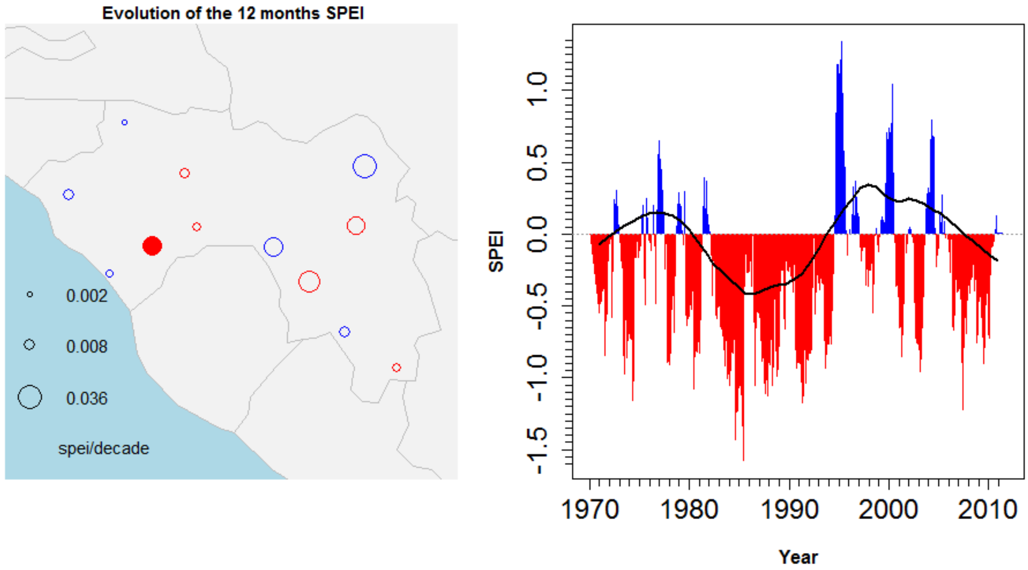


Figure 4-90: Same as in Figure 4-83 except for twelve months SPEI index

Table 4-13: Summary of 1941-2010 nationwide average decadal trends

Series/indices	1941-2010	Positive		Negative	
		sign.	non-sign.	sign.	non-sign.
TxMean	*0.059|0.018:0.099*	4	2	0	2
TnMean	**0.081|0.041:0.12**	4	4	0	0
PRCPTOT	**-40.115|-62.79:-19.332**	0	0	6	5
Tx DJF	0.026|-0.023:0.071	0	7	0	1
Tx MAM	0.031|-0.023:0.082	0	6	0	2
Tx JJA	*0.064|0.002:0.12*	2	6	0	0
Tx SON	*0.093|0.04:0.141*	6	2	0	0
Tn DJF	0.067|-0.033:0.166	1	6	0	1
Tn MAM	**0.118|0.068:0.171**	7	1	0	0
Tn JJA	**0.08|0.043:0.114**	7	1	0	0
Tn SON	0.011|-0.028:0.054	0	6	0	2
DRY	**-12.228|-18.518:-5.904**	0	0	8	3
WET	**-26.263|-42.58:-9.156**	0	2	5	4
TN10P	**-0.979|-1.395:-0.523**	0	0	4	2
TN90P	**0.897|0.476:1.401**	5	1	0	0
TX10P	*-0.738|-1.156:-0.299*	0	0	5	1
TX90P	*0.632|0.062:1.159*	3	3	0	0
TNn	*0.145|0.046:0.244*	4	3	0	1
TNx	**0.148|0.099:0.203**	6	2	0	0
TXn	0.037|-0.013:0.088	1	5	0	2
TXx	0.016|-0.028:0.068	2	5	0	1
DTR	-0.049|-0.09:-0.009	0	0	0	8
SU25	-0.303|-1.454:0.978	4	3	0	1
TR20	0.833|-1.107:2.931	3	4	0	1
RX1day	**-1.738|-2.602:-0.726**	0	1	2	8
RX5day	**-3.879|-6.091:-1.593**	0	0	4	7
SDII	**-0.182|-0.285:-0.093**	0	3	2	6
R10mm	**-1.316|-1.941:-0.768**	0	0	4	7
R20mm	**-0.781|-1.161:-0.413**	0	0	5	6
R25mm	**-0.769|-1.111:-0.425**	0	1	5	5
R95p	**-17.022|-29.108:-6.89**	0	0	4	7
R95pTOT	**-0.005|-0.009:-0.001**	0	3	0	8
R99p	**-11.242|-15.989:-5.324**	0	3	2	6
R99pTOT	**-0.002|-0.005:-0**	0	4	0	7
Onset	0.282|-0.719:1.537	2	7	0	2
Retreat	*-1.032|-1.825:-0.284*	0	2	5	4
Length	-1.008|-2.772:0.444	0	2	2	7
TX50P	**2.445|1.211:3.867**	4	2	0	0
CDDcold	13.998|-1.424:26.436	3	3	0	0
WSDI2	0.511|-0.742:1.554	3	3	0	0
CSDI2	**-2.984|-3.957:-1.973**	0	0	6	0
CTN90pct HWA	**0.457|0.182:0.709**	1	4	0	0
CTN90pct HWF	*0.092|0:0.463*	1	3	0	0
CTX90pct HWA	0.086|-0.172:0.413	0	2	0	3
CTX90pct HWF	0.278|-0.483:0.313	0	4	0	1
RX2day	**-2.664|-4.028:-1.269**	0	1	3	7
CWD	**-0.426|-0.643:-0.192**	0	5	3	3
CDD	*3.051|0.516:5.638*	6	4	0	1
SPEI	**-0.012|-0.02:-0.005**	0	0	3	5
SPI	**-0.011|-0.019:-0.003**	0	0	5	6

Table 4-14: Summary of 1961-2010 nationwide average decadal trends

Series/indices	1961-2010	Positive		Negative	
		sign.	non-sign.	sign.	non-sign.
TxMean	**0.144|0.097:0.189**	8	1	0	0
TnMean	**0.182|0.121:0.247**	8	1	0	0
PRCPTOT	-33.052|-70.018:1.924	0	1	3	7
Tx DJF	*0.116|0.025:0.2*	5	3	0	1
Tx MAM	**0.089|0.014:0.177**	3	6	0	0
Tx JJA	**0.159|0.081:0.224**	7	2	0	0
Tx SON	**0.193|0.13:0.255**	9	0	0	0
Tn DJF	*0.279|0.126:0.446*	8	1	0	0
Tn MAM	**0.227|0.157:0.313**	9	0	0	0
Tn JJA	**0.113|0.059:0.163**	7	2	0	0
Tn SON	*0.095|0.034:0.147*	5	4	0	0
DRY	-9.971|-20.081:0.069	0	1	3	7
WET	-23.113|-52.772:5.882	0	4	3	4
TN10P	**-2.014|-2.739:-1.375**	0	0	5	2
TN90P	**1.894|1.205:2.787**	5	2	0	0
TX10P	**-1.561|-2.166:-0.988**	0	0	7	0
TX90P	**1.775|1.025:2.556**	7	0	0	0
TNn	0.239|0.077:0.383	4	4	0	1
TNx	**0.228|0.137:0.319**	7	2	0	0
TXn	0.089|-0.014:0.175	2	5	0	2
TXx	*0.077|-0.006:0.169*	3	4	0	2
DTR	-0.066|-0.127:-0.004	0	1	0	8
SU25	1.201|-1.125:3.563	5	2	0	2
TR20	*5.659|2.201:9.213*	5	4	0	0
RX1day	*-1.975|-3.498:-0.374*	0	1	2	8
RX5day	-3.601|-6.768:0.161	0	2	2	7
SDII	-0.039|-0.201:0.132	1	5	1	4
R10mm	-1.21|-2.132:-0.261	0	3	3	5
R20mm	-0.826|-1.582:-0.19	0	3	3	5
R25mm	*-0.772|-1.351:-0.14*	0	5	2	4
R95p	-12.989|-33.264:3.086	0	3	1	7
R95pTOT	-0.005|-0.012:0.003	0	9	0	2
R99p	**-10.654|-17.954:-2.911**	0	5	1	5
R99pTOT	-0.001|-0.004:0.001	0	6	0	5
Onset	0.578|-1.204:2.541	1	8	0	2
Retreat	-0.476|-1.592:0.512	0	4	0	7
Length	-0.298|-3.065:2.125	0	3	1	7
TX50P	**5.322|3.852:7.007**	7	0	0	0
CDDcold	**46.098|23.92:70.151**	6	1	0	0
WSDI2	**2.676|1.06:4.408**	5	2	0	0
CSDI2	**-5.416|-7.367:-3.979**	0	0	7	0
CTN90pct HWA	0.151|0.022:0.237	0	5	0	0
CTN90pct HWF	*0.463|0:1.045*	1	4	0	1
CTX90pct HWA	-0.156|-0.584:0.237	0	2	0	3
CTX90pct HWF	*0.451|0:0.883*	0	7	0	0
RX2day	*-3.11|-5.277:-0.287*	0	2	1	8
CWD	*-0.466|-0.862:-0.074*	0	4	1	6
CDD	-0.402|-3.479:3.36	0	8	0	3
SPEI	-0.01|-0.022:0.002	0	0	4	5
SPI	-0.009|-0.021:0.002	0	3	5	3

