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Projection of future temperature and precipitation in the Aga-Foua-Djilas basin in Senegal using the CMIP6 multi-model ensemble

Dione P.M.[1]*, Faye C.[1], Tolcher A.D.[2]

[1] *Department of Geography, UFR Science and Technology, Assane Seck University of Ziguinchor, Laboratory of Geomatics and Environment, BP 523 Ziguinchor (Senegal)*

[2] *School of Water Resources and Environmental Engineering, Haramaya Institute of Technology, Haramaya University, PO Box 138 Dire Dawa, (Ethiopia)*

**Philippe Malick Dione, Email address: pm.d11@zig.univ.sn*
Cheikh Faye, Email address: cheikh.faye@univ-zig.sn
Abebe Debele Tolche, Email address: abeberobe@gmail.com

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Abstract: Climate change poses high risks worldwide, including in Sahelian zones such as Senegal. It is having a major impact on biodiversity and water resources, compromising the development prospects of agricultural activities. The aim of this study is to determine annual and seasonal changes in temperature and precipitation in response to possible climate change scenarios in the Aga-Foua-Djilas basin. Data from five models (MRI-ESM2-0, CNRM-CM6-1 f2, CNRM-CM6-1-HR f2, GFDL-ESM4 and CESM2-WACCM) for the period 2021-2100 in a 20-year interval (2021-2040, 2041-2060, 2061-2080 and 2081-2100), with four emission scenarios (SSP 126, SSP 245, SSP 370 and SSP 585), are compared with those of the reference period 1985-2014, in order to analyze precipitation and temperature trends in the watershed. The results show rising minimum and maximum temperatures and falling precipitation. Under the more pessimistic SSP 585 scenario, minimum temperatures are projected to rise by +3.92°C and maximum temperatures by +4.41°C by 2100. Conversely, precipitation is forecast to fall by -36.1%. The results of the study provide important information for climate change adaptation scenarios and territorial planning in the Sahelian environment.

Keywords: *Projection; CMIP6; Climate change; Multi-model ensemble; Aga-Foua-Djilas; Senegal.*

1. Introduction

The distribution of precipitation and evaporation plays a crucial role in water resources, which are essential for human consumption and ecosystems (Milly *et al.*, 2005). However, climate change and the growing global population have emerged as significant factors that pose challenges to sustainable development and the preservation of natural systems. In the Anthropocene era, drought can no longer be considered a purely "natural hazard" due to human-induced changes (Gebremeskel Haile *et al.*, 2020; Tang, 2020). The effects of climate change on the environment and society are becoming more pronounced with increasing global warming (Touma *et al.*, 2015). Greenhouse gas emissions are a driving force behind regional warming and drying conditions, leading to a rise in mega-droughts worldwide (Ault *et al.*, 2016; Leng *et al.*, 2015). The combination of population growth and a higher demand for food has increased food insecurity, resulting in a challenge to the United Nations' 2030 zero hunger agenda, which emphasizes sustainable development (FAO, 2017; Fujimori *et al.*, 2019) . Furthermore, rapid population growth has increased water consumption, significantly increasing the frequency of global droughts by 27% (Wada *et al.*, 2013). Climate change is one of the most urgent challenges affecting both humans and natural ecosystems (IPCC Working Group 1 *et al.*, 2013). Without early and effective coping strategies and development programs, food and water insecurity are likely to worsen due to climate change (Misra *et al.*, 2015; AghaKouchak *et al.*, 2015; Alaqarbeh *et al.,* 2021; Laita *et al.,* 2024; Collins *et al.,* 2024).

General circulation models (GCMs) play a crucial role in predicting future climate, and they have been developed by numerous national and international institutions and research agencies. As these models are constructed based on different assumptions and mathematical representations of climate processes, they often yield varying climate projections (Konapala *et al.*, 2020; Laurent et *al.*, 2020). Therefore, selecting an appropriate climate model is not only the initial step for watershed modelers in climate change hydrological analysis but also critical. Unfortunately, this decision is frequently made with limited information about the quality and reliability of the models (Murphy *et al.*, 2004). To address this issue, the Intergovernmental Panel on Climate Change (IPCC) initiated Phase 6 of the Coupled Model Intercomparison Project (CMIP6) in the Sixth Assessment Report (AR5). This phase facilitated a multi-GCM approach by providing community-standard climate model outputs (Konapala *et al.*, 2020; Laurent *et al.*, 2020). By using multi-GCM ensembles, researchers were able to incorporate probabilistic methods to interpret climate predictions and develop climate adaptation plans.

The use of Shared Socio-economic Pathways (SSPs) as a core framework has become essential. These pathways establish a link between radiative forcing and socio-economic development, making them a crucial evidence base for the latest IPCC report (Chen *et al.*, 2019). Additionally, researchers have applied SSPs at various scales, as demonstrated by studies conducted by (Almazroui *et al.*, 2021; Hang, 2014). In the pursuit of more accurate predictions regarding runoff changes in specific regions under future scenarios, recent advancements have leveraged ensemble downscaled CMIP6 outputs (Sadio *et al.*, 2023). These outputs help to model the impact of climate change on rainfall and temperatures in regions such as the Aga-Foua-Djilas basin. It is important to note that different SSPs represent distinct paths of social and economic development. For instance, SSP126 represents a sustainable pathway with low radiative forcing, reflecting low vulnerability and manageable mitigation challenges. On the other hand, SSP245 is a middle-of-the-road scenario, implying medium SSP radiative forcing resulting from a combination of moderate social vulnerability and forcing mean radiative SSP, with land use and aerosol pathways not being extreme. The SSP370 follows a regional rivalry route, characterized by high unmitigated emissions due to moderate economic growth, a rapidly expanding population, and slow technological changes in the energy sector, making mitigation efforts challenging (O'Neill *et al.*, 2014).

A wide range of scenarios has been an essential aspect of climate change research for several decades. These scenarios account for various potential socio-economic changes and uncertainties in future anthropogenic drivers of climate change. Climate models utilize input data from these scenarios to estimate responses to different conditions and explore potential feedback and sensitivities. However, it has come to our attention that no study specifically assessing climate change in the Sahelian environment of Senegal has been conducted using the most recent data and results from the CMIP6 project. To fill this gap, our study focuses on data from the reference period of 1985-2014 and utilizes model results (ACCESS-ESM1-5, BCC-CSM2-MR, and MRI-ESM2-0) for four 20-year periods (2021-2040, 2041-2060, 2061-2080, and 2081-2100). We project precipitation and temperature trends in the Aga-Foua-Djilas basin using four emission scenarios: SSP 126, SSP 245, SSP 370, and SSP 585. Our analysis encompasses the near future (2021-2040), mid-future 1 and 2 (2041-2060 and 2061-2080), and far future (2081-2100). The specific objective of our study is to quantify the annual and seasonal changes in climate variables (precipitation and temperature) in response to potential climate change scenarios in the Aga-Foua-Djilas basin. Our research results will be valuable for formulating future development policies in the water resources sector of the Aga-Foua-Djilas basin and other basins in Sahelian areas, aiming to adapt to climate change.

2. Materials and methods

2.1 Study area

Aga-Foua-Djilas watershed is located in the north and northwest part of the Sine Saloum delta (**Figure 1**). The latter is one of the major hydrological basins that drain Senegal. It is drained by a network of rias, the two main ones bearing the names of Sine and Saloum. The basin has many small lowlands, despite the persistent drought, even though draining large quantities of runoff water each winter. Geographically, it extends from 14°15'N to 14°25'N latitudes, and 16°37'W and 16°53'W longitudes. It covers an area of 317.5 km^2, with a perimeter of 115.7 km. Administratively, it straddles the Communes of Malicounda, Sandiara, Séssène and Nguénièné (Department of Mbour), Tattaguine, Loul Séssène and Djilas (Department of Fatick).

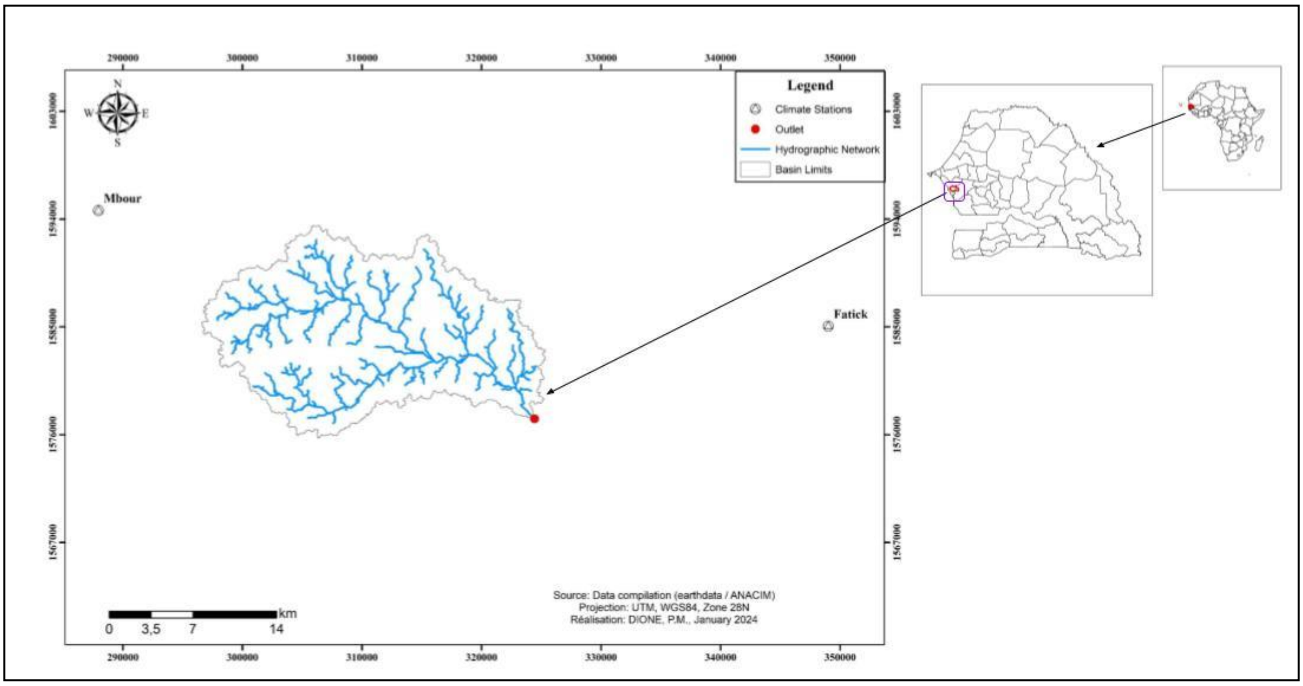

Figure 1: Study area map

2.2. Data used

Developing the future climate is a major challenge for governments, particularly when establishing their public development policies. Knowledge of future climate trends makes it possible to anticipate their negative effects and associated risks. This facilitates the implementation of appropriate adaptation strategies and informed decision-making. As agricultural activities in underdeveloped countries are largely dependent on rainfall, knowledge of rainfall impulses in the short, medium and long term helps them plan their development more effectively. This knowledge of future climate is also essential for assessing water resources. The latter are mainly dependent on the amount of rainfall received.

Historical data and CMIP6 data are used to analyses climate change in the Aga-Foua-Djilas basin. The historical data covers the period of 1985-2014 was used as reference period data. These data measured in the field at the Mbour and Fatick climate stations closer to the basin. For the climate projections, the latest simulations CMIP6 presented in the IPCC's 6th Assessment Report were used. Twenty models were obtained from the https://climexp.knmi.nl/selectfield_cmip6.cgi?id=someone@somewhere interface (consulted on 01 July 2023) (**Table 1**). The design capability of these models has been evaluated, and five of the most suitable models were selected. This selection resulted in a robust representation of the climate system, capturing both the mean state and variability effectively. These are models frequently used in Africa and have performed well in characterizing climate change in the continent, as in the rest of the world. The images downloaded are in GeoTiff format and include the following variables: average maximum temperature (°C), average minimum temperature (°C) and cumulative rainfall over the month (mm).

