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Climate services platform to support information on projected changes on climate indices: Case of West Africa

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DEDICATION

This thesis is dedicated to my loving parents, siblings, and my religious guide Cheikh Mouhamadou Fadel Mbacké. Thank you for your unwavering moral and financial support, as well as your prayers.

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ABSTRACT

Extreme climate events in West Africa have increased, posing potential risks and harmful consequences for the region's natural ecosystems and human populations. In order to develop effective adaptation strategies, it is essential to have access to information on these extreme events. Climate services are important in providing information about the climate to assist in decision-making. This study aimed to develop a web-based climate services platform that specifically addresses changes in rainfall and temperature extremes indices in West Africa. The study used data from the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6) with a spatial resolution of 25 km. Projections were made under three Shared Socio-economic Pathways (SSP1……) for the near future (2031–2060) and far future (2071–2100). 14 indices of the Expert Team on Climate Change Detection and Indices (ETCCDI) were used for this study. First, the ensemble mean of 15 NEX-GDDP-CMIP6 models was compared with observational data (CHIRPS and ERA5) for the period 1985–2014 over West Africa considering variables such as maximum, minimum, and mean temperature as well as precipitation. The results showed that the ensemble mean of the models and the observational data have similar patterns, although the ensemble mean of the models tends to overestimate in certain areas. Subsequently, the changes in the aforementioned indices were projected for Burkina Faso as a case study. The findings clearly showed the influence of global warming on all regions of the country. The projections of temperature extreme indices are more pronounced with the SSP585 scenario and towards the end of the century. In contrast to temperature changes, precipitation changes in Burkina Faso exhibited distinct variations displaying a combination of increasing and decreasing trends. To better understand these indices in the easiest way, a web-based platform was developed. Its aim is to make these indices accessible through an interface, enabling users to gain a comprehensive understanding of future climate indices projections in regional and local contexts across West Africa.

Keywords: Climate services; Climate indices; CMIP6; Burkina Faso; West Africa.

RESUME

Les événements climatiques extrêmes en Afrique de l'Ouest ont augmenté, entraînant des risques potentiels et des conséquences néfastes sur l'écosystème et la population. Afin de développer des stratégies d'adaptation efficaces, il est essentiel d'avoir accès à des informations sur ces évènements extrêmes. Les services climatiques jouent un rôle très important dans la fourniture des informations climatiques afin d'aider à la prise de décision. Cette étude visait à développer une plateforme de suivi des indices d'extrêmes climatiques en Afrique de l'Ouest. L'étude utilise des données provenant de la NEX-GDDP-CMIP6 avec une résolution spatiale de 25 km. Les projections ont été réalisés selon trois trajectoires socio-économiques partagées (SSP1...) pour le futur proche (2031-2060) et le futur lointain (2071-2100). 14 indices du Groupe d'experts sur la détection et les indices du changement climatique (ETCCDI), ont été utilisés pour cette étude. Dans un premier temps, nous avons comparé la moyenne des 15 modèles du NEX-GDDP-CMIP6 aux données d'observation (CHIRPS et ERA5) pour la période 1985-2014 en Afrique de l'Ouest, en tenant compte de variables telles que la température maximale, minimale et moyenne, ainsi que les précipitations. Les résultats ont montré que la moyenne des modèles et les données d'observation présentent des schémas similaires, bien que la moyenne des modèles à tendance de surestimer dans certaines régions. Ensuite, les changements dans les indices mentionnés ont été projetés pour le Burkina Faso à titre d'étude de cas. Les résultats ont montré clairement l'influence du réchauffement climatique sur toutes les régions du pays. Les projections des indices extrêmes de température sont plus marquées avec le scénario SSP585 et dans le futur lointain (2071-2100). En contraste avec les changements de température, les variations des précipitations au Burkina Faso ont montré des différences marquées, affichant une combinaison de tendances à la hausse et à la baisse. Pour enrichir la compréhension de ces indices, une plateforme a été développée pour rendre ces indices accessibles via une interface de visualisation, permettant aux utilisateurs de comprendre de manière approfondie les projections futures des indices climatiques dans des contextes régionaux et locaux en Afrique de l'Ouest.

Mots clés : Services climatiques ; Indices climatiques ; CMIP6 ; Burkina Faso; Afrique de l'Ouest.

Contents

ACRONYMS AND ABBREVIATIONS

WASCAL : West African Science Service Centre on Climate Change and Adapted Land Use.

EDICC : Ecole Doctorale Informatique et Changement Climatique

UN : United Nation

IPCC : Intergovernmental Panel on Climate Change

GDP : Gross Domestic Product

WMO : World Meteorological Organization.

CHIRPS : Climate Hazards Group InfraRed Precipitation with Station data

GFCS : Global Framework for Climate Services

BMBF : German Ministry of Education and Research

GSP : Graduate Study Program

NASA : National Aeronautics and Space Administration

NEX-GDDP-CMIP6: NASA Earth Exchange Global Daily Downscaled Projections

CMIP6 : Coupled Model Intercomparison Project 6th phase

GCMs : General Circulation Models

ITCZ : Intertropical Convergence Zone

ITD : Intertropical Discontinuity

ETCCDI : Expert Team on Climate Change Detection and Indices

SSPs : Shared Socioeconomic Pathways

IT : Information Technology

CDO : Climate Data Operators

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INTRODUCTION

The concentration of greenhouse gases in the atmosphere has experienced a notable rise due to human activities, which include the utilization of fossil fuels, deforestation, and unsustainable agricultural practices(Fang et al., 2021). This amplification of the natural greenhouse gases effect contributes to additional warming of the Earth's surface and atmosphere. Consequently, it poses potential risks and detrimental impacts on both natural ecosystems and human populations. It reduces the availability of nutritious food and clean water and destroys ecosystems and safe living environments. This leads to malnutrition, and disease, and makes youth particularly vulnerable(Pietro et al., 2013).

Africa is not a significant source of greenhouse gases emissions. Only a small portion, around 2-3 percent, of global carbon dioxide emissions from energy and industrial sources(UN, 2006). Yet it suffers significant loss and damage from the resulting climate change. West Africa, renowned for its diverse ecosystems and significant reliance on agriculture, faces unique vulnerabilities to the impacts of climate change. It is already experiencing loss of life, impacts on human health, reduced economic growth, water scarcity, reduced food production, loss of biodiversity, and impacts on human settlements and infrastructures (Dr Christopher et al., 2022). The primary effect of climate change on various sectors in West Africa stems from extreme events and this is due to the fact that the occurrence of extreme events, such as heatwaves, heavy precipitation, and droughts amplifies the impact associated with changes in the average climate (Dibi-Anoh et al., 2022). Analyses of long-term climatic characteristics of climate extreme events, including their intensity, duration, and frequency, are needed for developing adaptation plans. One approach to assess the occurrence, severity, and duration of these extreme events, is to calculate climate extreme indices based on daily time series of temperature and rainfall (Peterson et al., 2002). Understanding and effectively responding to projected changes in climate extreme indices in West Africa is imperative for informed decision-making, adaptive planning, and bolstering regional resilience. Acquiring knowledge and access to relevant information is necessary for the responsible stakeholders to take the right decisions, in both public and private organizations.

Climate services have emerged as a pivotal tool providing, accessible and actionable information on climate change and its consequences to help individuals, organizations, and communities to take appropriate actions in response to climate variability and change (Frizen, 2015). These services are designed to meet the specific information needs of users, including experts and non-experts, by facilitating convenient access to reliable climate data, analysis, and interpretation. By leveraging computer-based technologies and innovative approaches, climate services can enhance the accessibility, practicality, and utility of climate change analysis. In West Africa, climate services such as Climate data and information, Scientific publications, Capacity building and training, and Early warning systems are playing an important role in decision-making. Although there are many useful climate services, the climate web-based platform is among the most reliable service for distributing, documenting, and visualizing data in a standardized manner (Blaschek et al., 2015).

To advance the research work, a climate services platform that offer a powerful visualization which allows users to analyze and interpret climate extreme indices data more effectively will be build. Through interactive maps, charts, and graphs, complex climate information can be visualized in a comprehensible way.

1. PROBLEM STATEMENT

Climate change is affecting resources across many sectors in West Africa. Taking agriculture as an example, according to the World Bank, the sector contributes to around 35% of GDP and employs up to 65% of the population (World Bank, 2023). The projection of climate models showed that a distinct dry period is expected from the 2060s till the end of the century with a significant increase in air temperature up to 6.5 ℃ in West Africa(Ajayi et Ilori, 2020; Sylla et al., 2016). Since more than 90% of our agriculture is rainfed, strong scientific assimilation such as accessing, analyzing, and interpreting climate-change information on the effects of these changing climate patterns on vital sectors is needed to reduce the effect of climate impacts and the risks associated with them. According to the World Meteorological Organization (WMO), there is an increasing demand from society and governments to have better sub-seasonal, seasonal, and longer-time scale predictions and longer-term climate projections to support decision-making and adaptation efforts(WMO, 2019).

The resulting insights into climate projection data and scientific publications play an important role in making decisions and developing a better adaptation plan. But the major barrier to good climate change adaptation planning can be climate data, which is often hard to find, understand and apply to decision-making processes. In most cases, research outcomes are not directly suitable for actual user needs, or they lack necessary competences and support to interpret and use the available information. Some of those major obstacles that limit access to the use of climate information in decision-making can be a mismatch between the complexity of the model's outputs (format, size). In addition, the lack IT (Information Technology) skills of users, misunderstanding of the information provided in scientific publications or reports, and a lack of common understanding and vocabulary between researchers and users(Sultan et al., 2020).

Climate services, however, were established to fill this gap between science and practice and to respond to the needs of users for information on climate change and its impacts. These services enable both experts and non-experts to easily find the data and information they need, or allow providers to better structure the way data and information are provided.

To bridge the climate service gap in West Africa, an illustrative example of leveraging computer-based technologies to develop tools that enhance the accessibility, practicality, and usefulness of climate change analysis is presented. This approach aims to support communities, federal agencies, and other government entities to have a comprehensive understanding of their current vulnerability to climate risks, thereby empowering them to fortify their resilience plans.

2. RESEARCH QUESTIONS

The main research question underlying this study is How can climate services be used as a proxy between climate change projections and decision-makers to improve population's resilience in West Africa?

From the above main question, three specific questions are derived:

- What are the major climate indices in the West Africa region?
- What would be the projected changes in different climate indices under the shared socio-economic pathways (SSPs) in the region?
- How can the projected changes in climate indices in West Africa be made accessible to users?

3. RESEARCH HYPOTHESES

The main hypothesis:

Accessible online information on projected climate indices in West Africa can facilitate a better understanding and use of climate information.

Specifics hypothesis:

- Warm days, warm night, cool days, cool night, heavy precipitation, consecutive dry days and consecutive wet days are the major climate indices in West Africa;
- The models project an increase in the magnitude of the different climate indices identified in the West Africa region;
- The design of a platform with projected climate indices makes decision-making easier for end-users.

4. AIM AND RESEARCH OBJECTIVES

The main objective of this study is to design a platform that showcases projected climate indices in West Africa.

Specific objectives:

To achieve the main objective, we need to achieve the following objectives:

- Identify the main climate indices in West Africa;
- project the main climate indices in West Africa under the new climate change scenarios;
- design a platform to tailor projected climate indices for end-user decision-making.

5. THESIS STRUCTURE

The structure of this thesis encompasses a general introduction, followed by three chapters, and concludes with a general summary of the study. The organization of the content is as follows:

- **The introduction** presents the overall context and justification of the study. Then problem statement is followed by research questions, research hypotheses, and research objectives.
- **Chapter 1**: The literature review presents the main results of related works.
- **Chapter 2**: Study Area, Data collection, Method, Data Processing, and the Data analysis.
- **Chapter 3**: Results and discussion
- **Conclusion and perspectives**. This last part concludes the thesis while recalling the objectives and how this work can be deepened.

CHAPTER 1: LITERATURE REVIEW

1.1 Climate extreme Indices and their Relevance to West Africa

1.1.1 Climate extreme events in West Africa

Climate extreme events can be the time and place when weather, climate, or environmental conditions such as temperature, precipitation, drought, or flooding exceed a threshold value near the upper or lower axes of the historical measurements(Amelie et al., 2022). Due to its limited adaptive capacity, West Africa is the most vulnerable region to climate variability and extreme events(Field et Barros, 2014; Quenum et al., 2019). According to (De Longueville et al., 2020), West Africa is expected to be one of the regions that facing significant climate change impacts in the future. They also projected a significant decrease in the total annual rainfall (amount and duration) and an increase in dry spells occurring during the rainy season. Furthermore, a warming trend has been identified for the climate of West Africa, with significant heatwave and notable episodes of droughts. The occurrences of these drought and heatwave episodes has been investigated over the study area in previous studies (Hulme et al., 2001; S. Nicholson, 2005; S. E. Nicholson et al., 1996; van de Giesen et al., 2010).

1.1.2 Overview of climate extreme indices

A climate index is a calculated value that can be used to describe the state and changes observed within the climate system. These indices are quantitative measures used by climate services to provide valuable information to decision-makers. They provide valuable information for analyzing and understanding the occurrence, intensity, and duration of extreme weather conditions(Felix et al., 2021). International collaboration has taken place within the CC1/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI) (Karl et al. 1999; Peterson et al. 2002). Within the framework of this working group, 27 core indices of extremes were defined, and they are based on daily temperature values and daily precipitation amounts. These indices provide descriptions of specific attributes of extreme events, such as their frequency, intensity, and duration.

1.1.3 Key climate indices for West Africa

The selection of climate extreme indices for West Africa is based on the climate events frequently observed in the region. These indices were specifically selected to capture and analyze the characteristics of these events. However, it is important to note that the choice of indices may vary depending on the specific research objectives and available data. Researchers and Climate scientists in West Africa may consider additional or different indices depending on their study needs and the particular climatic events they wish to investigate. For instance, Alamou et al., (2022) focused on assessing the impact of stratospheric aerosol geoengineering on extreme precipitation and temperature indices in West Africa and selected 16 of the 27 extreme indices provided by the ETCCI. Similarly, Quenum et al., (2021) used 24 of these indices to evaluate spatiotemporal changes in temperature and precipitation in West Africa. Hountondji et al., (2011) also selected 12 specific indicators to study the trends in extreme rainfall events in Benin. Barry et al., (2018) employed 24 indicators to evaluate climate extremes and climate change indices in West Africa.

The studies cited show that a range of extreme climate indices are used to evaluate different facets of climate variability and change in West Africa (Tables 1 and 2). Overall, they show that most of the indices provided by the ETCCI are applicable and relevant in the West African context.

Table 1: Temperature indices summary

Common name	**Indices**	**Description**	**Units**
Cool nights	TN10p	Number of days when TN (daily minimum temperature) < 10th percentile of the control period	days
Warm nights	TN90p	Number of days when TN > 90th percentile of the control period	days
Tropical nights	TR	Annual count of days when TN > 20°C	days
Summer days	SU	Annual count of days when TX (daily maximum temperature) > 25°C	days
Warm days	TX90p	Number of days when TX > 90th percentile of the control period	days
Cool days	TX10p	Number of days when TX < 10th percentile of the control period	days
Cold spell duration indicator	CSDI	Annual count of days with at least 6 consecutive days when TN < 10th percentile	days

		of the control period	
Warm spell duration indicator	WSDI	Annual count of days with at least 6 consecutive days when TX > 90th percentile of the control period	days

Table 2 : Precipitation indices summary

Common name	**Indices**	**Description**	**Units**
Consecutive dry days	CDD	Maximum number of consecutive days with RR < 1 mm	days
Consecutive wet days	CWD	Maximum number of consecutive days with RR >= 1 mm	days
Simple daily intensity index	SDII	Annual total precipitation divided by the number of wet days (defined as PRCP>=1.0 mm) in the year	mm/days
Max 1-day precipitation amount	RX1day	Annual maximum 1 -day precipitation	mm
Max 5-day precipitation amount	RX5day	Annual maximum consecutive 5-day precipitation	mm
Number of heavy precipitations	R10mm	Annual count of days when PRCP >= 10 mm	days
Number of very heavy precipitation	R20mm	Annual count of days when PRCP >= 10 mm	days
Annual precipitation	P annual	Annual precipitation	mm

1.2 Climate Services

1.2.1 Definition and scope of climate services

A climate service is the provision of climate-related information, data, and resources to help in decision-making and allows stakeholders to understand and address the effects of climate change (Fig.1). It deals with making a wealth of climate data, projections, forecasts, trends, economic analysis, assessments, and other scientific climate findings accessible to the public (Swart et al., 2021). This accessibility helps in formulating strategies to mitigate society's vulnerability to climate change. Climate services encompass various tasks such as gathering data, analyzing it, creating models, and effectively communicating climate information to different user groups.

Figure 1: Need of climate services (Source:(GFCS, 2018)).

1.2.2 Overview of existing climate services web-based in Africa

Climate services in West Africa are essential for providing accurate and timely climate information to help in decision-making and enhance climate adaptability in the region. Climate services web-based refer to digital platforms, or systems that provide climate information, data, and tools to help various sectors, such as agriculture, water resources management, disaster risk reduction, and public health, make informed decisions in the face of climate variability and change. In Africa, there are several existing climate services platforms:

- The Africa GeoPortal (Fig.2) focuses on sharing and inspiring users to generate innovative solutions that address practical challenges. It promotes the sharing of user-generated outputs (scientific paper, result on projected change in climate variability etc.), enabling others to leverage these ideas for implementing successful initiatives throughout Africa. (https://www.africageoportal.com/)

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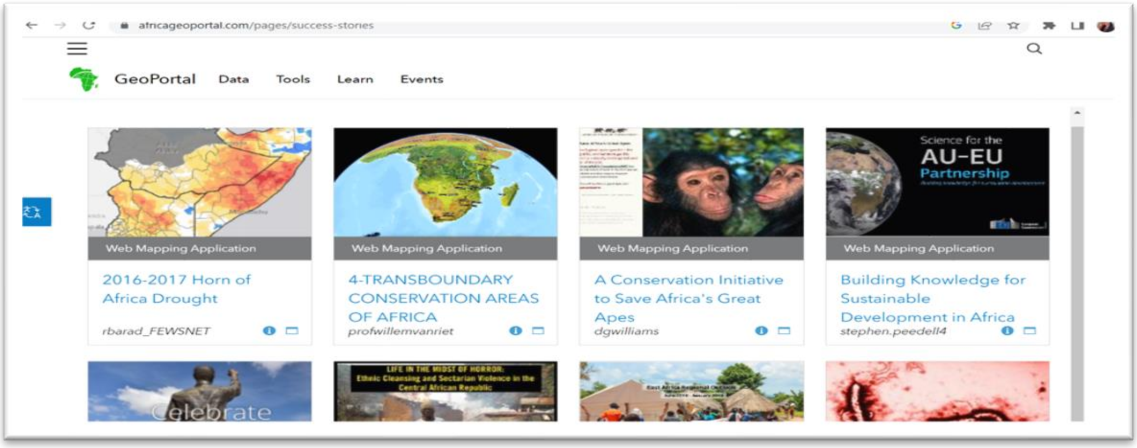


Web Mapping Application
2016-2017 Horn of Africa Drought
rbarad_FEWSNET

Web Mapping Application
4-TRANSBOUNDARY CONSERVATION AREAS OF AFRICA
profwillemvanriet

Web Mapping Application
A Conservation Initiative to Save Africa's Great Apes
dgwilliams

Web Mapping Application
Building Knowledge for Sustainable Development in Africa
stephen.peedell4

Figure 2: Online geoportal for inspiring users to generate innovative solution in Africa.

- WASCAL portal (Fig.3) is a platform that aim to store and preserve data and other digital resources produced through WASCAL projects. It facilitates access to this research data for the wider research community, ensuring its availability for further analysis and utilization. (https://wascal-dataportal.org).

