



**Climate Atlas of Bhutan (1996- 2025):
Climatology of Temperature and Rainfall**

**National Centre for Hydrology and Meteorology
Royal Government of Bhutan**

March 2026

Authors

Ms. Pema Syldon, Senior Hydromet Officer, NCHM

Ms. Ugyen Lhamo, Hydromet Officer, NCHM

Mr. Ugyen Chopel, Deputy Chief Statistician, NCHM

Mr. Sangay Tshering, Hydromet Officer, NCHM

Mr. Kinley Tenzin, Hydromet Officer, NCHM

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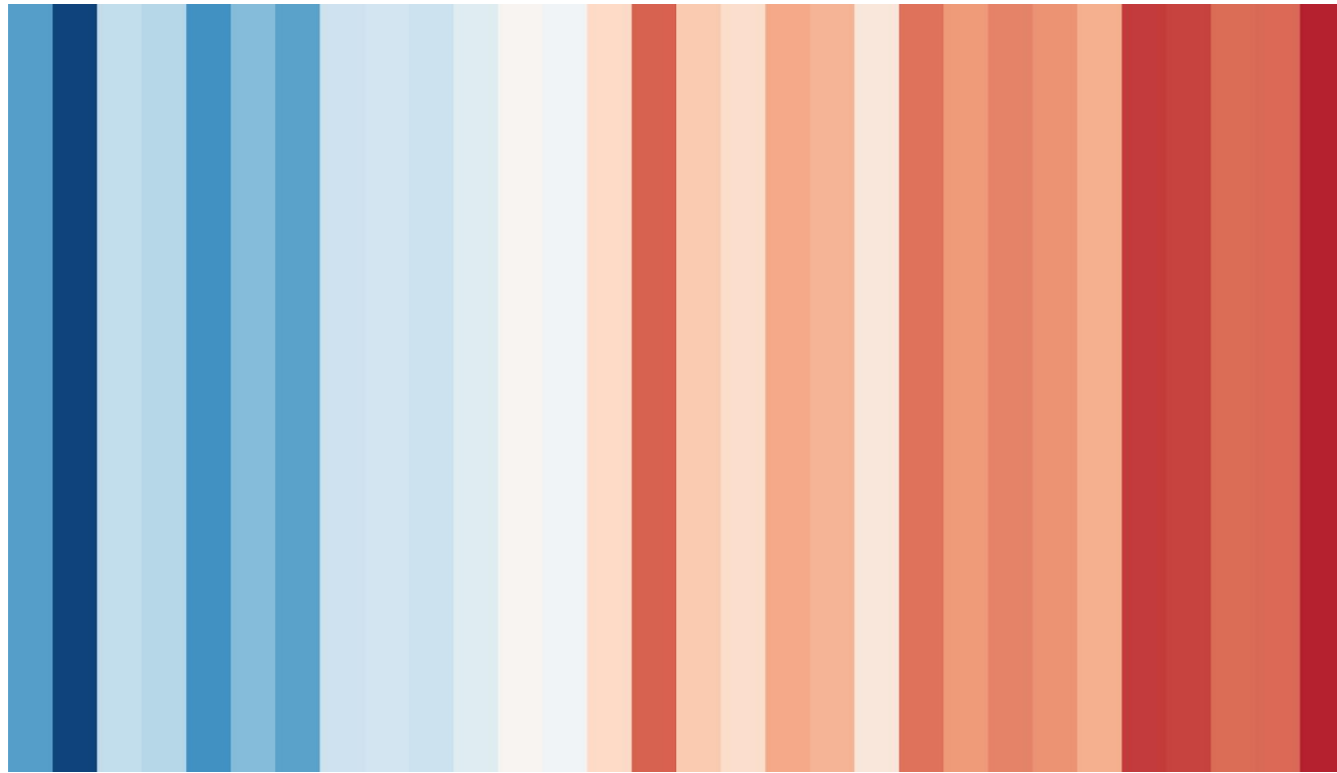
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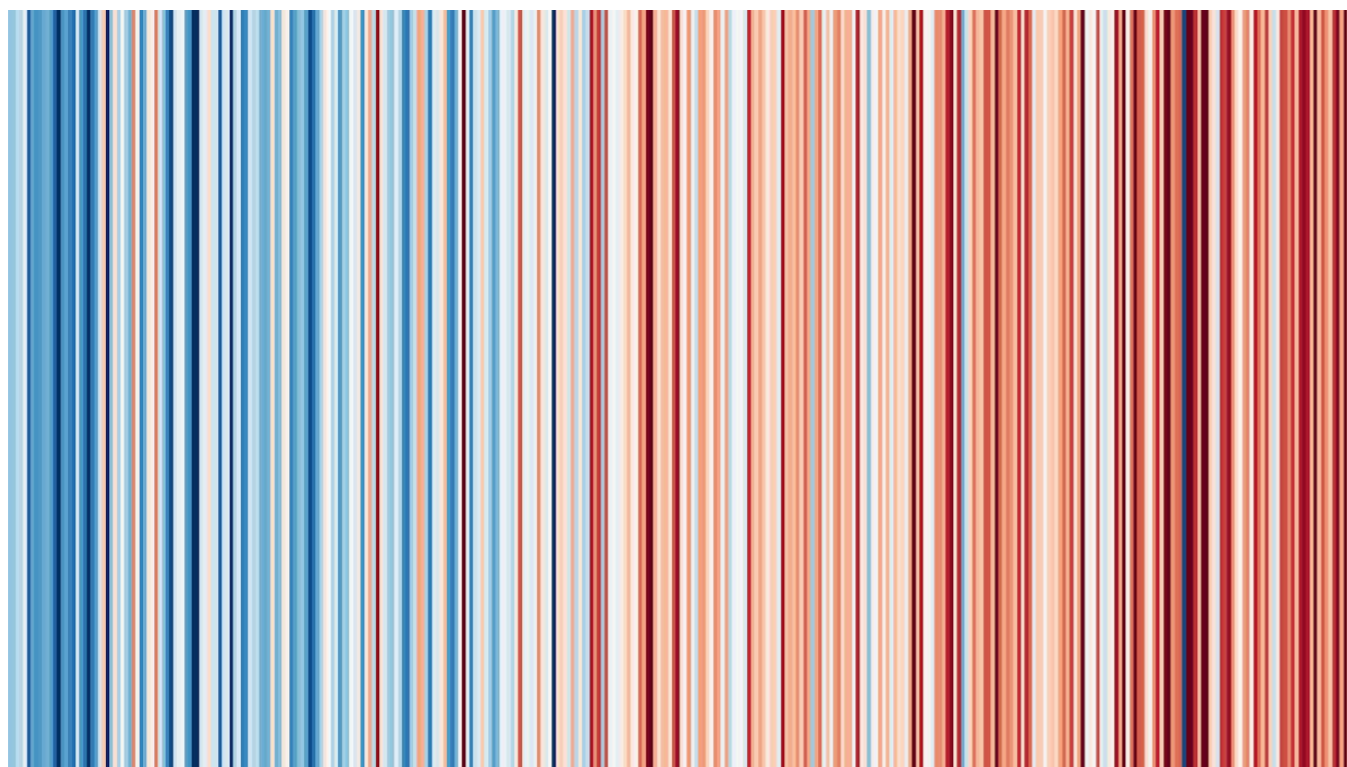
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Climate stripes are a simple visual representation of long- term temperature change over time. Each vertical stripe represents the average temperature for a specific year relative to a long- term reference period. Cooler years are shown in shades of blue, while warmer years are shown in shades of red.

They clearly illustrate how temperatures have shifted from cooler conditions in earlier decades to warmer conditions in recent years. This visualization provides an intuitive summary of long- term temperature trends and helps readers quickly understand the magnitude and direction of climate change over the study period.



These climate stripes were produced using the daily maximum and minimum temperatures to compute the daily mean temperature. A reference climatology was calculated using the 1996- 2020 baseline period, and temperature anomalies were obtained by subtracting this baseline mean from each corresponding annual or monthly value.

The anomalies are visualized as climate stripes, where each vertical stripe represents a single year (or month) in chronological order. A color range of red and blue was applied, with red shades indicating warmer- than- average conditions and blue shades indicating cooler- than- average conditions relative to the baseline.

Climate Stripes of annual mean temperature for Bajo station 1996- 2025), top showing annual anomalies and bottom showing monthly anomalies.

Forward

Bhutan's unique geographical setting, characterized by steep elevation gradients and complex mountain terrain, gives rise to significant spatial and seasonal variations in climate across the country. Understanding these climatic patterns is essential for informed planning, sustainable resource management, and strengthening resilience to climate-related hazards. In this context, the *Climate Atlas of Bhutan (1996- 2025): Climatology of Temperature and Rainfall* represent an important step toward consolidating and communicating the country's climate information in a clear, accessible, and scientifically robust manner.

This atlas provides a comprehensive analysis of temperature and rainfall patterns across Bhutan based on three decades of observational data. By presenting long-term climatological averages, seasonal variations, and spatial distributions through maps and visual analyses, the publication offers valuable insights into the country's climate system.

Such information is critical for a wide range of users, including policymakers, planners, researchers, and practitioners working in sectors such as agriculture, water resources, infrastructure development, disaster risk reduction, and environmental management.

As Bhutan continues to experience the impacts of climate variability and global climate change, strengthening climate services and improving access to reliable climate information have become increasingly important. The National Centre for Hydrology and Meteorology remains committed to advancing the science, monitoring,

and communication of weather and climate information in support of national development priorities and public safety. This Climate Atlas contributes to that effort by transforming observational data into practical knowledge that can support evidence-based decision-making and climate-resilient planning.

The preparation of this atlas reflects the dedication and collaborative efforts of the technical team at the Centre who have worked diligently to compile, analyze, and interpret the data. I would like to extend my sincere appreciation to all staff whose contributions have made this publication possible. Also, to the Enhancing Climate Resilience of Urban Landscapes and Communities in the Thimphu-Paro Region of Bhutan Project, for funding the Climate Information Mapping workshop in February 2026.

It is my hope that this Climate Atlas will serve as an authoritative reference on the country's climate and will support continued research, planning, and policy development aimed at strengthening the nation's resilience to climate variability and change.



Director General

National Centre for Hydrology and Meteorology
Royal Government of Bhutan

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Introduction

Bhutan is a mountainous landlocked country located in the eastern Himalayas. The country covers an area of 38,394 square kilometers out of which 70% is under forest cover, 7% under snow and glaciers, 3% under cultivation and agriculture land, and 4% under meadows and pastures (NSB, 2025). The country is characterized by rugged terrains, with elevation ranging from 160 m to more than 7000 m, and can be divided into three distinct climatic zones; cold alpine snow-capped mountain with annual rainfall around 400mm in the north, cool winter and hot summer temperate climate in the central parts, and humid and subtropical with temperature between 15- 30°C throughout the year with total annual rainfall of 2000- 5000 mm in the southern plains (NCHM, 2024).

These distinctive climatic zones are due to the topography of the country, along with the relative distance from the coast, Bay of Bengal, which controls the extent of moisture from the southwest summer monsoon. Furthermore, the control exerted by the dry winter-air mass from the northern high altitude, western disturbance, and the periodic impacts from the remnants of the cyclonic systems from the Bay of Bengal contribute to the climate of the country. These climatic conditions give rise to the winter season from December to February, pre monsoon/spring from March to May, summer monsoon from June to September, post monsoon/ autumn from October to November. Summer monsoon contributes to 73% of the total rainfall in the country, with winter only 1% (Dorji et al. 2021).

The country's complex terrain with a large elevation range results in local climate variability that cannot be adequately described by station

data alone. Therefore, this climate atlas converts station data into continuous gridded climate information, establishing a nationally consistent climatological baseline for the period from 1996- 2025. This nationally derived observation-based information will complement the coarse global climate datasets, which sometimes lack to interpret features of mountainous regions.

The spatial climatology will contribute to the interpretation of extreme weather events in relation to local conditions, and will support evidence-based planning and decision-making, strengthening the delivery of climate services by enabling users to access location specific climate information. This will provide reference for climate monitoring, seasonal assessment, impact-forecasting, and sectorial planning such as for climate sensitive sectors such as hydropower, agriculture, and construction, which are major contributors to the national Gross Domestic Product, with 20- 25%, 14%, 10- 15% respectively (MoF, 2025). Therefore, the atlas is a foundational national product that transforms long-term observation data into spatial climate knowledge. It will form the baseline for climate change assessment and adaptive planning, and will provide foundation for understanding of the future climate conditions in the country.

Data and Method

The climatology for temperature and rainfall was computed from 125 and 98 observation stations respectively (Figure 1) under the National Centre for Hydrology and Meteorology (NCHM). There are a few observation stations in the higher mountains, however the network spans a broad range of elevations and climatic zones enabling the

representation of strong topographic controls on temperature and rainfall.

The climate normals are computed from 1996- 2025, in accordance with standard practice for long- term climatological assessments (WMO, 2017; Aguilar et al., 2003; WMO, 2025). Daily maximum temperature, minimum temperature and rainfall were aggregated to produce the seasonal and annual averages. Only stations with sufficiently long and reliable dataset were used for analysis. Data underwent quality check, consistency and homogeneity check, and missing values were treated using climatological averages to maintain temporal continuity.