To determine the impact of climate change on future rainfall and temperatures in the study basin, four climate change scenarios are used, known as SSPs (Shared Socioeconomic Pathways). These describe alternative futures for socio-economic development and represent, based on narrative and quantitative variables, how the world could evolve in the coming decades and what challenges these changes pose for mitigation and adaptation. The SSP1 scenario combines low levels of mitigation and adaptation challenges, SSP3 assumes high population growth and low economic development, and the SSP2 scenarios are defined as intermediate between those corresponding to SSP1 and SSP3. The SSP5 storyline maintains low population growth. This scenario assumes that low population growth is also accompanied by rapid technological advancements and intensive use of fossil fuels.

These families of scenarios, known as SSPs, have been defined according to the scale of the adaptation and mitigation challenges facing societies (O'Neill *et al.*, 2016):

- SSP1 (low adaptation challenge, low mitigation challenge) describes a world marked by strong international cooperation, giving priority to sustainable development, very close to the "Proaction" family;
- SSP2 (medium adaptation challenge, medium mitigation challenge) describes a world characterised by the continuation of current trends, very close to the 'Inertia' family;
- SSP3 (high adaptation challenge, high mitigation challenge) presents a world affected by competition between countries, slow economic growth, policies geared towards security and industrial production and little concern for the environment, very close to the "Retrenchment" family;
- SSP5 (low adaptation challenge, high mitigation challenge) describes a world that focuses on the traditional and rapid development of developing countries, based on high energy consumption and carbon-emitting technologies; the rise in living standards makes it possible to increase the capacity to adapt, thanks in particular to the reduction in extreme poverty. This is the future described by the "Growth at any price" family.

Overall, these scenarios maintain high mitigation challenges, as the levels and type of energy assumed lead to a world of high emissions and a subsequent temperature increase of around 5 degrees Celsius by 2100.

Table 1: Characteristics of the climate models (bold style font refers to the model with high accuracy and used in the study)

MCG name	Institute/Country	Variant-id	Horizontal resolution	Country
ACCESS-ESM1-5	Commonwealth Scientific and Industrial Research Organisation	r1i1p1f1	1.9° × 1.2°	Australia
BCC-CSM2-MR	Beijing Climate Center	r1i1p1f1	1.13° × 1.13°	China
FIO-ESM-2-0	First Institute of Oceanography	r1i1p1f1	0.54°x1.1°	China
MRI-ESM2-0	**Meteorological Research Institute**	**r1i1p1f1**	**1.13° × 1.13°**	**Japan**
MIROC-ES2L f2	Japanese Modeling Community	r1i1p1f1	1.41 × 1.41	Japan
CanESM5 p1	Canadian Center for Climate Modelling and Analysis	r1i1p1f1	*2.75° x 2.8125° (in mm)*	Canada
CanESM5 p2	Canadian Earth System Model	r1i1p1f1	2.81° × 2.81°	Canada
IPSL-CM4A-MR	Pierre Simon Laplace Institute	r1i1p1f1	2.50° × 1.26°	France
CNRM-CM6-1 f2	**Météo-France/National Centre for Meteorological Research**	**r1i1p1f1**	**0.5° x 0.5°**	**France**
CNRM-CM6-1-HR f2	**Météo-France/National Centre for Meteorological Research**	**r1i1p1f1**	**1.48° X 1.48°**	**France**
MPI-ESM1-2-LR	Max Planck Institute for Meteorology	r1i1p1f1	1.88° × 1.88°	Germany
MPI-ESM1-2-HR	Max Planck Institute for Meteorology	r1i1p1f1	0.94° × 0.94°	Germany
GFDL-ESM4	**Geophysical Fluid Dynamics Laboratory**	**r1i1p1f1**	**1.25° × 1.00°**	**USA**
GISS-E2-1-G p1	Goddard Institute for Space Studies (USA)	r1i1p1f1	2° × 2.5°	USA
CESM2-WACCM	**National Center for Atmospheric Research**	**r1i1p1f1**	**1◦ × 1.125◦**	**USA**
EC-Earth3	Swedish Meteorological and Hydrological Institute, Rossby Center	r1i1p1f1	0.70° × 0.70°	Swède
HadGEM3-GC31-LL f3	Met Office Hadley Centre	r1i1p1f1	1.25◦ × 1.875◦	UK
UKESM1-0-LL f2	National Institute of Meteorological Sciences/Korea Meteorological Administration	r1i1p1f1	1.875° x 1.25°	New Zealand
CMCC-CM2-SR5	Euro-Mediterranean Centre on Climate Change coupled climate model	r1i1p1f1	1.25 × 0.94	Italy

2.3. Methods

The results of twenty CMIP6 model simulations (**Table 1**) available at the time of this analysis were used in this study. For each model, the minimum, mean and maximum precipitation and temperatures for the first run ("r1i1p1f1") for the historical and projected experiments (shared socio-economic pathways) were used. These precipitation and maximum and minimum temperature data for the future period are subdivided into four characteristic periods for each scenario: the near future from 2021 to 2040 (horizon 2040 or beginning of the 21st century); the medium future 1, from 2041 to 2060 (horizon 2060 or middle of the 21st century); the medium future 2, from 2061 to 2080 (horizon 2080); the far future from 2081 to 2100 (horizon 2100 or end of the 21st century). Four SSP scenarios were evaluated for the periods 2021-2040 (horizon 2040), 2041-2060 (horizon 2060), 2061-2080 (horizon 2080) and 2081-2100 (horizon 2100), with a spatial resolution of 2.5° × 2.5° (Voldoire *et al*., 2019). The pixel point used to extract the data is projected at the watershed outlet.

To ensure the validity and reliability of the projected result, the CMIP6 simulated results were compared to the basin observation data. The data are first evaluated on the Aga-Foua-Djilas basin and have been corrected using the modified quantile method (Bai *et al*., 2016) which give good results compared to other methods. The climate stations of Mbour (for temperatures) and Fatick (for rainfall) were used as the basis for validation. These are the two measurement stations closest to the basin (**Figure 2**). For rainfall, the quantile method applied is that using a Delta multiplicative factor, while for temperatures, the quantile method applied is that using the difference. The model data are used and corrected individually by quantile methods before the ensemble averages are used. The results of the bias correction give a correlation coefficient of over 0.70 for temperature (compared with 0.63 for the raw data) and 0.80 for precipitation (compared with 0.76 for the raw data) between the results of the multi-model ensemble and the observations used.

The precipitation data used are those from five of the twenty models selected (such as MRI-ESM2-0, CNRM-CM6-1 f2, CNRM-CM6-1-HR f2, GFDL-ESM4 and CESM2-WACCM). They perform better in reproducing precipitation over the historical period and have been used to estimate precipitation and temperature in the basin over the future period. For temperatures, on the other hand, most of the models perform well and are capable of reproducing them in the basin over the historical period. The ensemble mean of these models was calculated for the analyses, which reduces the natural variability and systematic biases present in the individual models (Akinsanola & Zhou, 2019).

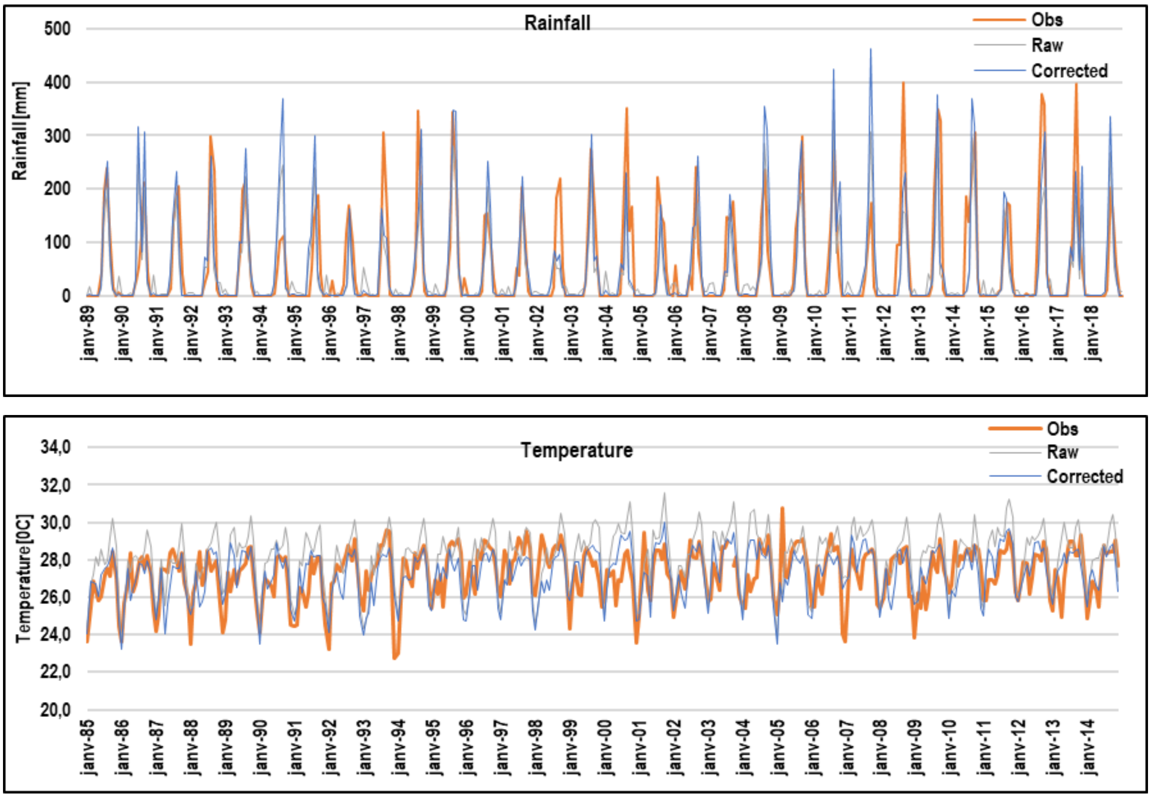

Figure 2: Comparison between observed, simulated and corrected precipitation and temperature data.

The assessment of simulated climate trends in the Aga-Foua-Djilas basin in Senegal represents an added value in the way it represents the real climate in specific regions, as it also facilitates the interpretation of model projections for the future.

3. Results

3.1. Temperature trends

The parameters under consideration include the minimum and maximum temperatures. The analysis examines annual and monthly values across different time periods, depending on the scenario. Annual values are compared to baseline temperatures from 1985-2014, which serve as the control period. Despite the detailed discussion in the subsequent section, Figures 3, 4, and 5 show an upward trend in minimum and maximum temperatures over time, starting from the early 21st century and extending to 2100. As we approach 2100, the increase becomes more pronounced, particularly in the pessimistic scenario (SSP 585). This temperature rise represents a logical continuation of the observed trend since 1985, despite the influence of climate change.

3.1.1. Minimum temperatures

3.1.1.1. Annual scale

On an annual basis, the minimum temperatures vary, ranging from 23.7°C (SSP 245 during 2021-2041) to 27.1°C (SSP 585 during 2081-2100). There is a gradual increase in minimum temperatures from one time period to the next, including 2081-2100 across all scenarios. Under the SSP 126 scenario, minimum temperatures are projected to reach 25°C at the end of the 21st century. Similar trends are observed in the other scenarios, with temperatures expected to reach and even exceed 26°C. In the context of the SSP 585 scenario, minimum temperatures fluctuate within the range of 24.9°C for 2041-2060 and are anticipated to rise to approximately 27.1°C by 2100.