WASCAL Data Discovery Portal

Provides public access for scientists and stakeholders to the WASCAL spatial data infrastructure (SDI)

Introduction

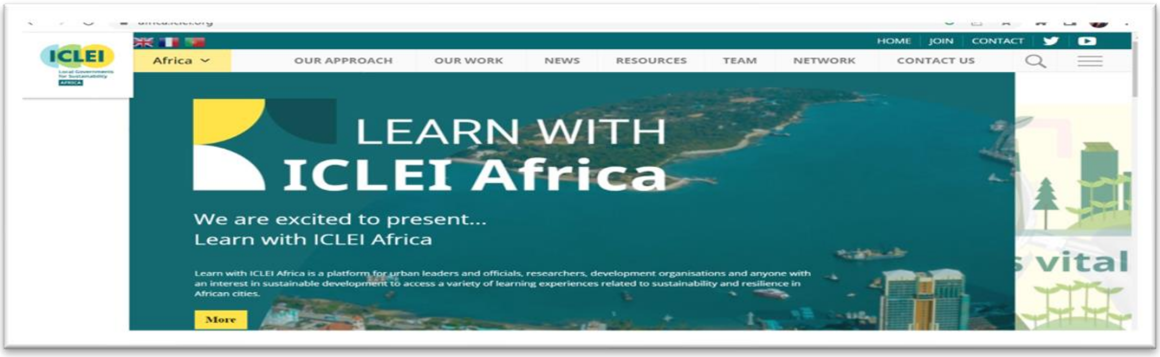
Within WASCAL a large number of heterogeneous data are collected. These data are mainly coming from

- different initiated research activities within WASCAL (Core Research Program, Graduate School Program)
- the hydrological-meteorological, remote sensing, biodiversity and socio economic observation netwrks within WASCAL,
- the activities of the WASCAL Competence Center in Ouagadougou, Burkina-Faso,

In order to facilitate the acquisition, provision, integration, management and exchange of these heterogeneous data resources within a scientific and non-scientific multiuser (distributed) environment the spatial data infrastructure (SDI) WADI (WAscal Data Infrastructure) has been build-up.

Figure 3: WASCAL online portal for data sharing in West Africa.

- ICLEI Africa (Fig.4) serves as a platform that establishes connections among leaders, accelerates the implementation of initiatives, and acts as a portal to solutions. It achieves these goals through capacity-building efforts, on-the-ground projects, and influencing policies. (https://africa.iclei.org/)



LEARN WITH
ICLEI Africa

We are excited to present...
Learn with ICLEI Africa

Learn with ICLEI Africa is a platform for urban leaders and officials, researchers, development organisations and anyone with an interest in sustainable development to access a variety of learning experiences related to sustainability and resilience in African cities.

Figure 4: ICLEI platform for inter-connecting leaders and offering climate solutions.

- The RCMRD GMES et Africa Geoportal (Fig.5) is a platform where users can explore and download GIS data, discover and build applications, and collaborate with others to address significant challenges. It enables users to analyze and integrate datasets through maps and provides opportunities for the development of innovative web and mobile applications. (https://gmesgeoportal.rcmrd.org/)

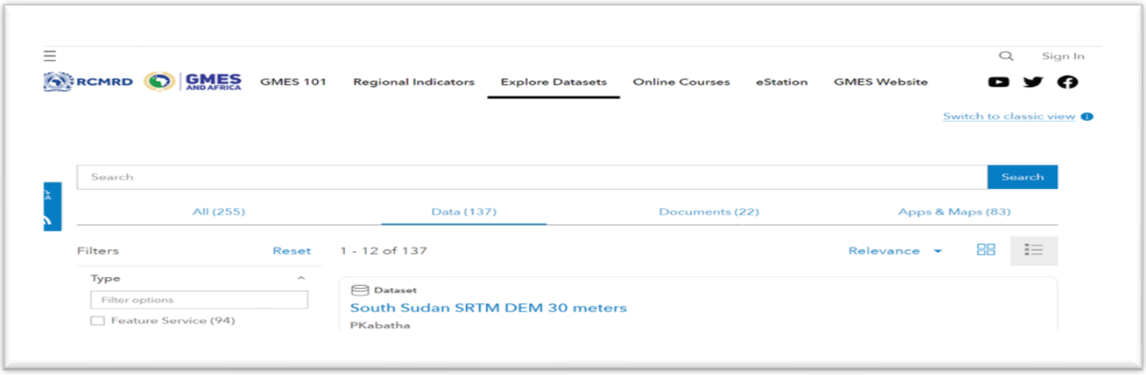
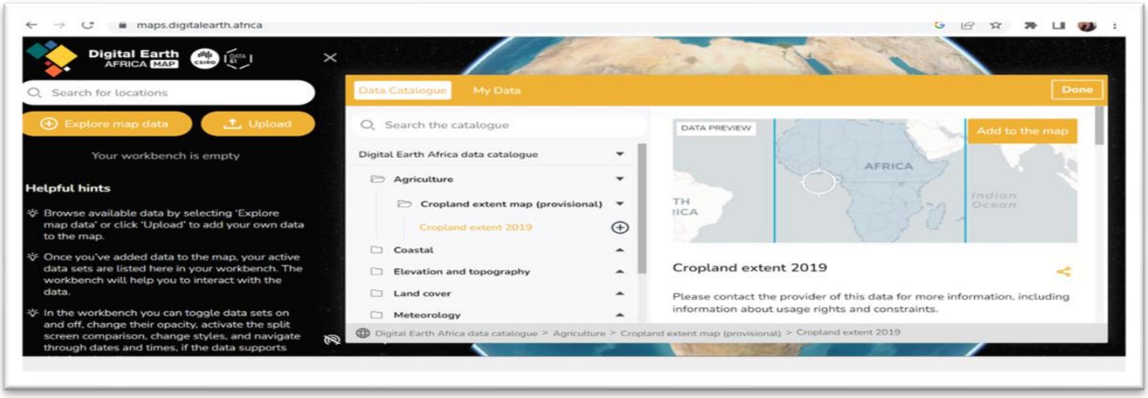


Figure 5: RCMRD GMES et Africa Geoportal for GIS data access.

- The Digital Earth Africa (DE Africa) (Fig.6) Map is a website designed for map-based interaction with the offerings and services of Digital Earth Africa. It aims to equip users with the necessary tools to explore the data and products provided by DE Africa. By utilizing satellite images, the Map enables users to visualize the diverse geography of the African continent and track its changes over time.

(https://maps.digitalearth.africa/)

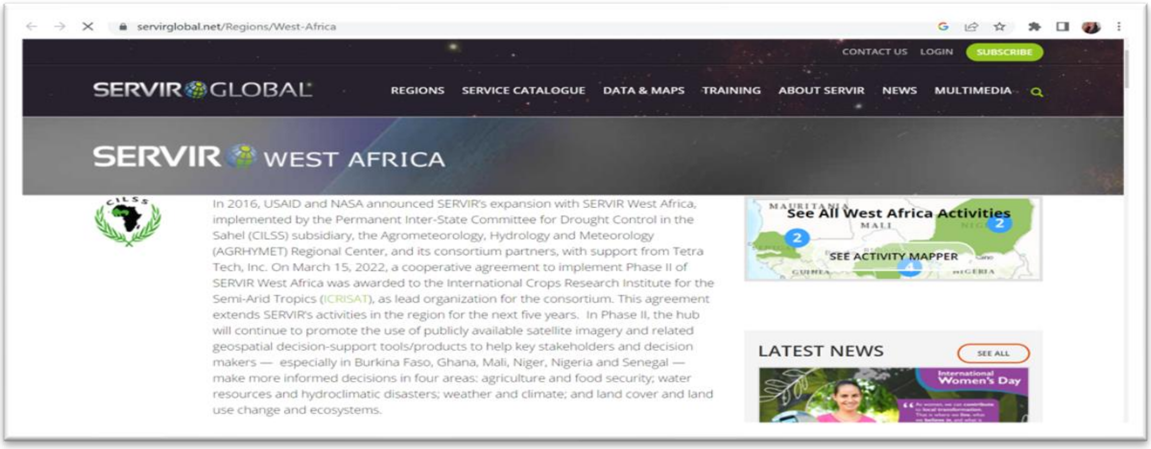


- Browse available data by selecting 'Explore map data' or click 'Upload' to add your own data to the map.
- Once you've added data to the map, your active data sets are listed here in your workbench. The workbench will help you to interact with the data.
- In the workbench you can toggle data sets on and off, change their opacity, activate the split screen comparison, change styles, and navigate through dates and times, if the data supports

Please contact the provider of this data for more information, including information about usage rights and constraints.

Figure 6: Digital Earth Africa (DE Africa) platform in data visualization.

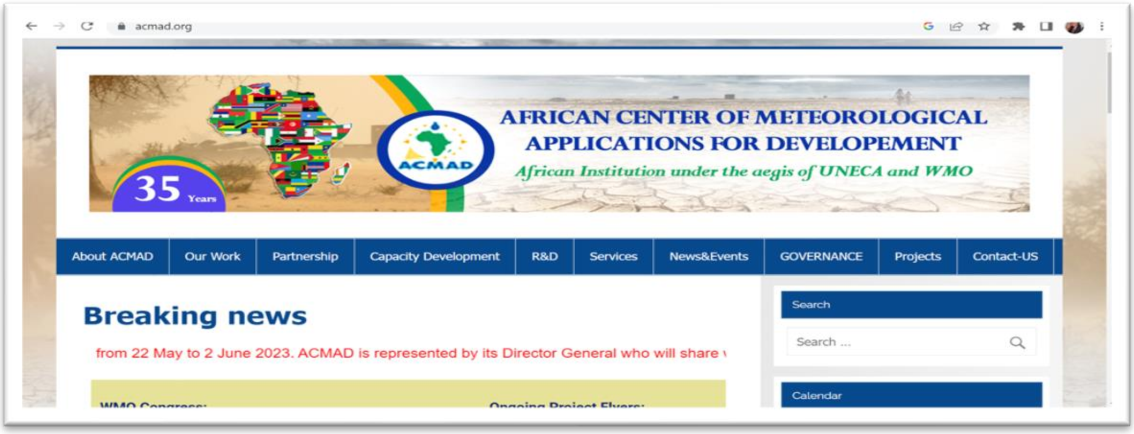
- SERVIR West Africa (Fig.7) was built with the objective to promote the utilization of openly accessible satellite imagery and associated geospatial decision-support tools and products. Its primary focus is to assist key stakeholders and decision-makers, especially in Burkina Faso, Ghana, Mali, Niger, Nigeria, and Senegal, in making well-informed decisions across four critical areas. These areas include agriculture and food security, water resources and hydroclimatic disasters, weather and climate, and land cover and land use change and ecosystems. The aim is to provide valuable support for decision-making processes in these domains. (https://servirglobal.net/Regions/West-Africa).



In 2016, USAID and NASA announced SERVIR's expansion with SERVIR West Africa, implemented by the Permanent Inter-State Committee for Drought Control in the Sahel (CILSS) subsidiary, the Agrometeorology, Hydrology and Meteorology (AGRHYMET) Regional Center, and its consortium partners, with support from Tetra Tech, Inc. On March 15, 2022, a cooperative agreement to implement Phase II of SERVIR West Africa was awarded to the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), as lead organization for the consortium. This agreement extends SERVIR's activities in the region for the next five years. In Phase II, the hub will continue to promote the use of publicly available satellite imagery and related geospatial decision-support tools/products to help key stakeholders and decision makers — especially in Burkina Faso, Ghana, Mali, Niger, Nigeria and Senegal — make more informed decisions in four areas: agriculture and food security; water resources and hydroclimatic disasters; weather and climate; and land cover and land use change and ecosystems.

Figure 7: SERVIR West Africa platform for openly accessible satellite imagery decision-support tools and products.

- Established in 1985 by the UNECA Conference of Ministers of Economy and Finance, the African Centre of Meteorological Applications for Development (ACMAD) (Fig.8) was built to serve as a continental hub for weather and climate monitoring and as an excellence center for applying meteorology to foster development. It enables provision of weather and climate monitoring, forecasts, and regional early warning systems for droughts, tropical cyclones, and other extreme weather events. In addition, it builds capacity, develops, methods and tools, and enhancing Africa's participation in global weather and climate programs. ACMAD also facilitates the establishment and sharing of databases and engages in meteorological research activities.
  (https://acmad.org/)



Breaking news

from 22 May to 2 June 2023. ACMAD is represented by its Director General who will share

Figure 8: African Centre of Meteorological Applications for Development (ACMAD) platform for weather and climate monitoring.

The importance of climate services web-based platform in Africa lies in their ability to centralize and provide easy access to climate information. They empower stakeholders, including policymakers, researchers, farmers, and communities, to make informed decisions and develop climate-resilient strategies. These platforms enhance the region's capacity to understand and respond to climate variability, extreme events, and long-term climate change. They foster collaboration, knowledge-sharing, and evidence-based planning, ultimately contributing to building climate resilience and sustainable development in Africa, especially for the West Africa region.

1.2.3 Challenges of these previous responses

- **Bridging the Gap between Scientific Research and Practical Application**

A research gap exists in effectively bridging the gap between scientific research on climate indices and its practical application in decision-making processes. Although the mentioned portals provide access to scientific outputs and data, there often exists a disconnect between the research conducted and its utilization by policymakers and practitioners. To address this gap, it is crucial to translate complex scientific information into user-friendly formats, understandable by the end-user. These efforts aim to ensure the relevance and usability of projected climate indices in decision-making contexts.

- **Addressing Data Accessibility**

Another research gap lies in addressing the challenges related to data accessibility and connectivity in accessing climate indices data in West Africa. Although the aforementioned portals allow data access, limitations still exist in certain regions, such as limited data access, and unadopted file output format. Innovative solutions such as open data access should be considered to fill this gap. These measures are aimed at enabling users in different regions to effectively access and use projected climate indicators, thereby improving data accessibility and availability.

- **The complexity of management**

Another gab to address is the complexity of these platform to manage by the end-user. Clear and comprehensive documentation, tutorials, and help guides can help users understand and navigate the platform effectively.

- **Gaps in tailoring climate indices platform in West Africa**

Despite the availability and functionality of existing web-based climate service platforms in West Africa, there are still gaps in the use of climate indices within these platforms. Initially, although these platforms provide access to climate data and information, climate indices need to be better integrated in their functionality. Climate indices play a key role in characterizing and quantifying climate extremes, which are extremely important for decision-making and adaptation planning. By integrating climate indices into platforms, users can directly access and analyze relevant indices adapted to their own needs. West Africa is a region with different climate patterns and local vulnerability. Therefore, there is a need to adapt existing climate indices to the specific needs and context of different parts of West Africa. Such an approach would increase the relevance and applicability of the indices, allowing users to obtain more meaningful and appropriate climate information for their location. One of the challenges in using climate indices is that they often involve complex calculations and statistical analyses, which can be difficult for non-expert users to understand and use effectively. To bridge this gap, improving user experience through intuitive interfaces, interactive visualizations and user-friendly tools is crucial. By adding these features to platforms, a wider range of stakeholders, including non-experts, could use climate indices to make decisions. This, in turn, would facilitate more informed decision-making, improve climate adaptability and resilience in various sectors of the region.

Addressing these research gaps in the literature will contribute to the advancement of knowledge and the development of practical solutions. This thesis presents a comprehensive climate services web-based platform for projected climate indices in regional and local which ensures accessibility, ease of interpretation, and relevance for decision-making processes.

CHAPTER 2: MATERIALS AND METHODS

To attain objectives, test the hypothesis, and answer the research questions of the study, several materials and methods were used. Fig.9 illustrates the conceptual framework of the study. First, West Africa was selected as the study area, followed by the data collection, method, data processing, and data analysis. The study ended with the development of a platform for climate services.

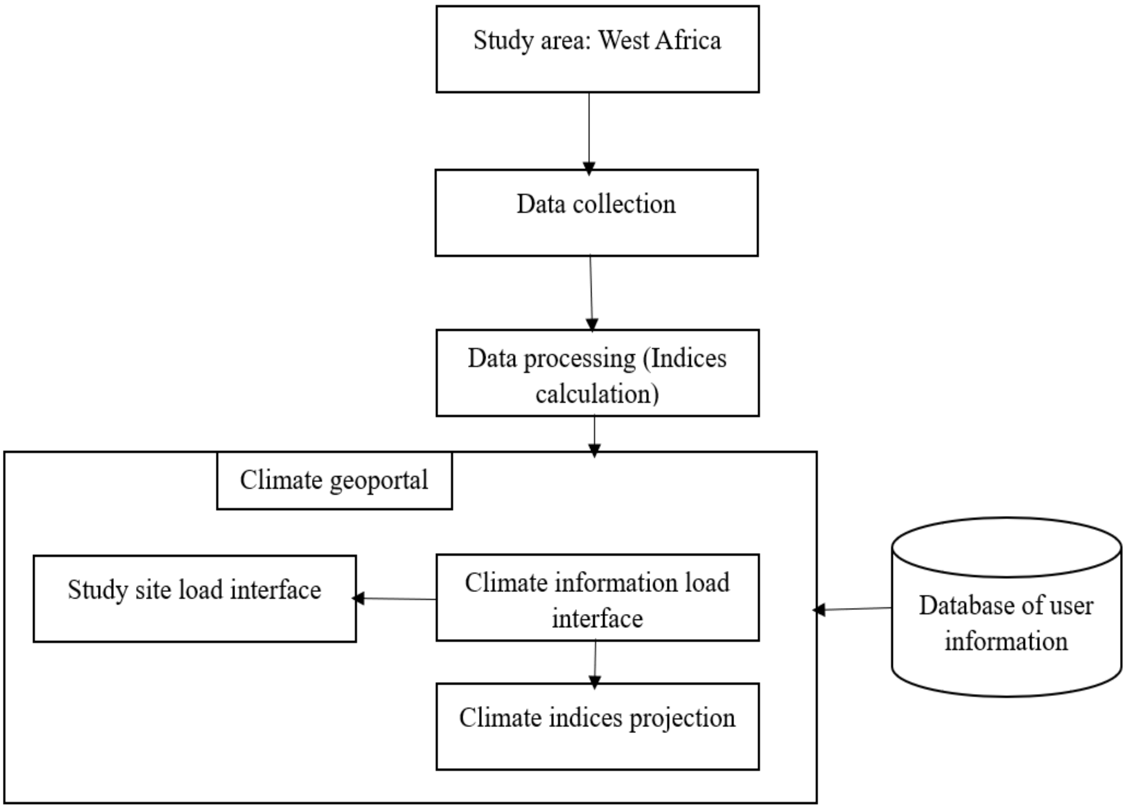


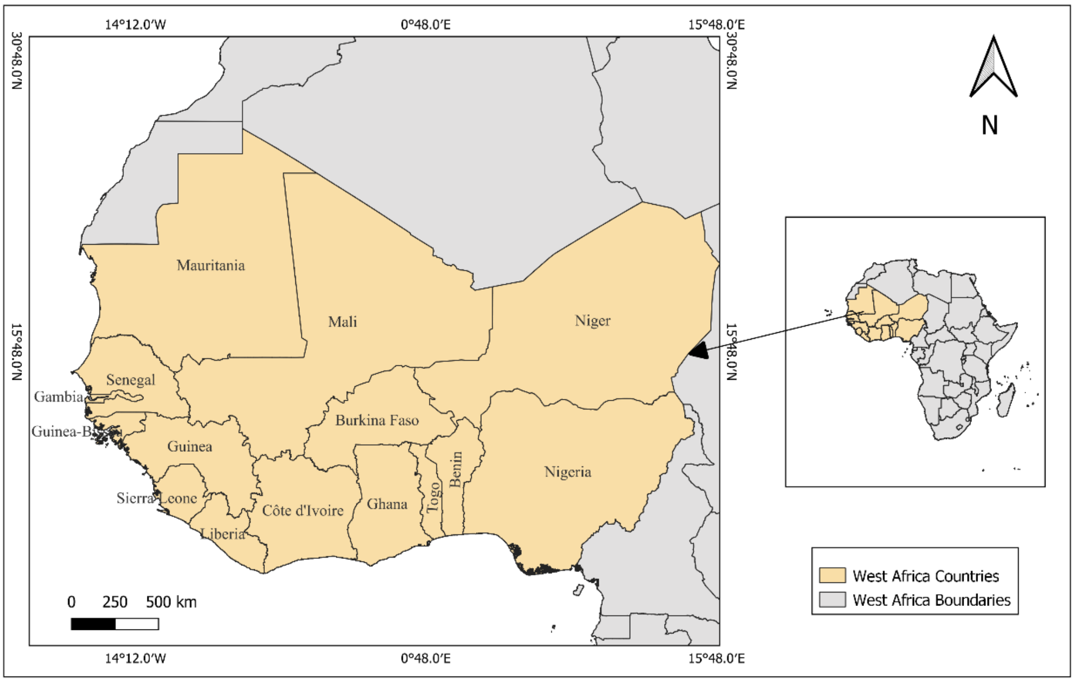
Figure 9: Conceptual framework

2.1 Study area

West Africa is bordered by the Atlantic Ocean to the west and south, the Mount Cameroon/Adamawa Highlands to the east, and its northern boundary is formed by Mauritania, Mali, and Niger. The region extends from the Sahara Desert in the north to the Gulf of Guinea in the south (Fig.10). West Africa comprises 16 countries, such as Benin, Burkina Faso, Cape Verde, Gambia, Ghana, Guinea, Guinea-Bissau, Côte d'Ivoire, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, Togo. The climate in West Africa is influenced by the interaction of different air masses such as northerly and southerly winds, jets, waves, and heat low. As described by Sylla et al., (2013), these factors interact with each other and have different impacts on the climate of the region as the Intertropical