Table 4-15: Summary of 1971-2010 nationwide average decadal trends

Series/indices	1971-2010	Positive		Negative	
		sign.	Non-sign.	sign.	Non-sign.
TxMean	**0.199|0.141:0.256**	11	1	0	0
TnMean	**0.245|0.143:0.333**	10	2	0	0
PRCPTOT	19.78|-14.926:50.405	2	5	0	5
Tx DJF	**0.189|0.095:0.285**	10	1	0	1
Tx MAM	**0.181|0.063:0.298**	6	6	0	0
Tx JJA	**0.194|0.105:0.278**	11	1	0	0
Tx SON	**0.193|0.111:0.276**	11	1	0	0
Tn DJF	**0.413|0.205:0.694**	8	4	0	0
Tn MAM	**0.281|0.176:0.372**	9	3	0	0
Tn JJA	**0.159|0.092:0.229**	8	4	0	0
Tn SON	0.112|0.029:0.196	2	10	0	0
DRY	-3.81|-16.213:8.378	0	4	1	7
WET	15.168|-10.965:45.185	1	8	0	3
TN10P	**-2.653|-3.66:-1.626**	0	0	8	2
TN90P	**2.672|1.657:3.945**	7	3	0	0
TX10P	**-2.048|-2.784:-1.274**	0	0	10	0
TX90P	**2.845|1.985:3.689**	9	1	0	0
TNn	0.309|0.132:0.536	4	7	0	1
TNx	**0.188|0.066:0.3**	4	7	0	1
TXn	0.073|-0.047:0.204	2	8	0	2
TXx	**0.131|0.028:0.225**	3	6	1	2
DTR	-0.067|-0.15:0.026	0	3	0	9
SU25	4.118|0.082:9.36	5	5	1	1
TR20	**9.847|4.758:15.143**	8	4	0	0
RX1day	-0.321|-2.565:1.712	0	4	0	8
RX5day	1.5|-3.58:6.323	0	6	0	6
SDII	0.136|-0.054:0.32	1	8	0	3
R10mm	-0.417|-1.543:0.798	0	11	0	1
R20mm	-0.039|-0.756:0.801	1	8	0	3
R25mm	-0.008|-0.657:0.534	1	8	0	3
R95p	12.068|-9.738:28.193	0	7	0	5
R95pTOT	0.001|-0.009:0.011	0	9	0	3
R99p	-3.587|-14.22:6.807	0	6	1	5
R99pTOT	0.001|-0.003:0.005	2	4	0	6
Onset	*2.177|-0.591:4.875*	1	9	0	2
Retreat	1.071|-0.312:2.4	1	9	0	2
Length	-0.683|-3.7:2.017	1	3	0	8
TX50P	**7.395|5.818:8.994**	10	0	0	0
CDDcold	**90.238|55.573:128.258**	8	2	0	0
WSDI2	**5.17|2.899:7.067**	7	3	0	0
CSDI2	**-6.18|-8.419:-3.954**	0	0	8	2
CTN90pct HWA	0.095|-0.11:0.269	0	8	0	1
CTN90pct HWF	0.303|-0.125:1.286	0	7	0	2
CTX90pct HWA	0.111|-0.408:0.62	0	3	0	4
CTX90pct HWF	*0.652|0:1.204*	0	6	0	1
RX2day	0.628|-2.262:3.268	0	7	0	5
CWD	-0.175|-0.604:0.256	0	9	0	3
CDD	1.129|-2.875:6.22	0	6	0	6
SPEI	0.005|-0.009:0.019	1	5	0	6
SPI	0.005|-0.007:0.016	1	7	0	4

4.14 CLIMATE INDICES CONNECTION TO SOI INDICES

The possible relationship between the teleconnection patterns and climate extremes is worthwhile investigating. Therefore to explore such possible associations, the SOI (Southern Oscillation Index) calculated as the difference in standardized pressure between Tahiti and Darwin has been selected. The negative phase of the SOI represents below-normal air pressure at Tahiti and above-normal air pressure at Darwin. Prolonged periods of negative (positive) SOI values coincide with abnormally warm (cold) ocean waters across the eastern tropical Pacific typical of El Niño (La Niña) episodes. To proceed with the investigation, chosen averaged climate indices have then been separated, on yearly basis, into EN (El Niño) and LN (La Niña) groups accordingly. Then trends have been computed for each group and assessed at 1 % level and 5 % level and results are summarized in Table 4-16.

Results suggest increasing annual total precipitation and heavy precipitation days in LN years. A similar pattern is seen for the SPEI index during the wet periods. Therefore, Guinea rainfall is rather associated with LN years, in consistent with Lutz et al. (2014) who found that before and after the ITCZ and the major center of convection have reached their northernmost positions, the Guinea and Sierra Leone coast receives less/more rainfall during EN/LN years. Extreme temperatures are linked to both EN and LN, but warming is stronger in the cold tail (TN10P, Tx10p) in EN years than in LN years and cooling is stronger in the warm tail (TN90P and TX90P) in LA years than in EN years. Thus LA years are associated with wetter and cooler conditions in Guinea. The factors producing wet conditions are not the reverse of those producing dry conditions neither the factors producing cool conditions are not the reverse of those producing warm conditions. In order to understand these associations, the underlying mechanisms via the general atmospheric circulation must be determined.

From Lutz et al. (2014) we notice that the influence of southeast Atlantic SST (Sea Surface Temperature) variability is not constrained to certain months or regions as might be thought from previous analyses. It plays an important role throughout the year, differing from region to region. More importantly, coupled variability is present on different time scales. Some links are only discovered on a monthly scale while other ones are stronger on the seasonal scale.

Recent studies analyzing multi-decadal variability show that the SST-rainfall relationship of a specific region may not be stationary over time. Losada et al. (2012) found that the relationship between tropical Atlantic SSTs and Sahel precipitation changes after the 1970s. Lutz et al. (2014) provided a comprehensive study of the influence of tropical Atlantic Ocean variability on Africa western coast precipitation. In contrast to remarkably strong link of positive sign between SST and rainfall variability in some West African countries, only a minor or no significant connection was found with July-August-September month precipitation for Guinea.

Further analyzing the impact of Atlantic EN and LN events on Africa western coast precipitation, Lutz et al. (2014) found that cold water events are associated with an increase in boreal winter and spring months except March while warm water impact is found only in March.

Previous studies of temperature and precipitation in WA have linked climate variability to a number of large-scale forcing mechanisms (Losada et al., 2012; Rodríguez et al., 2011). While a comprehensive analysis of such mechanisms is beyond the scope of this thesis, this explorative analysis is provided.

Table 4-16: Relationship between SOI index and climate indices. Decadal trends and confidence intervals for chosen indices over 1941-2010 splitted into the EN and the LN periods

Series/Indices	**El Niño**	**La Niña**
TxMean	*0.721|0.094:1.213*	**0.253|0.141:0.353**
TnMean	0.156|-0.745:1.389	-0.112|-0.433:0.209
PRCPTOT	-0.947|-18.434:7.755	*3.128|0.052:20.357*
TN10P	**-6.9|-8.511:-3.894**	**-2.956|-3.739:-2.195**
TN90P	*-3.075|-4.958:-0.236*	-1.331|-3.07:0.063
TX10P	**-6.787|-9.103:-3.587**	**-3.336|-4.174:-2.444**
TX90P	-2.289|-6.036:0.31	**-1.318|-2.663:-0.331**
SDII	-0.067|-0.405:0.406	0.076|-0.117:0.237
R95P	0.43|-6.047:5.721	**2.447|0.694:7.293**
RX2day	-7.683|-20.7:8.3	2.925|-1.75:9.579
SPEI	0.003|-0.017:0.024	**0.015|0.006:0.024**

5. SUMMARY AND CONCLUSIONS

5.1. DISCUSSION

A quality controlled and homogenized daily precipitation and, daily maximum and minimum temperatures starting back to 1941 and ending in 2010 from twelve land based observational network dataset has been constructed and used to analyze temporal and geographical changes in mean and, in climate extremes and in climate change sectors specific indices. In the following results are discussed.

The findings reveal that at present time, trends of annual data, trends of seasonal data, and trends of several indices stand out most conspicuously. A general and significant warming on an annual and a seasonal basis has been observed over the study for both the daytime and the night time temperatures. Warming patterns of nighttime temperature and day time temperature initiated in the former period has significantly increased since mid 1990s at some station and at nationwide level. Seasonal visible warming trends in nighttime temperature include all season but to a lesser extend for SON. Similarly, seasonal visible warming trends in daytime temperature include all season.