The spatial interpolation of temperature was performed using kriging, a geospatial technique that takes account for both the distance and spatial autocorrelation among the observation points (Cressie, 1993; Pebesma, 2004). Observed temperature data from the stations, with their geographic coordinates were firstly quality- controlled, harmonized and concerted into a consistent spatial coordinate system of WGS84. A high- resolution, 1 km, grid covering the country was used for interpolation, ensuring spatially continuous temperature estimates. Elevation as a covariate was incorporated for trend modeling to include the influence of topography on temperature variability in a mountainous terrain of the country. Kriging with External Drift (KED) approach was used as it is suitable for complex terrain where elevation plays a dominant role in temperature distribution. A variogram was computed from the residuals of the trend model, which was used in the kriging interpolation to estimate temperature values.

Rainfall interpolation was prepared using a combination of Generalized Additive Model (GAM) with kriging. GAM was used to model the deterministic component of rainfall variability as a function of topographic predictors, including northness, and topographic position index (Hastie et al., 1990; Wood, 2017). The fitted GAM provided spatially continuous estimates of the large- scale rainfall trend, and residuals were computed as the difference between observed and modeled values, which was then interpolated using ordinary kriging.

A variogram model was used to describe the spatial structure of residuals, and kriging was applied to estimate residual values across the grid. The final rainfall estimates were obtained by combining the GAM- predicted trend with the kriged residuals and back- transforming the results to the original scale (Goovaerts, 2000; Hengl et al., 2007).

The analysis has been made for annual, seasonal and monthly spatial distribution for annual mean maximum and minimum temperature, and annual mean rainfall from 1996- 2025, comprising of 30- year climatological data in the country. Furthermore, relationship between elevation and temperature has been made for annual and seasonal time periods. To determine the trend of temperature and rainfall, interannual variability with decadal segregation along with anomaly has been studied.

Temperature Climatology

Annual Mean Maximum Temperature

Bhutan | Baseline climatology | Unit: °C

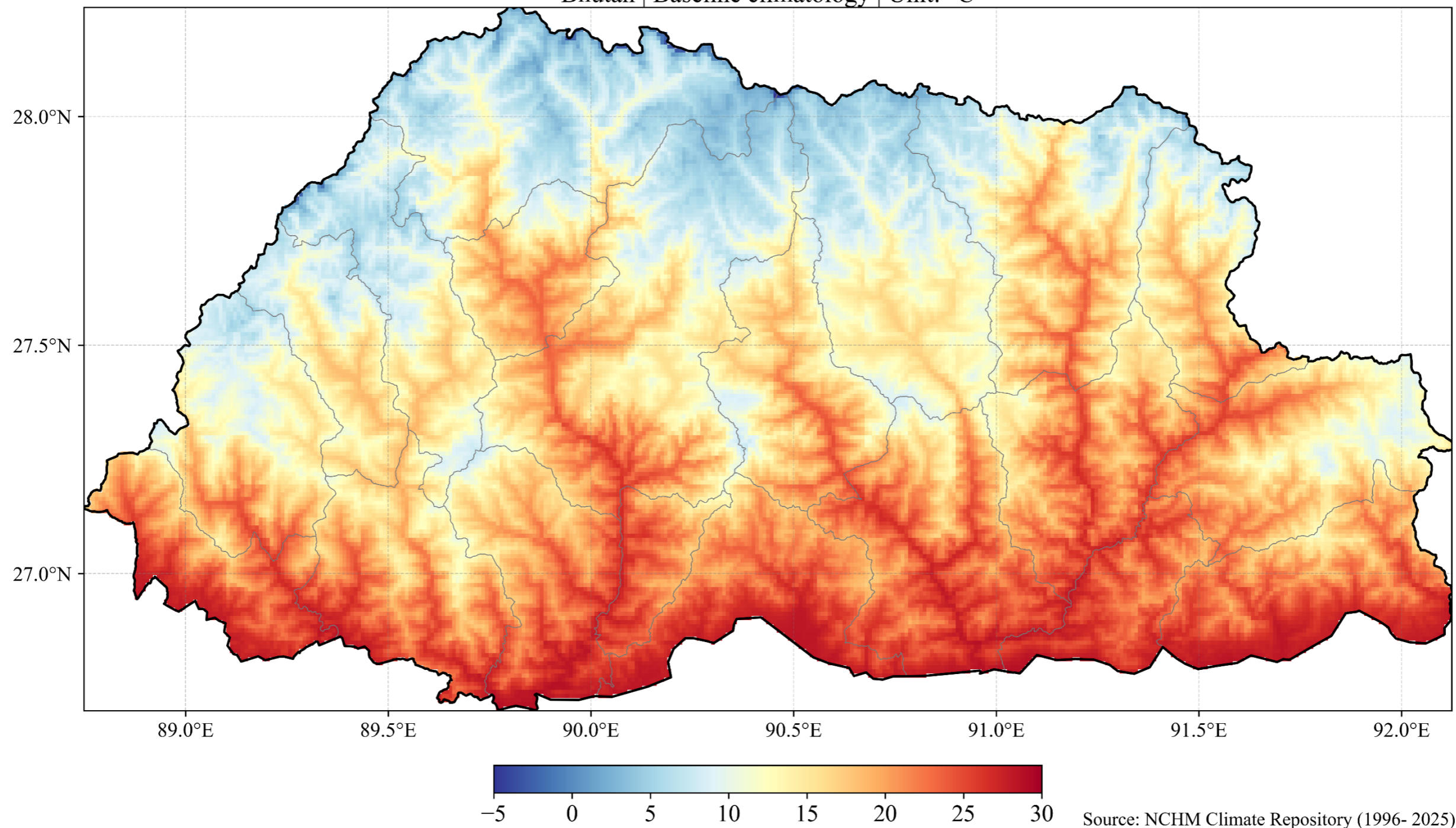
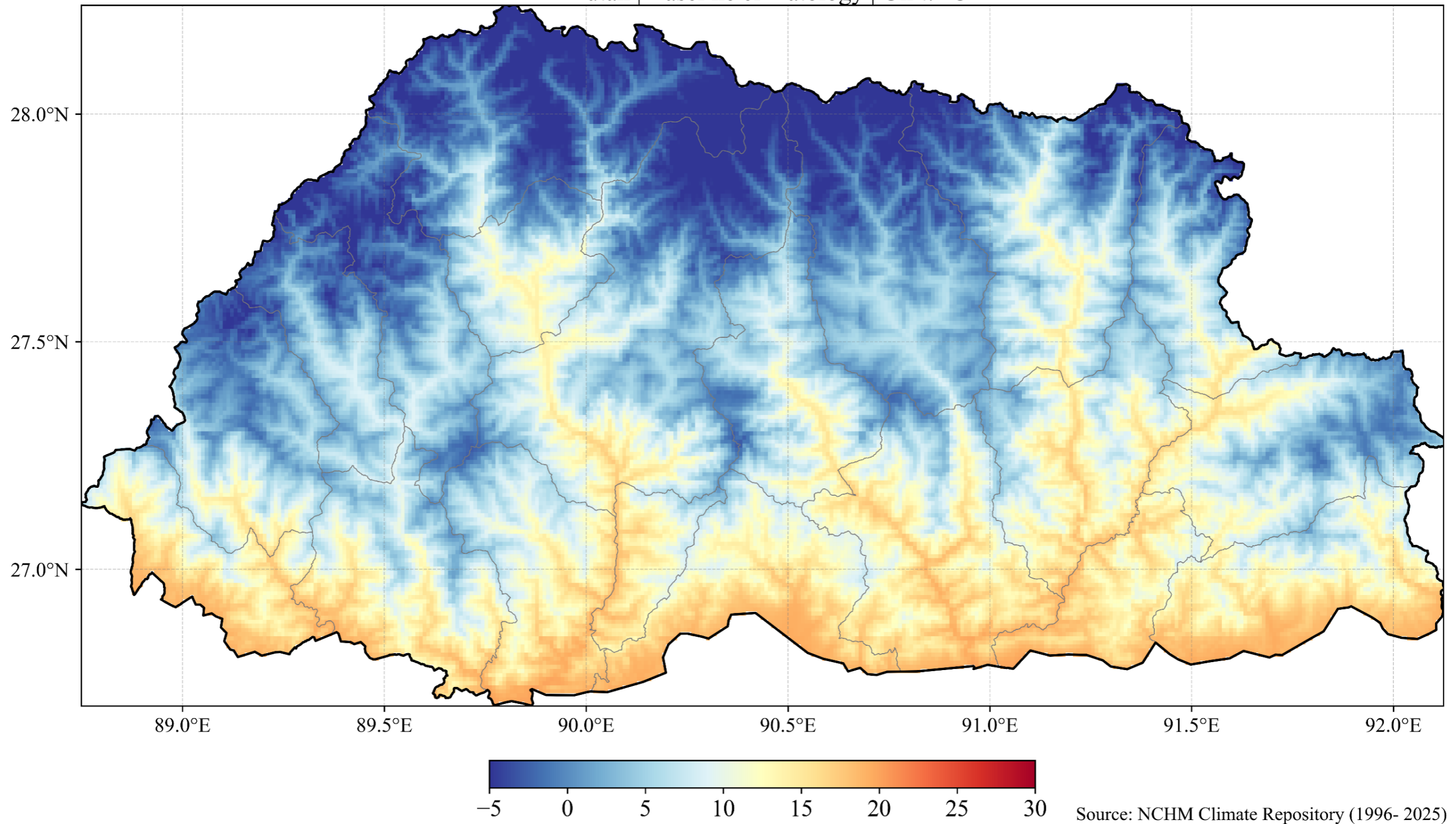


Figure 2: Spatial distribution of annual mean maximum temperature of Bhutan (1996- 2025)

The spatial distribution of annual mean maximum temperature across the country from 1996- 2025 shows strong influence of topography and elevation. Warmer climates are observed at the southern foothills and low- lying valleys, with temperatures running from 25- 30 °C, whereas the northern and higher elevations see values less than 10 °C. The gradual transition from warmer to cooler temperatures from the south to the north highlights the country's elevation gradient on how temperature decreases with increasing elevation. Warmer temperatures are also along the river valleys and lower basins indicating the reduced elevations.

Annual Mean Minimum Temperature

Bhutan | Baseline climatology | Unit: °C



The spatial distribution of annual mean minimum temperature across the country from 1996- 2025 further highlights the influence of elevation and terrain of the country. Warmer conditions are evident towards the southern foothills with temperature running from 15- 20°C, and colder towards the northern high altitudes even reaching below 0°C. The north- south temperature gradient can be seen corresponding to the country elevation differences. This is also noticeable along the river valleys and basins.

Seasonal Mean Maximum Temperature

Bhutan | Baseline climatology | Unit: °C

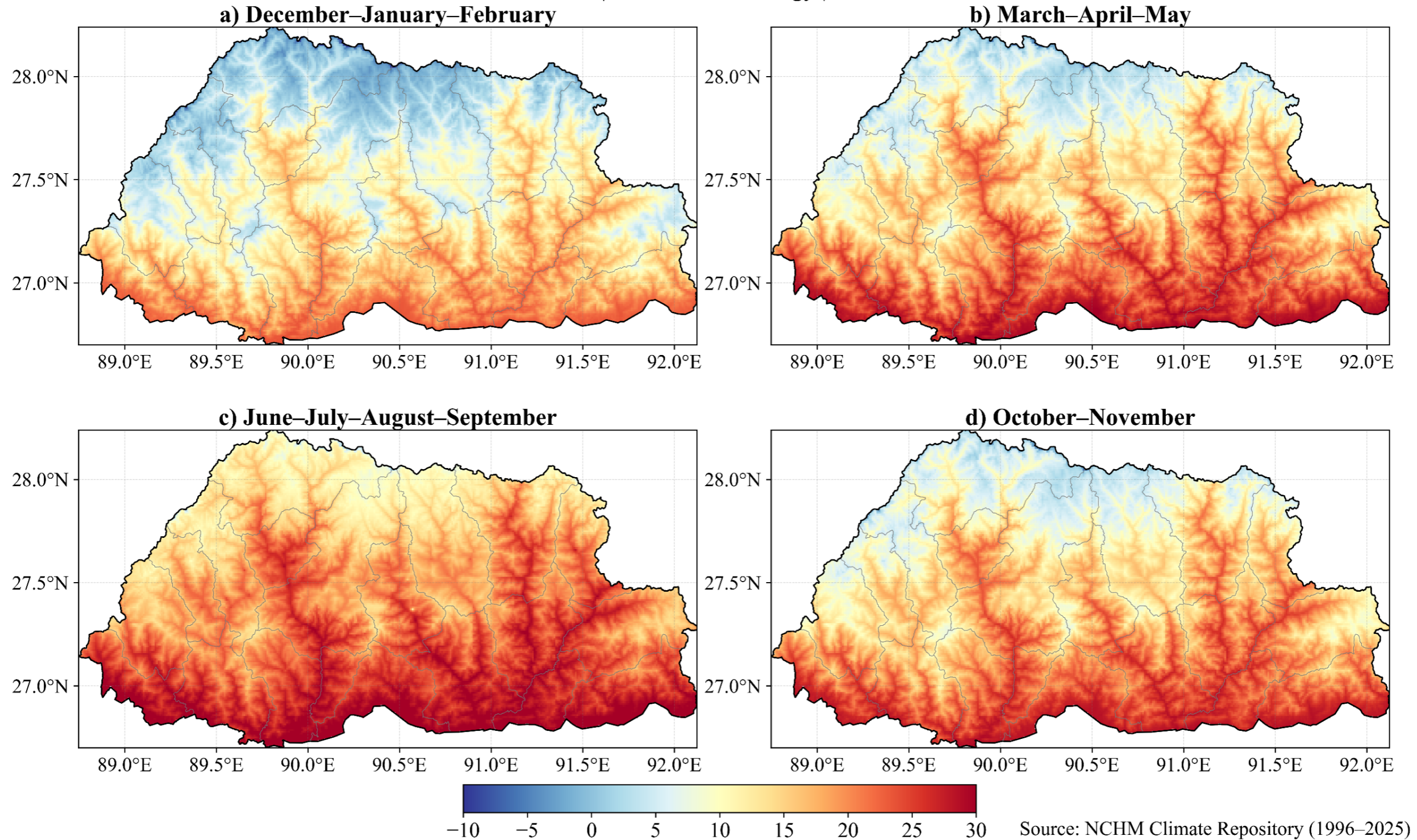


Figure 4: Spatial distribution of seasonal mean maximum temperature in Bhutan (1996- 2025)