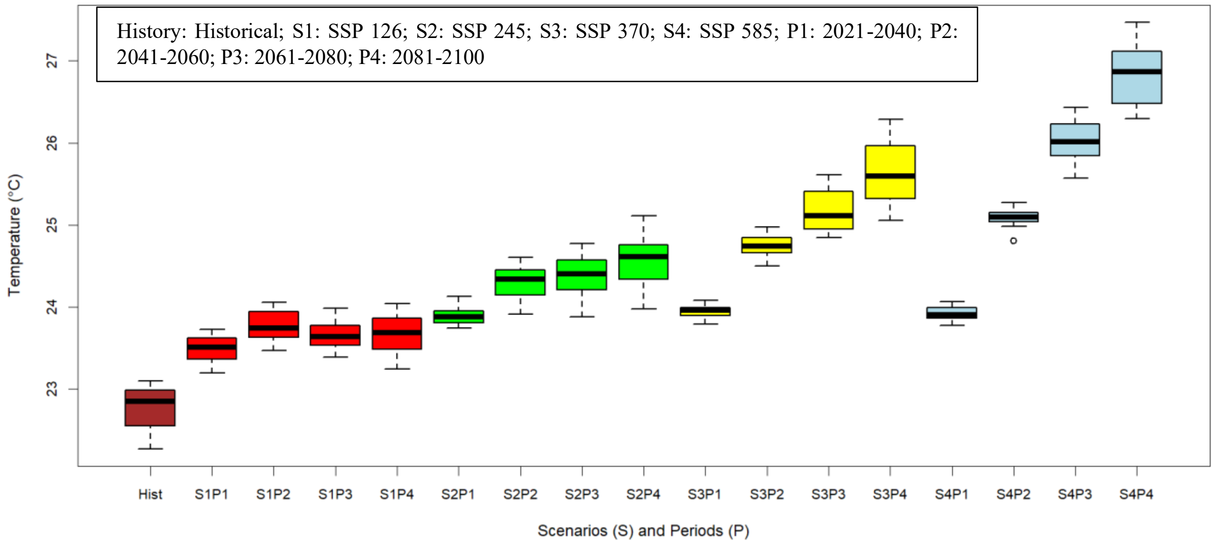

Figure 3: Minimum temperature trends by period and scenario in the Aga-Foua-Djilas basin

In comparison to the reference period of 1985-2014, there is a general increase in minimum temperatures across all four scenarios, with particularly high increases in more pessimistic scenarios such as SSP 585 towards the end of the century, as depicted in Figures 3 and 4. The spatial and temporal variability of annual minimum temperatures in the basin is illustrated through box and whisker plots, as presented in **Figure 3**. When the median closely aligns with the mean, it suggests a symmetrical distribution of the data, while a median below the mean indicates a positive or rightward skew, and a median above the mean indicates a negative or leftward skew (Jenifer & Jha, 2021). Mean annual minimum temperatures are higher (at 27.1°C) in the SSP 585 scenario over the 2081-2100 period and lower (at 23.7°C) in the SSP 245 scenario over 2021-2040 period (a difference of 3.4°C).

Compared with the reference period 1985-2014, this generalized rise in minimum temperatures is the case for the various scenarios, and even more so for the more pessimistic scenarios such as SSP 585 as we approach the end of the century, as shown in **Figures 3** and **4**. The spatial and temporal variability of annual minimum temperatures in the basin is shown using box and whisker plots, as shown in **Figure 3**. When the median is almost equal to the mean, it indicates that the data have a symmetrical distribution, while when the median is below the mean, it indicates that the data have a positive or rightward tilt, and when the median is above the mean, it indicates that the data have a negative or leftward tilt (Jenifer & Jha, 2021). Mean annual minimum temperatures are higher (at 27.1°C) in the SSP 585 scenario and over the 2081-2100 period and lower (at 23.7°C) in the SSP 245 scenario and over the 2021-2040 period (a difference of 3.4°C), as shown by the longest boxes in the SSP 585 scenario and over the 2081-2100 period respectively, with varying degrees of temporal variation. On the other hand, the shortest boxes are found in the SSP 126 and SSP 245 scenarios and over the 2021-2040 period.

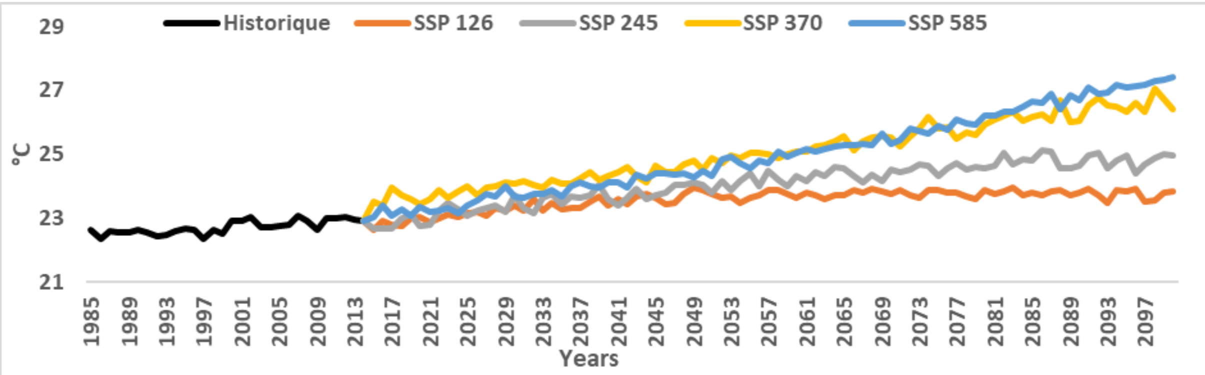

Figure 4: Changes in annual minimum temperatures over the historical period (1985-2014) and the future period (2015-2100) under the SSP 126, SSP 245, SSP 370 and SSP 585 scenarios at the outlet of the Aga-Foua-Djilas basin.

Figure 5 illustrates the spatial and temporal patterns of minimum temperatures across different scenarios and years. The data confirms a consistent rise in minimum temperatures over time, with a more notable increase in the more pessimistic model. In the basin, the spatial variation of minimum temperatures ranges from 23.3°C to 29.8°C, with higher values observed for the SSP 585 scenario during the period 2081-2100. A comparison of the minimum temperature during the reference period (1985-2014), which was recorded at 23.2°C, indicates a maximum increase of 3.92°C by the end of the 21st century under the SSP 585 scenarios (**Table 2**). The increase's magnitude is directly related to the model's pessimism and the projection's duration. Specifically, the temperature rise during the period 2021-2040 is 1.08°C, 0.52°C, 1.13°C, and 0.79°C for the SSP 126, SSP 254, SSP 370, and SSP 585 scenarios, respectively. However, during the final period (2081-2100), the temperature increase reaches unprecedented levels of 2.06°C, 1.91°C, 3.46°C, and 3.92°C for the SSP 126, SSP 254, SSP 370, and SSP 585 scenarios, respectively.

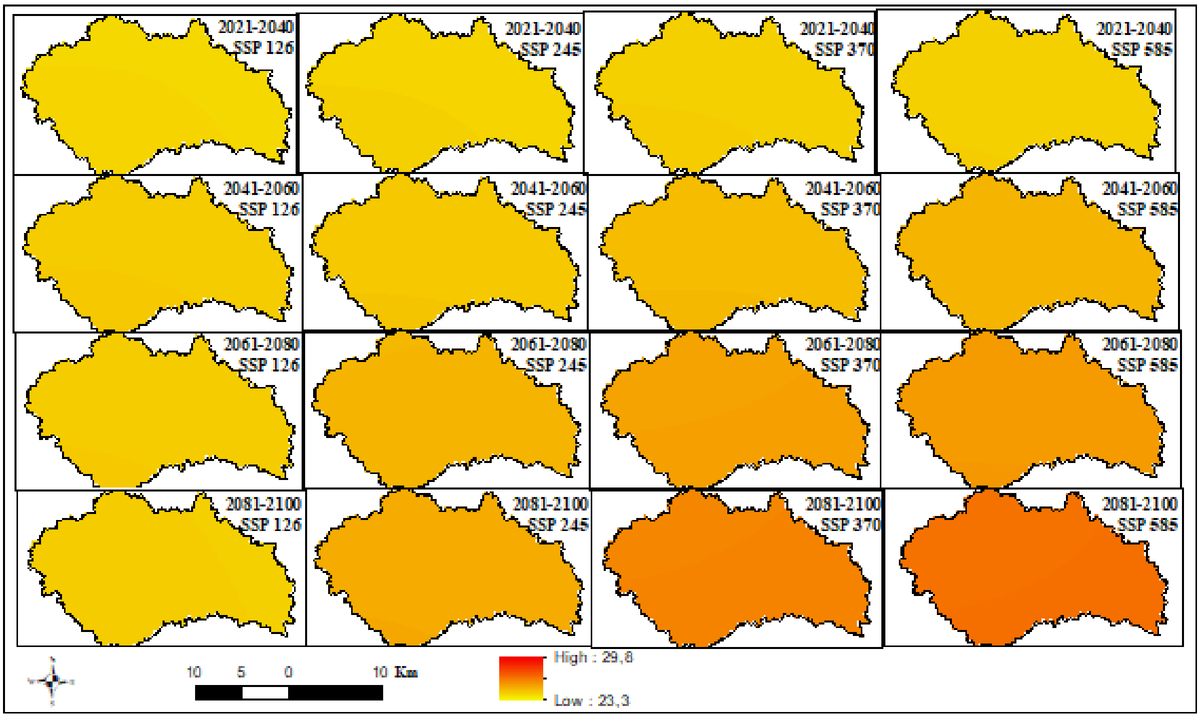

Figure 5: Spatial distribution of minimum temperatures in the Aga-Foua-Djilas basin according to periods and scenarios

Table 2: Future changes in minimum temperatures (in °C) on an annual scale over the four future periods in the Aga-Foua-Djilas basin.

	1985-2014	2021-2040	Difference	2041-2060	Difference	2061-2080	Difference	2081-2100	Difference
SSP 126	23.2	24.3	1.08	24.7	1.51	25.0	1.78	25.2	2.06
	1985-2014	**2021-2040**	**Difference**	**2041-2060**	**Difference**	**2061-2080**	**Difference**	**2081-2100**	**Difference**
SSP 245	23.2	23.7	0.52	24.3	1.12	24.7	1.54	25.1	1.91
	1985-2014	**2021-2040**	**Difference**	**2041-2060**	**Difference**	**2061-2080**	**Difference**	**2081-2100**	**Difference**
SSP 370	23.2	24.3	1.13	25.0	1.86	25.8	2.63	26.6	3.46
	1985-2014	**2021-2040**	**Difference**	**2041-2060**	**Difference**	**2061-2080**	**Difference**	**2081-2100**	**Difference**
SSP 585	23.2	24.0	0.79	24.9	1.69	25.8	2.64	27.1	3.92

3.1.1.2. Monthly scale

For all the scenarios and all the periods, the same rate of change in minimum temperatures is forecast, with a monogenic trend marked by a single peak (**Figure 6** and **Table 3**). They will rise from January to July, drop slightly in August, rise again in September and then fall again from October. The drop in August is attributable to cloud cover, as it is the wettest month of the year. January will always be the month with the lowest temperatures, and July and September will be the months with the highest.

Variations in monthly temperatures are contingent upon the specific scenario. For instance, in the SSP 126 scenario, the projected minimum temperature for January is 21.4°C (2021-2040), with an anticipated increase to 22.2°C in 2061-2080 and 22.4°C in 2061-2080. In October, temperatures are expected to surpass 26°C (26.4°C in 2021-2040 and 27.7°C in 2081-2100) (**Figure 6**). Conversely, the SSP 245 scenario, an intermediate projection indicating a modest temperature escalation, forecasts a rise in minimum temperatures from 20.8°C in January during the initial period (2021-2040) to 22.3°C in the period 2081-2100. In October, temperature is projected to increase from 25.8°C in the near future to 27.4°C in the far future, representing a 1.6°C elevation (**Figure 6**). In contrast, the SSP 370 and 585 scenarios, which are the most pessimistic, suggest that if global conditions align with the assumptions of these models, January will experience minimum temperatures of 21.5°C in the medium future (SSP 370) and 21.2°C in the far future (SSP 585). The most substantial temperature rise is anticipated in September and October over the years, with minimum temperatures in these months expected to escalate from 28.3°C in the period 2061-2080 to 29.5°C in the period 2081-2100, reflecting a 1.2°C increase (**Figure 6**).