Most of trends in seasonal and annual precipitation data are not sufficiently large or persistent enough to be considered as strongly suggestive of a changing climate. Nonetheless, real changes in climate remain the most likely explanation for the most visible changes. Some of the seasonal rainfall trends had seemingly significant changed during one sub-period and had more or less remained at these levels during the subsequent sub-periods.

Climatic as well as non-climatic factors might influence the rise of air temperature that attribute to extremes indices. The contributing factors could be either influence of large scale circulations or effects of urbanization (Hartmann, et al., 2013; Zhou and Ren, 2011). For the special case of Guinea, we believe that the effect of urbanization on the temperature extremes is not the main contributing factor. All the observational stations used in this study are located at airports except Kindia and Mamu and comply with WMO standards sitting and most of them are in more rural areas except Conakry. Even so, the changes in temperature extreme patterns are still similar in all the stations including the city of Conakry. Homogeneity is an obvious requirement for a robust analysis of climate time series. While time series that are used for indices calculations have been adjusted to improve homogeneity, some aspects of these records may remain inhomogeneous, and this should be borne in mind when interpreting changes in indices.

Daily data homogenization is difficult because of its high variability when compared to monthly or annual data, and also because inhomogeneities due to a change in station location or instrument may alter behavior differently under different weather conditions. There is still to understand in daily data homogenization technique. In this thesis, we carried out meticulous quality control and homogeneity adjustment in Guinea daily precipitation and daily temperatures data using Homer output files of detected breaks from monthly data. Freitas et al. (2013) also used homer to homogenized Portugal monthly air temperature data.

Additionally, calculating some indices may be challenging even though they have simple definitions. ETCCDI percentile-based temperature indices are an example (Zhang et al., 2011). These indices are computed by counting the number of days in a year for which daily values exceed a time of year dependent threshold. This threshold is defined as a percentile of daily observations for a 5-day window centered upon the calendar day of interest during a base period which is fixed to a common period, such as 1961–1990 recommended by WMO as reference period for averaging and, also to allow indices comparison across stations with different record lengths and, as well for easy updating as new daily data become available (Zhang et al., 2011). Another problem arises when it comes to calculating the regional average when the number of stations varies over time as the mean depends on this number. Additionally, Owing to natural variability, trends based on short records are very sensitive to the beginning and end dates and do not in general reflect long-term climate trends (Hartmann, et al., 2013). The presence of missing data in the underlying time series does not improve the situation either. Every effort has to be made to avoid data gaps, correct all erroneous values and validate or disqualify doubtful data detected by QC procedures by choosing appropriate procedures (Brunet et al., 2013). These are some of the issues that one should be aware of when it comes to trends analysis.

Current results suggest a general significant warming over each sub-period and over the entire period on annual Tx mean and Tn mean. For the recent period 1971-2010 these trends are estimated to be 0.199 ºC/decade and 0.245 ºC/decade respectively for annual Tx mean and annual Tn mean. On seasonal basis, except Tn SON all seasons significantly contributed in day time and in nighttime temperatures warming though Tn DJF and Tn MAM show the highest magnitudes. These warming patterns concur with Aguilar et al. (2009) and Barry et al. (2014) findings.

Because of their disproportionate impact on society and ecosystems compared to changes in mean climate, it is very important to understand changes in extremes climate events. Over all study periods, Guinea has experienced significant decreases of cold nights and significant decreases of cold days. Similarly, warm nights and warm days have significantly increased in Guinea over all periods. These warming patterns are in agreement with regional (Aguilar et al., 2009, Barry et al., 2014) and global findings (Donat et al., 2013a).

The analysis shows increases of Tn 90^{th} and Tx 90^{th} percentile heat waves amplitude and frequency in Guinea, though only Tx 90^{th} heat waves frequency shows significant patterns over the period 1971-2010. Similar patterns are seen over the former period with significant increases of Tn 90^{th} percentile heat waves amplitude and frequency; and finally over the period 1961-2010 both Tn 90^{th} and Tx 90^{th} percentile heat waves frequency show significant increasing patterns in Guinea. Overall warming trends detected in cold spells duration and warm spells duration indices are supported by those reported by Barry et al. (2014) analyzing West African extremes and Kruger et al. (2014) analyzing South African extremes. The need for cooling houses has also significantly increased over time in Guinea, consistent with warming patterns. Even though in Guinea summer days and tropical nights are not uncommon, it is noteworthy that they have become more common than ever. Since the fourth IPCC assessment report many studies have analyzed local to regional changes in temperature extremes in more detail, specifically addressing different heat wave aspects such as frequency, intensity, duration and spatial extent (Hartmann et al., 2013). Recent available studies also suggest that the number of cold spells has reduced significantly since the 1950s (Donat et al., 2013a, 2013b). However, confidence on a global scale is medium owing to lack of studies over Africa among other reason.

There is no consistent pattern in annual total precipitation changes. The largest trends toward significant decreases in annual total precipitation are observed during the former and 1961-2010 periods with estimated trends at -40.115 mm/decade (significant at 1 %) for 1941-2010 period and -33.052 mm/decade (non-significant) for 1961-2010 period while the recent period show non-significant wetting trends at nationwide level. At regional level Aguilar et al. (2009) found decreasing total precipitation in Guinea contrasting our findings though the periods of studies are different. In addition recent studies found significant decreasing trends in precipitation over WA using GHCNv3 (Global Historical Climatology Network Version 3) data set, GPCC (Global Precipitation Climatology Centre V6) dataset by Becker et al. (2013) and a reconstructed dataset by Smith et al. (2012). On the contrary our results are supported by those from Hartmann et al. (2013) who reported that precipitation has increased over tropical lands area during the last decades. But Hartmann et al. (2013) stated that confidence in precipitation change averaged over global lands area is medium after 1950 because of insufficient data. Furthermore global trends for the period 1951–2008 show a mix of statistically non-significant positive and negative trends in total precipitation changes (Hartmann et al., 2013).

These apparent contradictions can be explained by the difference between the number and length of the series used in the study, as well as quality control and homogenization process carried on these series.

Annual total precipitation results analysis shows that Guinea has seen a succession of periods of deficits and periods of excess rainfall, albeit one cannot talk about cycle. The most significant variations are observed in 1980s, during which there is a fairly significant decrease in annual rainfall. It is likely that human activities have certainly helped increase the phenomenon of drought. We can cite the example of deforestation. Over the decades deforestation has grown considerably so that, although it can not be considered as the main cause of the drought, can not be alien to the decrease in annual rainfall.

At nationwide level annual total precipitation shows significant changes towards drier climate over the former period. Similar significant drying patterns are seen on seasonal precipitation over the former period. Contrariwise, over the period 1961-2010 both nationwide average of annual total precipitation and nationwide average of seasonal rainfall exhibit non-significant changes towards drier climate. Over the recent period, nationwide average of annual total precipitation and nationwide average of wet season precipitation show non-significant changes towards wetting climate; and nationwide average of dry season precipitation show non-significant changes towards drying climate.

Additionally the annual cumulative rainfall is analyzed over two non overlapping periods. The results suggest changes towards a general pattern of drying conditions from the period 1941-1970 to the 1971-2010 one. Comparatively to the period 1941-1970, all stations are deficient over the period 1971-2010, except Faranah. This deficit varies significantly from one station to another. The rainiest stations are affected as much as the driest. Furthermore the four natural regions are also affected by this decline in cumulative annual precipitation though Middle Guinea is less affected. Boke (27.75 %) and Conakry (17.51 %) in Lower Guinea, Kankan (23.93 %) and Siguiri (13.6 %) in Upper Guinea and Macenta (17.12 %) in Forest Guinea are the ones that show the must significant deficit.

Despite all the reservations we have wished to recall the results we report are consistent with other studies. We think especially (thought the periods are not exactly the same) of the study by Nicholson et al. (2000) who stated that rainfall during the period 1968-1997 has been on average 15 to 40 % lower than 1931-1960 rainfall over the West Africa.

The results of the investigation on how ENSO affect Guinea climate extremes suggest increasing annual total precipitation and heavy precipitation days in LN years. These results are corroborated by Druyan (2011), Paeth et al. (2011) and Lutz et al. (2014).

At nationwide level, trends analysis indicates changes in precipitation extremes are consistent with a wetter climate over the recent period, although with a less spatially coherent pattern of change than the temperatures, in that there are stations that show increasing trend and stations that show decreasing trend and a lower level of statistical significance than for temperatures change, in agreement with Sen Roy and Rouault, (2013). Contrariwise trends analysis over the former period is consistent with significant drying climate while analysis over the period 1961-2010 shows non-significant drying climate. Drying weather has also been reported by Aguilar et al. (2009) for Guinea.