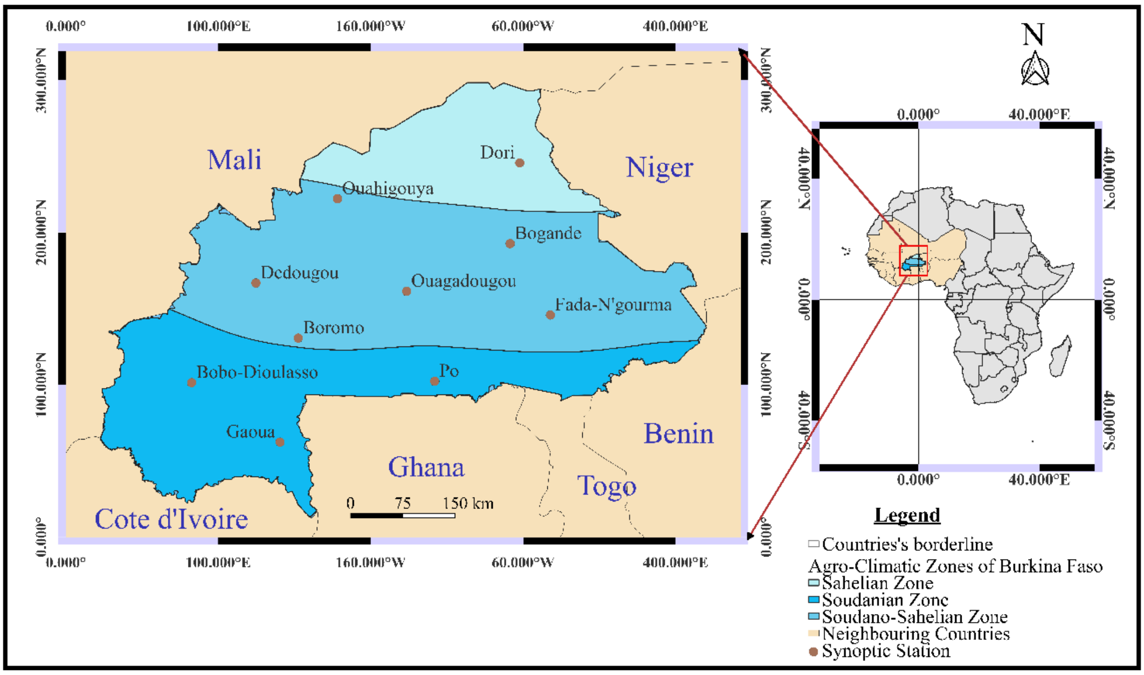
Convergence Zone (ITCZ) moves north and south throughout the year. Hot, dry continental air masses originate from the northern high-pressure system. These air masses lead to the dry and dusty Harmattan winds that, blow from the Sahara across most of West Africa countries from November to February. During the summer season, the arrival of moist equatorial air masses from the Atlantic Ocean results in the occurrence of the annual monsoon rains (S. E. Nicholson, 2013). Annual average minimum and maximum temperatures range between 16 and 20 °C and between 27 and 35 °C, respectively, with variations depending on the distance from the ocean (Ly et al., 2013). The average annual rainfall ranges from 200 to 1200 mm, as reported by (Salack et al., 2015).

This study encompasses the entire region of West Africa as the study area. However, Burkina Faso was specifically chosen as the focal point and case study for detailed analysis and investigation. Burkina Faso is a landlocked country in West Africa, located between Mali, Niger, Benin, Togo, Ghana, and Cote d'Ivoire with three climatic zones (Fig.11). The anomaly of the indices provided are projected under the three different scenarios: SSP126, SSP245, and SSP585. The study considered the ensemble mean of the 15 NEX-GDDP-CMIP6 models and examined two time periods: the near-period (2030-2060) and the far-period (2071-2100) for each climate index.



Source: ArcGIS Hub Date: july 2023 Author: Mame Diarra DIOUF

Figure 10: Study domain, showing the West Africa countries



Source: ANAM (climatology 1991-2020) Date: June 2023 Author: Mame Diarra DIOUF

Figure 11: Location of Burkina Faso

2.2 Data

The model dataset utilized for the study was the Coupled Model Intercomparison Project 6th phase (CMIP6) database (precipitation and temperatures), and the observational datasets were CHIRPS, and ERA5.

Observed CHIRPS, and ERA5 Datasets

CMIP6 climate simulations were compared with observational datasets consisting of: 1) The daily maximum temperature (Tasmax), minimum temperature (Tasmin) and mean temperature (Tas) data from the ERA5 reanalysis product (Temperature: https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels?tab=form) which is the fifth-generation reanalysis from the European Centre for Medium-Range Weather Forecasts (ECMWF) with a horizontal grid spacing of ~ 31 km (Sawadogo et al., 2021). It was built from the Era-Interim dataset and provides a high spatial and temporal resolution reference data and 2) Daily precipitation (Pr) data observation from CHIRPS (Precipitation: http://iridl.ldeo.columbia.edu/SOURCES/.UCSB/.CHIRPS/.v2p0/) that is a 30+ year quasi-global rainfall dataset ranging from 1981 to the near present. It blended with in-situ station data to create a gridded rainfall time series(Funk et al., 2015).

To be consistent with the simulation model periods, we adopted a spatial resolution of both ERA5 and CHIRPS in 0.25° × 0.25° (~ 25km × 25km).

Both these datasets provide valuable information for comparing and evaluating the CMIP6 climate simulations.

Model CMIP6 dataset

The datasets of the CMIP6 is an updated version of phase 5 (CMIP5) with similar levels of radiative forcing for 2100, but having added socio-economic conditionalities, the scenarios called RCP (Representative Concentration Pathway) in phase 5 are now called SSP (Shared Socioeconomic Pathways) for phase CMIP6 with SSP1-2.6, SSP2-4.5 and SSP5-8.5 (O'Neill et al., 2016). The datasets are divided into two phases, historical and projection, for all models utilized in the study. General circulation models (GCMs) play a crucial role in climate modeling and scenario development under CMIP6. These models have been developed to accurately capture a wide range of physical phenomena taking place in the atmosphere, ocean, cryosphere, and land surface. However, it is important to understand that GCMs have certain limitations in accurately capturing spatial detail and may have biases compared to observations(CIESIN, 1996). To overcome these limitations and ensure consistency with historical climate records, the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6) dataset was created(Thrasher et Wang, 2022). This dataset offers downscaled climate scenarios derived from GCM runs performed under CMIP6. Its primary purpose is to address the shortcomings of GCM outputs by providing adjusted future climate projections. The NEX-GDDP-CMIP6 dataset encompasses downscaled projections from 35 CMIP6 GCMs and covers four Shared Socioeconomic Pathway (SSP) scenarios for the period from 2015 to 2100. Additionally, it includes historical climate data spanning from 1950 to 2014. The spatial resolution of each climate projection in the dataset is 0.25° × 0.25° (~ 25km × 25km) allowing for more detailed analysis at a local or regional scale.

The datasets used in this study are from the NEX-GDDP-CMIP6, published into the NASA Center for Climate Simulation and were freely accessed at https://www.nccs.nasa.gov/services/data-collections/land-based-products/nex-gddp-cmip6.

In this study, the period of interest for the calculation of the extreme climate indices was 1960–2100. The CMIP6 models of interest are illustrated in Table 3. In total, 15 CMIP6 models that made available both precipitation and temperature were used.

Table 3: List of models used in CMIP6 compilation

Model Name	Modeling Center	Responsible Institution
ACCESS-CM2	CISRO-ARCCSS	CSIRO (Commonwealth Scientific and Industrial Research Organization, Australia), and ARCCS (Australian Research Council Centre of Excellence for Climate System Science
ACCESS-ESM1-5	CISRO	CSIRO (Commonwealth Scientific and Industrial Research Organization, Australia)
BCC-CSM2-MR	BCC	Beijing Climate Center
MPI_ESM1-2-HR	MPI-M DWD DKRZ	Max Planck Institute for Meteorology (MPI-M)
MPI-ESM1-2-LR		
MRI-ESM2	MRI	Meteorological Research Institute
NESM3	NUIST	Nanjing University of Information Science and Technology
NORESM2-LM	NCC	Norwegian Climate Centre
NORESM2-MM		
CANESM5	CCCma	Canadian Centre for Climate Modelling and Analysis
CMCC-ESM2	CMCC	Euro-Mediterranean Center on Climate Change
HADGEM3-GC31-II	MOHC-NERC	UK Met Office Hadley Centre
MIROC-ES2I	MIROC	Atmosphere and Ocean Research Institute (The
MIROC6		University of Tokyo), Center for Climate system Research - National Institute for Environmental Studies
GISS-E2-1-G	GISS	NASA-GISS Goddard Institute for Space Studies USA

Shared Socioeconomic Pathways (SSPs)

Scenarios play an important role in climate change research. It is an essential component in understanding our influence on the planet. They offer a window into the future, enabling researchers to explore and analyze the consequences of various near-term choices on the long-term outlook (Bassetti, 2022). The Shared Socioeconomic Pathways (SSPs) were developed to be utilized in sophisticated Integrated Assessment Models. These models make assumptions about the potential changes in factors like how population, education, energy consumption, technology, and more, may change over the next century and with assumptions about the level of ambition in terms of mitigating climate change(HabitatSeven et al., 2023). The SSPs encompass three key pathways(Ludwig et Hensel, 2022):

- SSP585: This scenario represents the upper range of these scenarios mentioned above, with an additional radiative forcing of 8.5 W/m² by 2100. It can be seen as an updated version of the CMIP5 scenario RCP8.5, incorporating socioeconomic considerations.
- SSP245: Serving as an update to the RCP4.5 scenario, SSP245 reflects a medium pathway for future greenhouse gas emissions, with an additional radiative forcing of 4.5 W/m² by 2100. This scenario assumes the implementation of climate protection measures.
- SSP126: With a radiative forcing of 2.6 W/m² by 2100, SSP126 is a revised version of the optimistic scenario RCP2.6, designed to simulate a development compatible with the 2°C target. Like to SSP245, this scenario, too, assumes the adoption of climate protection measures.

2.3 Methods

The approach adopted in this study consisted of:

- Calculation of the selected climate indices;
- Evaluation of the ensemble mean of 15 NEX-GDDP-CMIP6 models's performance;
- Analysis of the spatial trends of the computed extreme indices;
- Analysis of the temporal trends of the computed extreme indices;
- Simulation of the platform.

2.4 Data processing

Selected climate indices

Among the 27 indices provided by ETCCDI, 14 indices that capture not only the intensity and duration of changes in temperature and precipitation, but also the frequency and length of heavy precipitation events were used for this study (Table 4). The indices were classified into 5 groups:

- Absolute extreme indices include precipitation indices (RX1day and RX5day, representing the maximum amount of precipitation in a 1-day and over a consecutive 5-day period) and temperature indices (TXM for average maximum daily temperature, TNM for average minimum daily temperature and TMM for average mean temperature).
- Threshold exceedance indices, such as R10mm and R20mm, indicate the number of days in which a specific precipitation threshold (10mm and 20mm) is exceeded.
- Duration-based indices focus on the length of wet and dry spell durations. Examples include CDD (Consecutive Dry Days) and CWD (Consecutive Wet Days).
- Percentile-based indices are based on percentiles and provide insights into the distribution of precipitation and temperature. They include TN10p (coldest 10% of daily minimum temperatures), TX10p (coldest 10% of daily maximum temperatures), TN90p (warmest 90% of daily minimum temperatures), TX90p (warmest 90% of daily maximum temperatures).
- Other indices include PRCPTOT, which represents the total precipitation amount during a specified period.

To calculate these indicators, the Climate Data Operators (CDO) commands was utilized. CDO is a collection of operators designed for processing climate and forecast model data in a standardized manner. By using the CDO commands, the annual values of each index listed in Table 5 at each gridpoint for the years in the period of 1960–2100 for each of the CMIP6 model were computed. Additional information regarding the command used can be found in the provided link: https://slides.com/wachsylon/cdoetccdi#/4/1

Table 4: List of climate indices selected

Element	Index	Descriptive name	Definition	Units

Tm	TMm	Mean Tas	Average value of daily mean temp	ºC
Tn	TNm	Mean Tmin	Average value of daily minimum temp	ºC
Tn	Tn10p	Cool nights	Percentage of days when TN<10th percentile	Days
Tn	Tn90p	Warm night frequency	Percentage of days with TN>90th percentile	Days
Tx	TXm	Mean Tmax	Average value of daily maximum temp	ºC
Tx	Tx10p	Cool day frequency	Percentage of days when TX<10th percentile	Days
Tx	Tx90p	Warm day frequency	Percentage of days when TX>90th percentile	Days
Pr	RX1day	Maximum 1-day precipitation	Maximum 1-day precipitation	mm
Pr	RX5day	Maximum 5-day precipitation	Maximum 5-day precipitation	mm
Pr	R10mm	Number of heavy precipitation days	Annual count of days when PR>=10mm	Days
Pr	R20mm	Number of very heavy precipitation days	Annual count of days when PR>=20mm	Days
Pr	CDD	Consecutive dry days	Maximum number of consecutive dry	Days
Pr	CWD	Consecutive wet days	Maximum number of consecutive wet days	days
Pr	PRCPTOT	Annual total wet-day precipitation	Annual total PRCP in wet days (RR>=1mm)	mm

2.5 Data analysis

The analysis consists of three main approaches. Firstly, the performance of the ensemble mean of 15 NEX-GDDP-CMIP6 models in reproducing Tasmax, Tasmin, Tas, and Pr compared to ERA5 and CHIRPS datasets respectively for the historical period 1985-2014 over West Africa was assess.

Following this evaluation, the anomalies of spatial and temporal patterns of these climate indices, selected under the three Shared Socioeconomic Pathways (SSPs) within the country among West Africa countries chosen as the case study were analyze. For each model, and for each of the four selected essential climate variables (Tasmax, Tasmin, Tas and Pr), 30-year climatology was formed. The baseline interval (1985-2014) was derived from the historical simulations, while the future periods (2031-2060 and 2071-2100) were computed for all three SSPs (SSP126, SSP245 and SSP585).

Finally, an interactive web-based platform was made to represent these indices projection via an interface. It allows the user to select an index and then compare the results across the different scenarios over the West Africa regions. all projection indicators were present as an annual anomaly. This Web App was developed using the Python programming language (high-level data structures, high productivity, and open source) with the framework flask in the backend side and a JavaScript framework Angular (a high-quality app with less code, less time spent on debugging, and high scalability potential) in frontend side (Fig.12). PyCharm and visual code were used as an integrated development environment for writing. Other tools were used: a) xampp software was used to handled MySQL and b) Database MySQL was used to store information about the end-user.

The computed indices produced data that is stored in NetCDF format, both for historical and scenarios. On the backend side (Python), to compute the annual anomaly for a selected index, area, scenario(s), model(s), and period, the following steps are followed:

Historical: 1960-2014

- The script defines a list of climate models (**modelList**) that are included in the ensemble.
- For each model in the **modelList**, the script reads the corresponding netCDF file that contains the data for that model.
- The data is then processed to extract the values for a specific region (Burkina Faso in this case). This is done by masking the data based on the shapefile that define the region of interest.

- For each year in the dataset, the script calculates the average of the data across the region for each model.
- After processing all the models, the script obtains an array (**ListAVGModels**) that contains the average values for each model and year.
- Finally, the script calculates the ensemble mean by taking the average of the values across all models for each year. This is done by using the np.mean() function on the array **ListAVGModels**.
- The result is an array (**ListEnsMean**) that represents the ensemble mean of the values for each year.
- To calculate the anomaly, the reference period 1985-2014 is selected from the array (**ListEnsMean**) which is applied the np.mean() across all the year(**MeanRef**) and the result value is subtracted in each year of the array (**ListEnsMean**).

Scenarios: 2015-2100

- This process is repeated for different scenarios (SSP126, SSP245, and SSP585) to calculate ensemble means for each scenario.
- For the anomaly, the value **MeanRef** computed in the historical is subtracted in each year of the resulting ensemble mean array of the scenario.

The result was stored in a dictionary and sent to the front-end (AngularJS) which displays it in time series.

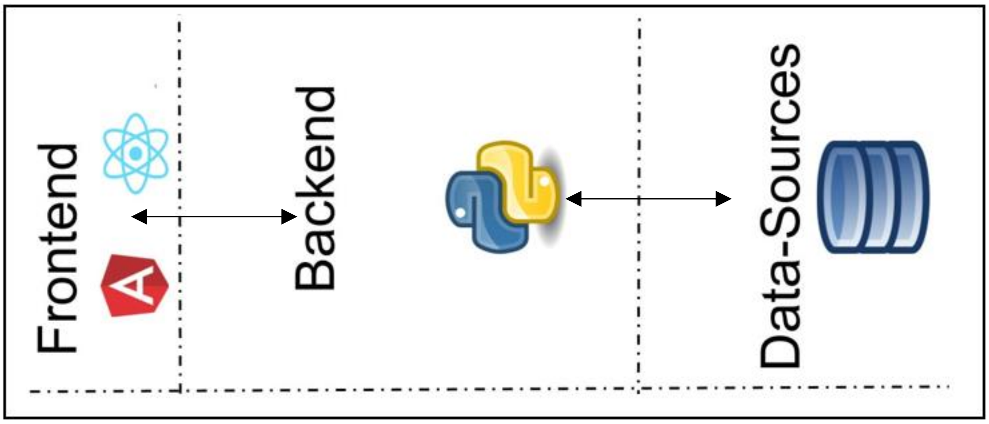


Figure 12: Web site component

CHAPTER 3: RESULTS AND DISCUSSION

3.1 Results

3.1.1 Model evaluation

3.1.1.1 Rainfall

Fig.13, shows the cumulative spatial distribution of overage rainfall over the period 1985-2014 for both ensemble mean of 15 NEX-GDDP-CMIP6 models and observational from CHIRPS data over West Africa. Total annual rainfall varies across the study domain, ranging from 0 to 2800 mm/year. In the Sahel zone, annual rainfall is very low, 0 to 1200 mm/year includes, Mali, Niger, Senegal, Burkina Faso, and Nigeria. The CHIRPS data exhibit a higher coverage of low precipitation, while moderate precipitation (400-800 mm/year) is observed in the southern region of Senegal, Gambia, Mali, and Burkina Faso. Comparatively, the ensemble mean of 15 NEzX-GDDP-CMIP6 models data show lower coverage of low precipitation, and the observed moderate precipitation extends from the south to the north of these regions, ranging from 400-1200 mm/year.