Table 1 : Inter-monthly variation in minimum temperatures by scenario and period in the Aga-Foua-Djilas basin

SSP 126	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
2021-2040	21.4	21.9	22.6	22.8	22.5	24.1	26.0	26.3	26.6	26.6	24.9	22.2
2041-2060	21.8	22.7	23.0	23.1	22.8	24.3	26.4	26.8	27.1	27.1	25.4	22.7
2061-2080	22.2	22.9	23.5	23.3	23.1	24.2	26.5	27.1	27.5	27.4	25.7	23.1
2081-2100	22.4	23.0	23.5	23.7	23.4	24.6	26.7	27.5	27.8	27.7	26.1	23.2
SSP 245	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
2021-2040	20.8	21.5	22.1	22.4	22.4	23.7	25.5	25.8	25.9	25.8	23.9	21.5
2041-2060	21.2	22.1	22.7	22.7	22.9	24.1	26.1	26.5	26.7	26.5	24.8	22.0
2061-2080	21.9	22.5	23.3	23.1	23.1	24.4	26.4	26.9	27.0	26.9	25.3	22.6
2081-2100	22.3	22.9	23.6	23.5	23.4	24.7	26.7	27.3	27.5	27.4	25.5	23.1
SSP 370	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
2021-2040	21.5	22.0	22.6	22.4	22.6	24.3	26.1	26.4	26.7	26.7	24.8	22.3
2041-2060	22.2	22.8	23.3	23.1	23.1	24.8	26.7	27.2	27.5	27.5	25.7	23.2
2061-2080	23.3	23.6	24.1	23.8	23.6	25.2	27.3	27.9	28.3	28.4	26.8	24.3
2081-2100	24.3	24.6	25.0	24.6	24.4	25.8	27.9	28.7	29.1	29.2	27.8	25.3
SSP 585	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
2021-2040	21.2	21.5	22.0	22.3	22.5	23.9	25.7	26.1	26.4	26.3	24.4	22.0
2041-2060	22.0	22.6	23.3	23.1	23.0	24.6	26.6	27.0	27.2	27.2	25.5	23.0
2061-2080	23.2	23.6	24.1	24.0	23.9	25.3	27.3	27.9	28.3	28.3	26.7	24.2
2081-2100	24.7	25.0	25.5	25.2	24.9	26.4	28.3	29.2	29.5	29.5	28.2	25.8

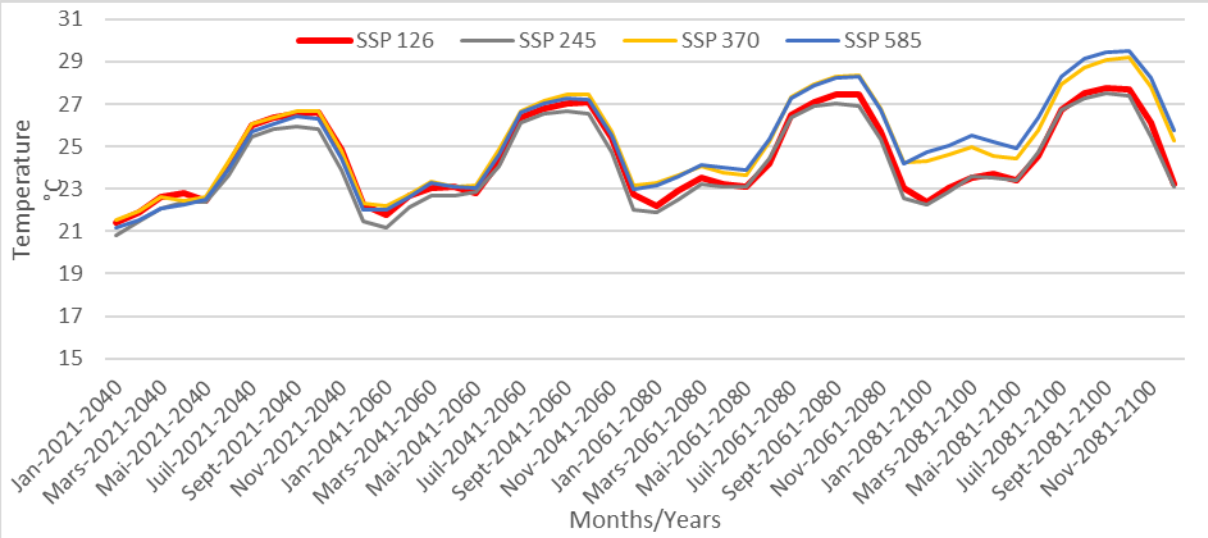

Figure 6: Trends in minimum monthly temperature by scenario and period in the Aga-Foua-Djilas basin

3.1.2. Maximum temperatures
3.1.2.1. Annual scale

On an annual scale, the maximum temperature follows the same pattern as the minimum temperatures. For instance, it will increase from 32.2°C to 36.6°C under SSP 585 for the period 2081-2100. The optimistic SSP 126 and SSP 370 models approach shows a slight increase in maximum temperature even not to exceed 35°C in the far future (2081-2100). For the SSP 245 scenario, during the 2061-2080 and 2081-2100 periods, maximum temperatures will be 35.4°C and 35.8°C slightly greater than SSP 126 and SSP 370 scenarios. For the SSP 585 scenario, maximum temperatures will approach 35°C for 2041-2060 period. By 2100, the SSP 585 scenario predicts a maximum temperature of 36.6°C, and this value increases the maximum temperature of +4.41°C in comparison to the reference period. Compared with the reference period 1985-2014, this generalized rise in maximum temperatures is the case for the various scenarios, as noted for maximum temperatures, and even more so for the more pessimistic scenarios such as SSP 585 as we approach the end of the century (**Figure 7**).

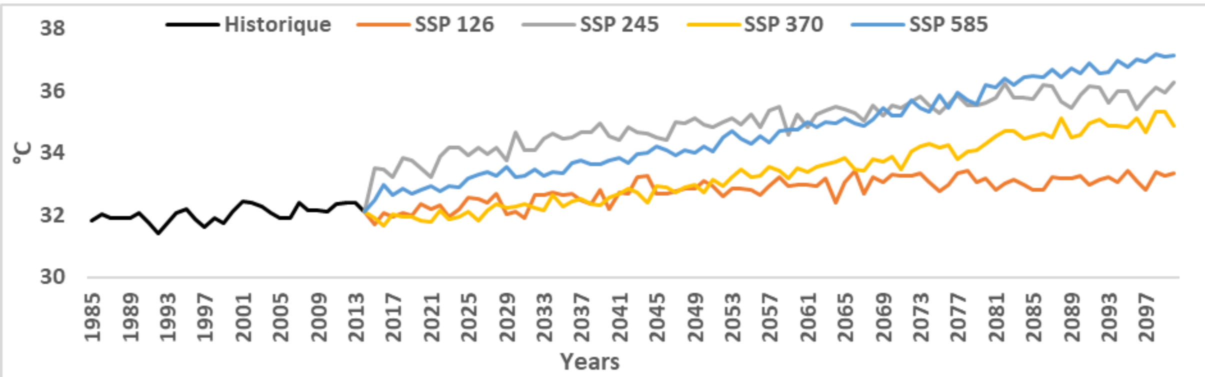

Figure 7*:* Changes in annual maximum temperatures over the historical period (1985-2014) and the future period (2015-2100) under the SSP 126, SSP 245, SSP 370 and SSP 585 scenarios at the outlet of the Aga-Foua-Djilas basin.

The spatial and temporal variability of annual maximum temperatures in the basin is shown using box and whisker plots, as shown in **Figure 8**. The mean values of annual maximum temperatures are higher (at 36.6°C) in the SSP 585 scenario over the 2081-2100 period, and lower (at 32.2°C) in the

SSP 370 scenario over the 2021-2040 period (a difference of 4.4°C). The longest boxes are found in the SSP 585 scenario and over the 2081-2100 period, with varying degrees of temporal variation, while the shortest boxes are found in the SSP 126 scenario and over the 2021-2040 period.

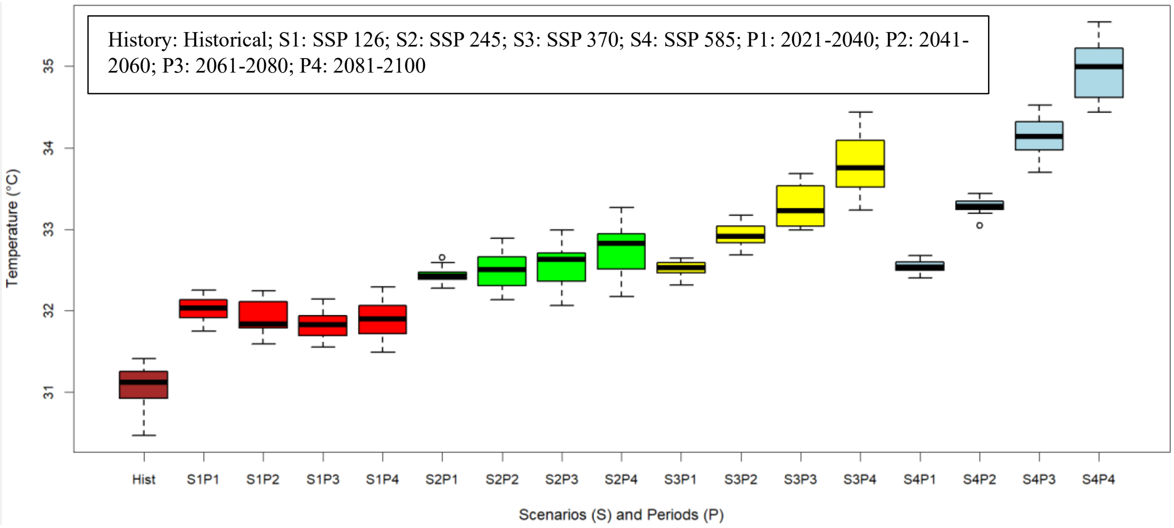

Figure 8: Maximum temperature trends by period and scenario in the Aga-Foua-Djilas basin

Figure 9 gives an overview of the spatial and temporal distribution of maximum annual temperatures according to the periods selected and the scenarios used. From the near to the far future, temperatures will rise. From a spatial perspective, the highest temperatures will be found in the eastern part of the basin, compared to the western part.

This maximum temperature varies spatially from 29.4°C to 38.2°C and remains higher for the SSP 585 scenario over the period 2081-2100 (**Figure 9**). Compared with the reference period (1985-2014), the rise in maximum temperatures is more severe than the rise in minimum temperatures. For the SSP 125 scenario, which is the most optimistic, it will be 2.36°C in the far future. Over the same period, the SSP 245 scenario is forecast to rise by 3.62°C, the SSP 370 by 2.54°C and the pessimistic scenario by 4.42°C. While over the period 2021-2040, the rise in maximum temperatures is only 1.12°C, 1.95°C, 0°C and 1.99°C respectively for the SSP 126, SSP 254, SSP 370 and SSP 585 scenarios, over the far future (2081-2100) (**Table 4**).