The spatial distribution of seasonal mean maximum temperature in the country from 1996- 2025 highlights the temperature variability throughout the year. The winter season, from December, January and February indicated the lowest temperature in the year. The temperature during the pre- monsoon season (May- April- May) starts to increase significantly. Warmest conditions are seen using the monsoon season from June to September. Temperatures start to decline gradually during post- monsoon seas of October and November, with the transition to winter months. The north- south temperature gradient is evident,

showing the strong influence of the country's elevation. Warmer temperatures are mostly seen in the southern low- plains and river valleys, whereas cold prevail over the higher Himalayas regions.

The same observation can be made from the seasonal mean minimum temperature, and monthly mean maximum and minimum temperature which are shown as follows.

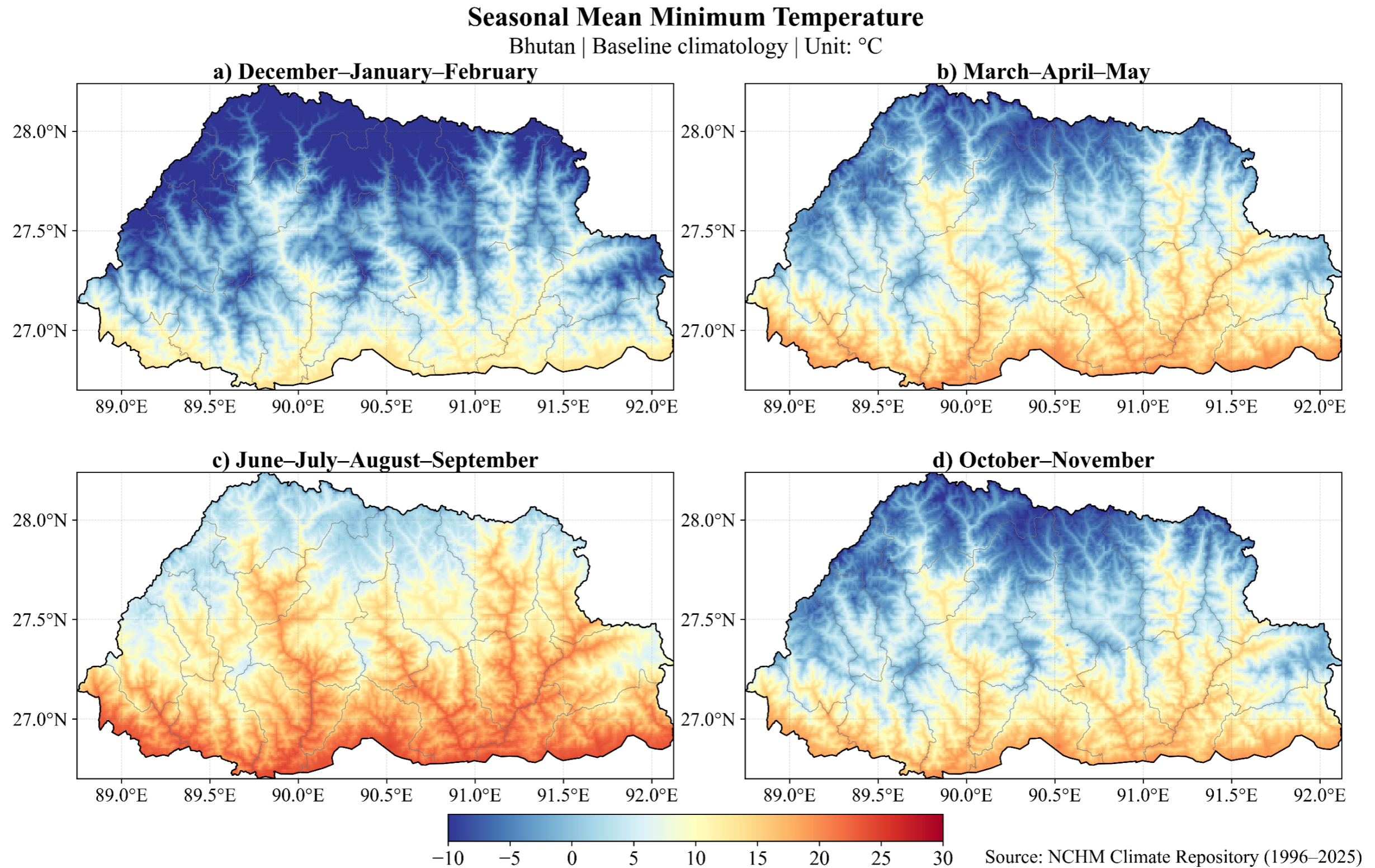
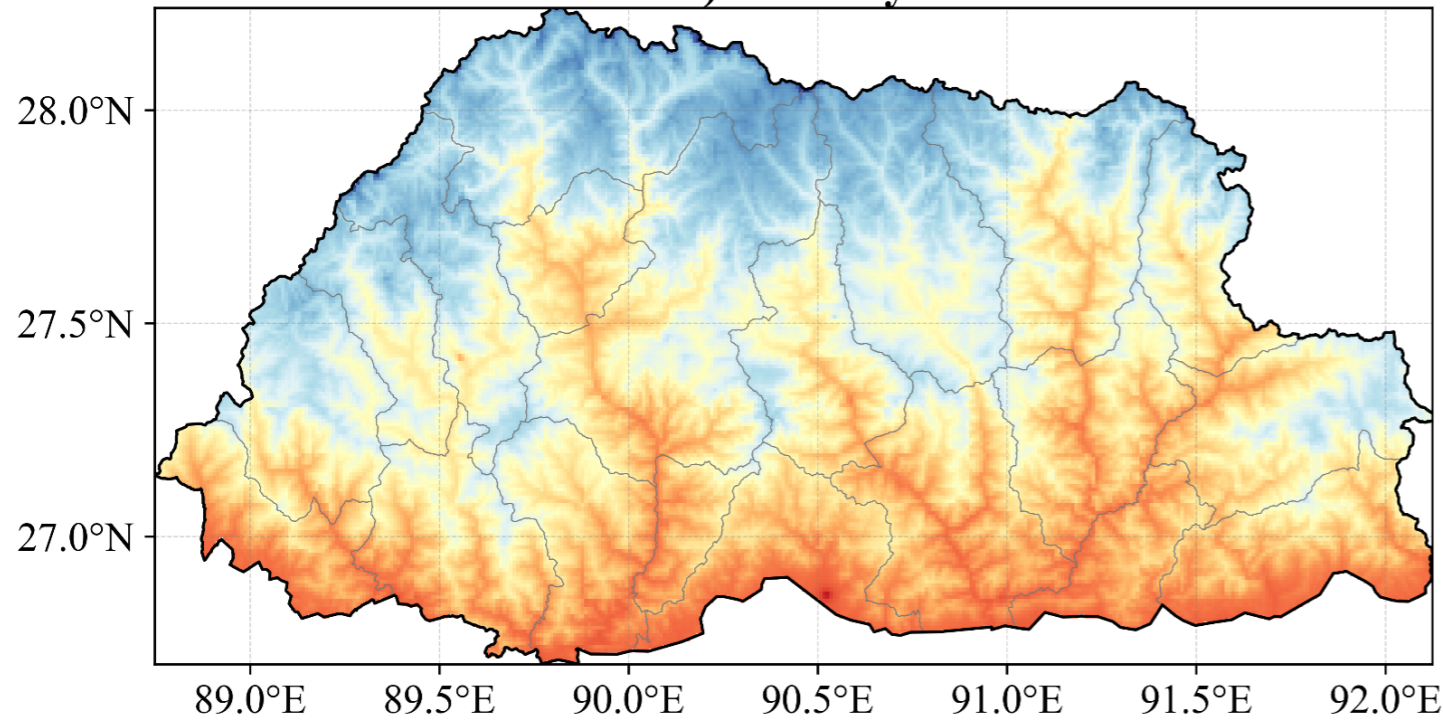


Figure 5: Spatial distribution of seasonal mean minimum temperature in Bhutan (1996- 2025)