The Savannah zone has more annual rainfall distribution than the Sahel, ranging from 400-2000 mm/year in the CHIRPS data, while the ensemble mean of 15 NEX-GDDP-CMIP6 models data indicate more intense precipitation ranging from 800-2800 mm/year covering, Burkina Faso, Mali, Nigeria, Côte d'Ivoire, Ghana, Togo, and Benin. The Guinean zone exhibits the highest distribution of rainfall, with the ensemble mean data showing more intense rainfall (1200 up to 2800 mm/year) compared to the CHIRPS data (800-2400 mm/year) in this zone.

In summary, the Sahel zone has the lowest rainfall distribution, followed by the Savannah zone, and the Guinean zone receives the highest rainfall distribution. The CHIRPS and CMIP6 data generally show similar precipitation patterns, but the ensemble mean of 15 NEX-GDDP-CMIP6 models provides slightly denser coverage of low precipitation zones.

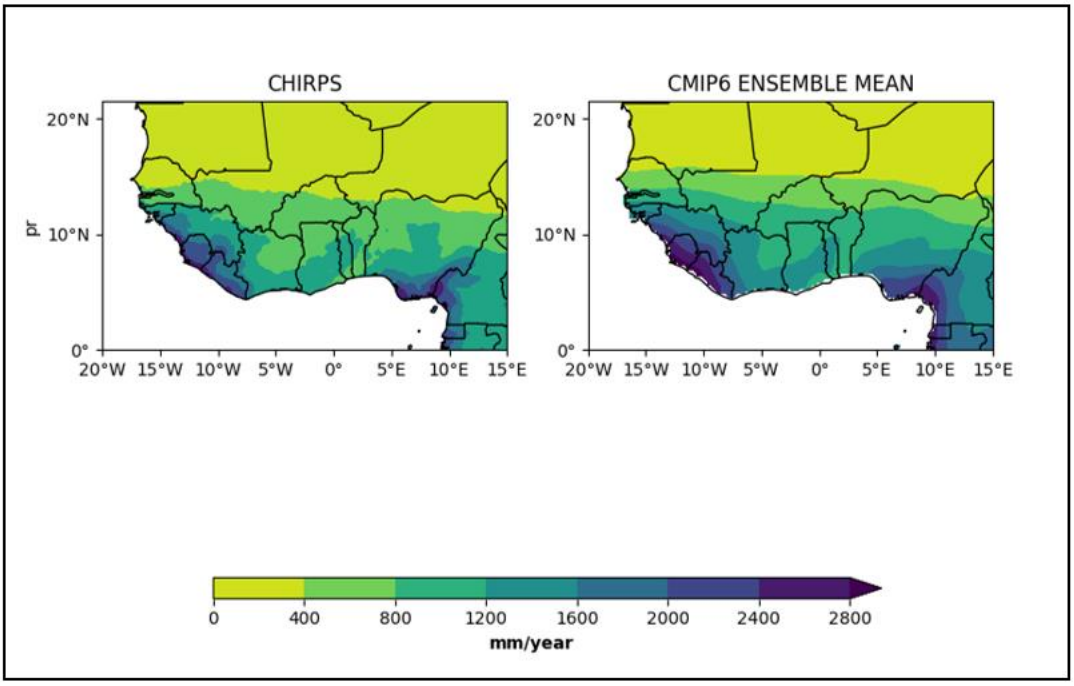


Figure 13: Cumulative spatial distribution of the rainfall over West Africa in the present climate (1985-2014).

Fig.14 presents the bias between the ensemble mean of 15 NEX-GDDP-CMIP6 models and CHIRPS datasets. This figure provides valuable insights into the difference observed between the two datasets. Notably, negative values ranging from -400 to 0mm/year are evident in the Sahel region and certain areas of the savanna zone located at northern Côte d'Ivoire, northern Ghana, southern Burkina Faso, and northern Guinea. These negative values indicate that the ensemble mean of 15 NEX-GDDP-CMIP6 models underestimates the CHIRPS dataset in these regions. Conversely, in the northern part encompassing the Guinea zone and the Savannah, a positive difference is observed between the datasets. This discrepancy can be attributed to the ensemble mean of 15 NEX-GDDP-CMIP6 models's tendency to overestimate CHIRPS, particularly in regions such as Cameroon's mountains, the Sierra Leone coast, and the Guinea mountains.

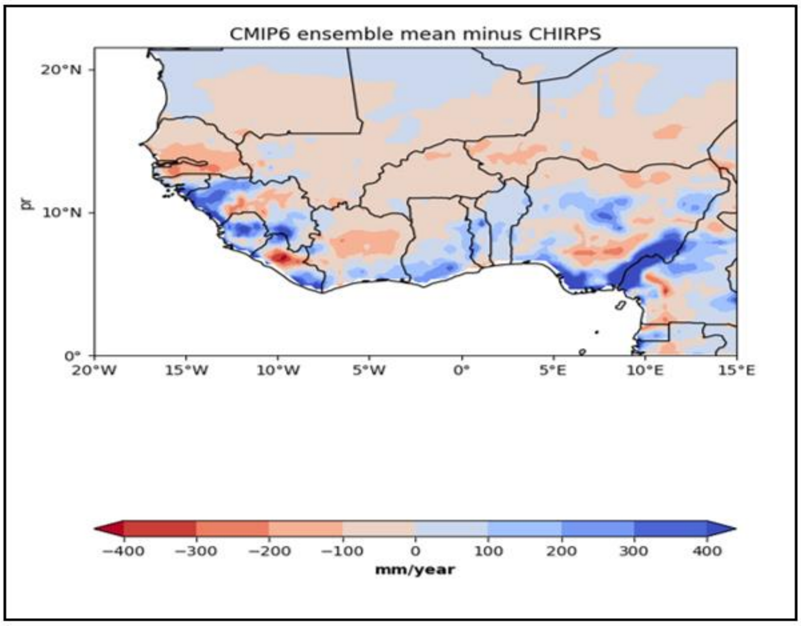


Figure 14: Ensemble mean of 15 NEX-GDDP-CMIP6 models annual rainfall minus CHIRPS mean annual rainfall.

3.1.1.2 Temperatures

Fig.15 represents the annual average of minimum, mean, and maximum temperature (Tasmin, Tas, and Tasmax respectively) over the period 1985-2014 for both the ensemble mean of 15 NEX-GDDP-CMIP6 models and observational from ERA5 data over West Africa. The Tasmin, Tas, and Tasmax revealed that, for ERA5 as well as the ensemble mean of 15 NEX-GDDP-CMIP6 models, the temperatures varied widely. In relation to Tasmin, it was observed that all minima were concentrated in the northern and southern of the region, with additional scattered occurrences in the mountainous areas of Cameroon and the Guinea mountains. The temperature range for both ERA5 and the ensemble mean of 15 NEX-GDDP-CMIP6 models was recorded between 16 to 32°C, with the ensemble mean of 15 NEX-GDDP-CMIP6 models slightly higher than ERA5. Regarding the maxima of tasmin, they were predominantly observed with the ensemble mean of 15 NEX-GDDP-CMIP6 models in the Sahel zone and the western part of the Guinean zone with temperatures ranging from 28 to 36°C.

For Tas, the lowest values were identified in the northeastern regions and the Guinean zone, similar to Tasmin. Additionally, some were found scattered around Cameroon's mountains and Gabon's forests. The temperature range in these areas varied from 20 to 36°C. Conversely, the highest temperature values were observed in the Sahel zone, reaching up to 36°C for both datasets where the ensemble mean of 15 NEX-GDDP-CMIP6 models has more coverage of the highest temperatures. The same temperature patterns observed for Tas and Tasmin were also noted for Tasmax, with extreme values ranging from 32 up to 36°C for all the region except the Guinean zone which face the lowest temperature ranging from 24 to 28 °C. These results show that both datasets agreed that the hottest area was the Sahel band, situated at the borders of Mali, Mauritania, Senegal and Niger.

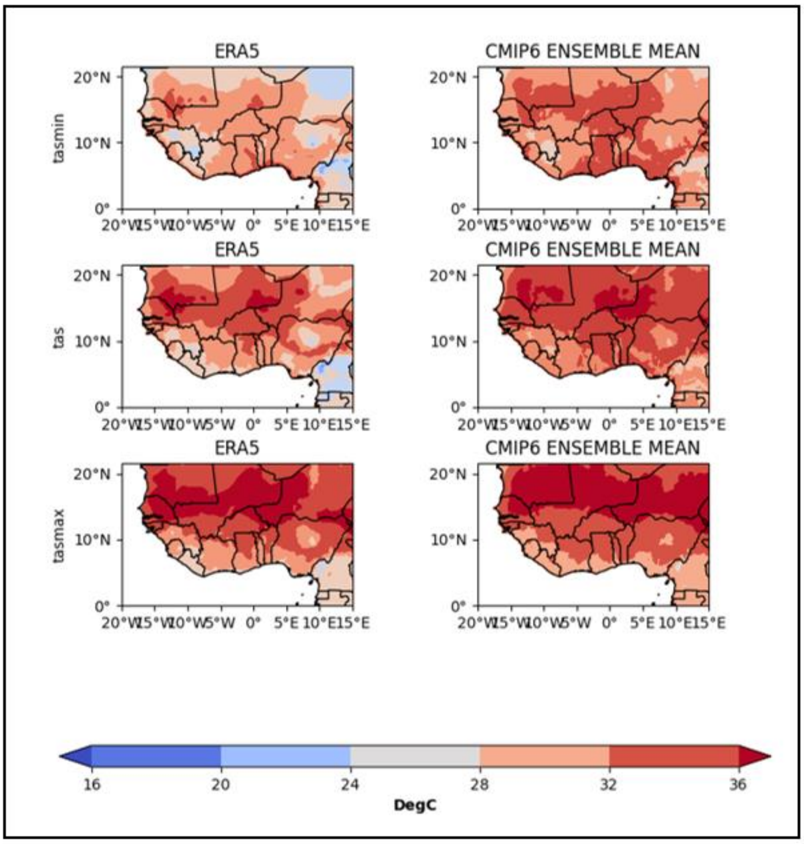


Figure 15: Average annual temperature over West Africa in the present climate (1985-2014).

Fig.16 presents the difference observed between the ERA5 and ensemble mean of 15 NEX-GDDP-CMIP6 models datasets. Regarding the variable Tasmin, negative values are observed in the Guinean zone and the Savanna zone. These findings indicate that the ensemble mean of 15 NEX-GDDP-CMIP6 models underestimates the ERA5 dataset. Conversely, in the northern part and the Sahel zone, a positive difference is observed between the datasets. This can be attributed to the overestimation of the ensemble mean of 15 NEX-GDDP-CMIP6 models in these regions. For Tas and Tasmax, the patterns exhibit similar trends, with positive values across the region, suggesting that the ensemble mean of 15 NEX-GDDP-CMIP6 models overestimates the ERA5 data on these zones.

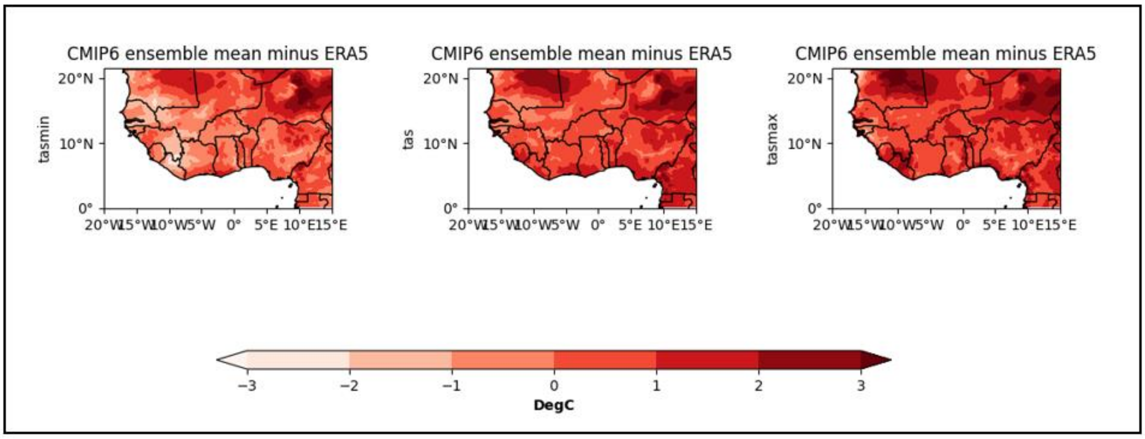


Figure 16: Ensemble mean of 15 NEX-GDDP-CMIP6 models annual temperature minus ERA5 mean annual temperature.

3.1.2 Analysis of spatial and temporal patterns of climate indices anomalies for both the 2031–2060 and 2071–2100 periods under the SSP126, SSP245 and SSP585

3.1.2.1 Spatial patterns of the temperature indices anomalies under SSP126, SSP245 and SSP585 over Burkina Faso

Minimum, Mean, and Maximum Temperature

Fig.17 shows spatial patterns of the minimum, mean, and maximum temperatures anomalies over the average period 2031–2060 under SSP126, SSP245, and SSP585 scenarios with the ensemble mean of 15 NEX-GDDP-CMIP6 models in Burkina Faso. The findings suggest that Burkina Faso is projected to undergo a high rise in minimum, mean, and maximum temperatures across the three different scenarios, ranging from 1.1 to 2.07℃. The outcomes reveal a progressive increase in temperature for SSP126, SSP245, and SSP585, respectively. Under the SSP126 scenario, an increase in minimum temperature ranging from 1.24 to 1.36°C was expected. Similarly, the mean temperature is projected to increase within the range of 1.17 to 1.34°C, and the maximum temperature was expected to fall within the range of 1.1 to 1.34°C. Anticipated high temperatures were predicted for the Sahelian zone, while the lowest temperatures were expected in the Soudanian zone. Regarding the SSP245 scenario, the projections suggest a moderate temperature increase compared to the other scenarios. The minimum temperature is projected to rise between

1.47 and 1.68°C, while the mean temperature is expected to increase between 1.35 and 1.58°C. The maximum temperature is projected to rise within the range of 1.18 to 1.5°C. However, the SSP585 scenario reveals the highest temperature increase for Burkina Faso in comparison to the SSP126 and SSP245. The minimum temperature is projected to rise from 1.83 to 2.07°C. Similarly, the mean temperature is expected to increase within the range of 1.62 to 1.95°C, while the maximum temperature is projected to fluctuate between 1.83 and 2.07°C. In terms of the average of the far period from 2071 to 2100 (as shown in Fig.18), the temperature is forecasted to continue increasing across all three scenarios. Particularly, the SSP585 scenario is projected to have a greater rise in minimum, mean, and maximum temperatures with values of 5.07, 4.78, and 4.49°C respectively compared to the SSP126 and SSP245 scenarios. It is worth noting that the most substantial temperature increases are expected in the Sahelian zone for all three variables. However, SSP585 projects the highest temperature rise than the other scenario. The increase in minimum temperature was greater than that in mean and maximum temperature.

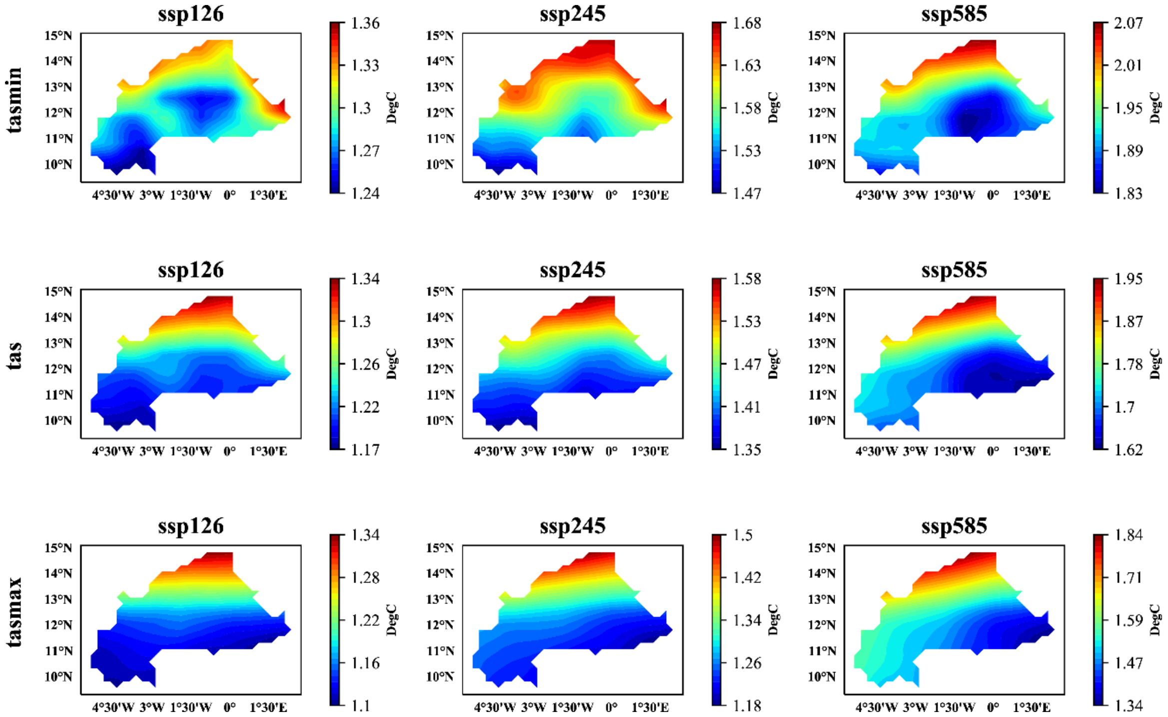


Figure 17: Spatial patterns of the minimum (tasmin), mean (tas), and maximum (tasmax) temperature (°C) anomalies over the period 2031–2060 under the SSP126, SSP245, and SSP585.

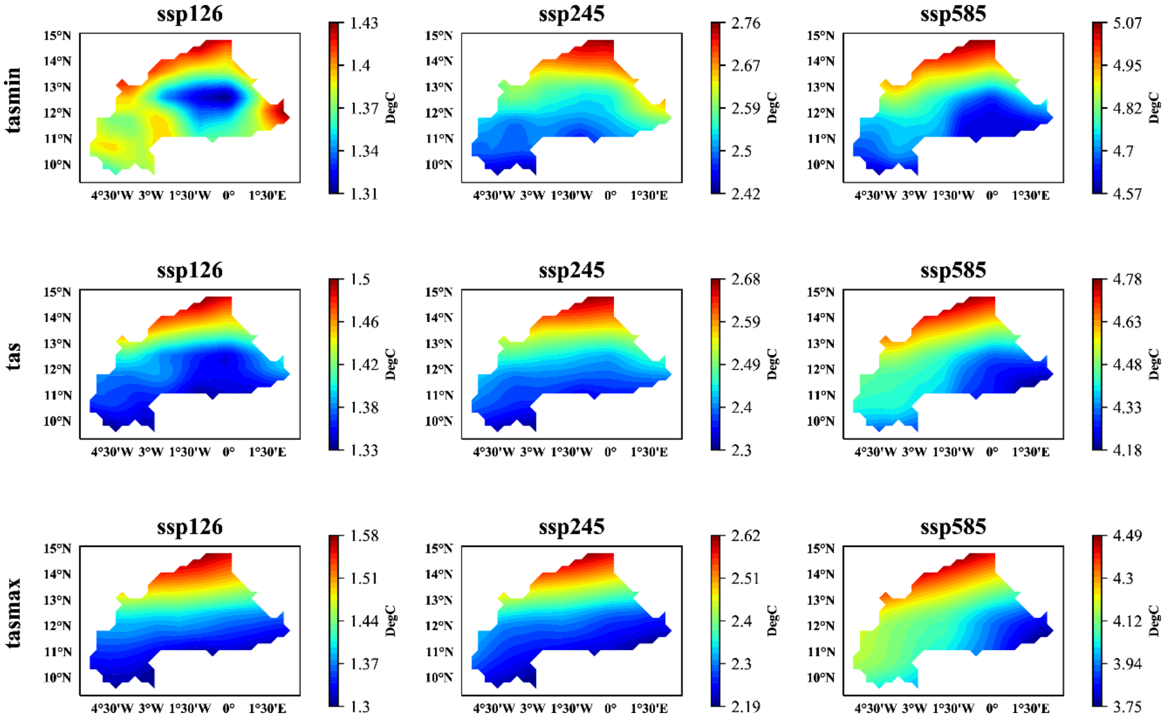


Figure 18: Spatial patterns of the minimum (tasmin), mean (tas), and maximum (tasmax) temperature (°C) anomalies over the period 2071–2100 under the SSP126, SSP245 and SSP585.