Table 2 : Future changes in maximum temperatures (in °C) on an annual scale over the four future periods in the Aga-Foua-Djilas basin

SSP									
SSP 126	**1985-2014**	**2021-2040**	**Difference**	**2041-2060**	**Difference**	**2061-2080**	**Difference**	**2081-2100**	**Difference**
	32.2	33.3	1.12	33.8	1.59	34.2	2.01	34.6	2.36
SSP 245	1985-2014	2021-2040	Difference	2041-2060	Difference	2061-2080	Difference	2081-2100	Difference
	32.2	34.2	1.95	34.9	2.64	35.4	3.14	35.8	3.62
SSP 370	1985-2014	2021-2040	Difference	2041-2060	Difference	2061-2080	Difference	2081-2100	Difference
	32.2	32.2	0	33.0	0.82	33.8	1.60	34.8	2.54
SSP 585	1985-2014	2021-2040	Difference	2041-2060	Difference	2061-2080	Difference	2081-2100	Difference
	32.2	33.3	1.09	34.3	2.06	35.3	3.08	36.6	4.41

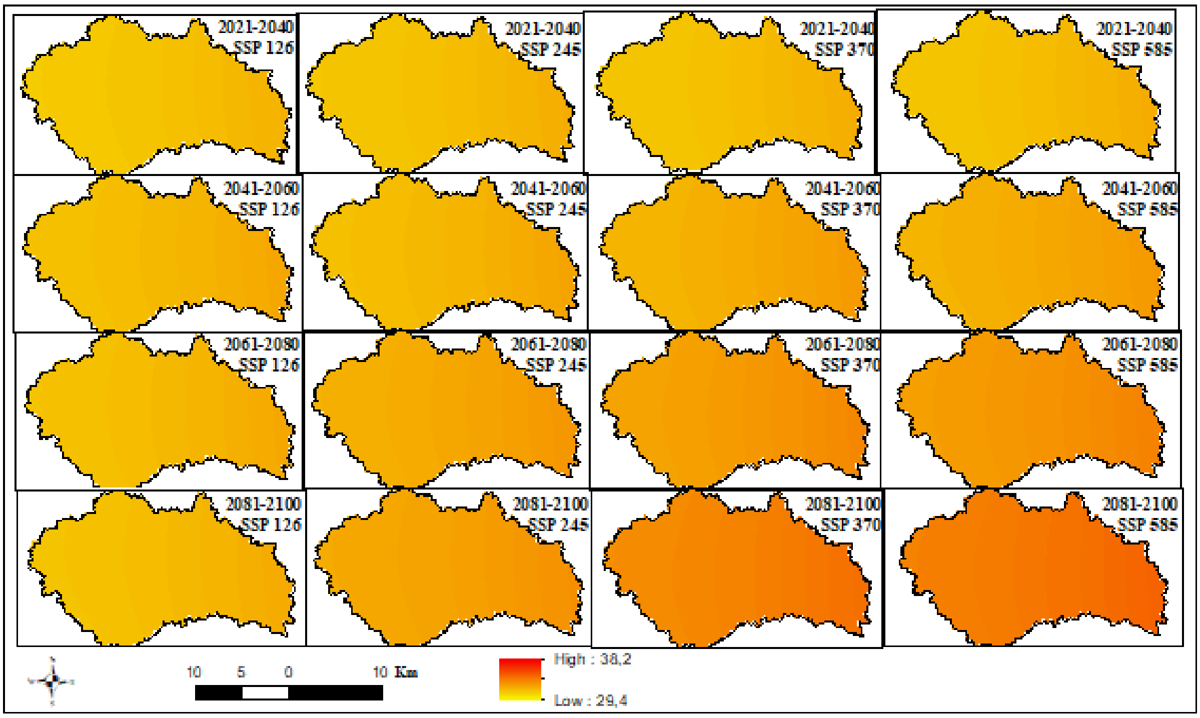

Figure 9: Spatial distribution of maximum temperatures in the Aga-Foua-Djilas basin according to periods and scenarios

3.1.2.2. Monthly scale

The examination of the data presented in **Table 5** and **Figure 10** reveals a bimodal pattern, characterized by an overall increase in maximum temperatures from January to March-April, followed by a decline from May to August, another increase from September to November, and a subsequent decrease from December to January. This rate of change is the same for all periods and scenarios. March, April and November will record the highest maximum temperatures (these are the two maxima), while January and August will be the months with the lowest temperatures (these are the two minima), whatever the scenario and the period.

Under the SSP 126 scenario, monthly maximum temperatures will hover around 33°C throughout the study period. In March, it will reach 34.9°C over the period 2041-2060 and 35.9°C between 2081 and 2100. It will be lower in August, ranging from 32.6°C in the near future to 34.4°C in the far future.

Under the SSP 245 scenario, maximum temperatures will rise from 32.8°C in January over the period 2021-2040 to 34.5°C over the period 2081-2100, an increase of 1.7°C. In May, the rise will be 1.1°C between 2021-2040 (34.8°C) and 2081-2100 (35.9°C). The biggest rise is forecast for September (2.2°C). So, in the near future, the maximum temperature for this month, which, along with August, is the wettest of the year, will be 33.2°C, rising to 35.4°C, an increase of 2.2°C.

Under the SSP 370 scenario, despite the fact that it is more pessimistic than the SSP 126 and SSP 245 scenarios, lower temperatures are forecast for January in the 2021-2040 period (30.9°C). These will then rise to 34°C over the period 2081-2100. Under this scenario, the temperature range between the near future and the distant future will increase in March. Maximum temperatures will rise from 33.6°C to 36.2°C. In August, the range will be greater. Over the period 2021-2040, the SSP 370 scenario predicts temperatures of 31.2°C, compared with 34.2°C over the period 2081-2100, an increase of 3°C. November will also be marked by a high temperature range of 3.1°C (33°C over the period 2021-2041 and 36.1°C over the period 2081-2100).

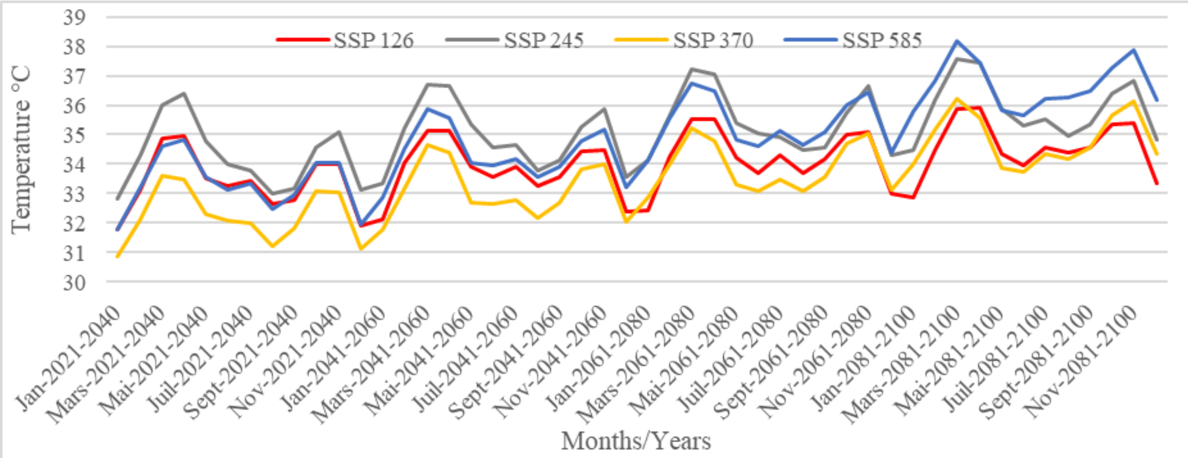

Figure 10: Trend in maximum monthly temperature by scenario and period in the Aga-Foua-Djilas basin

Table 3 : Inter-monthly variation in maximum temperatures by scenario and period in the Aga-Foua-Djilas basin

SSP 126	J	F	M	A	M	J	J	A	S	O	N	D
2021-2040	31.8	33.1	34.9	34.9	33.5	33.3	33.4	32.6	32.8	34.0	34.0	31.9
2041-2060	32.1	34.0	35.1	35.1	33.9	33.6	33.9	33.2	33.6	34.4	34.5	32.4
2061-2080	32.4	34.3	35.5	35.5	34.2	33.7	34.3	33.7	34.2	35.0	35.1	33.0
2081-2100	32.9	34.5	35.9	35.9	34.4	34.0	34.6	34.4	34.5	35.3	35.4	33.3
SSP 245	J	F	M	A	M	J	J	A	S	O	N	D
2021-2040	32.8	34.3	36.0	36.4	34.8	34.0	33.8	33.0	33.2	34.6	35.1	33.1
2041-2060	33.4	35.2	36.7	36.6	35.3	34.5	34.7	33.8	34.1	35.2	35.9	33.6
2061-2080	34.1	35.7	37.2	37.0	35.4	35.0	34.9	34.5	34.5	35.8	36.6	34.3
2081-2100	34.5	36.2	37.6	37.4	35.9	35.3	35.5	35.0	35.4	36.4	36.9	34.8
SSP 370	J	F	M	A	M	J	J	A	S	O	N	D
2021-2040	30.9	32.1	33.6	33.5	32.3	32.1	32.0	31.2	31.8	33.1	33.0	31.1
2041-2060	31.8	33.2	34.7	34.4	32.7	32.7	32.8	32.2	32.7	33.8	34.0	32.1
2061-2080	32.9	34.0	35.2	34.8	33.3	33.1	33.5	33.1	33.6	34.7	35.1	33.1
2081-2100	34.0	35.2	36.2	35.6	33.9	33.7	34.3	34.2	34.5	35.7	36.1	34.3
SSP 585	J	F	M	A	M	J	J	A	S	O	N	D
2021-2040	31.8	33.2	34.6	34.8	33.6	33.1	33.3	32.5	33.0	34.0	34.1	32.0
2041-2060	32.9	34.5	35.9	35.6	34.0	34.0	34.2	33.6	33.9	34.8	35.2	33.2
2061-2080	34.1	35.5	36.7	36.5	34.8	34.6	35.1	34.7	35.1	36.0	36.5	34.4
2081-2100	35.8	36.8	38.2	37.5	35.8	35.7	36.2	36.3	36.5	37.3	37.9	36.2

Under the SSP 370 scenario, despite the fact that it is more pessimistic than the SSP 126 and SSP 245 scenarios, lower temperatures are forecast for January in the 2021-2040 period (30.9°C). These will then rise to 34°C over the period 2081-2100. Under this scenario, the temperature range between the near future and the distant future will increase in March. Maximum temperatures will rise from 33.6°C to 36.2°C. In August, the range will be greater. Over the period 2021-2040, the SSP 370 scenario predicts temperatures of 31.2°C, compared with 34.2°C over the period 2081-2100, an increase of 3°C. November will also be marked by a high temperature range of 3.1°C (33°C over the period 2021-2041 and 36.1°C over the period 2081-2100).

Under the SSP 585 scenario, which is the scenario that forecasts record temperatures with greater temperature ranges. January will be marked by a temperature range of 4°C between 2021-2041 and 2081-2100. Maximum temperatures will rise from 31.8°C to 35.8°C. April will be warmer, but with a smaller amplitude between periods. This will be 2.7°C between 2021-2040 (with 34.8°C) and 2081-2100 (with 37.5°C). After January, August will record the lowest maximum temperatures, but will have the highest temperature range (3.8°C). Over the period 2021-2040, a maximum temperature of 32.5°C is forecast, rising to 36.3°C over the period 2081-2100. November, one of the hottest months of the year, will see its maximum temperatures rise from 34.1°C in the near future to 37.9°C in the far future under this scenario.

3.1.3. Average temperatures

3.1.3.1. Annual scale

The trend in mean temperatures remains the same as that for minimum and maximum temperatures (**Figures 11, 12** and **13**, and **Tables 6 and 7**). Projected mean temperatures have shown upward trends, ranging from 27.6°C under SSP 245 and SSP 370 for 2021-2040 to 29.9°C under SSP 585 for 2081-2100. Projected mean temperatures will be higher under the far-future period under the SSP 585 scenario (**Figure 11**).

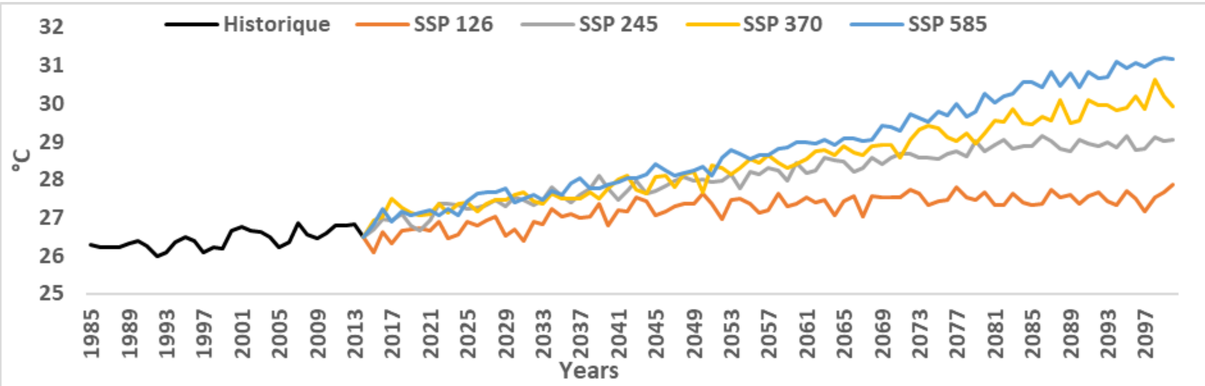

Figure 11: Trends in mean temperature by period and by scenario in the Aga-Foua-Djilas basin

Compared with the reference period 1985-2014, this generalized rise in average temperatures is the norm for the various scenarios, and even more so for the more pessimistic scenarios such as SSP 585 as we approach the end of the century (**Figure 12**). This rise can reach a temperature change of +4.08°C for the far future and under scenario 585 (**Table 6**).