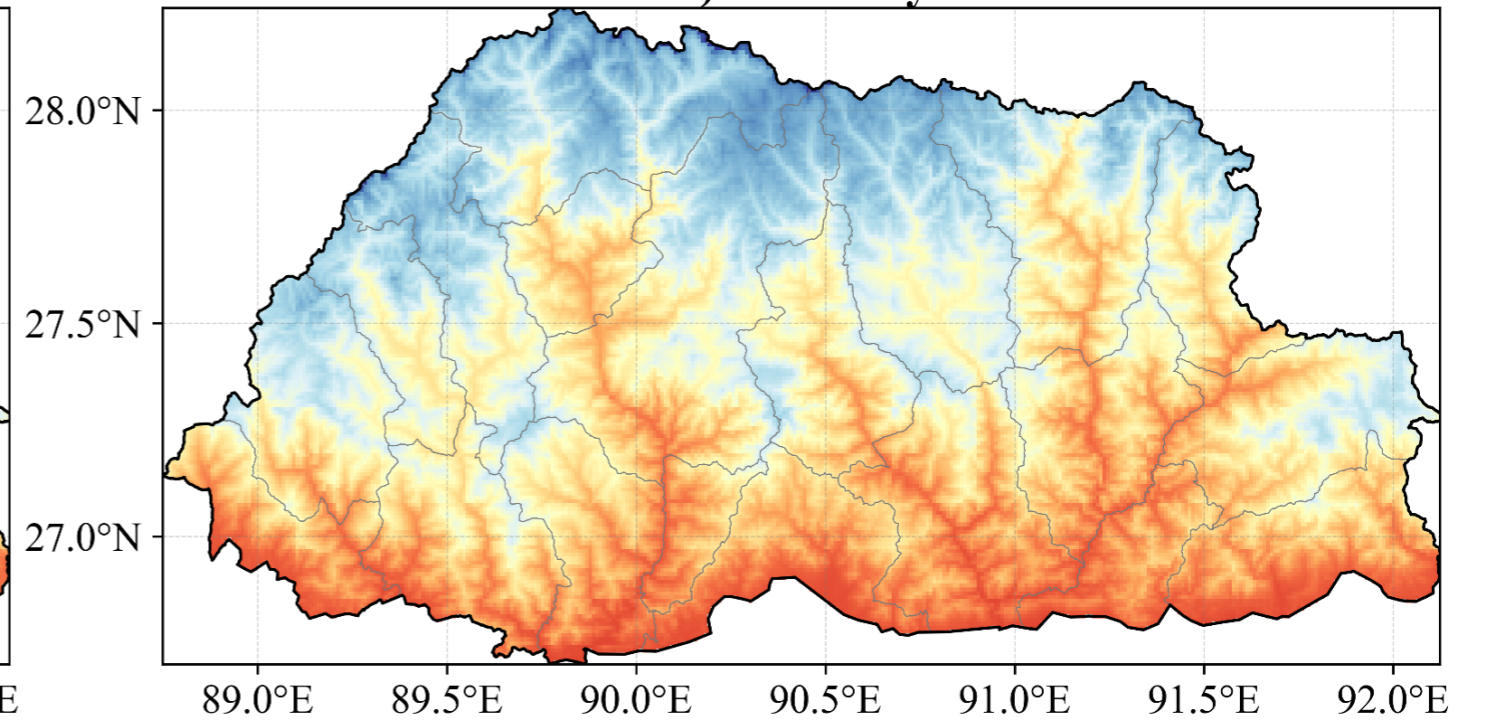
Monthly Mean Maximum Temperature

Bhutan | January–April | Baseline climatology | Unit: °C

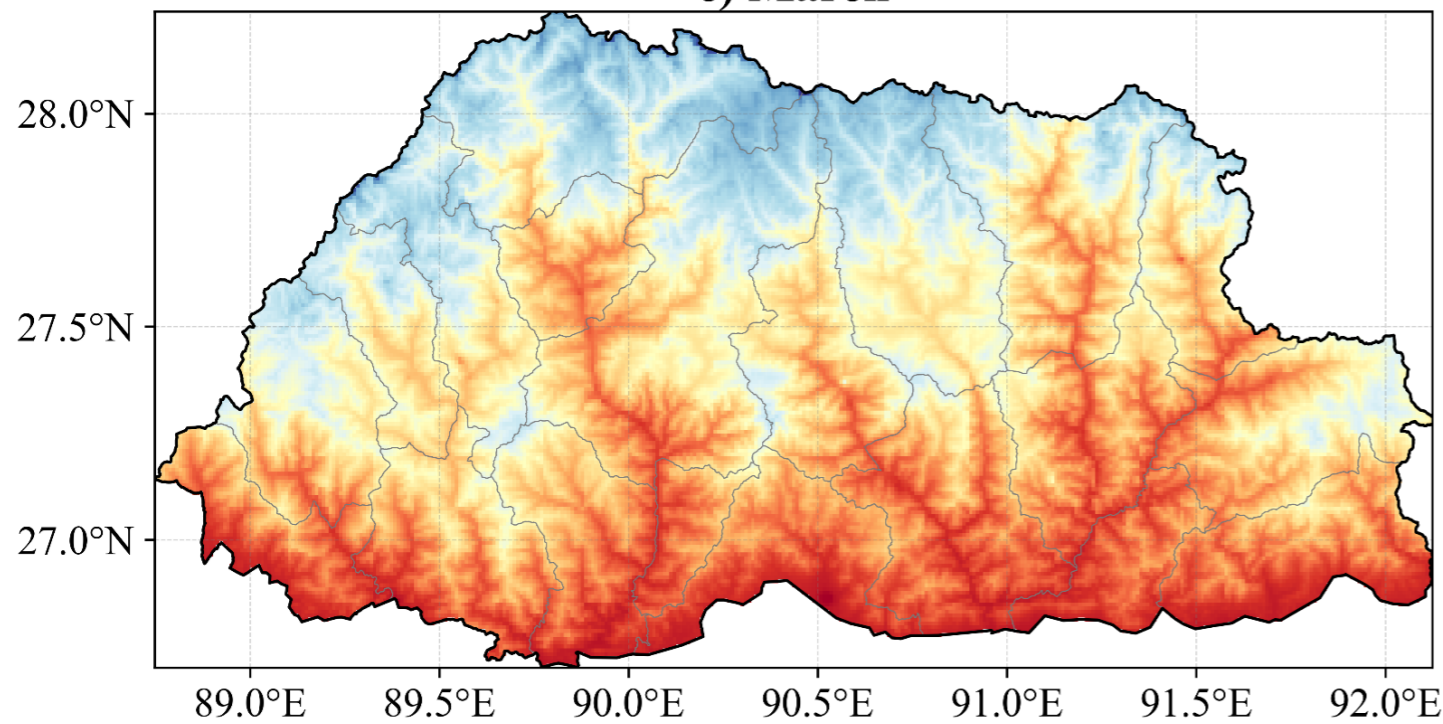
a) January



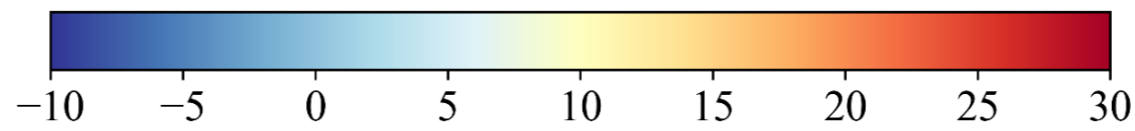
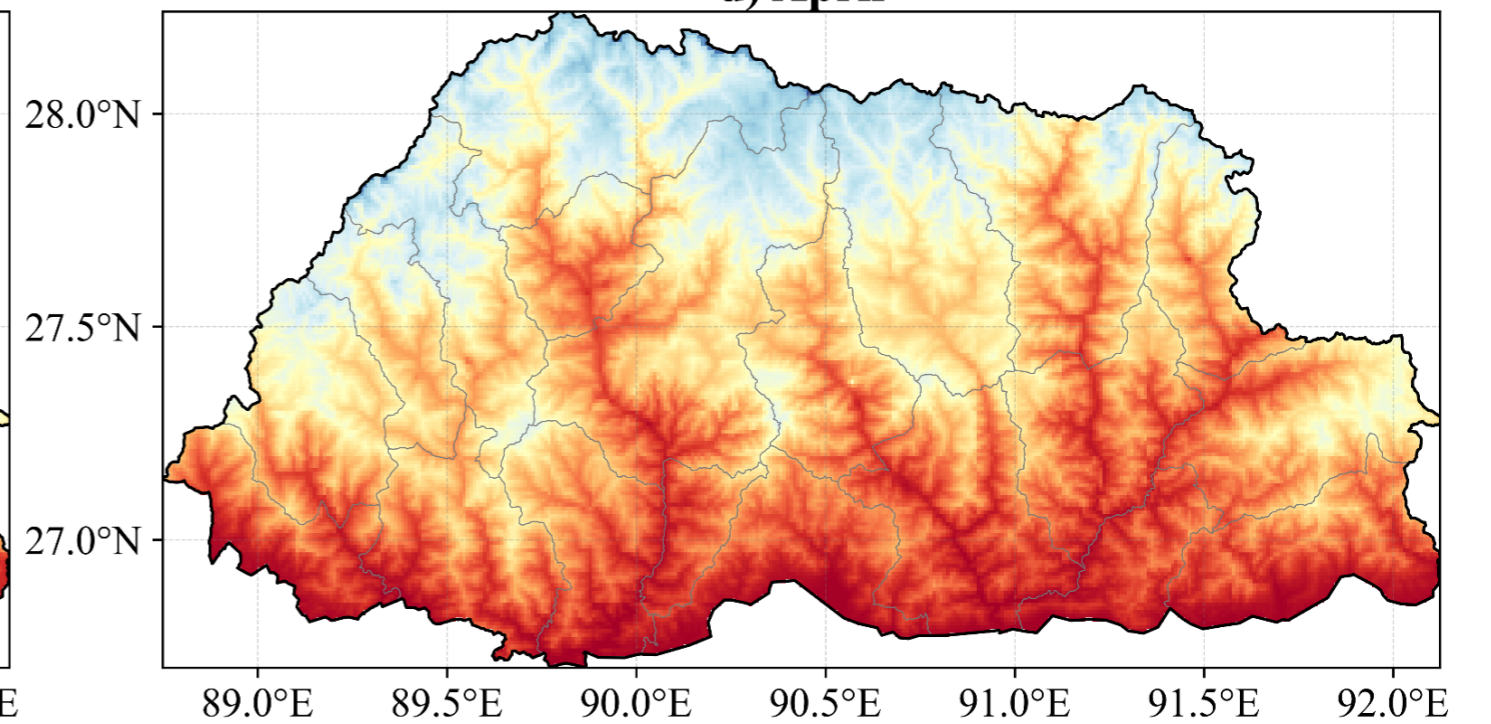
b) February



c) March



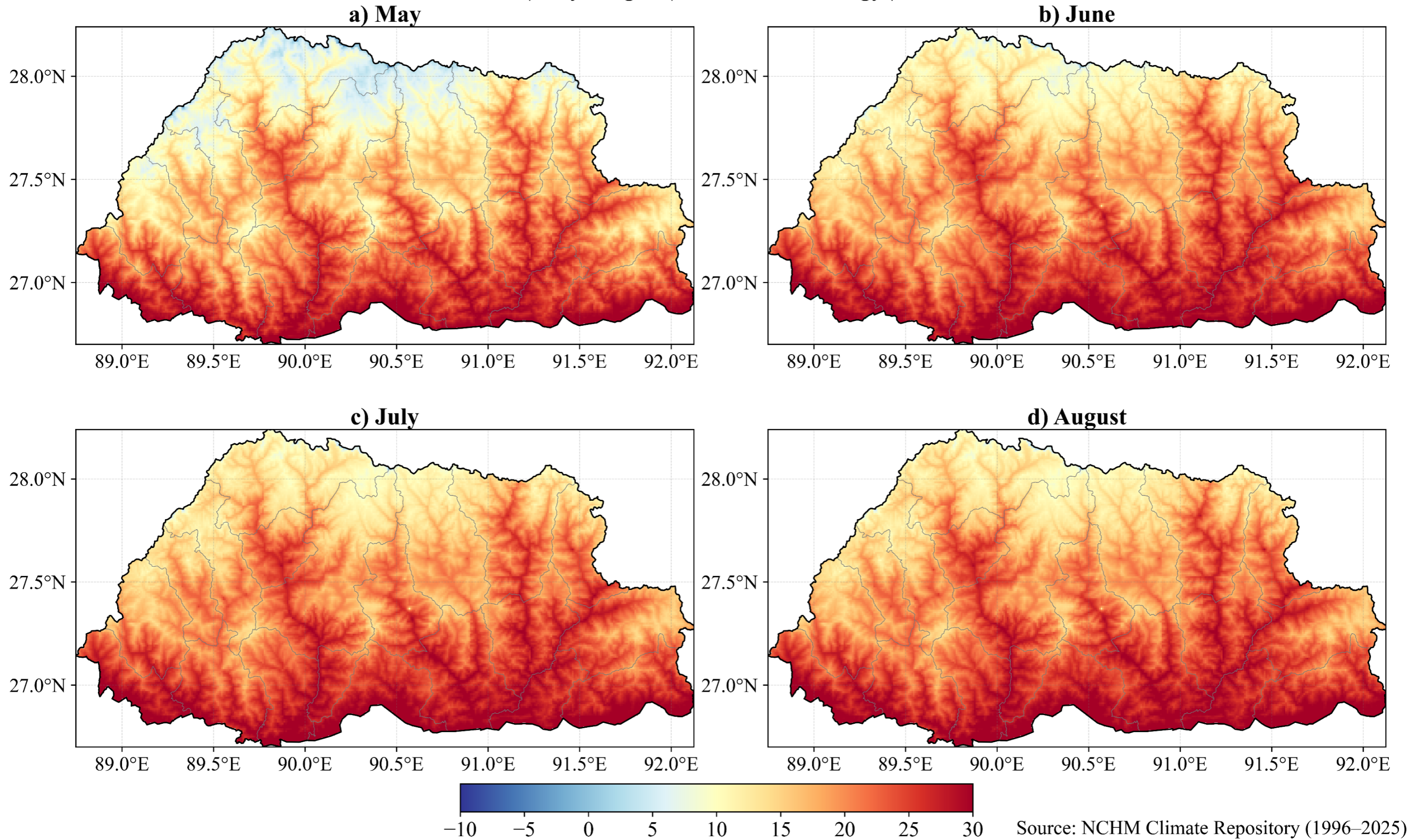
d) April



Source: NCHM Climate Repository (1996–2025)

Figure 6: Spatial distribution of monthly mean maximum temperature in Bhutan (1996- 2025)- a) January, b) February, c) March, d) April

Monthly Mean Maximum Temperature
Bhutan | May–August | Baseline climatology | Unit: °C



Source: NCHM Climate Repository (1996–2025)

Figure 7: Spatial distribution of monthly mean maximum temperature in Bhutan (1996- 2025)- a) May, b) June, c) July, d) August