Cold Extremes Indices (TN10p, TX10p)

The analysis of spatial patterns of cool days and cool nights anomalies demonstrate a consistent warming pattern across Burkina Faso for the average period 2031 - 2060 (Fig.19) under the three scenarios considered. Specifically, the result of the frequency of cool nights (TN10p) reveals a negative slope ranging from -7.2 to -5.78, -7.79 to -6.74, and -8.02 to -6.93 for SSP126, SSP245, and SSP585 respectively. These values demonstrate a high increase in nocturnal temperatures, implying that evenings have become warmer. Furthermore, there has been a noticeable decrease in the frequency of cool days (TX10p) as depicted in Figure 24b, across all three scenarios, with values spanning from -6.55 to -4.95, -6.79 to -5.04 and -6.57 -to 4.35 for SSP126, SSP245 and SSP585 respectively. These indices would continue decreasing with the average period 2071-2100 under the three scenarios (Fig.20). This decline in both cool nights and warm days has particularly impacted the all the region except the Sudanian zone. This warming trend is attributed to elevated maximum and minimum temperatures during the examined period, with the minimum temperature demonstrating a comparatively swifter rate of increase.

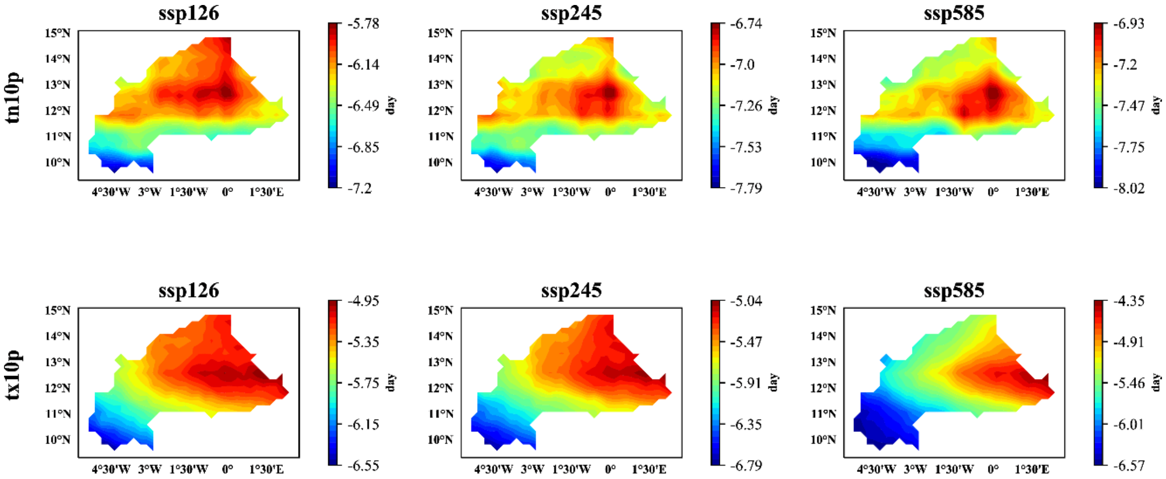


Figure 19: Spatial patterns of cool nights (tn10p) and cool days (tx10p) anomalies over the period 2031–2060 under the SSP126, SSP245 and SSP585.

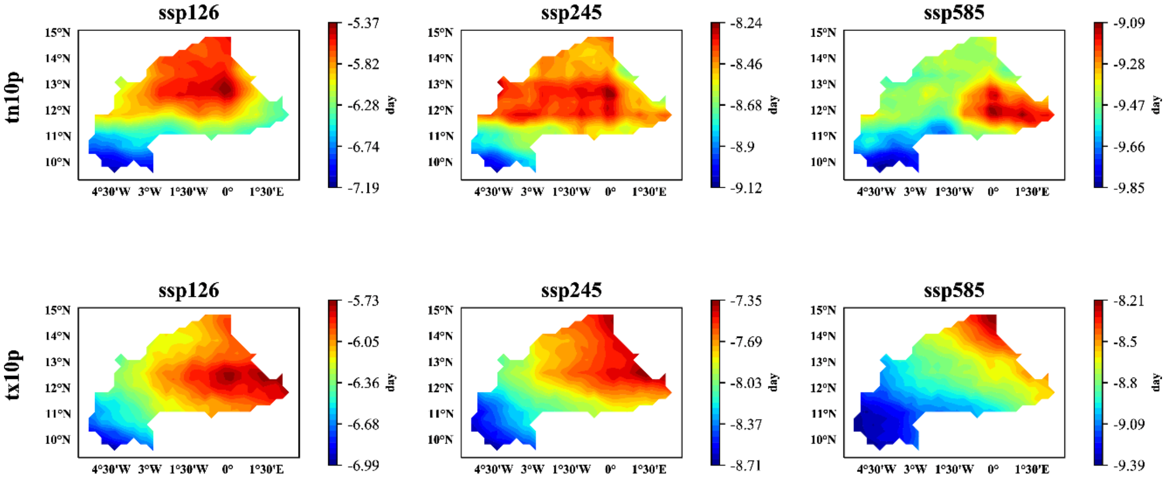


Figure 20: Spatial patterns of cool nights (tn10p) and cool days (tx10p) anomalies over the period 2071–2100 under the SSP126, SSP245 and SSP585.

Hot Extremes Indices (TX90p, TN90p)

Fig.21 show the spatial patterns observed in hot extremes indices anomalies over the average period 2031-2060 under the SSP126, SSP245, and SSP585 simulations The figure demonstrates that both warm nights (TN90p) and warm days (TX90p) exhibit a high temperature across all three scenarios. Specifically, under the SSP126 scenario, TN90p experiences an increase of approximately 20-33 days, while TX90p shows an increase of 15-20 days. Similarly, under the SSP245 scenario, TN90p increases by 25-38 days, and TX90p increases by 16-23 days. Finally, under the SSP585 scenario, TN90p increases by 32-46 days, while TX90p increases by 20-30 days. These indices continue to rise throughout the average extended period of 2071-2100 under all three SSP scenarios, as depicted in Fig.22. Notably, the Sudanian zone is projected to experience the highest nighttime temperatures, while the three zones (Sahelian zone, the Sudano-Sahelian zone, and Sudanian zone) of the region will likely witness the highest daytime temperatures except around Fada N'Gouma. The observed increases in hot extremes indices align with the concurrent rise in maximum temperatures for warm days (TX90p) and minimum temperatures for warm nights (TN90p).

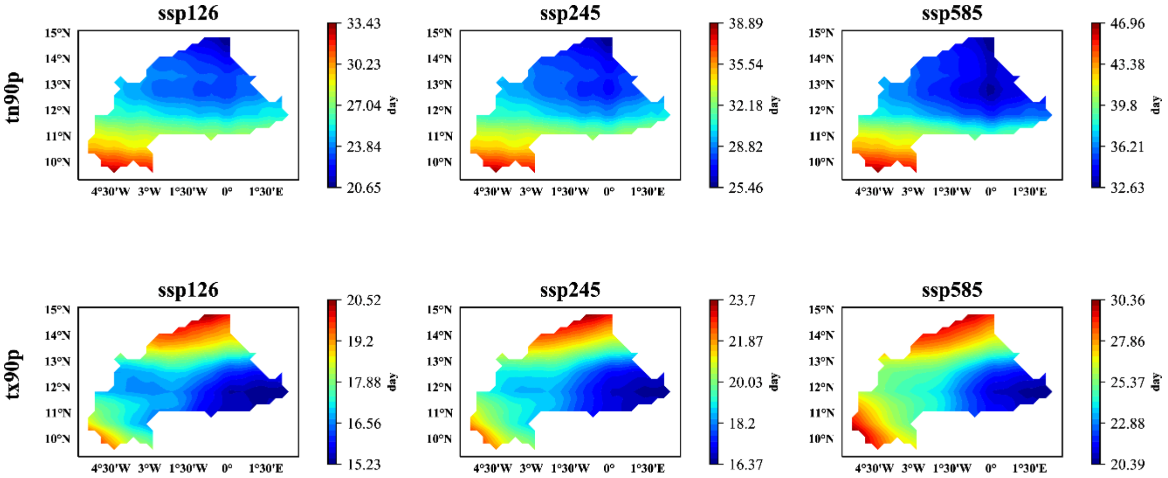


Figure 21: Spatial patterns of warm nights (tn90p) and warm days (tx90p) anomalies over the period 2031–2060 under the SSP126, SSP245 and SSP585.

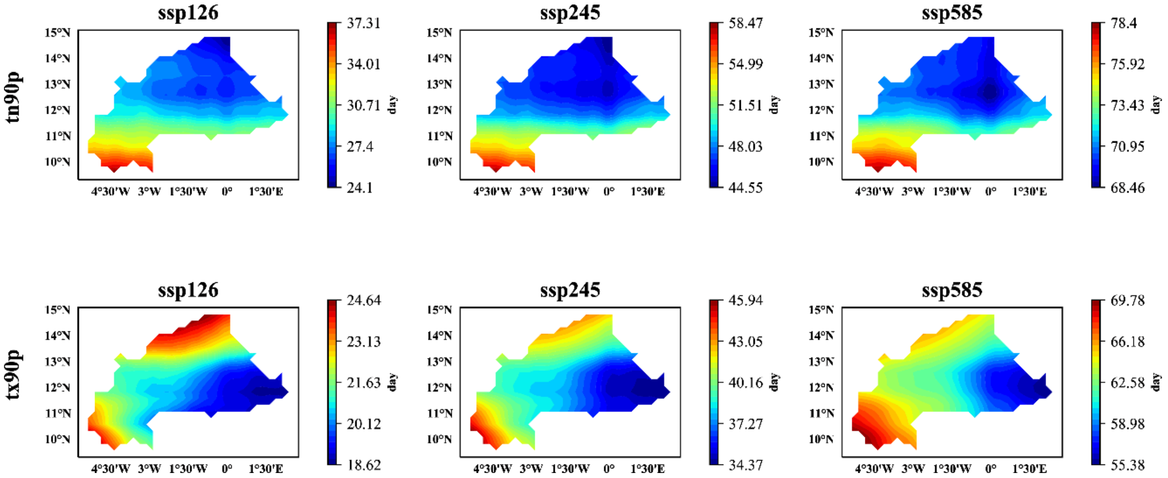


Figure 22: Spatial patterns of warm nights (tn90p) and warm days (tx90p) anomalies over the period 2071–2100 under the SSP126, SSP245 and SSP585.

3.1.2.2 Spatial patterns of precipitation indices anomalies under SSP126, SSP245 and SSP589

Total Annual Precipitation (PRCPTOT)

Fig.23 shows the spatial patterns in total annual precipitation anomalies in Burkina Faso for the average period of 2031 - 2060, as derived from the CMIP6 ensemble mean, under the SSP126, SSP245, and SSP585 scenarios. The analysis reveals a consistent pattern across all three scenarios, whereby the Sahelian zone and the eastern regions of the Sudano-Sahelian zone will experience a notable increase in annual precipitation with an amount exceeding 60mm for SSP126, 70mm for SSP245, and 91mm for SSP585. Conversely, a low change in precipitation is projected for the Sudanian zone, with a specific focus on the Gaoua and Banfora with amounts, falling below 60mm for SSP126, 70mm for SSP245, and 91mm for SSP585. Fig.24 which presents the long-term change in total precipitation during the average period 2071-2100, indicates a decrease under the SSP126 and a continual increase under the SSP245 and SSP585. In contrast, both the SSP126 and SSP245 scenarios exhibit limited variability throughout the respective periods examined.

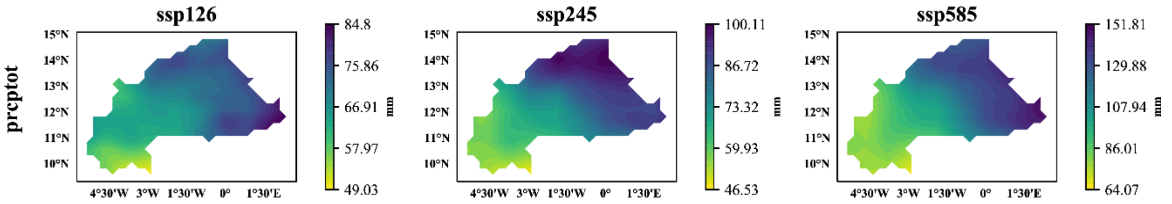


Figure 23: Spatial patterns of total annual precipitation (prcptot) anomalies over the period 2031–2060 under the SSP126, SSP245 and SSP585.

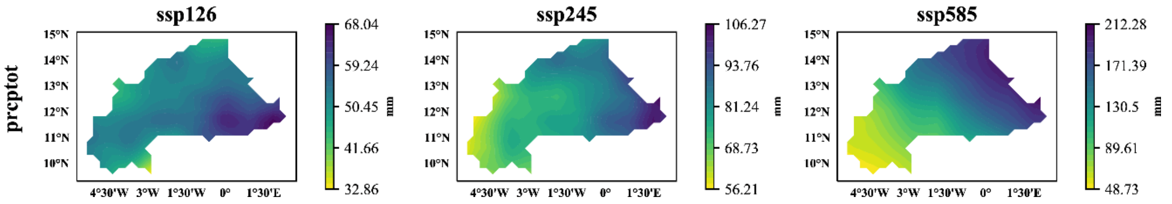


Figure 24: Spatial patterns of total annual precipitation (prcptot) anomalies over the period 2071–2100 under the SSP126, SSP245 and SSP585.

Precipitation Frequency Indices (R10mm, R20mm)

Fig.25 presents the spatial patterns in the occurrences of heavy rain days (R10mm) and very heavy rain days (R20mm) anomalies across Burkina Faso during the average period 2031-2060, considering the SSP126, SSP245, and SSP585 scenarios. The analysis reveals a slight increase in both R10mm and R20mm under all three SSPs, especially observed over the Sudano-Sahelian zone. Moreover, certain regions within the Sahelian zone, particularly around Dori, experience more increase in R10mm and R20mm, particularly under the SSP245 and SSP585 scenarios. To quantify these changes, the increase is less than 4 days (R10mm) and 2 days (R20mm) for SSP126, 4 days (R10mm) and 3 days (R20mm) for SSP245, and 6 days (R10mm) and 4 days (R20mm) for SSP585.

Moreover, the long-term projection from 1071 to 2100 in Fig.26, shows that under the SSP126 scenario, there is a minor decrease of less than 1 day in both R10mm and R20mm. However, under both the SSP245 and SSP585 scenarios, a consistent and slight increase of less than 1 day persists throughout the examined period. Overall, the variations in R10mm and R20mm are not very high across all periods under the three scenarios.

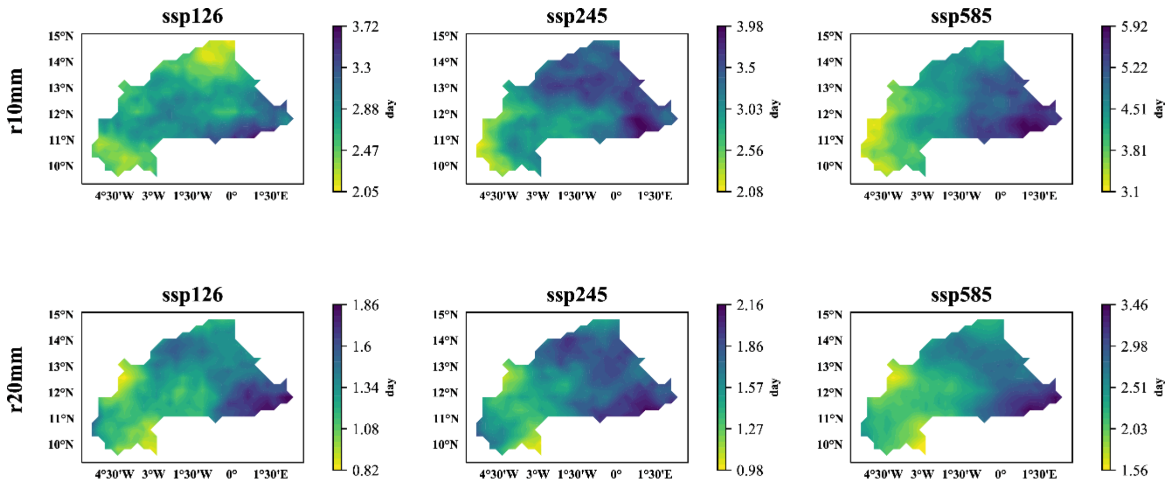


Figure 25: Spatial patterns of the Number of heavy precipitation days (r10mm) and the Number of very heavy precipitation days (r20mm) anomalies over the period 2030–2060 under SSP126, SSP245 and SSP585.

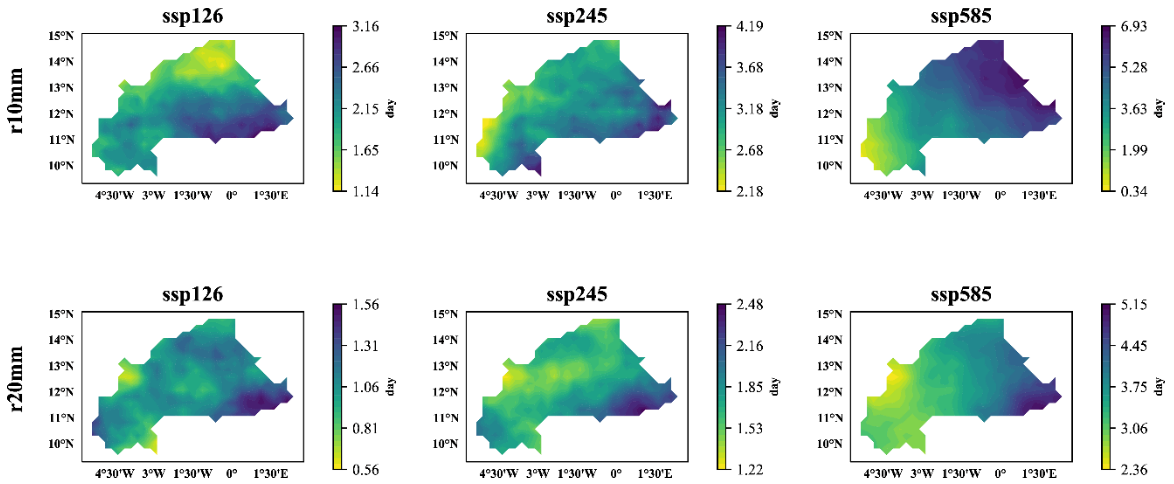


Figure 26: Spatial patterns of the Number of heavy precipitation days (r10mm) and the Number of very heavy precipitation days (r20mm) anomalies over the period 2071–2100 under SSP126, SSP245 and SSP585.

Precipitation Intensity Indices (RX1day, RX5day)

Fig.27 shows spatial patterns in Max 1-day precipitation amount (RX1day) and Max 5-day precipitation amount (RX5day) anomalies under SSP126, SSP245, and SSP585 scenarios over the period 2031-2060 in Burkina Faso. Across all three scenarios, both RX1day and RX5day exhibit a slight increase over Burkina Faso. The highest change is more expected in the Sahelian zone and the lowest around the Sudanian zone. For the RX1day, between the three SSPs, the difference follows the increase in radiative forcing with variation less than 2mm. Similarly, to RX5day with an increase less than 1mm. When considering future projections from 2071 to 2100 shown in Fig.28, a slight decrease is observed for these indices under the SSP126 scenario, while a continual increase is noted under the SSP245 and SSP585 scenarios. Similar to the findings in R10mm and R20mm, the variability in these results aligns.