Figure 13 shows the spatial and temporal distribution of average temperatures according to scenario and period. It confirms increase over the years, which becomes more pronounced the more pessimistic the model. In the basin, this average temperature varies spatially from 26.8°C to 32.6°C and remains higher for the SSP 585 scenario and over the period 2081-2100.

A comparison of the average temperature of the future period with that of the reference period (1985-2014), which stands at 26.7°C, shows an increase ranging from 0.85°C to 4.08°C (**Table 6**). The more pessimistic the model and the longer the years, the greater the rise. Specifically, the temperature rise over the period 2021-2040 is 0.98°C, 0.87°C, 0.85°C, and 0.96°C for the SSP 126, SSP 254, SSP 370, and SSP 585 scenarios, respectively. However, during the last period (2081-2100), the temperature increase reaches peak values of 2.08°C, 2.34°C, 3.20°C, and 4.08°C for the SSP 126, SSP 254, SSP 370, and SSP 585 scenarios, respectively.

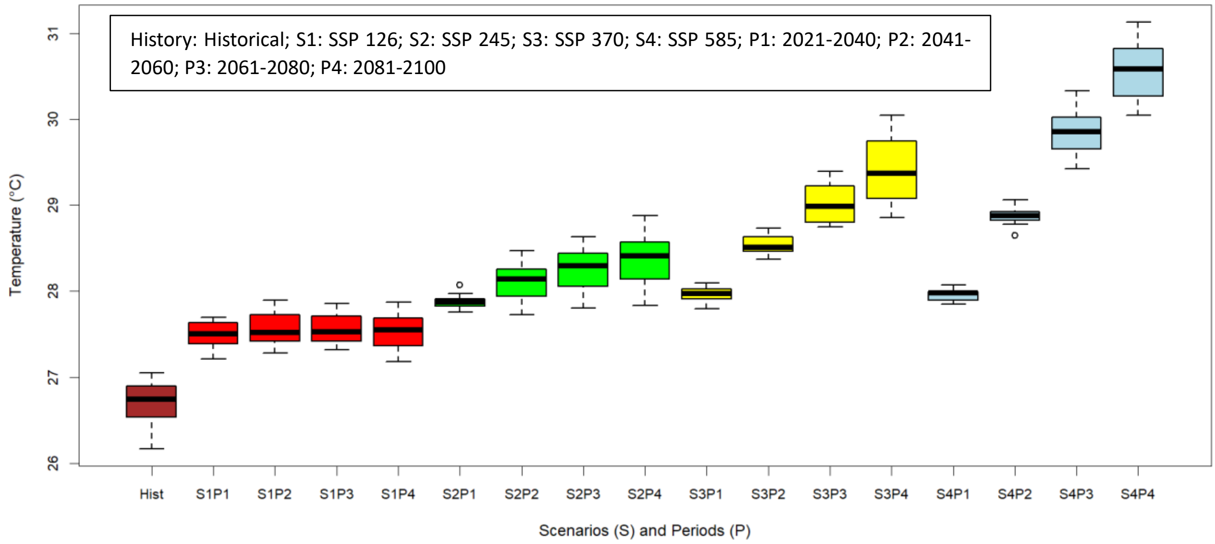

Figure 12: Trends in mean annual temperatures by period and by scenario in the Aga-Foua-Djilas basin

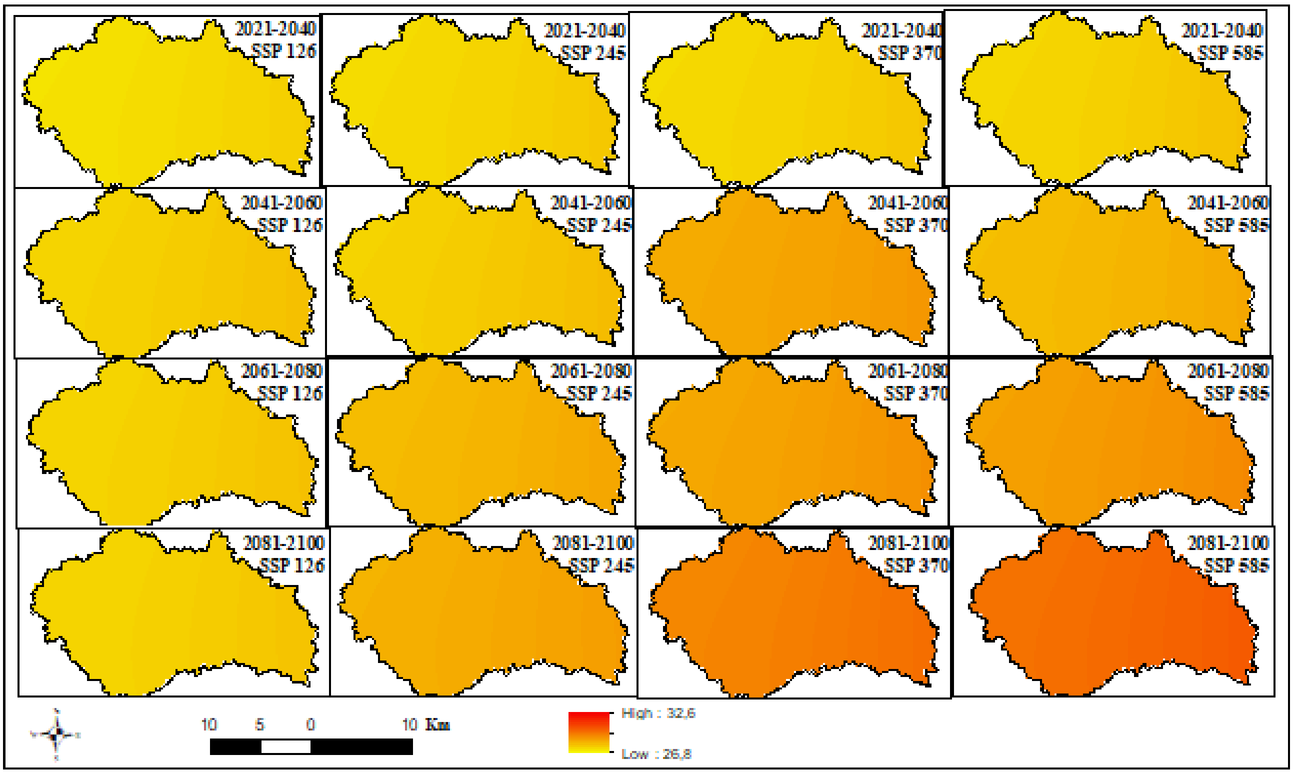

Figure 13: Spatial distribution of mean temperatures in the Aga-Foua-Djilas basin according to periods and scenarios

Table 4 : Future changes in mean annual temperatures (in °C) over the four future periods in the Aga-Foua-Djilas basin

SSP	1985-2014	2021-2040	Difference	2041-2060	Difference	2061-2080	Difference	2081-2100	Difference
SSP 126	26.7	27.7	0.98	28.2	1.44	28.5	1.76	28.8	2.08
SSP 245	1985-2014	2021-2040	Difference	2041-2060	Difference	2061-2080	Difference	2081-2100	Difference
	26.7	27.6	0.87	28.1	1.40	28.7	1.94	29.1	2.34
SSP 370	1985-2014	2021-2040	Difference	2041-2060	Difference	2061-2080	Difference	2081-2100	Difference
	26.7	27.6	0.85	28.3	1.59	29.1	2.33	29.9	3.20
SSP 585	1985-2014	2021-2040	Difference	2041-2060	Difference	2061-2080	Difference	2081-2100	Difference
	26.7	27.7	0.96	28.6	1.86	29.5	2.80	30.8	4.08

3.1.3.2. Monthly scale

For all scenarios and all periods, the same pattern of change in average temperatures is forecast, with a bimodal trend marked by two peaks in October (main maximum) and March and April (secondary maximum) (**Figure 14** and **Table 7**). Temperatures rise from January to March and April, fall slightly from May to August, rise again from September to October and then fall again from October onwards. The drop in August is attributable to cloud cover, as it is the wettest month of the year. January will always be the month with the lowest minimum temperatures (primary minimum), while August remains the month with the secondary minimum.

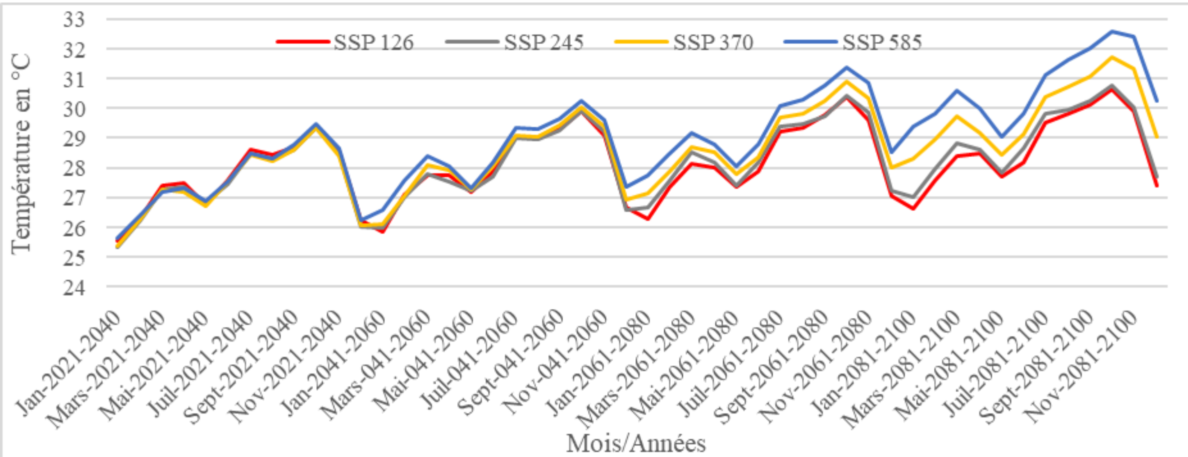

Figure 14: Trends in mean monthly temperature by scenario and period in the Aga-Foua-Djilas basin

Table 5 : Inter-monthly variation in mean temperatures by scenario and period in the Aga-Foua-Djilas basin

SSP 126	J	F	M	A	M	J	J	A	S	O	N	D
2021-2040	25.5	26.3	27.4	27.5	26.7	27.6	28.6	28.4	28.7	29.4	28.6	26.2
2041-2060	25.9	27.1	27.8	27.7	27.2	27.9	29.0	29.0	29.3	29.9	29.1	26.7
2061-2080	26.3	27.4	28.1	28.0	27.4	27.9	29.2	29.3	29.8	30.4	29.6	27.1
2081-2100	26.6	27.6	28.4	28.5	27.7	28.2	29.5	29.8	30.1	30.6	29.9	27.4
SSP 245	J	F	M	A	M	J	J	A	S	O	N	D

2021-2040	25.3	26.2	27.3	27.4	26.8	27.4	28.5	28.3	28.6	29.3	28.5	26.0
2041-2060	26.0	27.0	27.8	27.5	27.2	27.7	29.0	28.9	29.3	29.9	29.2	26.6
2061-2080	26.7	27.6	28.5	28.2	27.4	28.2	29.4	29.5	29.7	30.4	29.9	27.2
2081-2100	27.0	27.9	28.8	28.6	27.8	28.7	29.8	29.9	30.2	30.8	30.0	27.7
SSP 370	J	F	M	A	M	J	J	A	S	O	N	D
2021-2040	25.4	26.3	27.2	27.2	26.7	27.5	28.4	28.2	28.6	29.3	28.4	26.1
2041-2060	26.1	27.1	28.1	27.9	27.3	28.1	29.1	29.0	29.4	30.0	29.4	26.9
2061-2080	27.2	27.9	28.7	28.5	27.8	28.4	29.7	29.8	30.2	30.9	30.3	28.0
2081-2100	28.3	28.9	29.7	29.2	28.5	29.1	30.4	30.7	31.1	31.7	31.3	29.0
SSP 585	J	F	M	A	M	J	J	A	S	O	N	D
2021-2040	25.6	26.4	27.2	27.3	26.9	27.5	28.5	28.3	28.8	29.5	28.6	26.2
2041-2060	26.6	27.6	28.4	28.1	27.3	28.2	29.4	29.3	29.7	30.2	29.6	27.3
2061-2080	27.8	28.5	29.2	28.8	28.0	28.8	30.1	30.3	30.8	31.4	30.9	28.5
2081-2100	29.4	29.8	30.6	30.0	29.0	29.8	31.1	31.6	32.0	32.6	32.4	30.2

3.2. Precipitation trends

3.2.1. Annual scale

Unlike temperatures, rainfall has a downward trend. Rainfall is projected to fall in period, from near to far future in all scenarios. In general, as we get to 2100, the greater the drop will be, and more pronounced with SSP 585. However, the intermediate scenario SSP 370 is an exception, with the 2021-2040 and 2041-2060 periods being less rainy under this scenario than under the more pessimistic SSP 585. Another exception is SSP 245 for the period 2041-2060, which could be rainier under this scenario than under the more optimistic SSP 126. It should also be noted that the south and east of the basin will be the wettest parts, with average annual rainfall ranging from 695 mm to 386 mm (**Figure 15**)

The rainfall that the basin could receive will be between 400 and 500 mm in the near future (with values of 463 mm for SSP 126 and 483 mm for SSP 245 in the medium future 1). In the medium future 2, except for SSP 126 and SSP 245, which predicted rainfall of 420 mm and 427 mm respectively, all the other scenarios predicted lower rainfall that will not reach 400 mm. The same situation is forecast for the far future, with a more significant drop in rainfall.