Monthly Mean Maximum Temperature

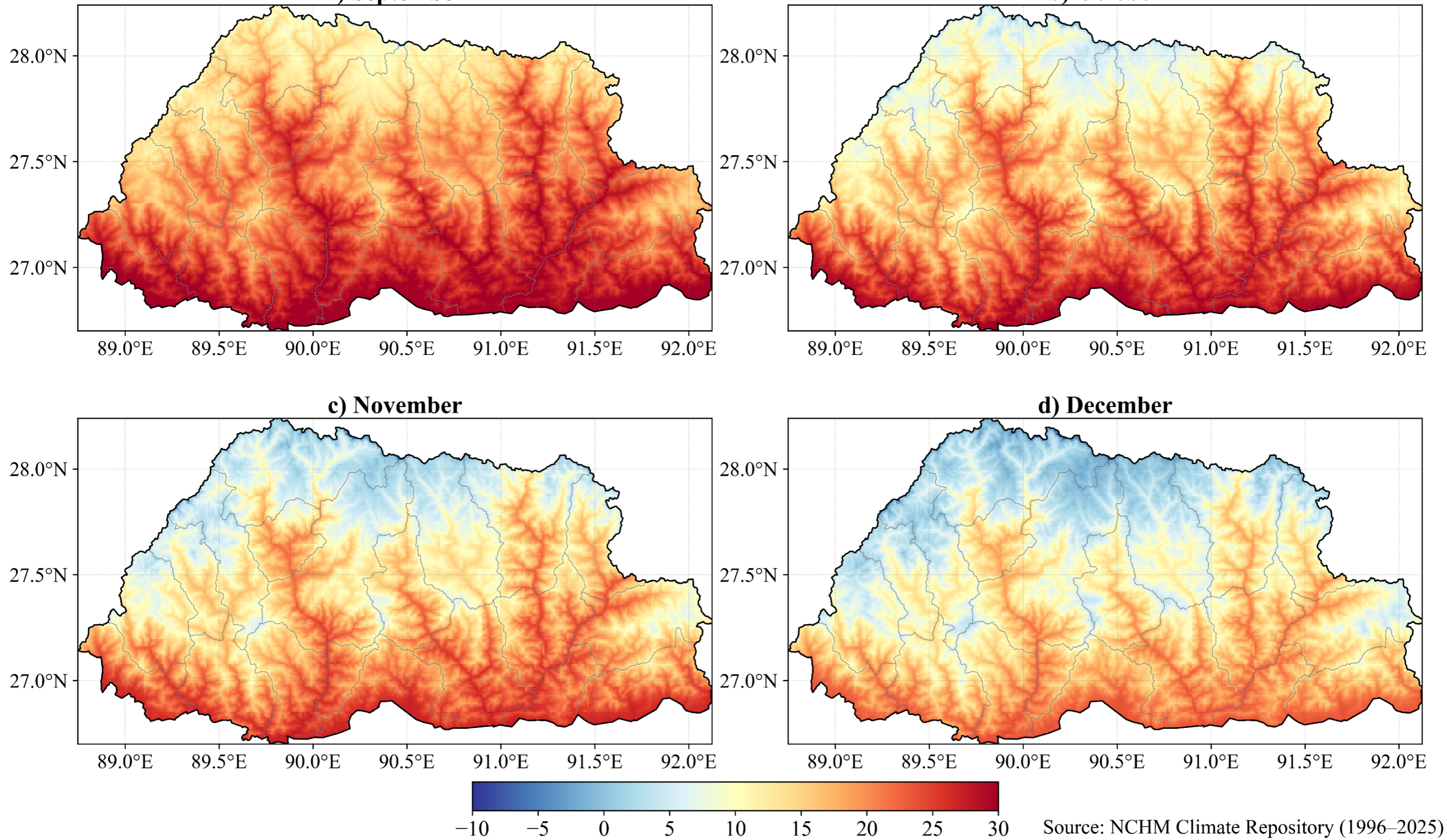
Bhutan | September–December | Baseline climatology | Unit: °C

a) September

b) October

c) November

d) December



Source: NCHM Climate Repository (1996–2025)

Figure 8: Spatial distribution of monthly mean maximum temperature in Bhutan (1996– 2025)- a) September, b) October, c) November, d) December

Monthly Mean Minimum Temperature
Bhutan | January–April | Baseline climatology | Unit: °C

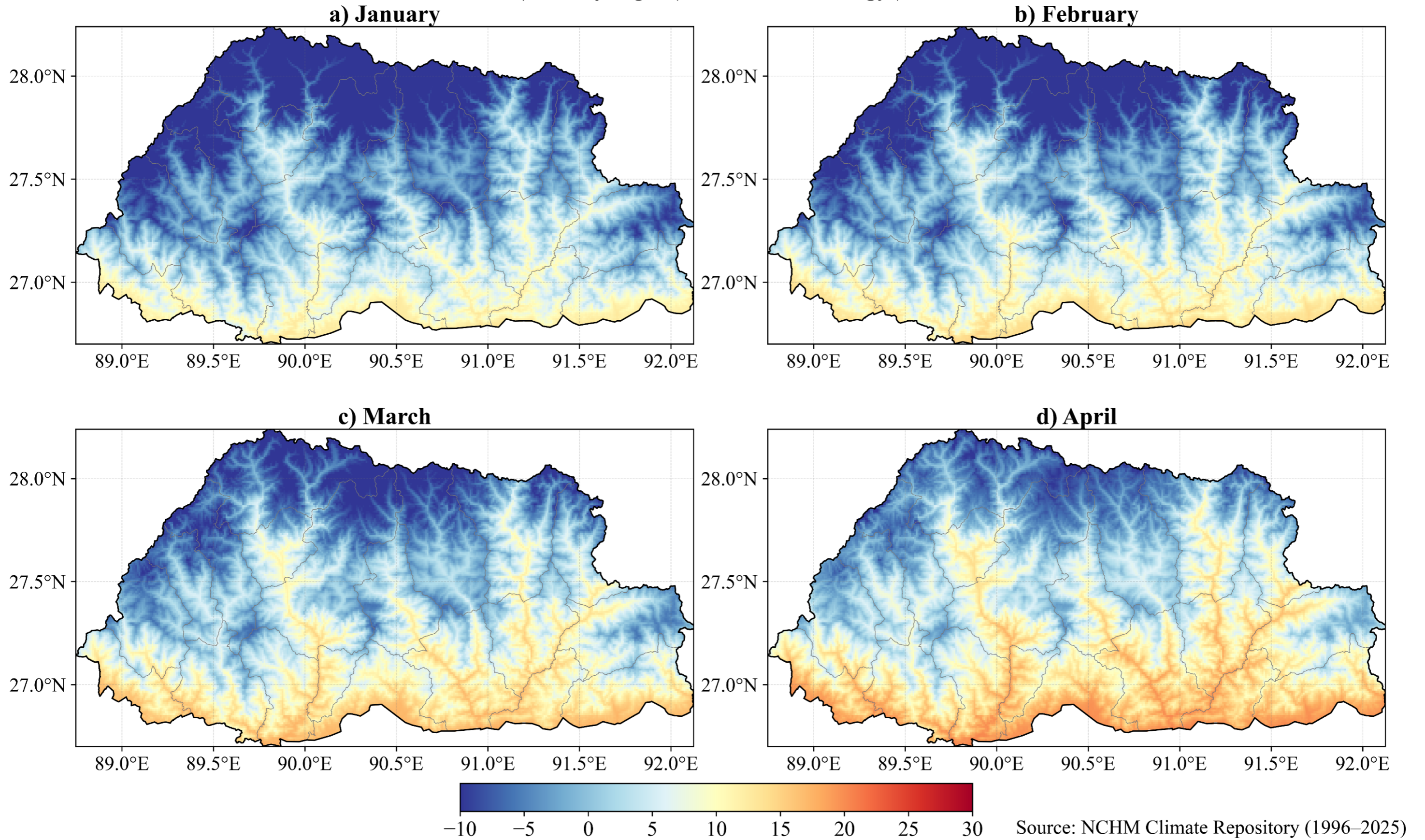
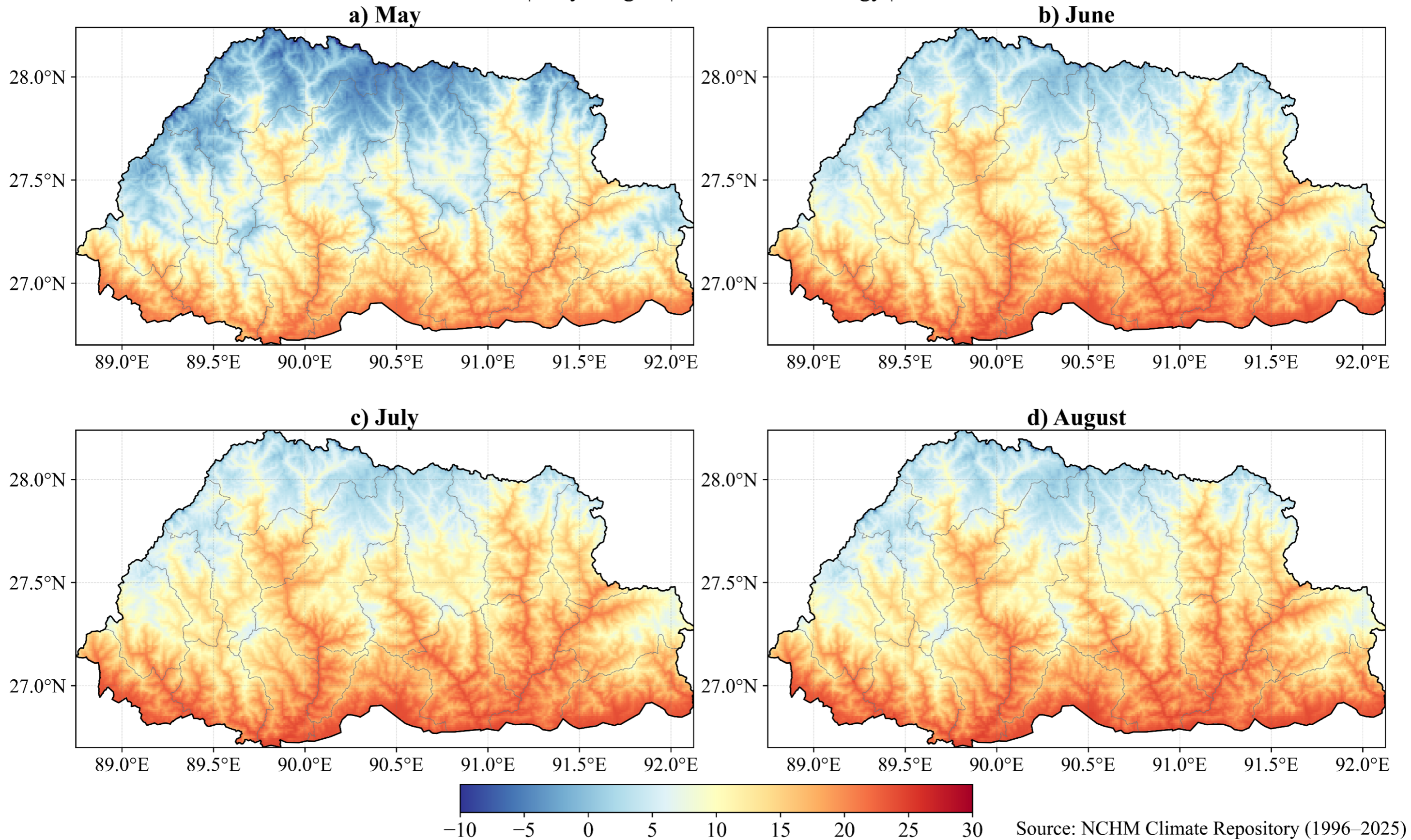


Figure 9: Spatial distribution of monthly mean minimum temperature in Bhutan (1996- 2025)- a) January, b) February, c) March, d) April

Monthly Mean Minimum Temperature

Bhutan | May–August | Baseline climatology | Unit: °C



Source: NCHM Climate Repository (1996–2025)