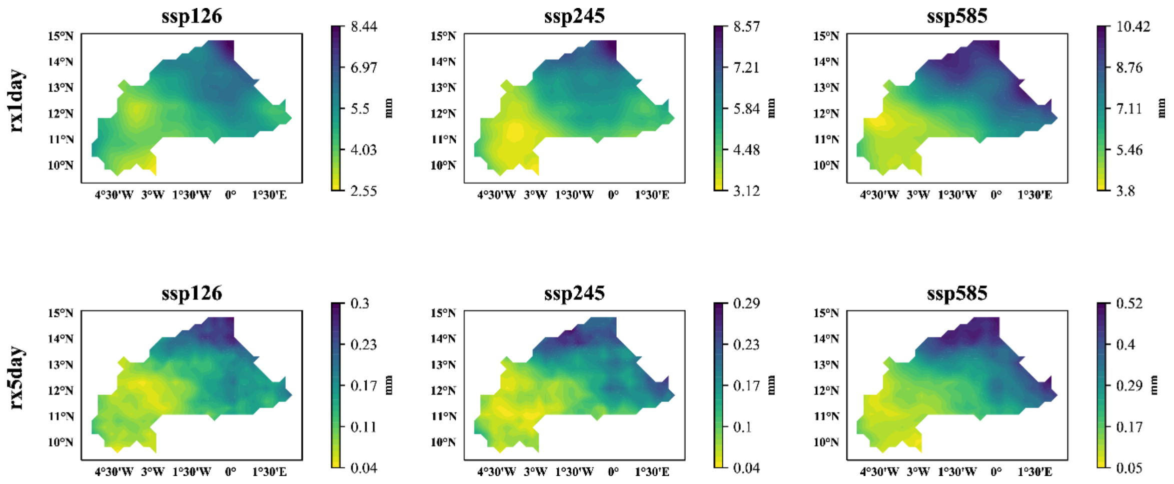


Figure 27: Spatial patterns of Max 1-day precipitation amount (rx1day) and Max 5-days precipitation amount (rx5day) anomalies over the period 2031–2060 under the SSP126, SSP245 and SSP585.

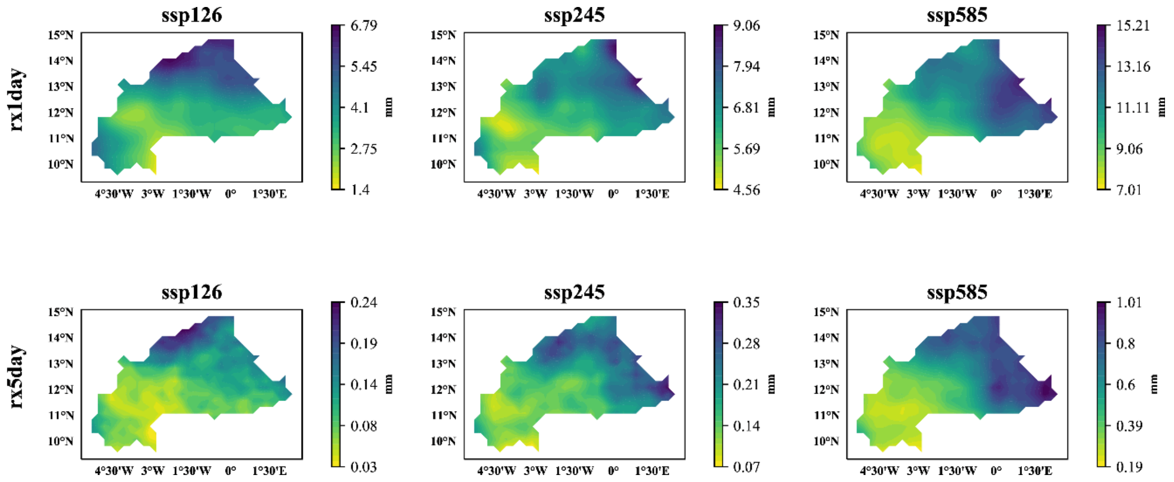


Figure 28: Spatial patterns of Max 1-day precipitation amount (rx1day) and Max 5-days precipitation amount (rx5day) anomalies over the period 2071–2100 under the SSP126, SSP245 and SSP585.

Precipitation Frequency Indices (CDD, CWD)

Fig.29 displayed the spatial variations in the number of Consecutive dry days (CDD) and the Consecutive wet days (CWD) anomalies across Burkina Faso from 2031 to 2060, considering SSP126, SSP245, and SSP585 scenarios. The result indicates that there is a small change in both CDD and CWD across the three SSPs. In all three scenarios, a slight increase in CDD is observed throughout Burkina Faso, with an exception in the southern part of the Sahelian zone in the SSP585. Conversely, for CWD, a small rise is anticipated across the region under all three SSPs, except in the Sahelian zone and certain areas of the Sudano-Sahelian zone, particularly around Fada N'Gouma region, specifically under the SSP126. Furthermore, it is important to note that Fig.30 provides a projection for the distant future, from 2071 to 2100. In these projections, the SSP126 and SSP245 show a gradual increase in CDD over the Sahelian and Sudano-Sahelian zones, when decreasing under the SSP585. However, under the SSP126 scenario, a slight decrease in CWD is observed throughout the Sahelian zone, while a continual increase is expected under SSP245 and SSP585.

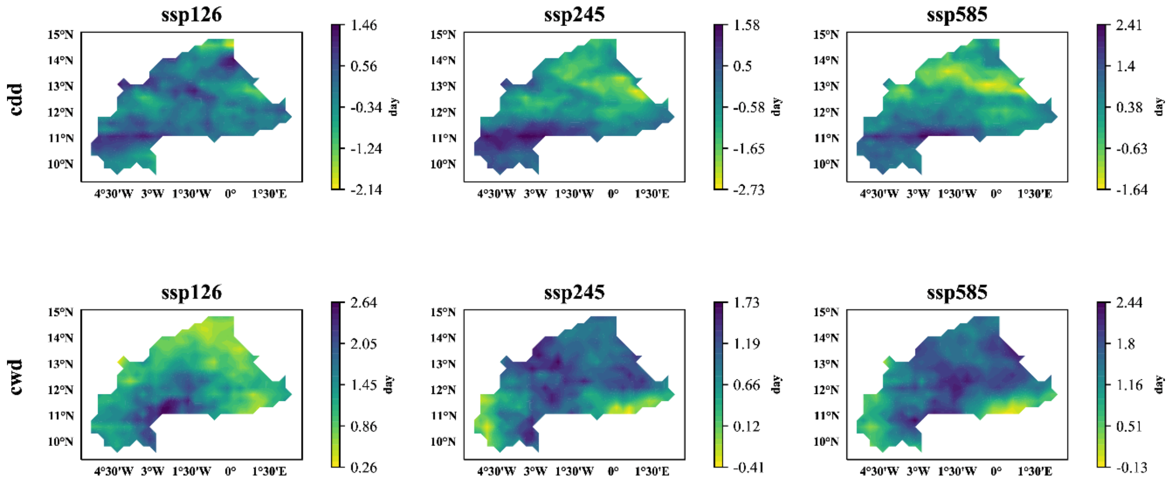


Figure 29: Spatial patterns of the number of Consecutive dry days (cdd) and the number of Consecutive wet days (cwd) anomalies over the period 2031–2060 under the SSP126, SSP245 and SSP585.

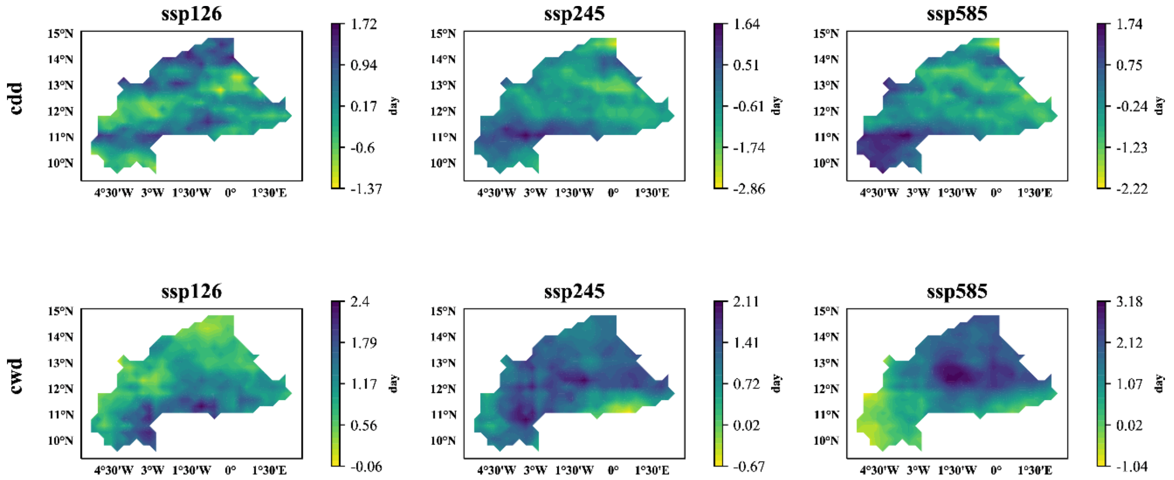


Figure 30: Spatial patterns of the number of Consecutive dry days (cdd) and the number of Consecutive wet days (cwd) anomalies over the period 2071–2100 under the SSP126, SSP245 and SSP585.

3.1.2.3 Temporal patterns of the temperature indices anomalies under SSP126, SSP245 and SSP589

Minimum, Mean, and Maximum Temperature / Hot Extremes Indices (TX90p,

TN90p)

Fig.31 illustrates the temporal patterns of average annual daily minimum, maximum, and mean temperature anomalies for both the 2031-2060 and 2071-2100 periods under the SSP126, SSP245, and SSP585 scenarios. The results reveal a relative increase in temperatures during the near future period (2031-2060), followed by a high increase during the far future period (2071-2100) across all three SSP scenarios. The degree of warming differs among the scenarios, with a noticeable divergence occurring after approximately 2057. Specifically, the minimum, mean, and maximum temperatures associated with the SSP585 scenario exhibit a continuous increase of less than 9°C in maximum by the end of the far future. In contrast, the corresponding variables derived from the SSP126 scenario start to decrease by less than -2°C in minimum. Meanwhile, the SSP245 scenario indicates a stabilization of the warming for these three temperature variables. Similarly, the trends observed in warm days (TX90p) and warm nights (TN90p) under the three scenarios (Fig.32) follow a similar pattern. The figures indicate a continuous increase of less than 95 days (TN90p) and 90 days (TX90p) in maximum for the SSP585 scenario, -25 days (TN90p) and -5 days (TX90p) in minimum for the SSP126 scenario and the SSP245 scenario indicates a stabilization of the warming for both TN90p and TX90 by the end of the century. Notably, the warming is more pronounced in nighttime temperatures compared to daytime temperatures during both the 2031-2060 and 2071-2100 periods.

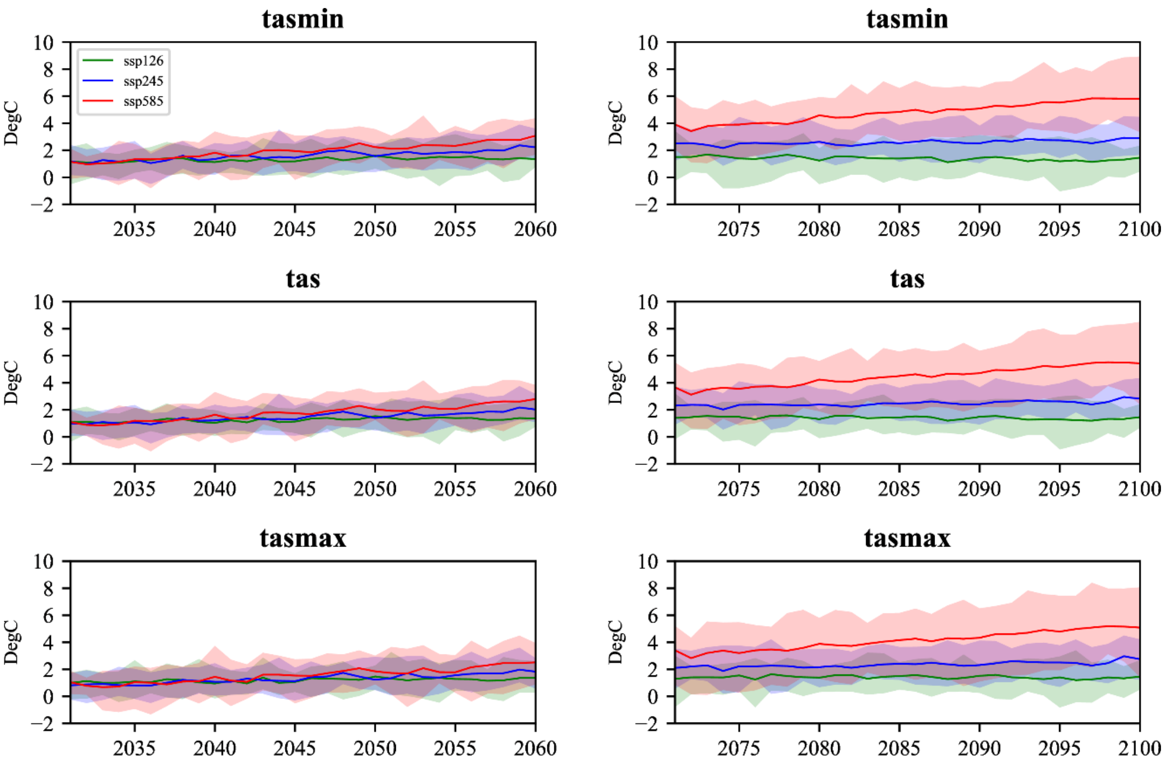


Figure 31: Temporal patterns of the minimum (tasmin), mean (tas), and maximum (tasmax) temperature (°C) anomalies from 2031 to 2060 and 2071 to 2100 under the SSP126, SSP245 and SSP585. The shaded colors show the maximum and the minimum of the models.

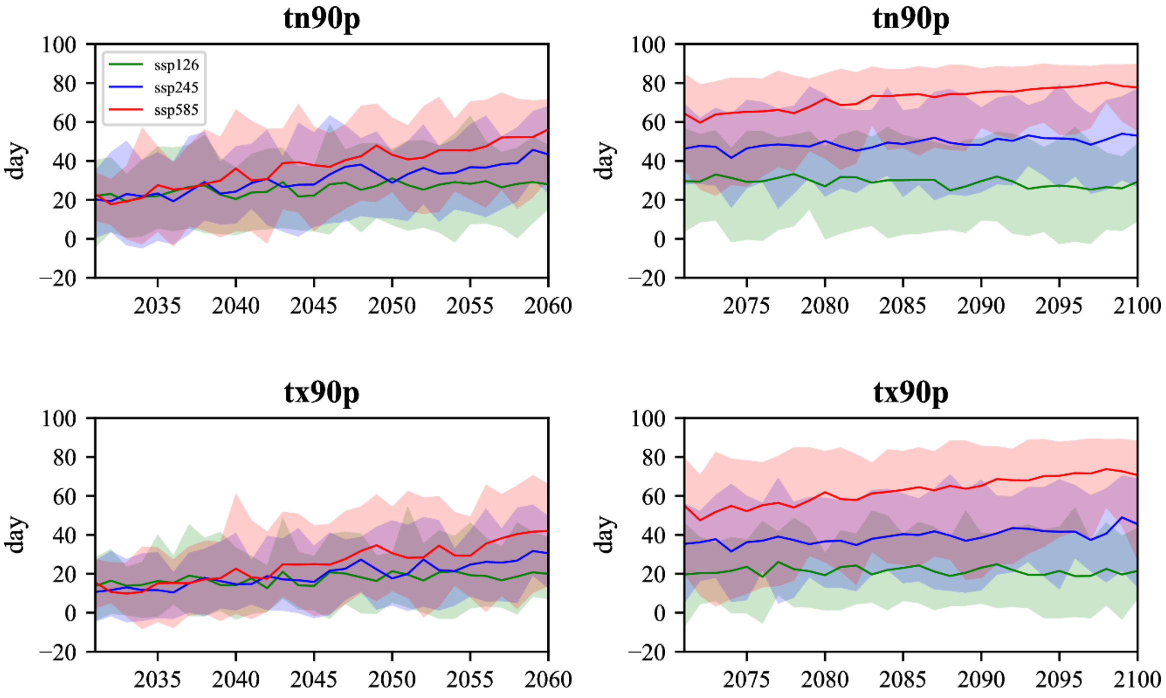


Figure 32: Temporal patterns of warm nights (tn90p) and warm days (tx90p) anomalies from 2031 to 2060 and 2071 to 2100 under the SSP126, SSP245 and SSP585.

Cold Extremes Indices (TN10p, TX10p)

Fig.33 displayed the temporal trends of the frequency of cool nights (TN10p) and cool days (TX10p) anomalies across the three SSPs scenarios in both the near future (2031-2060) and the far future (2071-2100). The findings revealed a substantial decrease in cool days and cool nights during the near future period (2031-2060), and a continual decrease was observed during the far future period (2071-2100) for all three SSPs scenarios. The divergence among the scenarios became apparent around 2077, where TN10p and TX10p associated with the three SSPs scenario started to remain constant, with values less than -10 days in the minimum by the end of the century. The observed alterations in the frequency of cool and warm days seemed relatively smaller in magnitude compared to the changes in the frequency of cool and warm nights.

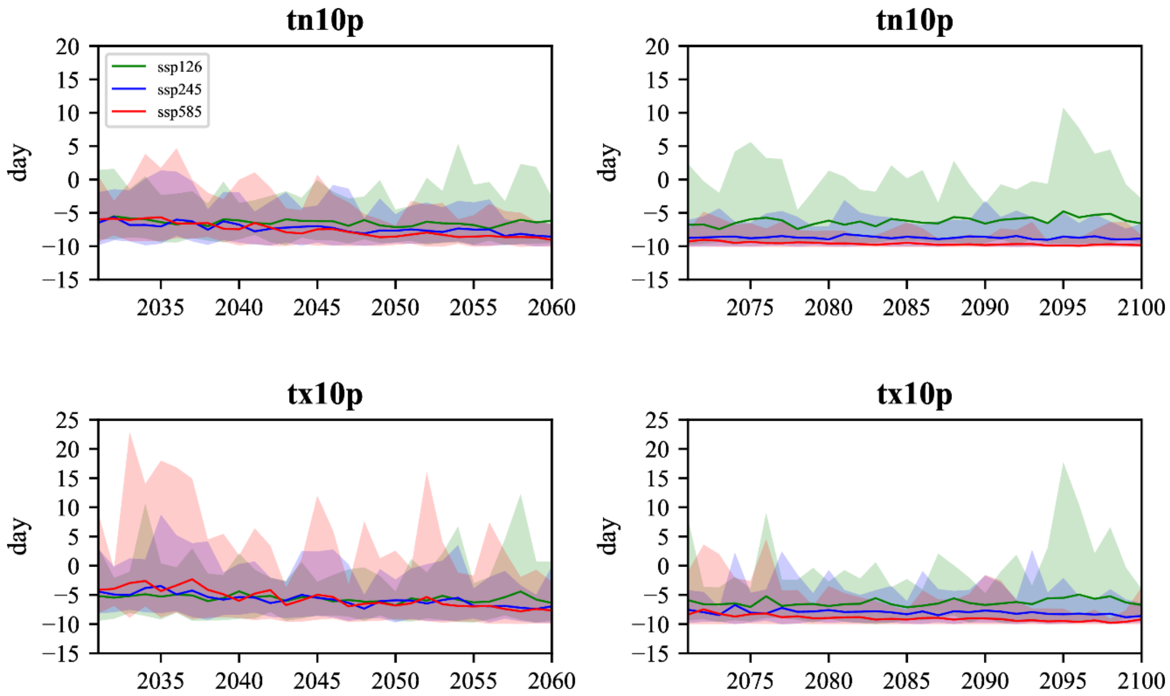


Figure 33: Temporal patterns of the number of cool nights (tn10p) and number of cool days (tx10p) from 2031 to 2060 and 2071 to 2100 under the SSP126, SSP245 and SSP585.