Figures 15 and **16** show the spatial and temporal variability of annual precipitation in the basin using box and whisker plots. Contrary to what has been noted for temperatures, it is found that mean annual precipitation values are lower (with 284 mm) in the SSP 585 scenario over the 2081-2100 period and higher (with 483 mm) in the SSP 245 scenario over the 2021-2040 period (i.e. a difference of 199 mm). Here, the longest boxes are found respectively in the SSP 126 scenario and over the 2021-2040 period, with varying degrees of temporal variation, and the shortest boxes are found in the SSP 585 scenario and over the 2081-2100 period.

The analysis of changes in climate response on an annual scale was carried out by comparing conditions in the near future (2021-2040), the medium future (2041-2060 and 2061-2080) and the far future (2081-2100) with the control period (1985-2014) or reference normal (**Table 6**).

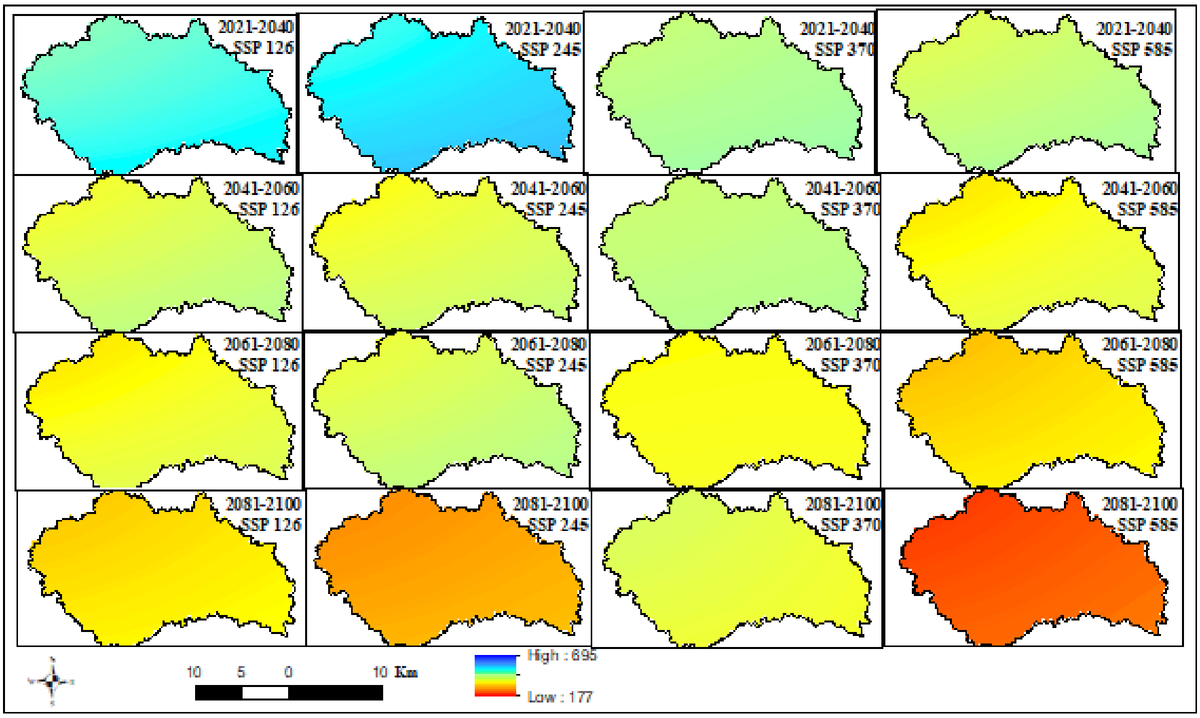

Figure 15: Spatial distribution of rainfall in the Aga-Foua-Djilas basin according to periods and scenarios

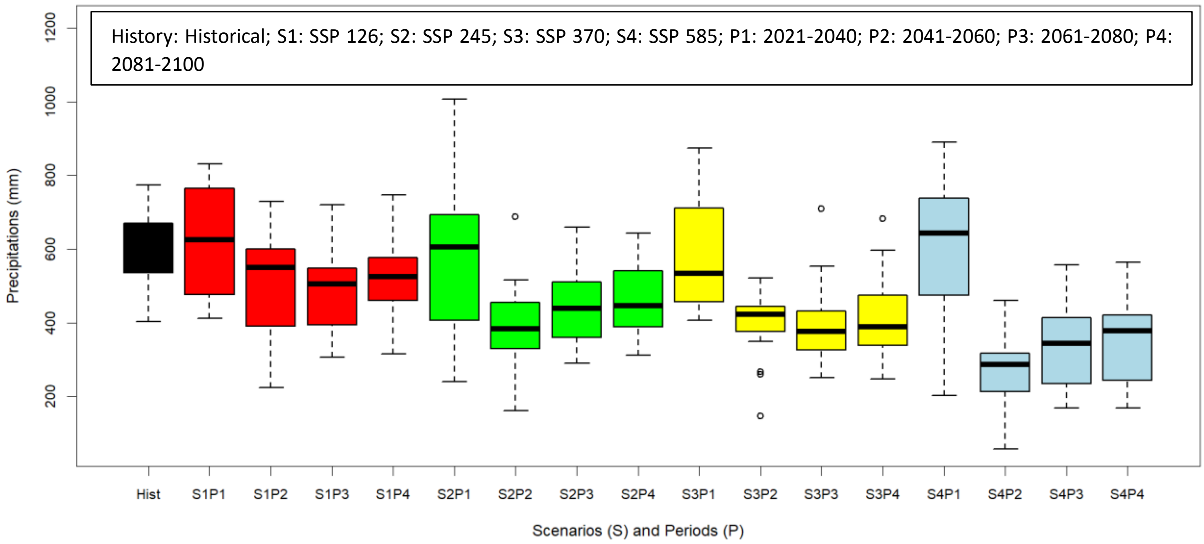

Figure 16: Rainfall trends by period and scenario in the Aga-Foua-Djilas basin

For the optimistic SSP 126 model, precipitation is forecast to be more abundant than in the reference period, although over the years the amount of water expected will decrease from 14.7% in 2061-2080 to 14.1% by 2100. In the near future, despite the drop in precipitation in other scenarios, surplus for the SSP 126 and SSP 245 scenarios. This surplus will be 4.27% and 8.7% respectively for the SSP 126 and SSP 245 scenarios, in contrast to the SSP 370 and SSP 585 scenarios for which a drop of -6.9% and -4.4% respectively will be noted in the basin. The future mean 1 will see a general fall in rainfall. The percentages decline in precipitation in this period for SSP 126, SSP 245, SSP 370, and SSP 585 are 5.56%, 3.8%, 17.2%, and 15.0% respectively.

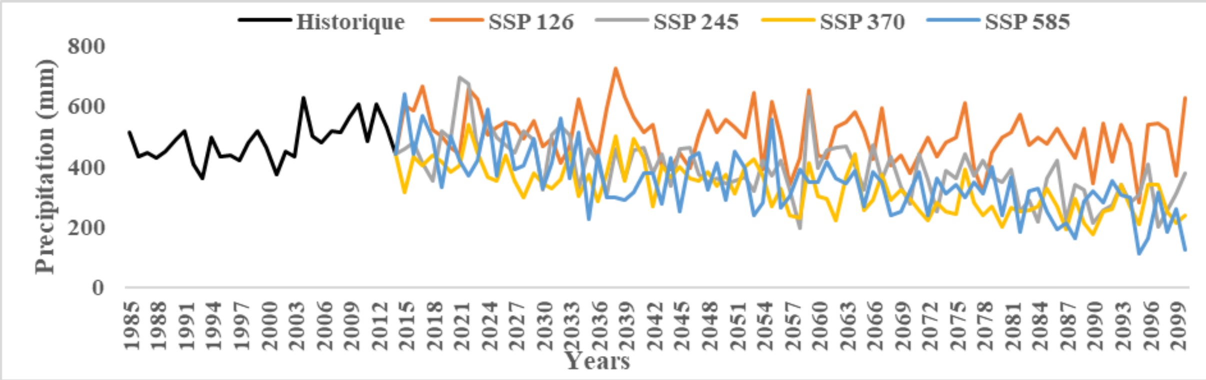

Figure 17: Changes in annual rainfall over the historical period (1985-2014) and the future period (2015-2100) under the SSP 126, SSP 245, SSP 370 and SSP 585 scenarios at the outlet of the Aga-Foua-Djilas basin.

In the medium and far future, rainfall will be lower than the reference normal. The more pessimistic the model, the greater the deficit, and the more the years go by, the greater the deficit. Over the period 2061-2080, the drop will be 8.7% with SSP 245, greater than 20% with SSP 370 (29.1%) and 22.8% for SSP 585. By the end of the 21^e century, a much more intense rainfall deficit is predicted, of 21.4% under SSP 245, which could be happen if the world is affected by competition between countries and pursues an industrial policy that shows little concern for the environment, 34.7% under SSP 370 and 36.1% under SSP 585. If the world plunges back into traditional development based on high energy consumption and carbon-emitting technologies, the rainfall deficit could reach 36.1% under the SSP 585 scenario over the 2081-2100 period in the basin.

Table 6 : Future changes in annual rainfall (in %) over the four future periods in the Aga-Foua-Djilas basin

SSP 126	**1985-2014**	**2021-2040**	**Difference**	**2041-2060**	**Difference**	**2061-2080**	**Difference**	**2081-2100**	**Difference**
	444	463	4.27	420	-5.56	379	-14.7	382	-14.1
SSP 245	1985-2014	2021-2040	Difference	2041-2060	Difference	2061-2080	Difference	2081-2100	Difference
	444	483	8.7	427	-3.8	406	-8.7	349	-21.4
SSP 370	1985-2014	2021-2040	Difference	2041-2060	Difference	2061-2080	Difference	2081-2100	Difference
	444	414	-6.9	368	-17.2	315	-29.1	290	-34.7
SSP 585	1985-2014	2021-2040	Difference	2041-2060	Difference	2061-2080	Difference	2081-2100	Difference
	444	425	-4.4	378	-15.0	343	-22.8	284	-36.1

A comparison of annual rainfall for the wettest and driest periods, compared with the reference period (1985-2014) of 444 mm, varies with scenarios. Over the period 2021-2040, an increase in precipitation of around 4.27% and 8.7% for the SSP 126 and SSP 254 scenarios respectively will be noted, hence decrease in trend will be noted for the SSP 370 and SSP 585 scenarios. Whereas, during the period from 2081 to 2100, a decline is projected in the values of -14.1%, -21.4%, -34.7%, and -36.1% for the SSP 126, SSP 254, SSP 370, and SSP 585 scenarios, respectively.