ETCCDI (Rx1day and Rx5day) and ET-CRSCI (Rx2day) precipitation absolute indices, like the other indices derived from precipitation show significant decreasing trends over the former period and over the period 1961-2010 except five days rainfall. Over the recent period, five days and two days rainfall show non-significant increase and one day precipitation shows non-significant decrease. Likewise, threshold indices (R10mm, R20mm and R25m) show significant decreasing patterns over the former period, suggesting that the number of heavy, very and extremely heavy precipitation days has significantly decreases. Non-significant drying patterns are seen over the recent period and over the period 1961-2010 except for extremely heavy precipitation days.

Given these results, it would be a significant contribution to refine this study by including data from rain gauge stations to compensate for the lack of data and the spacing of stations. Such efforts are critical for better understanding of climate, how it changes, and how these changes will affect our own lives and well being.

5.2. CONCLUSIONS

Our interest was to construct daily dataset for Guinea and use this dataset to analyze annual, seasonal and a range of temperature and precipitation extreme events. We now refer back to these two objectives, summarizing the main findings. With respect to the first objective, most advanced tools have been used to quality control and homogenized Guinea daily temperatures and precipitation data. One of the most important results of this thesis is that a quality controlled and homogenized yearly, monthly and daily dataset that contains three daily variables, temperature daily minimum, temperature daily maximum and 24 hours accumulated precipitation for Guinea is now available.

With reference to the second objective, first and foremost, in order to assess climate change indices trends spatial and temporal patterns, daily data from Guinea twelve synoptic weather stations have been extensively quality controlled and homogenized to construct the Guinea dataset. In addition, for the first time ever, the constructed dataset has been utilized to analyze climate change over Guinea at nationwide scale. From this dataset a number of yearly, monthly and extremes indices and mean have been calculated and the changes confidence level evaluated. The main findings are summarized follow:

- One of the most salient features regarding the spatial and temporal trend is the predominance warming patterns in both Tx and Tn annual mean.
- There have been no spatially coherent changes in the amount, frequency, intensity, and duration of extreme rainfall events across Guinea as a whole for the study period.
- Changes in extreme precipitation events have occurred on local scales.
- Changes in precipitation extremes are consistent with wetter conditions over the recent period and drier conditions over the former period and over the period 1961-2010.
- The rainiest years are linked to the La Niña.
- Rainfall during the 1971-2010 is on average some 13.6 % to 27.75 % lower than during the period 1941–1970.
- Confidence remains high for long-term decreases in heavy, very heavy and extremely heavy precipitation days but very low in short-term changes at nationwide level.
- It is certain that two days warm spells have increased and two days cold spells have decreased in Guinea.
- It is likely that the frequency of cold days and the frequency of cold night have decreased.
- Confidence is high in the increases of the frequency of warm days and the frequency of warm night.
- It is certain that summer days have increased in Conakry, Kindia, Koundara and Labe.

- It is certain that tropical nights have increased in Kindia and N'Zerekore.

- It is likely that wet season precipitation has increased in Koundara.

- It is likely that very heavy precipitation days have increased in Kissidougou and extremely heavy precipitation days have increased in Kindia.

- Overall three periods emerge from drought indices: the period prior to 1980 characterized by a very wet weather reaching a maximum during mid-1950; the 1980-1990 period which is characterized by a major drought peaking in 1984-85 and; the late and rather wetter period that goes from the second half of the 1990s to nowadays.

- Though there is no consistent regional trend pattern in wet season onset, retreat and length indices findings in these indices worth mentioning. Overall the onset tends to occur 2.2 day per decade late. Similarly wet season cessation tends to delay 1.1 day per decade, thus Guinea has experienced shortened rainy season.

REFERENCES

Aguilar E., Auer I, Brunet M, Peterson TC, Wieringa J. 2003: Guidelines on climate metadata and homogenization. WCDMP-No. 53, WMO-TD No. 1186. World Meteorological Organization, Geneva.

Aguilar E., Barry A, Brunet M, Ekang L, Fernandes A, Massoukina M, Mbah J, Mhanda A, Nascimento D, Peterson TC, et al. (2009): Changes in temperature and precipitation extremes in western Central Africa, Guinea Conakry and Zimbabwe, 1955–2006. J Geophys Res 2009, 114:D02115.

Aguilar E., Barry A.A, Mestre O. (2013): Adjusted monthly and precipitation values for Guinea Conakry (194-2010) using Homer; poster.

Alexander L.V., X. Zhang, T.C. Peterson, J. Caesar, B. Gleason, A.M.G. Klein Tank, M. Haylock, D. Collins, B. Trewin, F. Rahimzadeh, A. Tagipour, K.R. Kumar, J. Revadekar, G. Griffiths, L. Vincent, D.B. Stephenson, J. Burn, E. Aguilar, M. Brunet, M. Taylor, M. New, P. Zhai, M. Rusticucci, and J.L. Vazquez-Aguirre, 2006: Global observed changes in daily climate extremes of temperature and precipitation. Journal of Geophysical Research – Atmospheres, 111, D05109.

Alexander L. V., and J. M. Arblaster, 2009: Assessing trends in observed and modeled climate extremes over Australia in relation to future projections. Int. J. Climatol.,29, 417–435.

Alexander, L. V., P. Uotila, and N. Nicholls, 2009: Influence of sea surface temperature variability on global temperature and precipitation extremes. J. Geophys. Res. Atmos., 114, D18116.

Alexandersson, H., (1986): A homogeneity test applied to precipitation data. J. Climatol., 6: 661–675Allan, R. P., B. J. Soden, V. O. John, W. Ingram, and P. Good, 2010: Current changes in tropical precipitation. Environ. Res. Lett., 5, 025205.

AlSarmi, S., and R. Washington (2011): Recent observed climate change over the Arabian Peninsula, J. Geophys. Res., 116, D11109, doi:10.1029/2010JD015459.

Avila, F. B., A. J. Pitman, M. G. Donat, L. V. Alexander, G. Abramowitz (2012): Climate model simulated changes in temperature extremes due to land cover change, Journal of Geophysical Research-Atmospheres, 117, D04108.

Barnett, T.P., D.W. Pierce, H.G. Hidalgo, C. Bonfils, B.D. Santer, T. Das, G. Bala, A.W. Wood, T. Nozawa, A.A. Mirin, D.R. Cayan, and M.D. Dettinger, 2008: Humaninduced changes in the hydrology of the western United States. Science,319(5866), 1080-1083.

Barry A.A., J. Caesar , A. M. G. Klein Tank, E. Aguilar , Carol McSweeney, Ahmed M. Cyrille, M. P. Nikiema, K. B. Narcisse, F. Sima, G. Stafford, L. M. Touray, J. A Ayilari – Naa, C. L. Mendes,M. Tounkara, V.S. Gar-Glahn, M. S. Coulibaly, M. F. Dieh, , M. Mouhaimouni, E. J. O. Adeleke , E. Sambou, E.T. Laogbessi (2014): West Africa climate extremes and climate change indices (under preparation).

Barrucand, M., M. Rusticucci, and W. Vargas (2008): Temperature extremes in the south of South America in relation to Atlantic Ocean surface temperature and Southern Hemisphere circulation, Journal of Geophysical Research, 113, D20111.

Becker, A., et al., 2013: A description of the global land-surface precipitation data products of the Global Precipitation Climatology Centre with sample applications including centennial (trend) analysis from 1901–present. Earth Syst. Sci.Data, 5, 71–99.

Bindoff, N.L., P.A. Stott, K.M. AchutaRao, M.R. Allen, N. Gillett, D. Gutzler, K. Hansingo, G. Hegerl, Y. Hu, S. Jain, I.I. Mokhov, J. Overland, J. Perlwitz, R. Sebbari and X. Zhang, 2013: Detection and Attribution of Climate Change: from Global to Regional. 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 [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Bollasina, M. A., Y. Ming, and V. Ramaswamy, 2011: Anthropogenic aerosols and the weakening of the South Asian summer monsoon. Science, doi:10.1126/ science.1204994.

Brown, Paula J., Raymond S. Bradley, Frank T. Keimig, 2010: Changes in Extreme Climate Indices for the Northeastern United States, 1870–2005. J. Climate, 23, 6555–6572.

Brunet, M., O. Saladié, P. Jones, J. Sigró, E. Aguilar, A. Moberg, D.Lister, A. Walther and C. Almarza, 2008: A case study/guidance on the development of long-term daily adjusted temperature datasets. WCDMP No. 66 – WMO/TD-No. 1425.

Brunet, M., Jones, P. D., Jourdain, S., Efthymiadis, D., Kerrouche, M. and Boroneant, C. (2013): Data sources for rescuing the rich heritage of Mediterranean historical surface climate data. Geoscience Data Journal.

Burke, E.J., S.J. Brown, and N. Christidis, 2006: Modeling the recent evolution of global drought and projections for the twenty-first century with the Hadley Centre climate model. Journal of Hydrometeorology, 7(5), 1113-1125.

Burke, Eleanor J., Simon J. Brown, 2008: Evaluating Uncertainties in the Projection of Future Drought. J. Hydrometeor, 9, 292–299.