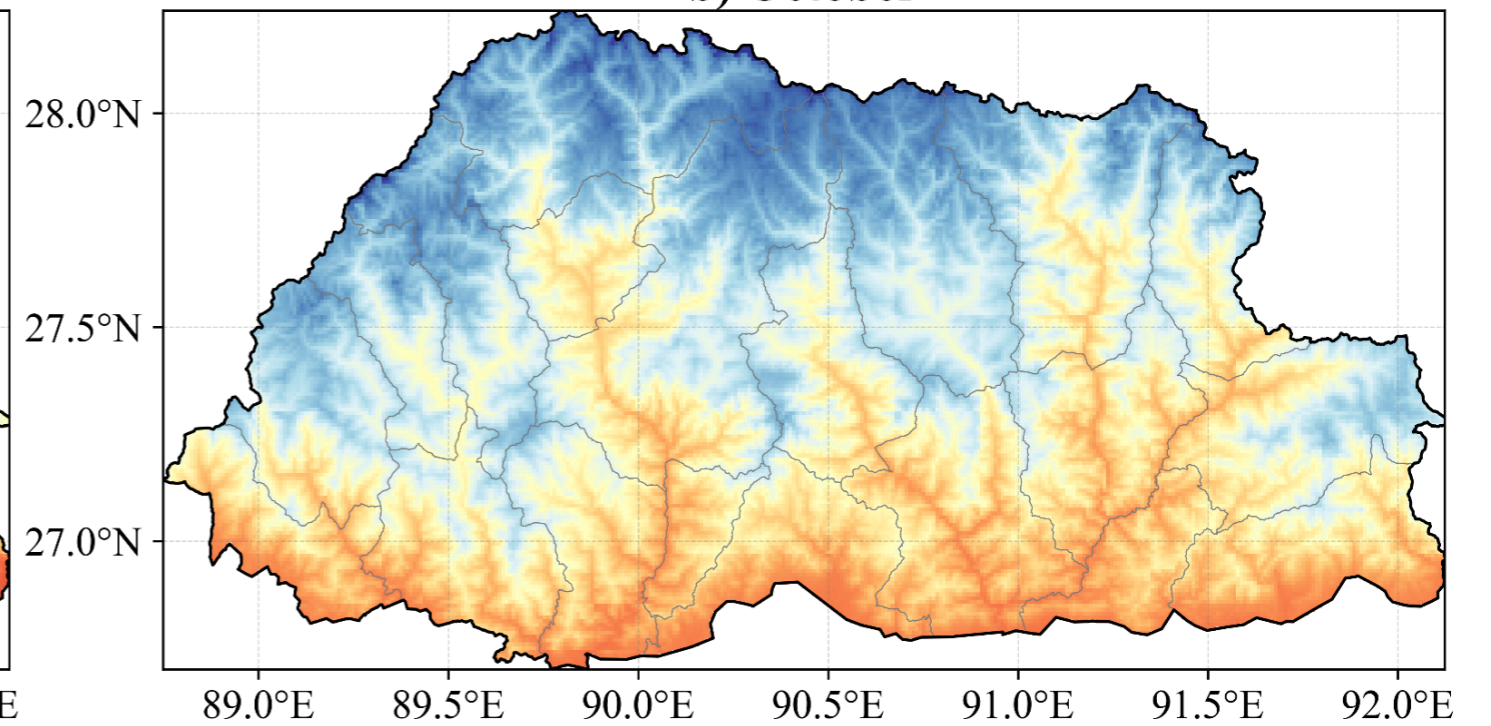
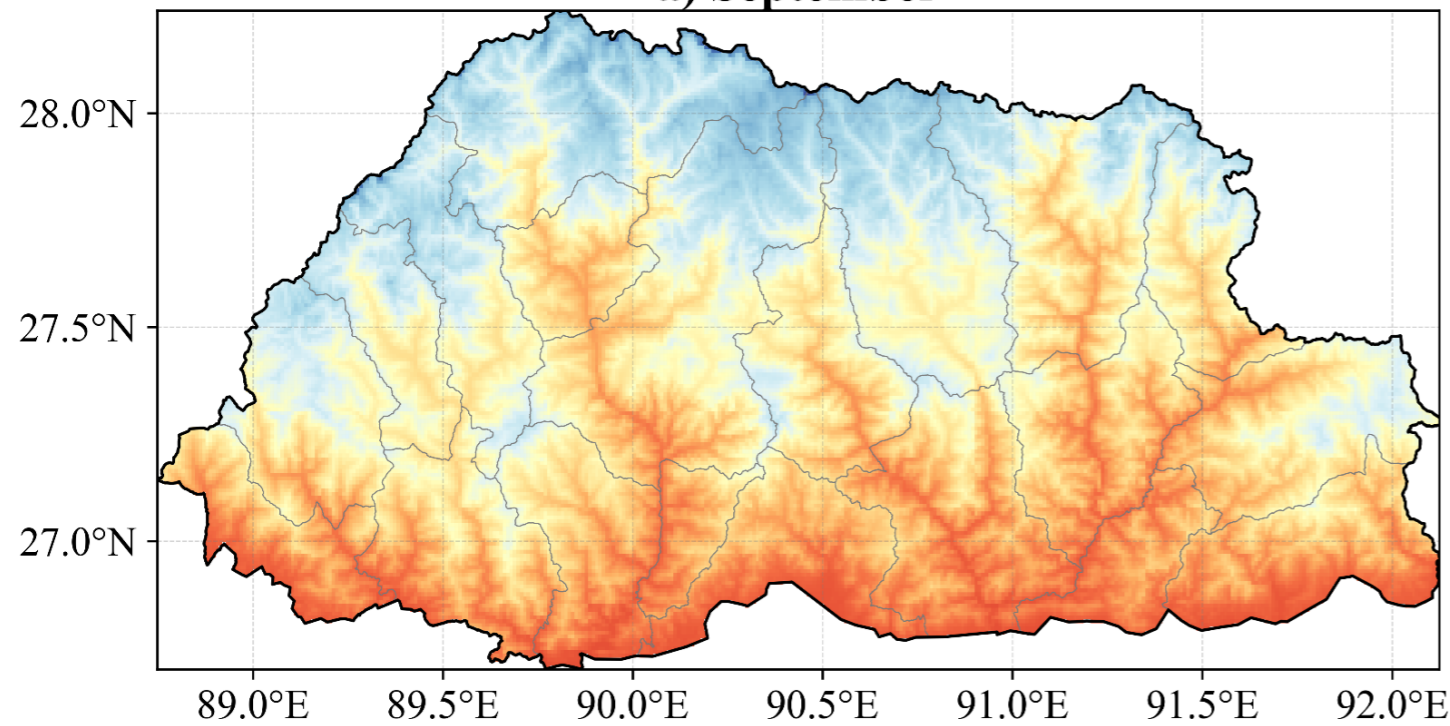
Figure 10: Spatial distribution of monthly mean minimum temperature in Bhutan (1996- 2025)- a) May, b) June, c) July, d) August

Monthly Mean Minimum Temperature

Bhutan | September–December | Baseline climatology | Unit: °C

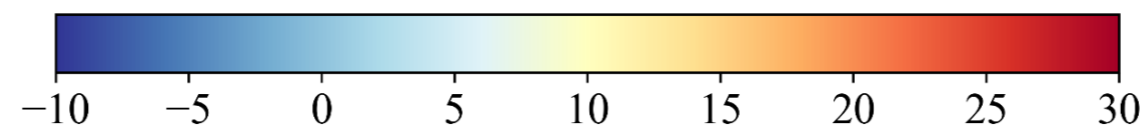
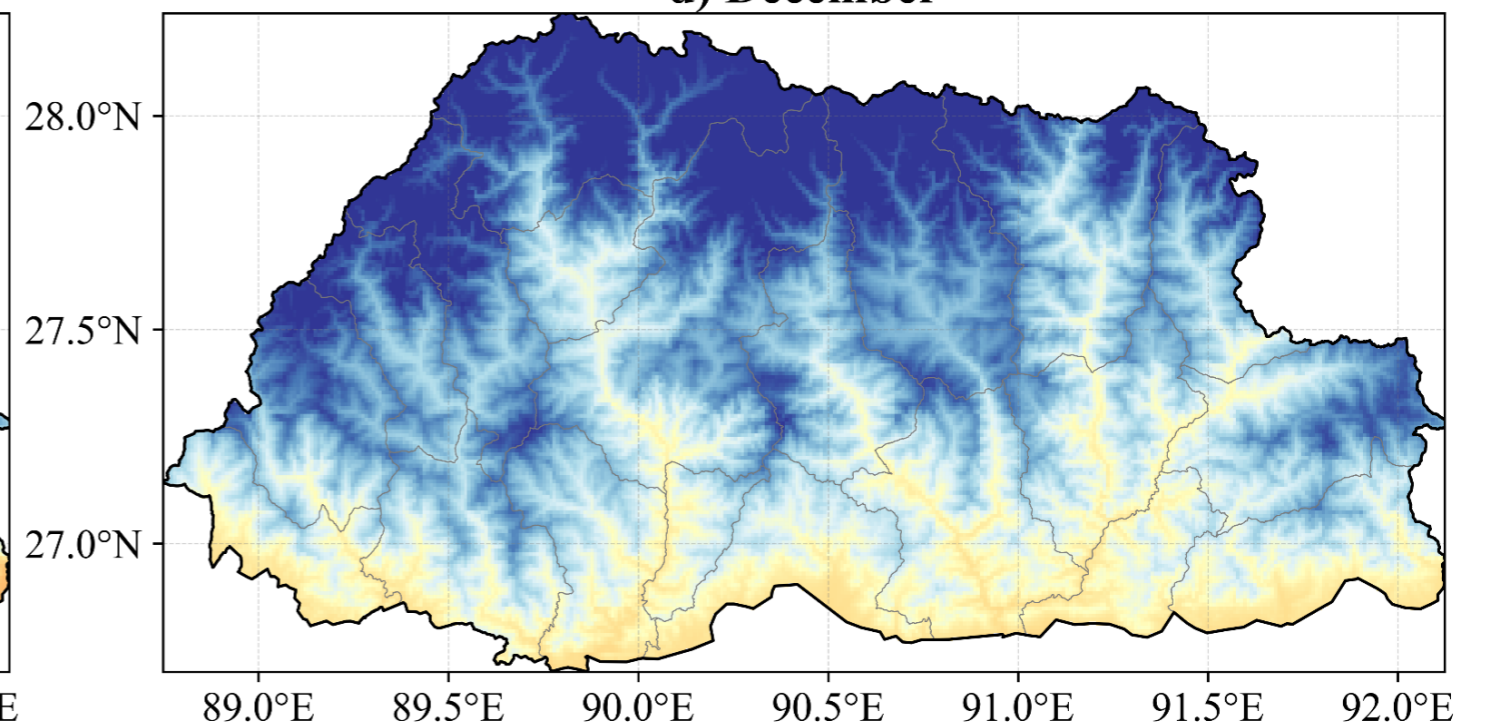
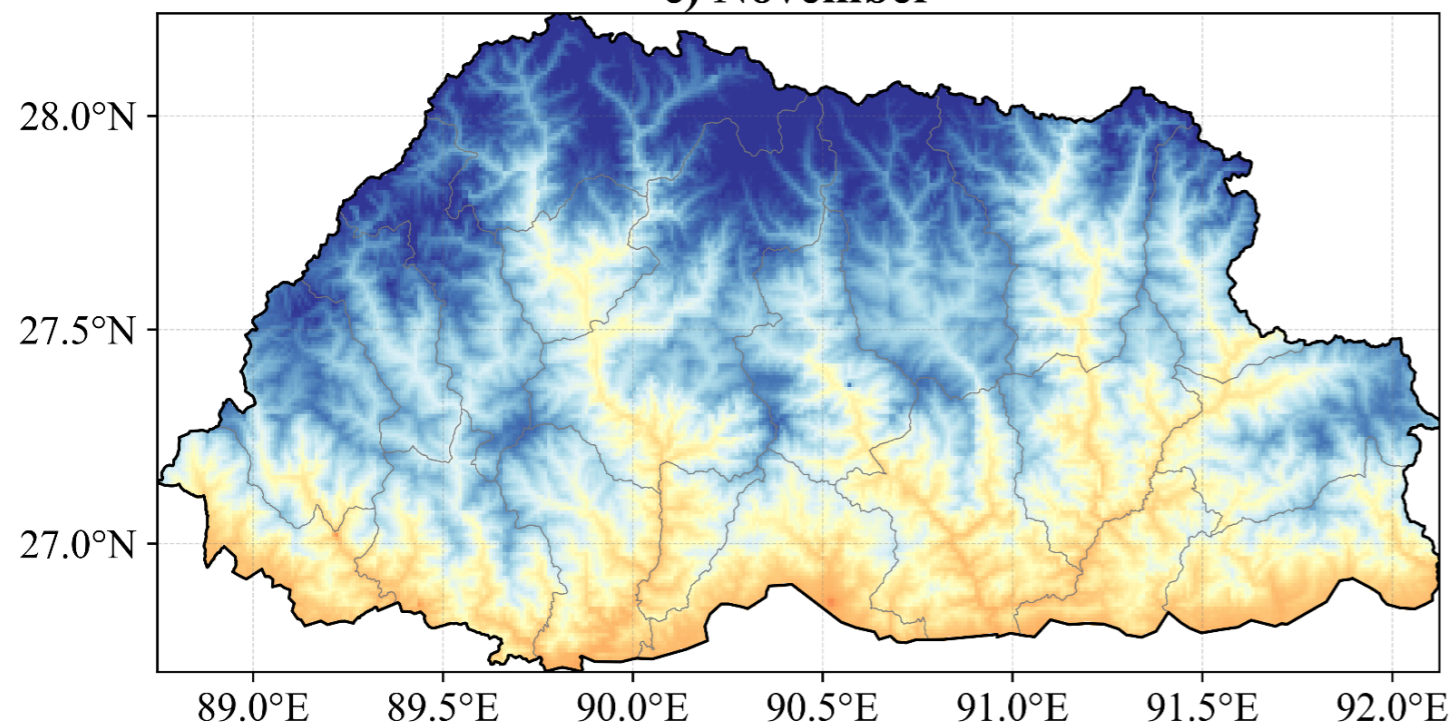
a) September

b) October



c) November

d) December



Source: NCHM Climate Repository (1996–2025)

Figure 11: Spatial distribution of monthly mean minimum temperature in Bhutan (1996- 2025)- a) September, b) October, c) November, d) December