3.1.2.4 Temporal patterns of the precipitation indices anomalies under SSP126, SSP245, and SSP589

Total Annual Precipitation (PRCPTOT), Precipitation Intensity Indices (RX1day, RX5day), Precipitation Frequency Indices (R10mm, R20mm, CDD, CWD)

When considering future projections, it is important to note that the evolution of precipitation exhibits distinct characteristics compared to temperature, displaying a combination of increasing and decreasing trends. Fig.34 shows the temporal trends of annual precipitation PRCPTOT in Burkina Faso under SSP126, SSP245, and SSP585 scenarios for the two periods (2031-2060 and 2071-2100). The findings indicate that all three scenarios exhibit a similar pattern, characterized by a mixture of positive and negative trends across both time periods, with an increase below 1100mm in the maximum extreme under the SSP585 at the end of the century. Similarly, other precipitation indices, including, R10mm, R20mm (Fig.35), CDD, CWD (Fig.36), and RX1day, RX5day (Fig.37), display indeterminate trends, with no clear directional patterns observed from 2031-2060 to 2071-2100. These results highlight the complex nature of future precipitation changes in Burkina Faso, with a lack of clear and consistent trends across the different scenarios and time periods.

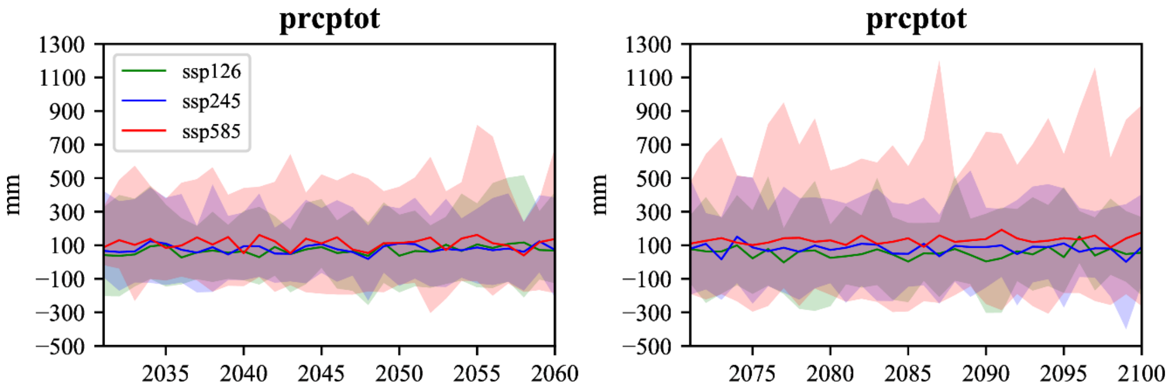


Figure 34: Temporal trends of the total annual precipitation (prcptot) anomalies from 2031 to 2060 and 2071 to 2100 under the SSP126, SSP245 and SSP585.

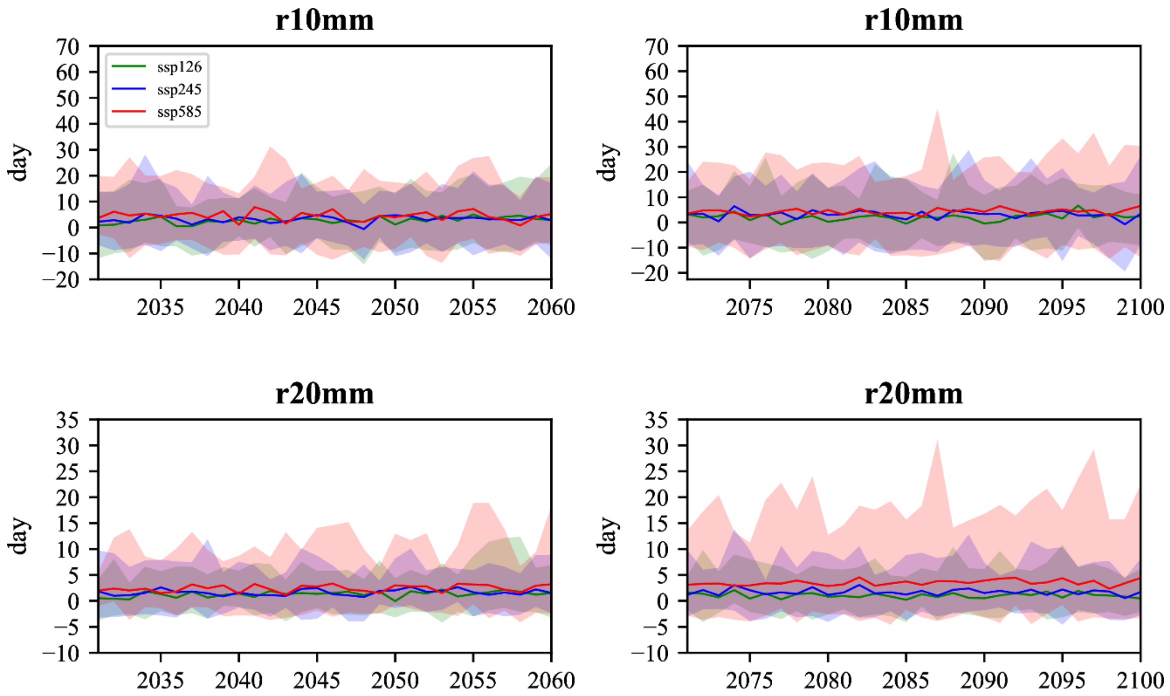


Figure 35: Temporal trends of the Number of heavy precipitation days (r10mm) and the Number of very heavy precipitation days (r20mm) anomalies from 2031 to 2060 and 2071 to 2100 under the SSP126, SSP245 and SSP585.

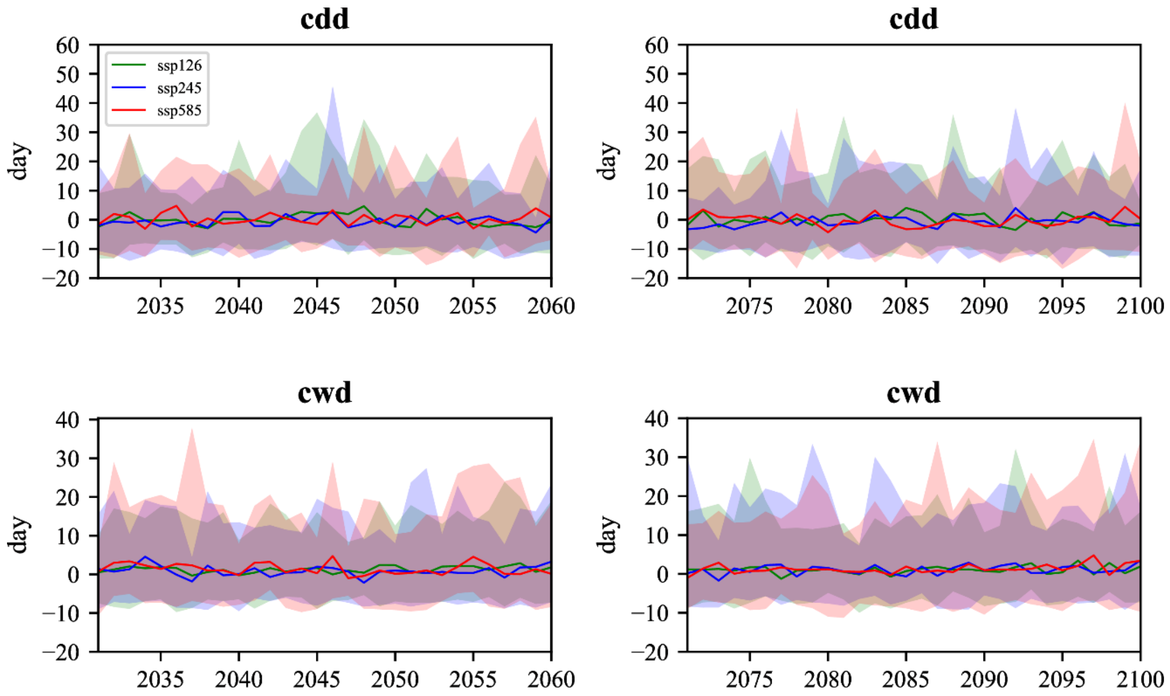


Figure 36: Temporal trends of the number of Consecutive dry days (cdd) and the number of Consecutive wet days (cwd) anomalies from 2031 to 2060 and 2071 to 2100 under the SSP126, SSP245 and SSP585.

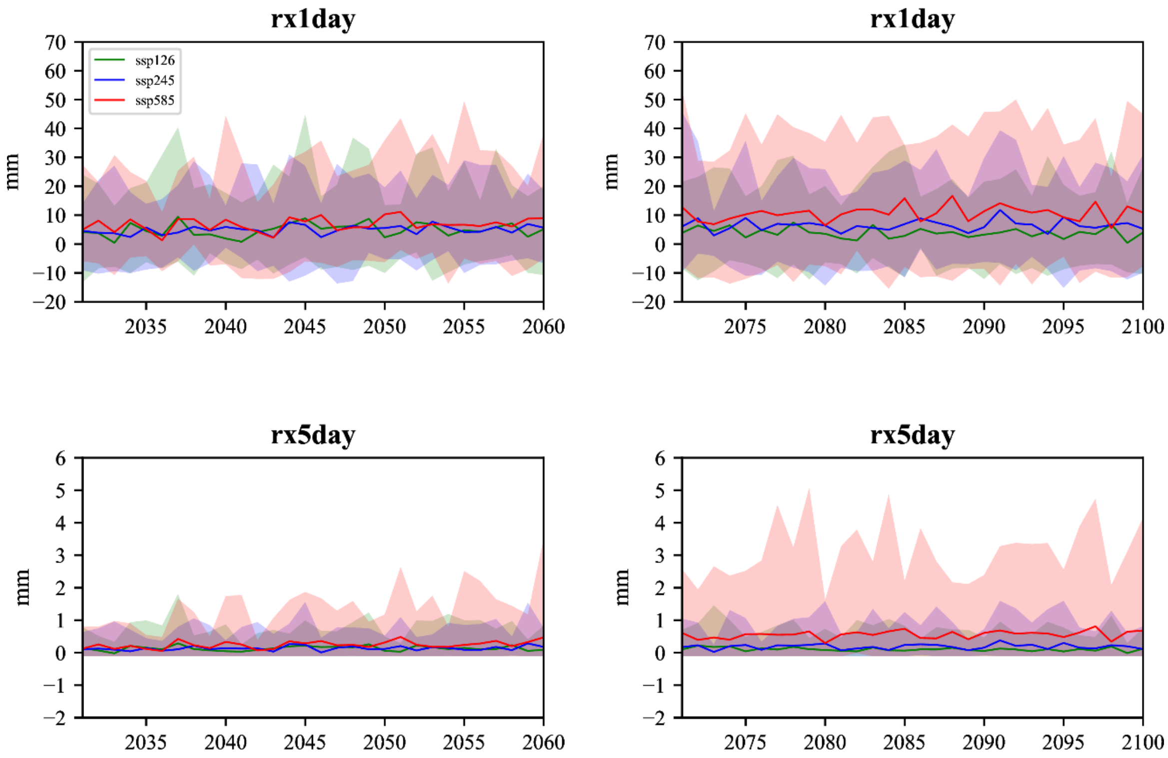


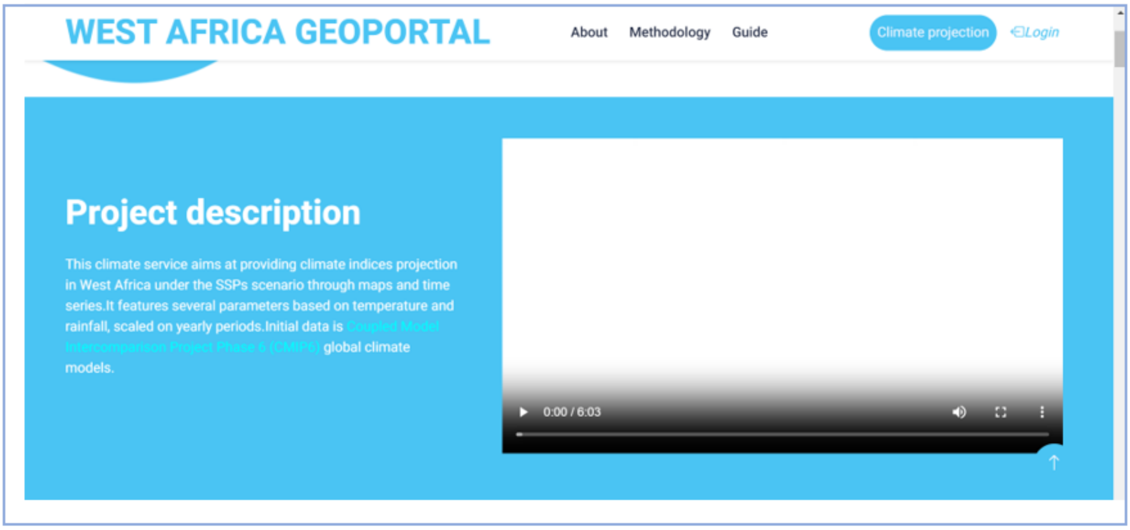
Figure 37: Temporal trends of the Max 1-day precipitation amount (rx1day) and Max 5-days precipitation amount (rx5day) anomalies from 2031 to 2060 and 2071 to 2100 under the SSP126, SSP245 and SSP585.

3.1.3 Presentation of the climate services web-based platform to simulate climate indices over West Africa under the SSP126, SSP245 and SSP586

The platform was designed to provide open access to climate data and related information in order to help users gain a deeper understanding of future climate indices projections with data aggregated at national and local levels. Its objective is to serve as a valuable resource for policymakers, development practitioners, and other individuals interested in evaluating climate data to assess potential future scenarios. The data utilized is presented in annual anomaly, showcasing inter-annual and spatial variability, and can be explored through a range of interactive visualizations.

Entering the geoportal

The main menu is showed in fig.38:



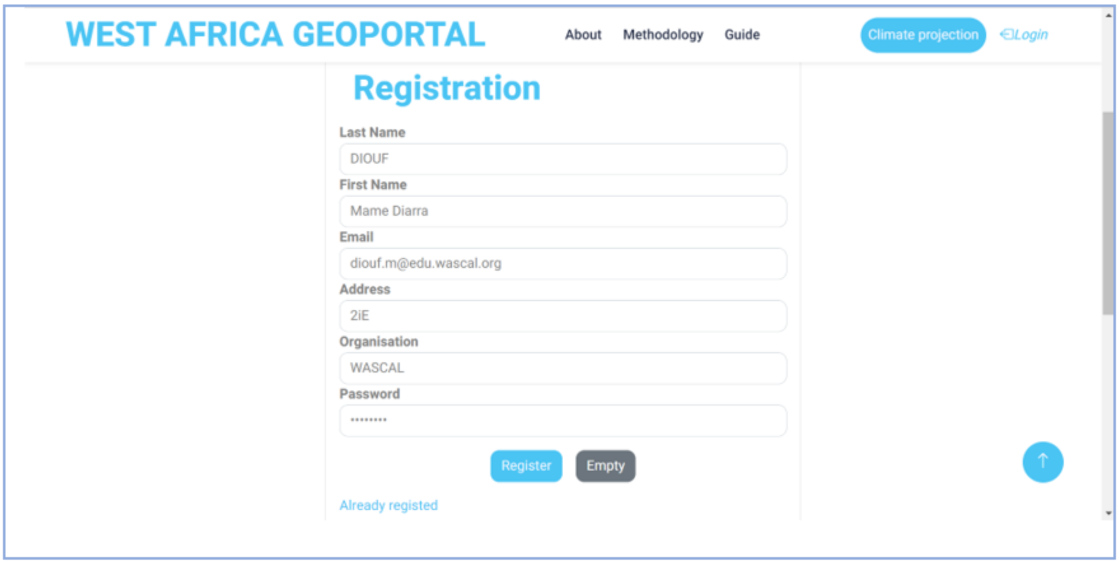
Project description

This climate service aims at providing climate indices projection in West Africa under the SSPs scenario through maps and time series.It features several parameters based on temperature and rainfall, scaled on yearly periods.Initial data is Coupled Model Intercomparison Project Phase 6 (CMIP6) global climate models.

Figure 38: The platform home page

Login page

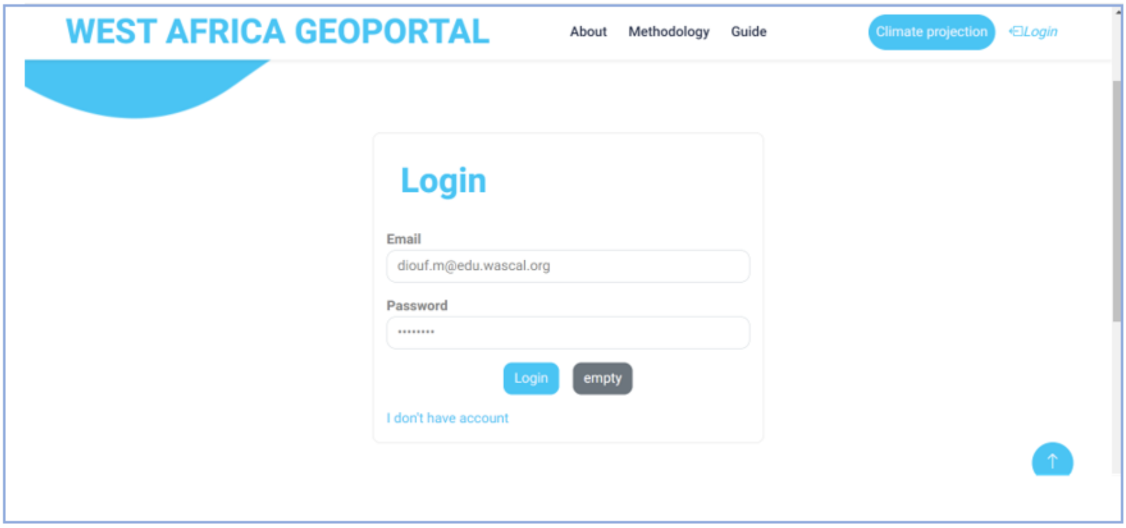
To explore the data interactive visualization pages, begin by creating an account (Fig.39) to have access and connect to the system (Fig.40). You can directly access to the: Methodology and Guide (to gain a more comprehensive understanding of the range of information available on the platform and the process of using it) without login.



Registration

Last Name: DIOUF
First Name: Mame Diarra
Email: diouf.m@edu.wascal.org
Address: 2iE
Organisation: WASCAL
Password: ••••••••

Figure 39: The platform registration page



Email: diouf.m@edu.wascal.org

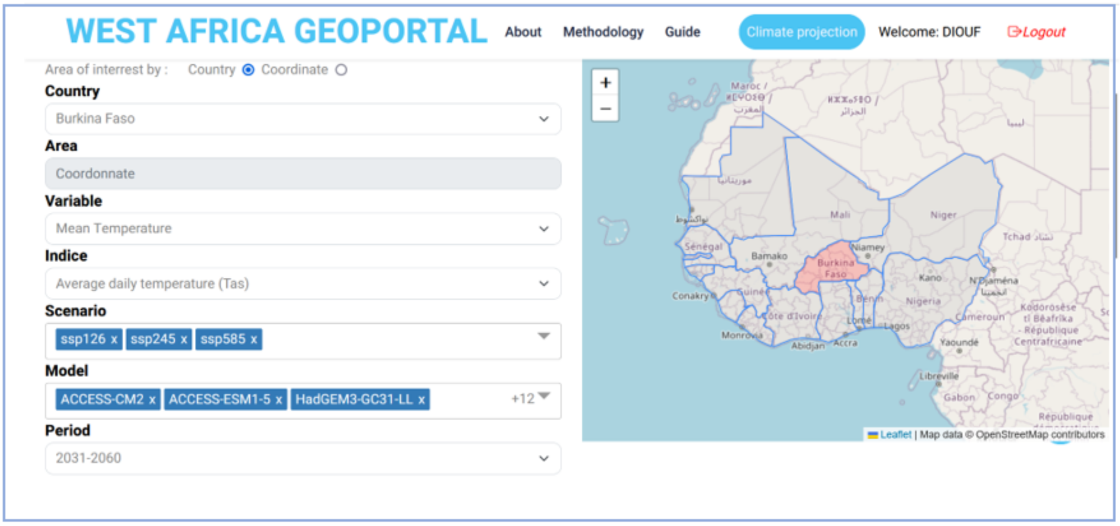
Password: ••••••••

Figure 40: The platform login page

Visualization page

The platform enables users to explore future climate scenarios through a wide variety of indicators, for different SSPs, and across different projected climatology (2031–2060, and 2071 – 2100). Therefore, maps and time series generated within the portal are a function of user selection (Fig.41):

- By default, country is selected as an area of interest (Click a point in the map or type coordinate location to select an area of interest if coordinate is selected);
- Use the menus “Variable”, “Indice” and “Model” to make a detailed selection (the possibility to select one or more model/scenario depending on the need);
- Click on the button “Generate Overview”.