Burkholder, B.A., and D.J. Karoly, 2007: An assessment of US climate variability using the Climate Extremes Index. In: Proceedings of the Nineteenth Conference on Climate Variability and Change, San Antonio, TX, 15-18 January 2007, pp. 2B.9.

Caesar J., Alexander LV, Trewin B, Tse-ring K, Sorany L, Vuniyayawa V, Keosavang N, Shimana A, Htay MM, Karmacharya J, et al.(2011): Changes in temperature and precipitation extremes over the Indo-Pacific region from 1971 to 2005. Int J Climatol 2011, 31:791–801.

Caesar, J., and J. A. Lowe, 2012: Comparing the impacts of mitigation versus nonintervention scenarios on future temperature and precipitation extremes in the HadGEM2 climate model. J. Geophys. Res., 117, D15109.

Camberlin, P., V. Moron, R. Okoola, N. Philippon, and W. Gitau, 2009: Components of rainy seasons' variability in Equatorial East Africa: onset, cessation, rainfall frequency and intensity. Theoretical and Applied Climatology, 98(3-4), 237-249.

Cardona, O., M. van Aalst, J. Birkmann, M. Fordham, G. McGregor, R. Perez, R. Pulwarty, E. Schipper, and B. Sinh (2012): Determinants of risk: Exposure and vulnerability, in Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC), pp. 65–108, Cambridge University Press, Cambridge, UK, and New York, NY, USA.

Cattiaux, J., P. Yiou, and R. Vautard, 2012: Dynamics of future seasonal temperature trends and extremes in Europe: A multi-model analysis from CMIP. Clim. Dyn., 38(9–10), 1949-1964, DOI: 10.1007/s00382-001-1211-1.

Caussinus H. and O. Mestre: Detection and Correction of Artificial Shifts in Climate Series. Journal of the Royal Statistical Society. Series C (Applied Statistics), 405-425

Christensen, J. H., et al., 2007: Regional climate projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller (eds.)] Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 847–940.

Christidis, N., P.A. Stott, S. Brown, G. Hegerl, and J. Caesar, 2005: Detection of changes in temperature extremes during the second half of the 20th century. Geophysical Research Letters, 32, L20716.

Christidis, N., P.A. Stott, G.S. Jones, H. Shiogama, T. Nozawa, and J. Luterbacher, 2011: Human activity and anomalously warm seasons in Europe. International Journal of Climatology,

Cardona, O., M. van Aalst, J. Birkmann, M. Fordham, G. McGregor, R. Perez, R. Pulwarty, E. Schipper, and B. Sinh, Determinants of risk: Exposure and vulnerability. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 65-108, 2012.

Dai, A.G., K.E. Trenberth, and T.T. Qian, 2004: A global dataset of Palmer Drought Severity Index for 1870-2002: Relationship with soil moisture and effects of surface warming. Journal of Hydrometeorology, 5(6), 1117-1130.

Dai, A., (2011a), Drought under global warming: a review. WIREs Clim Change, 2: 45–65. doi: 10.1002/wcc.81

Dai, A., 2011b: Characteristics and trends in various forms of the Palmer Drought Severity Index during 1900–2008. J. Geophys. Res. Atmos., 116, D12115.

Dai, A., 2013: Increasing drought under global warming in observations and models. Nature Clim. Change, 3, 52–58.

Dean, S.M. and P.A. Stott, 2009: The effect of local circulation variability on the detection and attribution of New Zealand temperature trends. Journal of Climate, 22, 6217-6229.

Deser, C., A. Phillips, V. Bourdette, and H. Y. Teng, 2012: Uncertainty in climate change projections: The role of internal variability. Clim. Dyn., 38, 527–546.

Donat, M.G., L. V. Alexander, H. Yang, I. Durre, R. Vose, R. J. H. Dunn, K. M. Willett, E. Aguilar, M. Brunet, J. Caesar, B. Hewitson, C. Jack, A. M. G. Klein Tank, A. C. Kruger, J. Marengo, T. C. Peterson, M. Renom, C. Oria Rojas, M. Rusticucci, J. Salinger, A. S. Elrayah, S. S. Sekele, A. K. Srivastava, B. Trewin, C. Villarroel, L. A. Vincent, P. Zhai, X. Zhang, S. Kitching (2013a): Updated analyses of temperature and precipitation extreme indices since the beginning of the twentieth century: The HadEX2 dataset, J. Geophys. Res. Atmos., 118, 2098–2118

Donat, M. G., L. V. Alexander, H. Yang, I. Durre, R. Vose, and J. Caesar, 2013b: Global land-based datasets for monitoring climatic extremes. Bull. Am. Meteor. Soc., 94, 997-1006.

Donat, M. G., et al., 2013c: Changes in extreme temperature and precipitation in the Arab region: Long-term trends and variability related to ENSO and NAO. Int. J. Climatol., doi:10.1002/joc.3707.

Druyan, L. M., (2011): Studies of 21st-century precipitation trends over West Africa. Int. J. Climatol., 31: 1415–1424. doi: 10.1002/joc.2180

Dulière, V., Yongxin Zhang, and Eric P. Salathé, 2013: Changes in Twentieth-Century Extreme Temperature and Precipitation over the Western United States Based on Observations and Regional Climate Model Simulations*. J. Climate, 26, 8556–8575.

Easterling, W.E, and Kates, RW., (1995): Indexes of leading climate indicators for impact assessment, Clim.Change, 31, 623-648.

Feulner, G., 2011: Are the most recent estimates for Maunder Minimum solar irradiance in agreement with temperature reconstructions? Geophys. Res. Lett., 38, L16706

Feyen, L. and Dankers R., 2009: Impact of global warming on streamflow drought in Europe. Journal of Geophysical Research – Atmospheres, 114, D17116.

Folland C.K., C. Miller, O. Bader,M. Crowe, P. Jones, N. Plumer, M. Richman, O.E. Parker,J. Rogers and P. Scholefield (1999): Workshop on indices and indicators for climate extremes, Asheville, NC, USA,3-6 June 1997, Climatic Change 42:31-43,199.

Folland CK ., Karl TR, Christy JR, Clarke RA, Gruza GV, Jouzel J, Mann ME, Oerlemans J, Salinger MJ, Wang SW. 2001: Observed climate variability and change. In Climate Change 2001: The Scientific Basis – Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press: New York; pp 99–181.

Freitas, L., Pereira M.G., Amorim L., Caramelo L., Mendes M., and Nunes F.L, (2013): Homogeneity of monthly air temperature in Portugal with HOMER and MASH, IDŐJÁRÁS Quarterly Journal of the Hungarian Meteorological Service Vol. 117, No. 1, January–March 2013, pp. 69–90

Frich, P., L. Alexander, P. Della-Marta, B. Gleason, M. Haylock, A. Klein Tank, and T. Peterson (2002): Observed coherent changes in climate extremes during the second half of the twentieth century, Clim. Res., 19, 193–212.

Fyfe, J. C., N. P. Gillett, and G. J. Marshall, 2012: Human influence on extra tropical Southern Hemisphere summer precipitation. Geophys. Res. Lett., 39, L23711.

Gandin, Lev S., 1988: Complex Quality Control of Meteorological Observations. Mon. Wea. Rev., 116, 1137–1156.

Gillett, N.P., D.A. Stone, P.A. Stott, T. Nozawa, A.Y. Karpechko, G.C. Hegerl, M.F. Wehner, and P.D. Jones, 2008: Attribution of polar warming to human influence. Nature Geoscience, 1, 750-754

Griffiths, G.M., M.J. Salinger, and I. Leleu, 2003: Trends in extreme daily rainfall across the South Pacific and relationship to the South Pacific Convergence Zone. International Journal of Climatology, 23(8), 847-869.

Guijarro A.,(2011): An R contributed package for homogenization of climatological series (and functions for drawing wind-rose and Walter&Lieth diagrams) Version 2.1, distributed under the GPL license (http://webs.ono.com/climatol/climatol.html).

Guinea : Ministère de l'agriculture, de l'élevage, de l'environnement, des eaux et forets, Guinée (2007): Plan d'action national d'adaptation aux changements climatiques de la république de Guinée.

Guttman, N. B., 1999: Accepting the Standardized Precipitation Index: a calculation algorithm, J. Am. Water Resour. As., 35, 311–322.

Gutowski, W.J., G.C. Hegerl, G.J. Holland, T.R. Knutson, L.O. Mearns, R.J. Stouffer, P.J. Webster, M.F. Wehner, and F.W. Zwiers, 2008a: Causes of observed changes in extremes and projections of future changes. In: Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands. [Karl, T.R., G.A. Meehl, D.M. Christopher, S.J. Hassol, A.M. Waple, and W.L. Murray (eds.)].A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC, pp. 81-116.

Gutowski, W.J., S.S. Willis, J.C. Patton, B.R.J. Schwedler, R.W. Arritt, and E.S. Takle, 2008b: Changes in extreme, cold-season synoptic precipitation events under global warming. Geophysical Research Letters, 35, L20710.