3.2.2. Monthly scale

On a monthly scale, rainfall trends show unimodal curves (**Table 10** and **Figure 18**). The months of July, August and September will receive the most rainfall, whatever the scenario and the period selected, and August will be the wettest month, followed by September. These three months alone will account for more than 85% of cumulative annual rainfall.

According to the SSP 126 scenario, the projected rainfall for July is approximately 76 mm in the near future, a level that will not be reached again during the other periods. In August, the forecast indicates an increase in rainfall to 182 mm over the 2021-2040 period, followed by a decrease to 136 mm over the 2081-2100 period. In September, the 140 mm mark will only be surpassed in the near future. Similarly, under the SSP 245 scenario, the monthly trend in precipitation is comparable to that of SSP 126 scenario. Over the 2021-2040 period (171 mm) and the 2041-2060 period (162 mm), August will experience higher levels of precipitation. However, there will be a decrease in cumulative rainfall in August by 46 mm between the first (171 mm) and last periods (125 mm). September will also witness a decline in rainfall between the near future (155 mm) and the far future (112 mm).

Under the SSP 370 scenario, the forecasted rainfall is anticipated to be lower than under the first two scenarios. Only August in the period 2021-2040 will experience rainfall in excess of 150 mm (157 mm). Over the years, the cumulative rainfall for each month will decrease. September will record 124 mm in the near future and 93.6 mm in the far future. For the same periods, rainfall in July will be 66.5 mm and 44.1 mm respectively. In contrast, under the SSP 585 scenario, which is the most pessimistic scenario, rainfall is expected to be significantly higher than under the SSP 370 scenario in the near and medium future. In 2021-2040, 66.7 mm, 169 mm, and 126 mm of precipitation are expected in July, August, and September respectively, whereas over the period 2081-2100, precipitation in these same months (July, August, and September) will decrease to 37.1 mm, 92.7 mm, and 95.8 mm respectively.

Under the SSP 126 scenario, forecasts for July show rainfall of around 76 mm in the near future, a level that will not be reached again during the other periods. In August, rainfall is expected to rise to 182 mm over the 2021-2040 period and fall to 136 mm over the 2081-2100 period. In September, the 140 mm mark will only be passed in the near future. Under the SSP 245 scenario, the monthly trend in precipitation is similar to that of scenario 126. Over the 2021-2040 period (171 mm) and the 2041-2060 period (162 mm), August will be wetter. August will see its cumulative rainfall fall by 46 mm between the first (171 mm) and last periods (125 mm). September will see a drop in rainfall between the near future (155 mm) and the distant future (112 mm).

Under the SSP 370 scenario, rainfall is forecast to be lower than under the first two scenarios. Only August in the period 2021-2040 will see rainfall in excess of 150 mm (157 mm). Over the years, the cumulative rainfall for each month will fall. September will record 124 mm in the near future and 93.6 mm in the distant future. For the same periods, rainfall in July will be 66.5 mm and 44.1 mm respectively. Under the SSP 585 scenario, which is the most pessimistic scenario, rainfall will be significantly higher than under the SSP 370 scenario in the near and medium future. In 2021-2040, 66.7 mm, 169 mm and 126 mm of precipitation are expected in July, August and September respectively, whereas over the period 2081-2100, precipitation in the same months (July, August and September) will decrease to 37.1 mm, 92.7 mm and 95.8 mm respectively.

Table 7 : Inter-monthly variation in rainfall by scenario and period in the Aga-Foua-Djilas basin

SSP 126	J	F	M	A	M	J	J	A	S	O	N	D
2021-2040	1.64	0.82	1.3	1.07	1.05	12	76	182	141	42.4	3.27	1.84
2041-2060	1.21	0.48	1.19	0.63	1.09	12.2	60.3	157	136	43.6	4.12	1.64

2061-2080	1.43	0.39	1.46	0.44	1.11	9.58	49.3	143	126	41.6	2.3	2.49
2081-2100	2.65	0.41	1.28	0.57	0.89	12	52.4	136	125	43.6	4.42	1.88
SSP 245	J	F	M	A	M	J	J	A	S	O	N	D
2021-2040	1.78	1.22	0.52	0.74	1.22	14.9	87.9	171	155	41.9	4.34	2.85
2041-2060	1.56	0.39	1.07	0.76	0.96	15	62	162	135	42.7	3.88	2.01
2061-2080	0.94	0.41	0.7	0.73	1.15	11.5	65	147	133	40.8	2.14	2.32
2081-2100	2	0.46	0.91	0.93	1.23	10.8	50.7	125	112	39.6	3.44	2.11
SSP 370	J	F	M	A	M	J	J	A	S	O	N	D
2021-2040	3.42	1.53	1.55	1.14	1.64	15.3	66.5	157	124	34.2	3.1	3.99
2041-2060	2.75	1.45	1.59	1.22	1.11	10.2	54.2	141	118	30.3	3.27	3.76
2061-2080	1.95	1.01	1.48	1.05	1.16	9.3	49.3	112	102	28.8	2.87	3.33
2081-2100	1.94	0.99	1.88	1.39	1.2	9.24	44.1	100	93.6	27.5	3.84	4.19
SSP 585	J	F	M	A	M	J	J	A	S	O	N	D
2021-2040	2.31	0.94	0.35	0.55	1.63	13.3	66.7	169	126	39.1	3.32	1.73
2041-2060	1.18	0.61	0.35	0.63	1.04	11	55.3	130	132	41.5	2.81	2.06
2061-2080	1.1	1.26	0.56	0.61	1.00	8.28	43.9	126	116	40.1	2.44	2.04
2081-2100	1.75	0.56	0.93	0.55	0.93	9.89	37.1	92.7	95.8	37.8	3.9	1.93

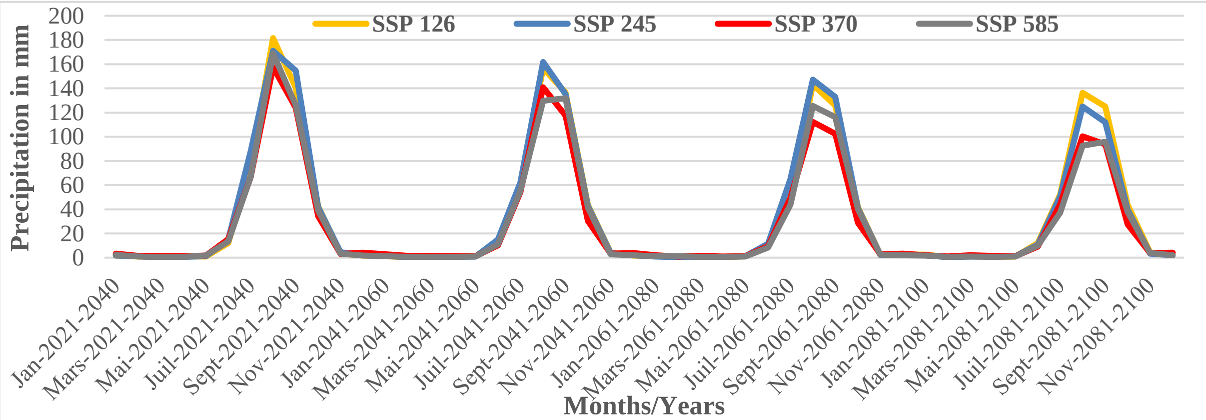

Figure 18: Trends in monthly rainfall by scenario and period in the Aga-Foua-Djilas basin

4. Discussion

The analysis of data from the Aga-Foua-Djilas basin indicates a consistent increase in both minimum and maximum temperatures until the end of the 21st century. On an annual scale, minimum temperatures are projected to range between 21.2°C (under the optimistic SSP 126 scenario over 2021-2041) and 23.9°C (under the pessimistic SSP 585 scenario over 2081-2100). Maximum temperatures follow a similar pattern, rising from 34.3°C for all scenarios during the period 2021-2040 to 37.4°C (under SSP 585 for the period 2081-2100). Notably, the optimistic SSP 126 scenario does not predict maximum temperatures reaching 35°C even in the far future (Almazroui *et al.*, 2021; Mbaye *et al.*, 2019; Sadio *et al.*, 2020). In contrast to temperature trends, the basin is expected to experience a decline in precipitation over time, regardless of the scenario. This downward trend in rainfall ranges from 444 mm to 284 to 284 mm under SSP 585 scenario, indicating potential challenges in water availability for agricultural use, despite the basin's strong agricultural potential. These climate trends based on the SSP scenarios align with previous research conducted around Senegal and beyond (Parsons, 2020; Phan & Nguyen, 2023; Rivera & Arnould, 2020). Notably, they differ from earlier studies that reported statistically insignificant upward trends in precipitation in some regions (Almazroui *et al.*, 2020; Díaz *et al.*, 2021; Ortega *et al.*, 2021). Global climate models, particularly the new generation developed within the CMIP6 project, have been valuable tools for understanding past and future climate changes. They offer increased complexity in modeling physical processes and higher spatial resolution, allowing for more detailed assessments of climate change (Alemayehu & Bewket, 2017) in the central highlands of Ethiopia have been reported (Eyring *et al.*, 2016). The research presented here provides the first predictions of temperature and precipitation changes in the Aga-Foua-Djilas basin. Due to data limitations, validation was only for monthly data from 1985 to 2014. Additionally, the downscaling process of climate models for the basin introduces some uncertainties (Marotzke *et al.*, 2017; 'The CMIP6 Landscape', 2019). Future climate projections involve uncertainties related to climate forcing scenarios, model structures, and intrinsic climate system variability. The forecast data presented covers a 20-year period and is most suitable for informing long-term development strategies. For short-term socio-economic development plans and water resource utilization, more detailed forecasting on an annual, monthly, or daily basis would be required (Girma *et al.*, 2016; Hawkins & Sutton, 2009).

5. Conclusion

Senegal is susceptible to fluctuations in climate, and it is anticipated that climate change will amplify the frequency and magnitude of natural disasters. The detrimental impacts of climate change have the potential to worsen existing social and economic challenges across the nation, particularly in areas where communities rely on climate-sensitive resources and rain-fed agriculture. This research was conducted to examine patterns in minimum and maximum temperatures as well as precipitation in the Aga-Foua-Djilas basin during the baseline period of 1985-2014 and the future period of 2021-2100, utilizing CMIP 6 projections under various Shared Socioeconomic Pathways (SSPs) including SSP 126, SSP 245, SSP 370, and SSP 585. In summary, the investigation of future climate in the Aga-Foua-Djilas basin indicates a rise in temperatures and a decline in precipitation, irrespective of the projection scenario, whether optimistic or pessimistic. Overall, the distribution of precipitation and temperature in the Aga-Foua-Djilas basin is intricate both spatially and temporally, encompassing both historical and future periods.

The overall increase in annual temperature observed in the study area is therefore largely attributed to an increase in minimum temperature. It is therefore imperative to adjust agricultural activity to the situation of variability and to devise planned climate change adaptation strategies in order to improve the adaptive capacity and resilience of small-scale rainfed farmers. The major problem with the distribution of rainfall in the study area is the inconsistency and change in the start and end periods rather than the total amount. The rains arrive late and end very early, making the cropping calendar shorter than before. In addition, irregular rainfall and prolonged dry spells during the main rainy season have been reported as major phenomena that adversely affect farming activity. Based on this knowledge of the future climate, it is important to assess the basin's water resources in the short, medium and long term. This will help to refine sustainable water management strategies and guide public agricultural policies.

A 20-year forecast to the end of the 21st century has shown that only monthly maximum and minimum temperatures are trending upwards. Mean annual precipitation, on the other hand, is on a downward trend. The seasonal distribution of precipitation in the scenarios is in line with observed data. However, this research also has several limitations, such as the fact that the reference data could only be used for comparison over a 30-year period (1985-2014). Based on the results of the research, it can be concluded that extracting model results (ACCESS-ESM1-5, BCC-CSM2-MR and MRI-ESM2-0) can calculate future data, even for small basins such as the Aga-Foua-Djilas basin. The results of this study have important implications for climate change adaptation scenarios and territorial planning in the Sahel. The methodology developed in this study can be used for reliable projections of future climate characteristics in any basin, and the results can be used in the development of adaptation and mitigation plans in Senegal. Future agricultural management strategies should also consider future conditions.

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