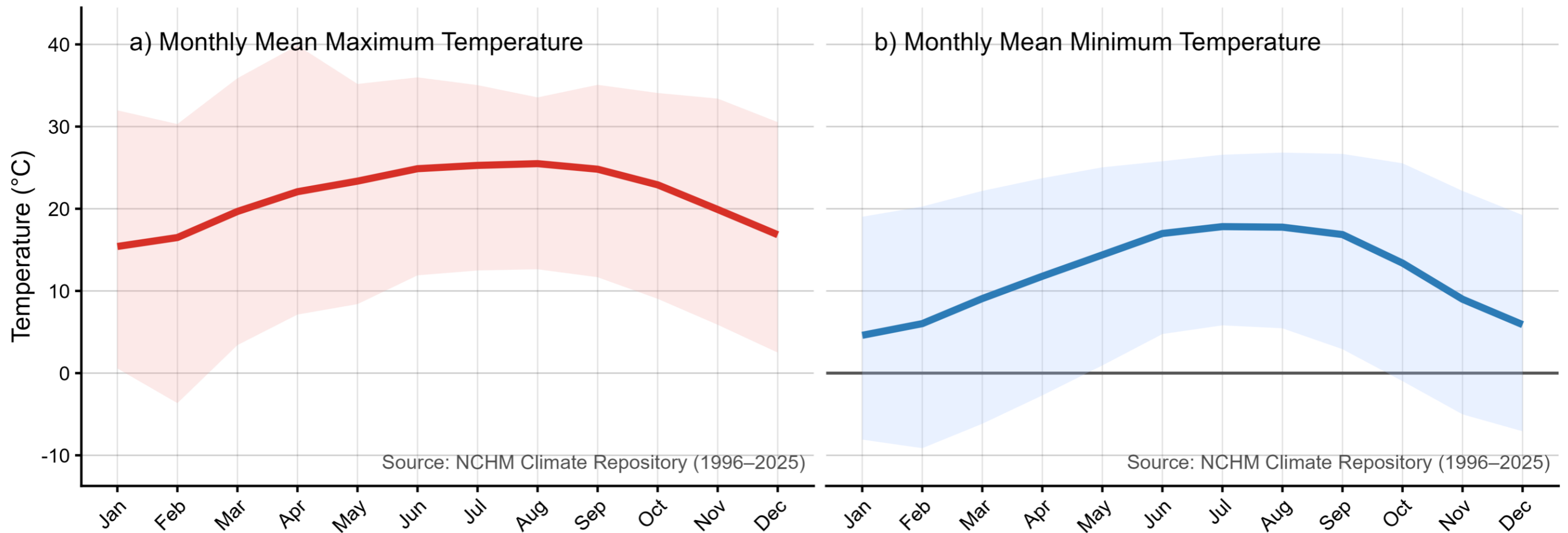


Figure 12: Monthly mean maximum and minimum temperature in Bhutan (1996- 2025) showing the seasonal cycle of temperature

The annual cycle of monthly mean maximum and minimum temperature in the country from 1996- 2025 clearly highlights the seasonal variability of temperature throughout the year. Both mean maximum and minimum temperature start to rise from January (around 15°C and 5°C for maximum and minimum temperature respectively) and peaks in the summer months of July and August (upto 25°C and 19 °C for maximum and minimum temperature respectively). The temperatures start to decline towards the winter months.

The shaded areas show the range of temperature variability, showing temperatures are generally more variable during the winter months compared to summer. The seasonal cycle indicated the country’s mountainous climate and influence of summer monsoon season.

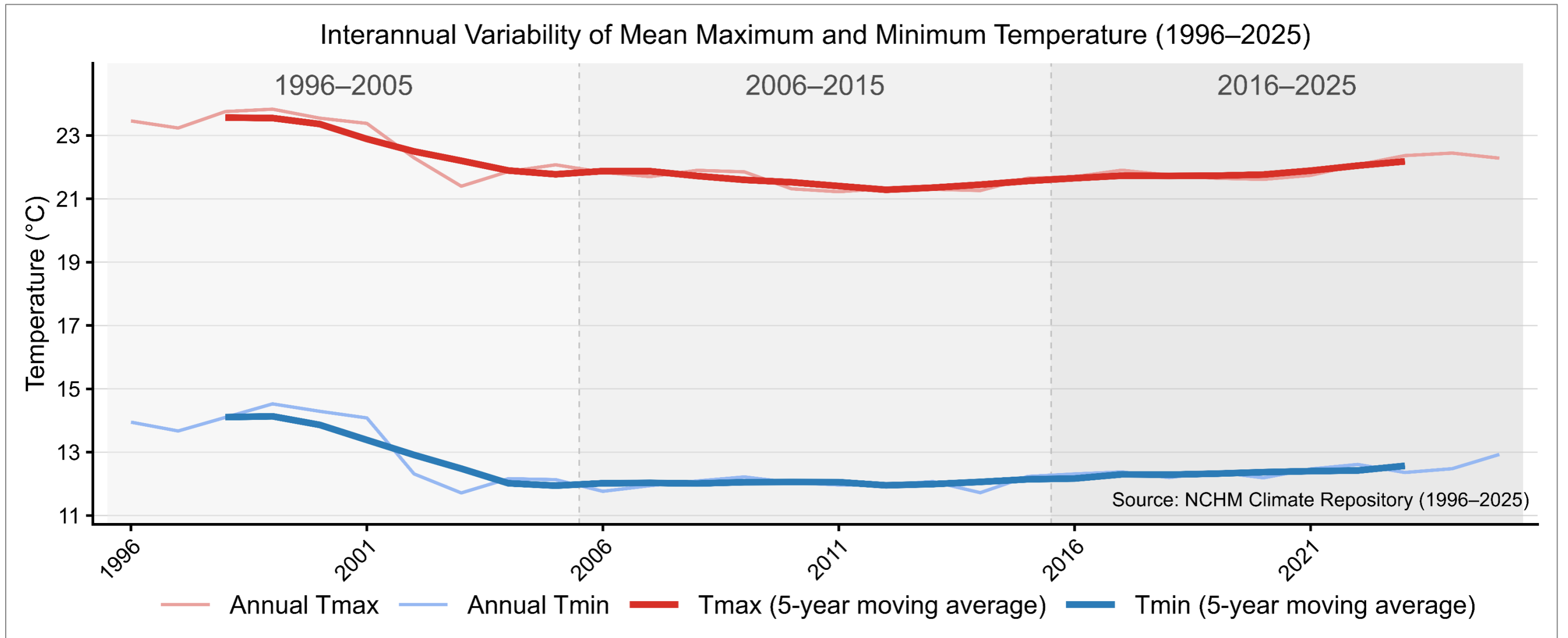


Figure 13: Interannual variability of mean maximum and minimum temperature (1996- 2025)

The annual mean maximum temperatures during the late 1990s and 2000s were relatively high, generally around 23.0- 23.5°C, while mean minimum temperatures ranged between 13.5- 14.5°C. A gradual decline in both temperatures are observed during the mid- 2000s to early 2010s, with mean maximum temperatures dropping to around 21.5- 22.0 °C and minimum temperatures to approximately 11.5- 12.0 °C. In the most recent decade from 2016 to 2025, temperatures show an increasing trend, with mean maximum temperatures increasing to around 22.0- 22.5 °C and mean minimum temperatures rising to about 12.5- 13.0 °C.

The 5 year moving averages indicate a moderate interannual variability with a gradual warming tendency in recent years, particularly after the mid- 2010s.

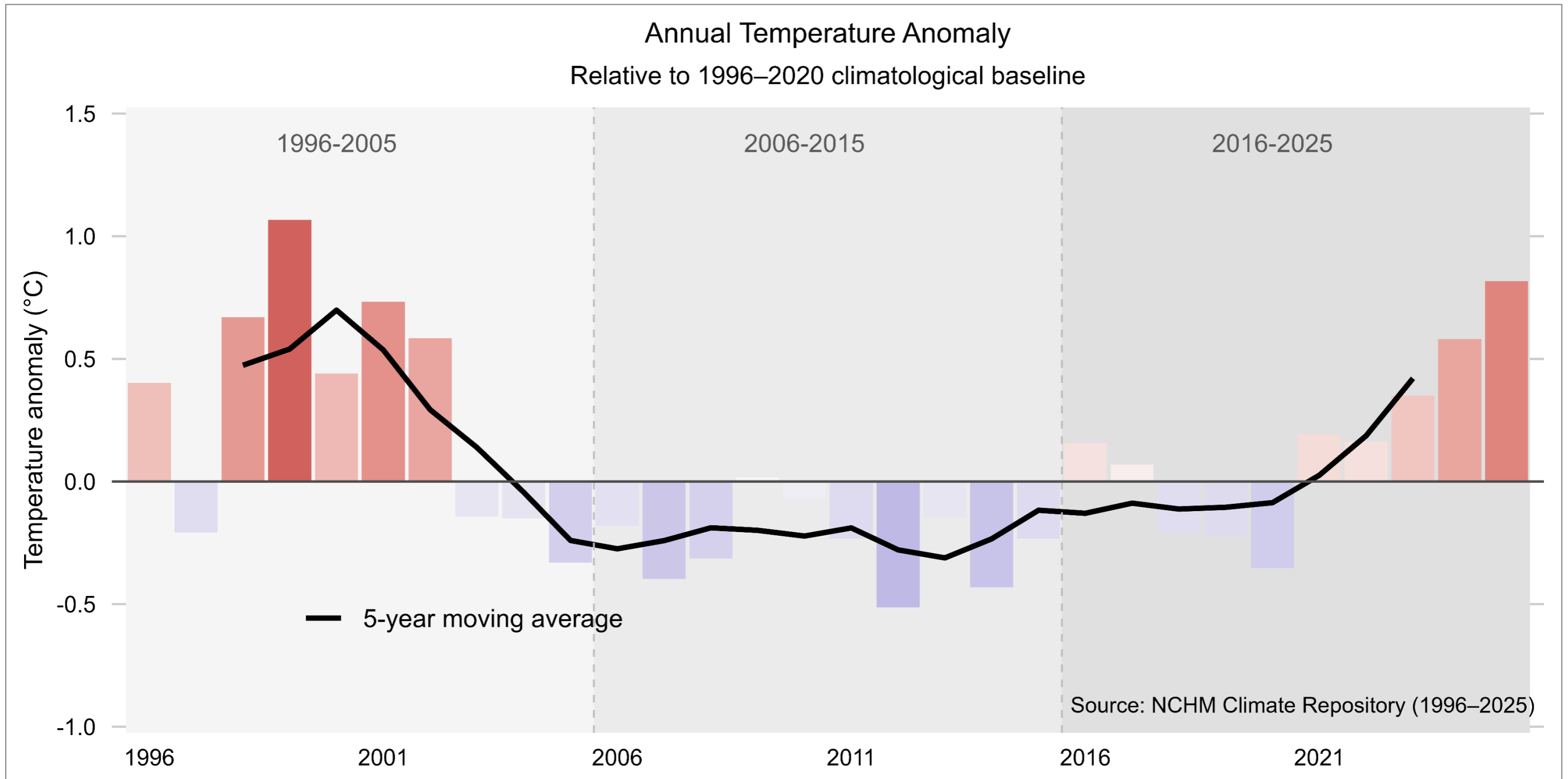


Figure 14: Annual temperature anomaly

The annual temperature anomaly was computed relative to baseline 1996- 2020, showing clear year- to- year variability in mean temperature over the years. Warmer than average years are more seen at the late 1990s and towards the later third decade. Cooler conditions are noticed from the mid- 2000s to around 2020. The black line showing the 5- year moving average highlights the pattern clearly, showing gradual recovery from the negative anomalies to a positive shift in the recent years. It indicates substantial interannual variability together with an emerging warming tendency in the later decade.

Relationship between Elevation and Temperature

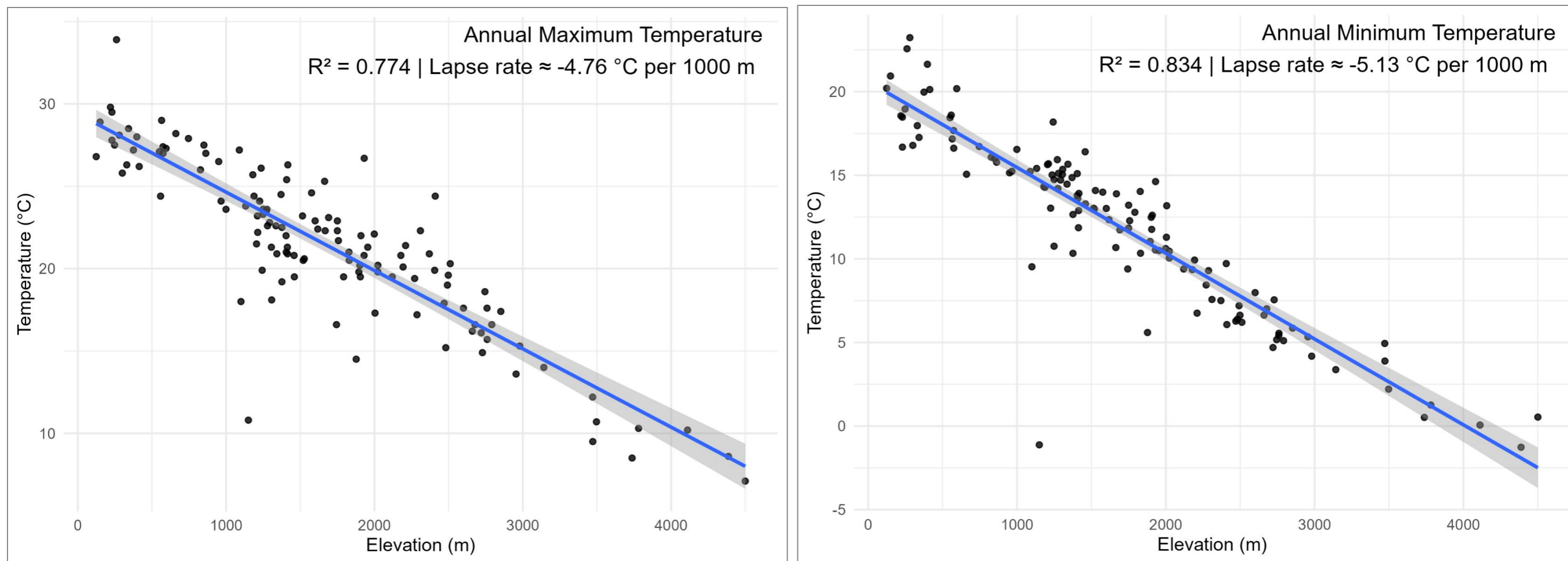


Figure 15: Relationship between elevation and annual maximum and minimum temperature

The scatter plots showing the relationship between elevation and annual maximum and minimum temperatures indicate a clear negative relationship between elevation and temperature, meaning that temperature decreases with the increase in elevation. The fitted regression lines highlight this trend for both maximum and minimum temperatures. The lapse rate is approximately -4.76°C per 1000 m, with a strong correlation of 0.774 for daytime temperatures. Whereas lapse rate of approximately -5.13°C per 1000 m with better correlation of 0.834 is indicated for nighttime temperatures.