Hanel, M. and Buishand T. A., 2011: Analysis of precipitation extremes in an ensemble of transient regional climate model simulations for the Rhine basin. Clim. Dyn., 36, 1135–1153.

Hartmann, D.L., A.M.G. Klein Tank, M. Rusticucci, L.V. Alexander, S. Brönnimann, Y. Charabi, F.J. Dentener, E.J. Dlugokencky, D.R. Easterling, A. Kaplan, B.J. Soden, P.W. Thorne, M. Wild and P.M. Zhai, 2013: Observations: Atmosphere and Surface. 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 [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Haylock MR., et al. (2006): Trends in total and extreme South American rainfall 1960–2000 and links with sea surface temperature. J Climate 2006, 19:1490–1512.

Hegerl, G.C., F.W. Zwiers, P. Braconnot, N.P. Gillett, Y. Luo, J.A. Marengo Orsini, N. Nicholls, J.E. Penner, and P.A. Stott, 2007: Understanding and Attributing Climate Change. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK, pp. 663-745

Hegerl, G., J. Luterbacher, F. Gonzalez-Rouco, S. F. B. Tett, T. Crowley, and E. Xoplaki, 2011: Influence of human and natural forcing on European seasonal temperatures. Nature Geosci., 4, 99–103.

Held, I.M. and Soden B.J., 2006: Robust responses of the hydrological cycle to global warming. Journal of Climate, 19(21), 5686-5699.

Heim, Richard R., 2002: A Review of Twentieth-Century Drought Indices Used in the United States. Bull. Amer. Meteor. Soc., 83, 1149–1165.

Heinrich, G., and A. Gobiet, 2011: The future of dry and wet spells in Europe: A comprehensive study based on the ENSEMBLES regional climate models. Int. J.Climatol, doi:658 10.1002/joc.2421.

Herath, S. and U. Ratnayake, 2004: Monitoring rainfall trends to predict adverse impacts – a case study from Sri Lanka (1964-1993). Global Environmental Change – Human and Policy Dimensions, 14(1), 71-79.

Hirabayashi, Y., S. Kanae, S. Emori, T. Oki, and M. Kimoto, 2008: Global projections of changing risks of floods and droughts in a changing climate. Hydrological Sciences Journal, 53(4), 754-772.

Hulme M., Ruth Doherty, Todd Ngara, Mark New and David Lister (2001): African climate change: 1900-2100; Published in Climate Research Vol. 17, No. 2. Online publication date: August 15, 2001

Im, E. S., Jung, I. W. and Bae, D. H. (2011): The temporal and spatial structures of recent and future trends in extreme indices over Korea from a regional climate projection. Int. J. Climatol., 31: 72–86.

Institut National de la Statistique, Guinea (2014): http://www.stat-guinee.org (last visit 01/09/2014)

IPCC, 2012: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp.

Jones, G. S., P. A. Stott, and N. Christidis (2008), Human contribution to rapidly increasing frequency of very warm Northern Hemisphere summers, J. Geophys. Res., 113, D02109

Jones, P. D., and M. Hulme (1996): Calculating regional climatic time series for temperature and precipitation: Methods and illustrations, Int. J. Climatol., 16, 361–377.

Jones, P. D., D. H. Lister, T. J. Osborn, C. Harpham, M. Salmon, and C. P. Morice, 2012: Hemispheric and large-scale land-surface air temperature variations: An extensive revision and an update to 2010. J. Geophys. Res. Atmos., 117, D05127.

Karl, T. R., P. J. Young, and W. M. Wendland, 1986: A model to estimate the time of observation bias associated with monthly mean maximum, minimum, and mean temperature for the United States. J. Climate Appl. Meteor., 25,145–160.

Karl, T. R., and C. N. Williams, 1987: An approach to adjusting climatological time series for discontinuous inhomogeneities. J. Climate Appl. Meteor., 26, 1744–1763.

Karl L.T., N.Nicholls and A. Ghazi (1999): CLIVAR/GCOS/WMO Workshop on indices and indicators for climate extremes, Workshop summary, Climatic Change 42: 3-7.

Kaufman, D. S., David P. Schneider, Nicholas P. McKay, Caspar M. Ammann, Raymond S. Bradley, Keith R. Briffa, Gifford H. Miller, Bette L. Otto-Bliesner, Jonathan T. Overpeck, Bo M. Vinther, Arctic Lakes 2k Project Members:2009: Recent warming reverses long-term arctic cooling. Science, 325, 1236–1239

Kiktev, D., D. M. H. Sexton, L. Alexander, and C. K. Folland (2003): Comparison of modeled and observed trends in indices of daily climate extremes, J. Climate, 16, 3560–3571.

Kirtman, B., S.B. Power, J.A. Adedoyin, G.J. Boer, R. Bojariu, I. Camilloni, F.J. Doblas-Reyes, A.M. Fiore, M. Kimoto, G.A. Meehl, M. Prather, A. Sarr, C. Schär, R. Sutton, G.J. van Oldenborgh, G. Vecchi and H.J. Wang, 2013: Near-term Climate Change: Projections and Predictability. 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 [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Klein Tank AMG., et al. (2006) Changes in daily temperature and precipitation extremes in central and south Asia. J Geophys Res 2006.

Klein Tank, A. M. G., F. W. Zwiers, and X. Zhang (2009): Guidelines on analysis of extremes in a changing climate in support of informed decisions for adaptation, Climate data and monitoring WCDMP-No. 72, WMO-TD No. 1500, 56pp.

Kruger, A.C., 2006: Observed trends in daily precipitation indices in South Africa: 1910-2004. International Journal of Climatology, 26(15), 2275-2285.

Kruger, A. C. and Sekele, S. S., (2013): Trends in extreme temperature indices in South Africa: 1962–2009. Int. J. Climatol., 33: 661–676.

Kuglitsch, F.G., A. Toreti, E. Xoplaki, P.M. Della-Marta, J. Luterbacher, and H. Wanner, 2009: Homogenization of daily maximum temperature series in the Mediterranean. Journal of Geophysical Research – Atmospheres, 114, D15108.

Lawrimore, J. H., M. J. Menne, B. E. Gleason, C. N. Williams, D. B. Wuertz, R. S. Vose, and J. Rennie, 2011: An overview of the Global Historical Climatology Network monthly mean temperature data set, version 3. J. Geophys. Res. Atmos., 116, D19121.

Lloyd-Hughes, B. and Saunders, M. A., (2002): A drought climatology for Europe. Int. J. Climatol., 22: 1571–1592. doi: 10.1002/joc.846

Losada T., Rodriguez-Fonseca B, Mohino E, Janicot S, Mechoso CR. 2012: Tropical SST and Sahel rainfall: a non-stationary relationship. Geophys. Res. Lett. 39: L12705, DOI: 10.1029/2012GL05423.

Lutz, K., Jacobeit, J. and Rathmann, J. (2014): Atlantic warm and cold water events and impact on African west coast precipitation. Int. J. Climatol.. doi: 10.1002/joc.3969

Manton, M.J., P.M. Della-Marta, M.R. Haylock, K.J. Hennessy, N. Nicholls, L.E. Chambers, D.A. Collins, G. Daw, A. Finet, D. Gunawan, K. Inape, H. Isobe, T.S. Kestin, P. Lefale, C.H. Leyu, T. Lwin, L. Maitrepierre, N. Ouprasitwong, C.M. Page, J. Pahalad, N. Plummer, M.J. Salinger, R. Suppiah, V.L. Tran, B. Trewin, I. Tibig, and D. Yee, 2001: Trends in extreme daily rainfall and temperature in Southeast Asia and the South Pacific: 1961–1998. International Journal of Climatology, 21(3), 269-284.

Marcott, S. A., J. D. Shakun, P. U. Clark, and A. C. Mix, 2013: A reconstruction of regional and global temperature for the past 11,300 years. Science, 339, 1198–1201

Mark S., Mickael Hayes; Deborah A. Wood, (2012): Standardized Precipitation Index User Guide, World Meteorological Organization WMO-No. 1090, Geneva, Switzerland.

McKee, T.B., N. J. Doesken, and J. Kliest, 1993: The relationship of drought frequency and duration to time scales. In Proceedings of the 8th Conference of Applied Climatology, 17-22 January, Anaheim, CA. American Meterological Society, Boston, MA. 179-184.

Meehl, G. A., et al., 2012: Climate system response to external forcings and climate change projections in CCSM4. J. Clim., 25, 3661–3683.

Mestre O., Domonkos P, Picard F, Auer I, Robin S, Lebarbier E, Böhm R, Aguilar E , Guijarro J, Vertacnik G, Klancar M, Dubuisson B, Stepanek P: 2013 HOMER : HOMogenisation softwarE in R- methods and applications.Idöjárás 117, 47-67

Min, S.K., and A. Hense, 2007: A Bayesian assessment of climate change using multimodel ensembles. Part II: Regional and seasonal mean surface temperatures. Journal of Climate, 20(12), 2769-2790.