Area of interrest by : Country ◉ Coordinate ○

Country
Burkina Faso

Area
Coordonnate

Variable
Mean Temperature

Indice
Average daily temperature (Tas)

Scenario
ssp126 x ssp245 x ssp585 x

Model
ACCESS-CM2 x ACCESS-ESM1-5 x HadGEM3-GC31-LL x +12

Period
2031-2060

Figure 41: Indices visualization interface

When “Generate Overview” is clicked then the “Time series”, “Spatial Plot” and “Table” options will appear (Fig.42).

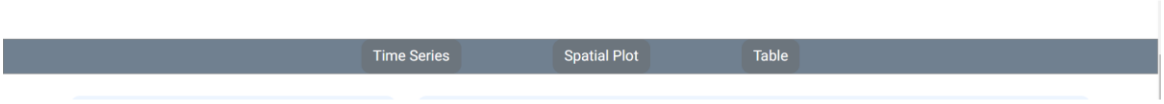
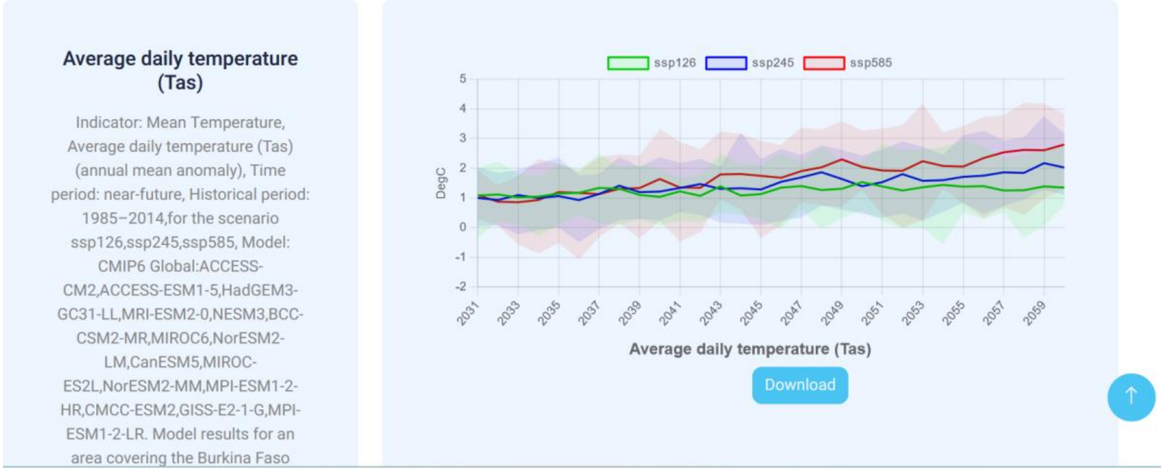


Figure 42: Visualization Options

The outcome offers a spatial and temporal pattern of the index within the chosen region (Fig.43 and 44). Based on the outcome, users can choose to download the graphical representations as images and data in the form of an Excel file (Fig.45). The platform provides also a long-term variation from the historical to the end of the century, with the period 1960-2100 (Fig.46).



Average daily temperature (Tas)

Indicator: Mean Temperature, Average daily temperature (Tas) (annual mean anomaly), Time period: near-future, Historical period: 1985–2014,for the scenario ssp126,ssp245,ssp585, Model: CMIP6 Global:ACCESS-CM2,ACCESS-ESM1-5,HadGEM3-GC31-LL,MRI-ESM2-0,NESM3,BCC-CSM2-MR,MIROC6,NorESM2-LM,CanESM5,MIROC-ES2L,NorESM2-MM,MPI-ESM1-2-HR,CMCC-ESM2,GISS-E2-1-G,MPI-ESM1-2-LR. Model results for an area covering the Burkina Faso

Figure 43: Temporal variability of average daily temperature under the SSP126, SSP245 and SSP585 during the period 2031-2060 over Burkina Faso.

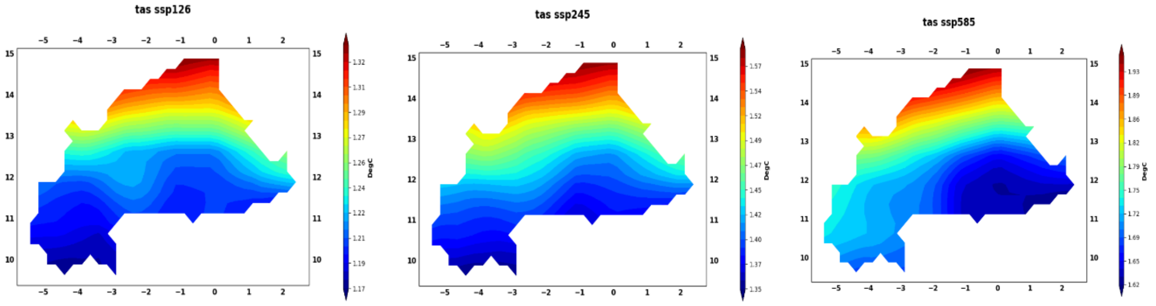
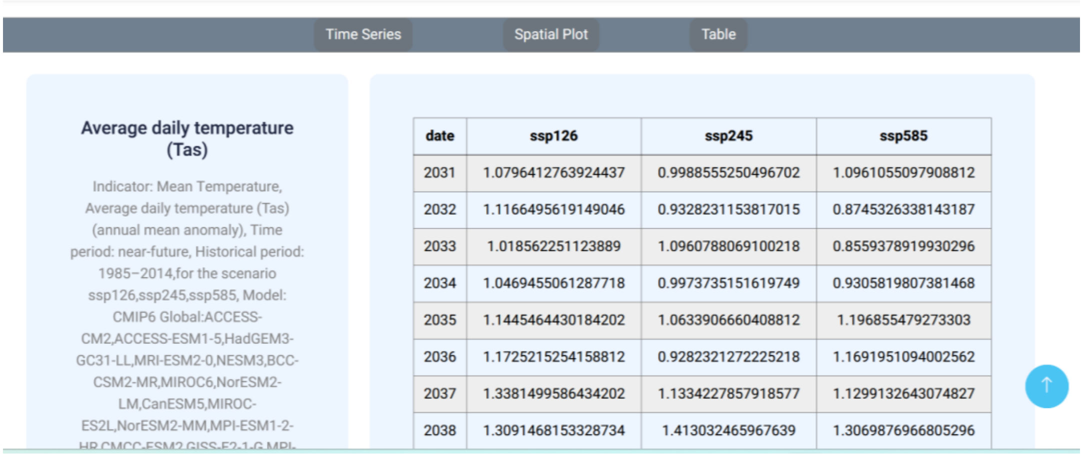


Figure 44: Spatial variability of average daily temperature under the SSP126, SSP245 and SSP585 during the period 2031-2060 over Burkina Faso.

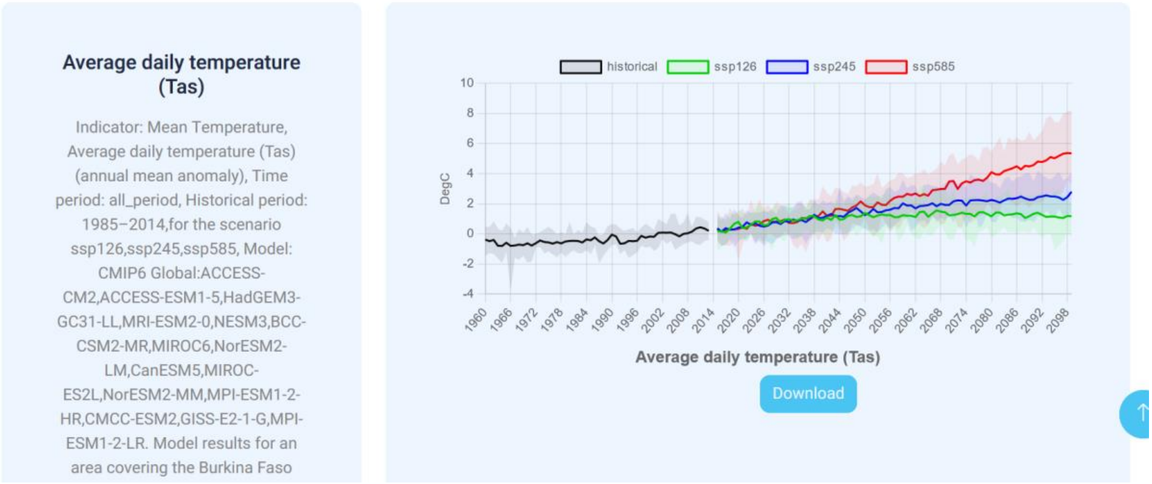


Average daily temperature (Tas)

Indicator: Mean Temperature, Average daily temperature (Tas) (annual mean anomaly), Time period: near-future, Historical period: 1985–2014,for the scenario ssp126,ssp245,ssp585, Model: CMIP6 Global:ACCESS-CM2,ACCESS-ESM1-5,HadGEM3-GC31-LL,MRI-ESM2-0,NESM3,BCC-CSM2-MR,MIROC6,NorESM2-LM,CanESM5,MIROC-ES2L,NorESM2-MM,MPI-ESM1-2-HR,CMCC-ESM2,GISS-E2-1-G,MPI-

date	ssp126	ssp245	ssp585
2031	1.0796412763924437	0.9988555250496702	1.0961055097908812
2032	1.1166495619149046	0.9328231153817015	0.8745326338143187
2033	1.018562251123889	1.0960788069100218	0.8559378919930296
2034	1.0469455061287718	0.9973735151619749	0.9305819807381468
2035	1.1445464430184202	1.0633906660408812	1.196855479273303
2036	1.1725215254158812	0.9282321272225218	1.1691951094002562
2037	1.3381499586434202	1.1334227857918577	1.1299132643074827
2038	1.3091468153328734	1.413032465967639	1.3069876966805296

Figure 45: Data of the average daily temperature under the SSP126, SSP245 and SSP585 during the period 2031-2060 over Burkina Faso.



Average daily temperature (Tas)

Indicator: Mean Temperature, Average daily temperature (Tas) (annual mean anomaly), Time period: all_period, Historical period: 1985–2014,for the scenario ssp126,ssp245,ssp585, Model: CMIP6 Global:ACCESS-CM2,ACCESS-ESM1-5,HadGEM3-GC31-LL,MRI-ESM2-0,NESM3,BCC-CSM2-MR,MIROC6,NorESM2-LM,CanESM5,MIROC-ES2L,NorESM2-MM,MPI-ESM1-2-HR,CMCC-ESM2,GISS-E2-1-G,MPI-ESM1-2-LR. Model results for an area covering the Burkina Faso

Figure 46: Temporal patterns of average daily temperature for the historical and future period ranging from 1960 to 2100 over Burkina Faso.

3.2 Discussion

In the initial analysis, the performance of the ensemble mean of 15 NEX-GDDP-CMIP6 models in simulating the cumulative distribution of rainfall and annual average temperature across West Africa during the historical period of 1985-2014 was assessed. The result show that observed datasets exhibited nearly the same patterns and magnitudes of rainfall distribution and temperature in many areas, but the ensemble mean of 15 NEX-GDDP-CMIP6 models shows a notable variation in comparison. These findings align with the conclusions drawn by Klutse et al., (2021); Quenum et al., (2021); Wang et al., (2020).

There is a definite upward trend in temperatures across many regions of the world. Our research focused on Burkina Faso during the periods of 2031-2060 and 2071-2100 under the SSP126, SSP245, and SSP585 scenarios, and it showed a significant increase in annual mean daily maximum, minimum, and mean temperatures. De Longueville et al., (2016) discovered the same warming trends over Burkina Faso, while, Alamou et al.,(2022); Quenum et al., (2021) in West Africa found similar warming trends. Regarding the temperature extreme changes in the whole of Burkina Faso, warm nights (TN90) and warm days (TX90p) indicated a general warming trend. These results were in line with the findings in Mouhamed et al., (2013) study during the period 1960–2010, where an upward trend was noted in TX90p and TN90p. Conversely, there was a declining trend observed in the occurrence of cold nights (TN10p) and cool days (TX10p) in southern Burkina Faso, a trend confirmed by Barry et al., (2018) for West Africa. Moreover, during both future periods of 2031-2060 and 2071-2100, the trends of warm nights (TX90p) and cool nights (TN10p) were more pronounced compared to warm days (TX10p) and cool days (TX90p) under all three SSPs, consistent with Sillmann et al. (2013) findings for all of Africa. The highest increase for all these variables were expected in the SSP585 scenarios and the lowest was observed in the SSP126. Rising greenhouse gas concentrations cause an increase in the spatial change of temperature, with the highest variability anticipated by the end of the century (2071-2100) as opposed to the middle of the century (2031-2060). According to Zhu et al. (2021), scenarios with higher greenhouse gas emissions are predicted to cause more significant temperature increases.

In contrast to temperature changes, precipitation changes in Burkina Faso exhibit distinct variations displaying a combination of increasing and decreasing trends. This observation aligns with the global-scale statement in the IPCC report (IPCC, 2013) and previous studies conducted by Barry et al., (2018); De Longueville et al., (2020); Quenum et al., (2021). Our analysis reveals a consistent pattern indicating a slight increase in annual precipitation (PRCPTOT) in the Sahelian zone and the eastern region of the Sudano-Sahelian zone under the SSP245 and SSP585 scenarios. This result is in line with Alamou et al., (2022), who reported slight increases in annual precipitation (PRCPTOT) in certain regions, including the Gulf of Guinea and parts of the Sahel (Burkina Faso, southern Mali, and western-southern Niger) but contrast under the SSP126 where a small decrease in the total annual precipitation was expected. Furthermore, our study also demonstrates a slight increase in the precipitation frequency indices (R10mm, R20mm), the precipitation intensity indices (RX1day, RX5day), and consecutive wet days (CWD) under SSP245 and SSP585, consistent with studies such as New et al., (2006). In contrast, the SSP126 scenario predicts a slight decrease in these indices. However, there were limited increases in consecutive dry days (CDD) across all three scenarios. This finding consists with Klutse et al., (2021). The changes in precipitation indices are not really influenced by the rise in greenhouse gas concentrations.

CONCLUSION AND PERSPECTIVES

1. Conclusion

The objective of this project was to develop a web-based climate services platform in West Africa that provides long-term spatial and temporal climate index changes for rainfall and temperature using the CMIP6 statistical downscaled data from the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6) under the SSP126, SSP245, and SSP585 scenarios. An evaluation of the performance of the ensemble mean of 15 NEX-GDDP-CMIP6 models utilized in this study, specifically in simulating rainfall and temperature patterns over the West Africa region during the historical period spanning from 1985 to 2014 was conducted. Based on the obtained results, it can be concluded that the ensemble mean of 15 NEX-GDDP-CMIP6 models effectively captures the average annual temperature and the overall rainfall patterns observed in West Africa. A comparison between the ensemble mean of 15 NEX-GDDP-CMIP6 models and the observed data from CHIRPS and ERA5 reveals a generally satisfactory agreement, albeit with a tendency towards overestimation of the ensemble mean of 15 NEX-GDDP-CMIP6 models in several areas. For the projection change of 14 indices from the ETCCDI, Burkina Faso served as a case study to simulate the web-based results for the three SSP scenarios. Based on literature review where all the 27 indices provided by the ETCCD are major climate indices in West Africa, the hypothesis 1 is verified. The results indicated a general warming trend in temperature indices across Burkina Faso for both the 2031-2060 and 2071-2100 periods. The Sahelian zone exhibited the highest temperature values, while the lowest values were observed in the Sudanian zone. In contrast, the observed trends in rainfall were not as consistent as those in temperatures in Burkina Faso. The region is projected to experience varying degrees of changes under different levels of scenarios and over different periods. The findings revealed some increases in annual total rainfall (PRCPTOT), the precipitation frequency indices (R10mm, R20mm), the precipitation intensity indices (RX1day, RX5day), and consecutive wet days (CWD) under both the SSP245 and SSP585 scenarios. However, a slight decrease was observed in these indices under the SSP126 scenario for the average periods of 2031-2060 and 2071-2100. Regarding consecutive dry days (CDD), a few increases were anticipated under all three scenarios during both average periods of 2031-2060 and 2071-2100. The results indicate that the hypothesis 2 is partially verified because the ensemble mean of the models project an increase in the magnitude of temperature indices and a combination of increase and decrease in precipitation indices in Burkina Faso. A platform was built to tailor these indices. The platform can help policymakers, development practitioners, and other individuals interested in evaluating climate data to assess potential future scenarios in the easiest way. Based on those result, the hypothesis 3 is verified.

2. Research contributions

The platform facilitates informing various stakeholders such as decision-makers, farmers, NGOs, and agricultural agencies. It enables to make choices regarding crop selection based on predicted rainfall and to monitor outbreaks of pests and diseases that can harm yields. This enables farmers to enhance productivity and minimize post-harvest losses. In situations of heavy rainfall, the platform provides valuable climate information that predicts the intensity of rainfall and identifies the area which will receive more rain. This allows decision-makers to plan and implement resilience measures for crucial infrastructure such as roads and communication systems, which are vital for maintaining market access and may be susceptible to damage from heavy rainfall. Additionally, the platform provides temperature information that assists decision-makers in identifying warmer areas suitable for tree planting to mitigate the impacts of climate change. Moreover, the platform supports community-based adaptation initiatives by providing resources for early warning systems and empowering communities to develop their adaptation strategies. Lastly, it serves as a valuable resource for researchers and students who may face challenges in accessing and processing data, enabling them to explore and utilize the available resources for their specific needs.

3. Limitations and future work

Two major limitations hinder the research process and limit the comprehensive understanding of climate change in West Africa. First, limited storage space to manage and store extensive daily temperature and precipitation data from 1960 to 2100 is a significant challenge. Limited storage infrastructure negatively affects the responsiveness of the platform, which can slow down data access and analysis processes. This limitation can cause delays, reduce efficiency, and prevent timely completion of tasks. Addressing inadequate storage infrastructure is critical to overcoming this limitation. Expanding the storage capacity would ensure sufficient and accessible space, which would increase the platform's responsiveness.

Second, the research focuses mainly on changes in temperature and precipitation, while considering other important climate factors. Climate systems are complex and are impacted by variables such as humidity, wind, and atmospheric circulation. Unfortunately, these factors are not included in the analysis, which limits a comprehensive understanding of climate change in West Africa and its effects on different sectors. Ignoring these climate variables can lead to an incomplete assessment of regional climate patterns and their effects. To address this limitation, future studies should include a larger number of climate variables in the analysis. Combining moisture, wind, and atmospheric circulation would allow a more comprehensive understanding of climate change in West Africa. Such a comprehensive approach would facilitate a more accurate assessment of potential impacts on sectors such as agriculture, ecosystems, and human health.

Regarding future work, the usefulness of this study would be increased by the application of seasonal forecasts of climate indices. Seasonal forecasts provide users with valuable information that allows them to predict climate conditions during certain seasons. By incorporating seasonal forecasts, decision-makers and stakeholders can make more informed choices and develop strategies adapted to anticipated climate conditions. In addition, enabling users to be able to load their own data into the platform would provide them with a more personalized and relevant analysis. The web-based platform would have the capability to process and calculate climate indices using the user's uploaded data. This expanded knowledge would enable decision-makers to develop targeted and sector-specific adaptation measures to effectively respond to the challenges posed by changing climate conditions.

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