Min, S.-K., X. Zhang, F.W. Zwiers, and G.C. Hegerl, 2011: Human contribution to more intense precipitation extremes. Nature, 470(7334), 378-381.

Mokssit, A. (2003), Development of priority climate indices for Africa: A CCI/CLIVAR workshop of the World Meteorological Organization, in Mediterranean Climate: Variability and Trends, edited by H. J. Bolle, pp. 116–123, Springer, New York.

Morak, S., Gabriele C. Hegerl, Nikolaos Christidis, 2013: Detectable Changes in the Frequency of Temperature Extremes. J. Climate, 26, 1561–1574.

Nairn, J., R. Fawcett, and D. Ray, 2009: Defining and predicting excessive heat events: A national system. CAWCR Tech. Rep.017, 83–86.

New, M., B. Hewitson, D.B. Stephenson, A. Tsiga, A. Kruger, A. Manhique, B. Gomez, C.A.S. Coelho, D.N. Masisi, E. Kulunaga, E. Mbambalala, F. Adesina, H. Saleh, J. Kanyanga, J. Adosi, L. Bulane, L. Fortunata, M.L. Mdoka, and R. Lajoie, 2006: Evidence of trends in daily climate extremes over southern and west Africa. Journal of Geophysical Research, 111, D14102.

Nichollls N. and William M., (1999): Workshop on indices and indicators for climate estremes, Asheville, NC, USA,3-6 June 1997 Breakout group B: Precipitation, Climatic Change 42:23-29,1999.

Nicholson S. E., B. Some, and B. Kone, (2000): An Analysis of Recent Rainfall Conditions in West Africa, Including the Rainy Seasons of the 1997 El Niño and the 1998 La Niña Years. J. Climate, 13, 2628–2640.

O'Gorman, P.A. and T. Schneider, 2009a: The physical basis for increases in precipitation extremes in simulations of 21st-century climate change. Proceedings of the National Academy of Sciences, 106(35), 14773-14777.

O'Gorman, P.A., and T. Schneider, 2009b: Scaling of precipitation extremes over a wide range of climates simulated with an idealized GCM. Journal of Climate, 22(21), 5676-5685.

Orlowsky, B., and S. I. Seneviratne (2012): Global changes in extreme events: Regional and seasonal dimension, Clim. Chang., 110, 669–696.

Osborn, T. J., K. R. Briffa, and P. D. Jones (1997): Adjusting variance for sample-size in tree-ring chronologies and other regional-mean time-series, Dendrochronologia, 15, 89–99.

Paeth, H., Fink, A. H., Pohle, S., Keis, F., Mächel, H. and Samimi, C. (2011): Meteorological characteristics and potential causes of the 2007 flood in sub-Saharan Africa. Int. J. Climatol., 31: 1908–1926. doi: 10.1002/joc.2199

Pall, P., M.R. Allen, and D.A. Stone, 2007: Testing the Clausius-Clapeyron constraint on changes in extreme precipitation under CO2 warming. Climate Dynamics, 28(4), 351-363.

Pall, P., T. Aina, D.A. Stone, P.A. Stott, T. Nozawa, A.G.J. Hilbberts, D. Lohmann, and M.R. Allen, 2011: Anthropogenic greenhouse gas contribution to flood risk in England and Wales in autumn 2000. Nature, 470(7334), 382-385.

Palmer, W.C., 1965: Meteorological Drought. Report 45, US Weather Bureau, Washington, DC.

Parker, D. E., T. A. Basnett, S. J. Brown, M. Gordon, E. B. Horton, and N. A. Rayner, 2000: Climate observations—The instrumental record. Space Sci. Rev., 94, 309–320.

Patz, J. A., D. Campbell-Lendrum, T. Holloway, and J. A. Foley (2005): Impact of regional climate change on human health, Nat. Rev., 438, 310–317.

Peterson, T. C., Vose, R., Schmoyer, R. and Razuvaëv, V. (1998a): Global historical climatology network (GHCN) quality control of monthly temperature data. Int. J. Climatol., 18: 1169–1179.

Peterson, T. C., Easterling, D. R., Karl, T. R., Groisman, P., Nicholls, N., Plummer, N., Torok, S., Auer, I., Boehm, R., Gullett, D., Vincent, L., Heino, R., Tuomenvirta, H., Mestre, O., Szentimrey, T., Salinger, J., Førland, E. J., Hanssen-Bauer, I., Alexandersson, H., Jones, P. and Parker, D. (1998b): Homogeneity adjustments of in situ atmospheric climate data: a review. Int. J. Climatol., 18: 1493–1517.

Peterson, T.C., and Coauthors (2001): Report on the Activities of the Working Group on Climate Change Detection and Related Rapporteurs 1998-2001. WMO, Rep. WCDMP-47, WMO-TD 1071, Geneve, Switzerland, 143pp.

Peterson, T.C., M.A. Taylor, R. Demerritte, D.L. Duncombe, S. Burton, F. Thompson, A. Porter, M. Mercedes, E. Villegas, R.S. Fils, A. Klein Tank, A. Martis, R. Warner, A. Joyette, W. Mills, L. Alexander, and B. Gleason, 2002: Recent changes in climate extremes in the Caribbean region. Journal of Geophysical Research – Atmospheres, 107, 4601.

Perkins, S. E., L. V. Alexander, 2013: On the Measurement of Heat Waves. J. Climate, 26, 4500–4517. doi: http://dx.doi.org/10.1175/JCLI-D-12-00383.1

Pezza, A. B., P. van Rensch, and W. Cai, 2012: Severe heat waves in southern Australia: Synoptic climatology and large scale connections. Climate Dyn., 38, 209–224, doi:10.1007/ s00382-011-1016-2.

Picard, F., Lebarbier, E., Hoebeke, M., Rigaill, G., Thiam, B. and Robin, S., 2011: Joint segmentation, calling and normalization of multiple CGH profiles. Biostatistics 12, 413–428.

Portmann, R.W., S. Solomon, and G. C. Hegerl (2009): Spatial and seasonal patterns in climate change, temperatures, and precipitation across the United States, Proc. Nat. Acad. Sci., 106, 7324–7329.

Power, S. B., F. Delage, R. Colman, and A. Moise, 2012: Consensus on 21st century rainfall projections in climate models more widespread than previously thought.J. Clim., doi::10.1175/JCLI-D-11-00354.1.

Radinović, D., and M. Ćurić (2012): Criteria for heat a nd cold wave duration indexes, Theor. Appl. Climatol., 107, 505–510.

Rajczak, J., P. Pall, and C. Schär (2013): Projections of extreme precipitation events in regional climate simulations for Europe and the Alpine Region, J. Geophys. Res. Atmos., 118, 3610–3626, doi:10.1002/jgrd.50297.

Renom M., M. Rusticucci, and M. Barreiro (2011): Multidecadal changes in the relationship between extreme temperature events in Uruguay and the general atmospheric circulation, Climate Dynamics, 37 (11–12), 2471–2480.

Robinson, W. A., R. Ruedy, and J. E. Hansen (2002): General circulation model simulations of recent cooling in the east-central United States, Journal of Geophysical Research, 107, no. D24, 4748

Rohde, R., et al., 2013: Berkeley Earth temperature averaging process. Geoinfor Geostat: An Overview, 1, doi:10.4172/gigs.1000103.

Rodríguez-Fonseca, B., Janicot, S., Mohino, E., Losada, T., Bader, J., Caminade, C., Chauvin, F., Fontaine, B., García-Serrano, J., Gervois, S., Joly, M., Polo, I., Ruti, P., Roucou, P. and Voldoire, A. (2011): Interannual and decadal SST-forced responses of the West African monsoon. Atmosph. Sci. Lett., 12: 67–74. doi: 10.1002/asl.308

Santer, B.D., C. Mears, F.J. Wentz, K.E. Taylor, P.J. Gleckler, T.M.L. Wigley, T.P. Barnett, J.S. Boyle, W. Bruggemann, N.P. Gillett, S.A. Klein, G.A. Meehl, T. Nozawa, D.W. Pierce, P.A. Stott, W.M. Washington, and M.F. Wehner, 2007: Identification of human-induced changes in atmospheric moisture content. Proceedings of the National Academy of Sciences, 104(39), 15248-15253.

Scaife, A. A., C. K. Folland, L. V. Alexander, A. Moberg, and J. R. Knight (2008): European climate extremes and the North Atlantic Oscillation, Journal Climate, 21, 72–83.

Schurer, A., G. Hegerl, M. E. Mann, S. F. B. Tett, and S. J. Phipps, 2013: Separating forced from chaotic climate variability over the past millennium. J. Clim., doi:10.1175/JCLI-D-12-00826.1.

Seneviratne, S.I., N. Nicholls, D. Easterling, C.M. Goodess, S. Kanae, J. Kossin, Y. Luo, J. Marengo, K. McInnes, M. Rahimi, M. Reichstein, A. Sorteberg, C. Vera, and X. Zhang, 2012: Changes in climate extremes and their impacts on the natural physical environment. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 109-230.

Sheffield, J. and Wood E.F., 2008: Global trends and variability in soil moisture and drought characteristics, 1950-2000, from observation-driven simulations of the terrestrial hydrologic cycle. Journal of Climate, 21(3), 432-458.

Sheffield, J., E. Wood, and M. Roderick, 2012: Little change in global drought over the past 60 years. Nature, 491, 435

Seleshi, Y. and Camberlin P., 2006: Recent changes in dry spell and extreme rainfall events in Ethiopia. Theoretical and Applied Climatology, 83(1-4), 181-191.

Sen Roy, S. and Rouault M., 2013: Spatial patterns of seasonal scale trends in extreme hourly precipitation in South Africa. Appl. Geogr., 39, 151–157.

Shahid, S., (2011): Trends in extreme rainfall events of Bengladesh. Theoretical and Applied Climatology, Volume 104, Issue 3-4 , pp 489-499

Shongwe, M.E., G.J. van Oldenborgh, B.J.J.M. van den Hurk, B. de Boer, C.A.S. Coelho, and M.K. van Aalst, 2009: Projected changes in mean and extreme precipitation in Africa under global warming. Part I: Southern Africa. Journal of Climate, 22(13), 3819-3837.

Shongwe, M.E., G.J. van Oldenborgh, B.J.J.M. van den Hurk, B. de Boer, C.A.S. Coelho, and M.K. van Aalst, 2011: Projected changes in mean and extreme precipitation in Africa under global warming. Part II: East Africa. Journal of Climate, 24(14), 3718-3732.

Sillmann, J., and E. Roeckner (2008): Indices for extreme climate events in projections of anthropogenic climate change, Clim. Change, 83–104.

Sillmann, J., V. V. Kharin, X. Zhang, F. W. Zwiers, and D. Bronaugh (2013a): Climate extremes indices in the CMIP5 multi-model ensemble: Part 1. Model evaluation in the present climate, J. Geophys. Res. Atmos., 118, 1716–1733.

Sillmann, J., V. V. Kharin, F. W. Zwiers, X. Zhang, and D. Bronaugh (2013b): Climate extremes indices in the CMIP5 multimodel ensemble: Part 2. Future climate projections, J. Geophys. Res. Atmos., 118, 2473–2493.

Smith, T. M., P. A. Arkin, L. Ren, and S. S. P. Shen, 2012: Improved reconstruction of global precipitation since 1900. J. Atmos. Ocean. Technol., 29, 1505–1517.

Stott, P.A., D.A. Stone, and M.R. Allen, 2004: Human contribution to the European heat wave of 2003. Nature, 432(7017), 610-614.

Stott, P. A., Gillett, N. P., Hegerl, G. C., Karoly, D. J., Stone, D. A., Zhang, X. and Zwiers, F. (2010): Detection and attribution of climate change: a regional perspective. WIREs Clim Change, 1: 192–211.

Sugiyama, M., H. Shiogama, and S. Emori, 2010: Precipitation extreme changes exceeding moisture content increases in MIROC and IPCC climate models. Proceedings of the National Academy of Sciences, 107(2), 571-575.

Tebaldi, C., K. Hayhoe, J.M. Arblaster, and G.A. Meehl, 2006: Going to the extremes. An intercomparison of model-simulated historical and future changes in extreme events. Climatic Change, 79(3-4), 185-211.

Tebaldi, C., J. M. Arblaster, and R. Knutti, 2011: Mapping model agreement on future climate projections. Geophys. Res. Lett., 38, L23701.

Terando, A., K. Keller, and W. E. Easterling (2012): Probabilistic projections of agro-climate indices in North America, J. Geophys. Res., 117, D08115.

Thompson, D., J. J. Kennedy, J. M. Wallace, and P. D. Jones, 2008: A large discontinuity in the mid-twentieth century observed global-mean surface temperature. Nature, 453, 646–649.

Trenberth, K.E., P.D. Jones, P. Ambenje, R. Bojariu, D. Easterling, A. Klein Tank, D. Parker, F. Rahimzadeh, J.A. Renwick, M. Rusticucci, B. Solden, and P. Zhai, 2007: Observations: Surface and atmospheric climate change. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, pp. 235-336.

Trewin, B., (2010): Exposure, instrumentation, and observing practice effects on land temperature measurements. WIREs Clim Change, 1: 490–506.

UNDP., United Nations Development Program (2009): UNDP project document Increasing resilience and adaptation to adverse impacts of climate change in Guinea's vulnerable coastal zones. Available at http://www.thegef.org/gef/sites/thegef.org/files/documents/document/12-01-09%20Council%20document.pdf

van der Schrier, G., J. Barichivich, K. R. Briffa, and P. D. Jones, 2013: A scPDSI-based global dataset of dry and wet spells for 1901–2009. J. Geophys. Res. Atmos., 118, 4025-4048.

Vidal, J., E. Martin, L. Franchisteguy, F. Habets, J. Soubeyroux, M. Blanchard, and M. Baillon, 2010: Multilevel and multiscale drought reanalysis over France with the Safran-Isba-Modcou hydrometeorological suite. Hydrol. Earth Syst. Sci., 14, 459–478.

Vincent, Lucie A., X. Zhang, B. R. Bonsal, W. D. Hogg, 2002: Homogenization of Daily Temperatures over Canada. J. Climate, 15, 1322–1334.

Vincent LA., Anguilar E, Saindou M, Hassane AF, Jumaux G, Roy D, Booneeady P, Virasami R, Randriamarolaza LYA, Faniriantsoa FR. (2011): Observed trends in indices of daily and extreme temperature and precipitation for the countries of the western Indian Ocean, 1961–2008. J. Geophys. Res., 116.

Vicente-Serrano, Sergio M., Santiago Beguería, and Juan I. López-Moreno, 2010: A Multiscalar Drought Index Sensitive to Global Warming: The Standardized Precipitation Evapotranspiration Index. J. Climate, 23, 1696–1718.

Vizy, Edward K., Kerry H. Cook, 2012: Mid-Twenty-First-Century Changes in Extreme Events over Northern and Tropical Africa. J. Climate, 25, 5748–5767.

Wang, B., and LinHo (2002): Rainy season of the Asian-Pacific summer monsoon, J. Climate, 15, 386–398.

Wang, J. and X. Zhang, 2008: Downscaling and projection of winter extreme daily precipitation over North America. Journal of Climate, 21(5), 923-937.

Wang, H. J., JIAN-QI SUN, Huo-Po Chen, Ya-LI Zhu, Ying Zhang, Da-Bang Jiang, Xian-Mei Lang, Ke Fan, En-Tao Yu, and Aang Song yang, 2012: Extreme climate in China: Facts, simulation and projection. Meteorol. Z., 21(3), 279–304.

Weisskopf, M. G., H. A. Anderson, S. Foldy, L. P. Hanrahan, K. Blair, T. J. Trk, and P. D. Rumm (2002): Heat wave morbidity and mortality, Milwaukee, Wis, 1999 vs 1995: An improved response?, Am. J. Public Health, 92, 830–833.

Willett, K.M., N.P. Gillett, P.D. Jones, and P.W. Thorne, 2007: Attribution of observed surface humidity changes to human influence. Nature, 449(7163), 710-712.

WMO. 2011: Guidelines to climatological practices, WMO No. 100, World Meteorological Organization, Geneva, Switzerland.

Yue, X., H. Liao, H. Wang, S. Li, and J. Tang, 2011: Role of sea surface temperature responses in simulation of the climatic effect of mineral dust aerosol,. Atmos. Chem. Phys., 11, 6049-6069, doi: 10.5194/acp-11-6049-2011.

Zhang, X., G. Hegerl, F. Zwiers, and J. Kenyon (2005a): Avoiding inhomogeneity in percentile-based indices of temperature extremes, J. Climate, 1641–1651

Zhang X., Aguilar E, Sensoy S, Melkonyan H, Tagiyeva U, Ahmed N, Kutaladze N, Rahimzadeh F, Taghipour A, Hantosh TH, et al. (2005b): Trends in Middle East climate extremes indices during 1930–2003. J Geophys Res 2005, 110:D22104.

Zhang, X., L. Alexander, G. C. Hegerl, P. Jones, A. K. Tank, T. C. Peterson, B. Trewin, and F. W. Zwiers (2011): Indices for monitoring changes in extremes based on daily temperature and precipitation data, WIREs Clim. Change. 2, 851–870.

Zhang Xuebin and Yue-Pilon (2013): Package ZYP (http://cran.rproject.org/web/packages/zyp/zyp.pdf)

Zhou Y, Ren G., 2011: Change in extreme temperature event frequency over mainland China, 1961–2008. Climate Resarch 50: 125–139. DOI: 10.3354/cr01053.

Zwiers, F.W., X. Zhang, and Y. Feng, 2011: Anthropogenic influence on long return period daily temperature extremes at regional scales. Journal of Climate, 24(3), 881-892.