This relationship of temperature with elevation further supports the influence of the country's elevation gradient on its temperature distribution, with warmer conditions towards the south and colder temperatures to the north. The results are supported further by the relationship between seasonal temperatures, as shown below.

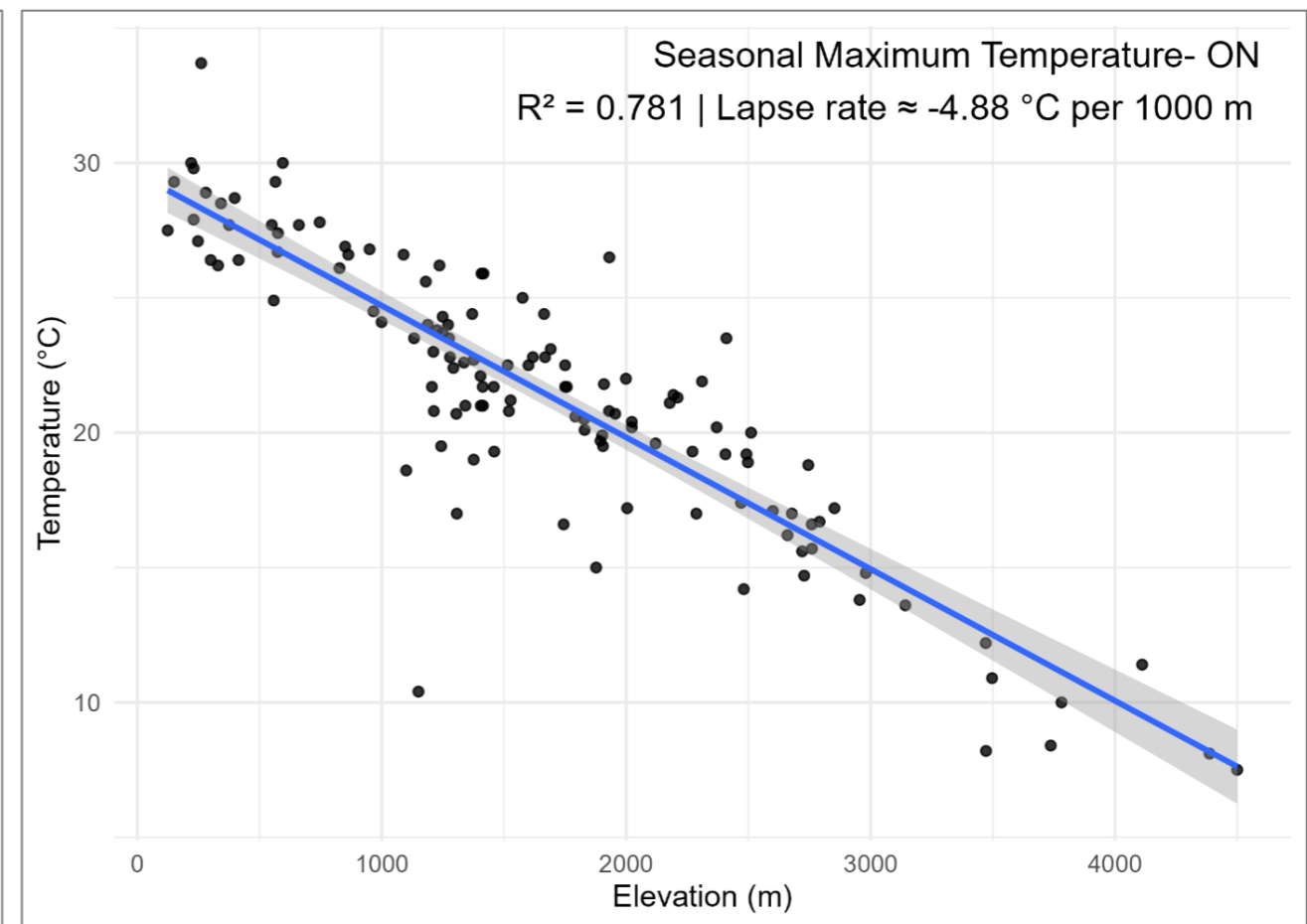
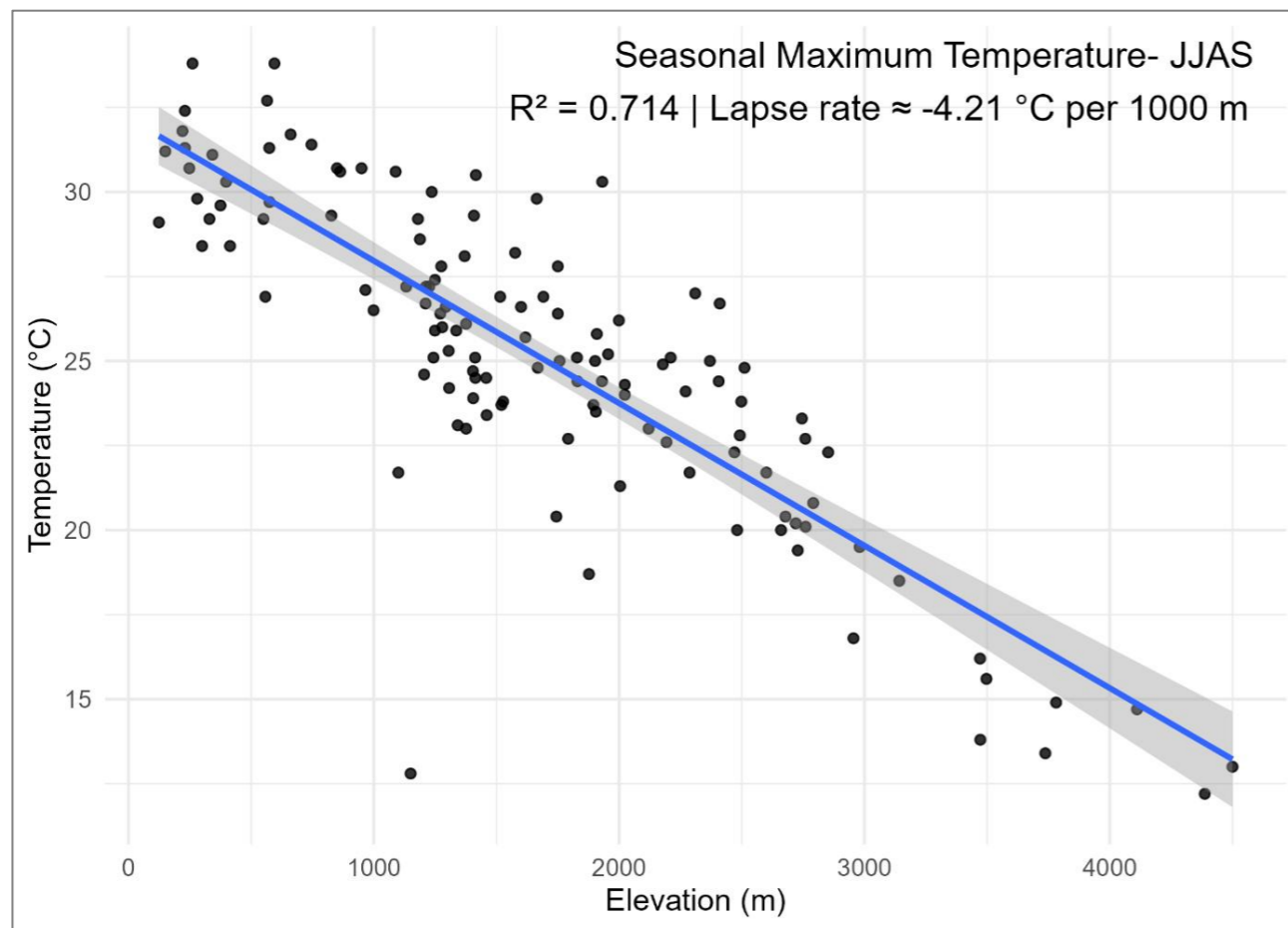
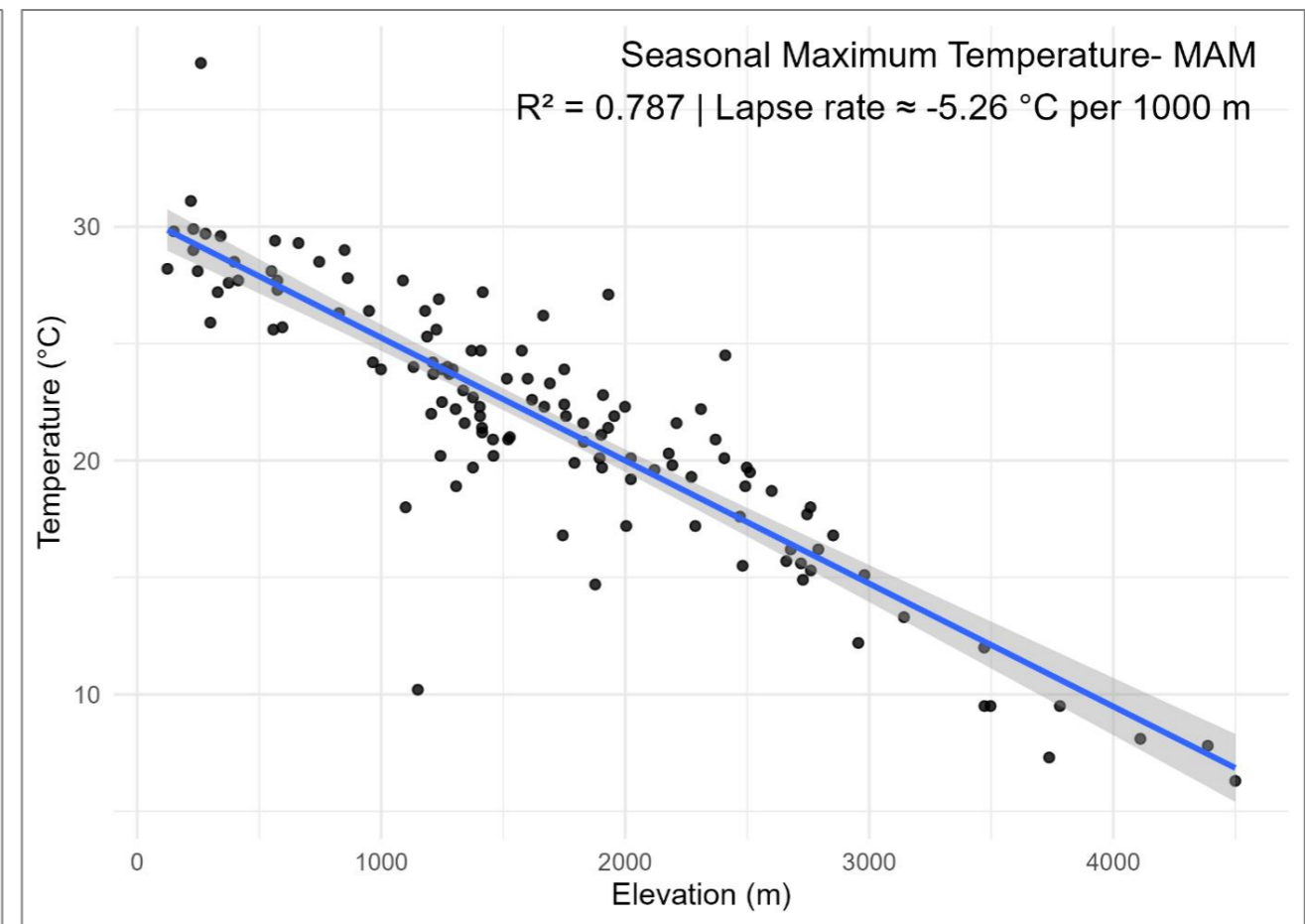
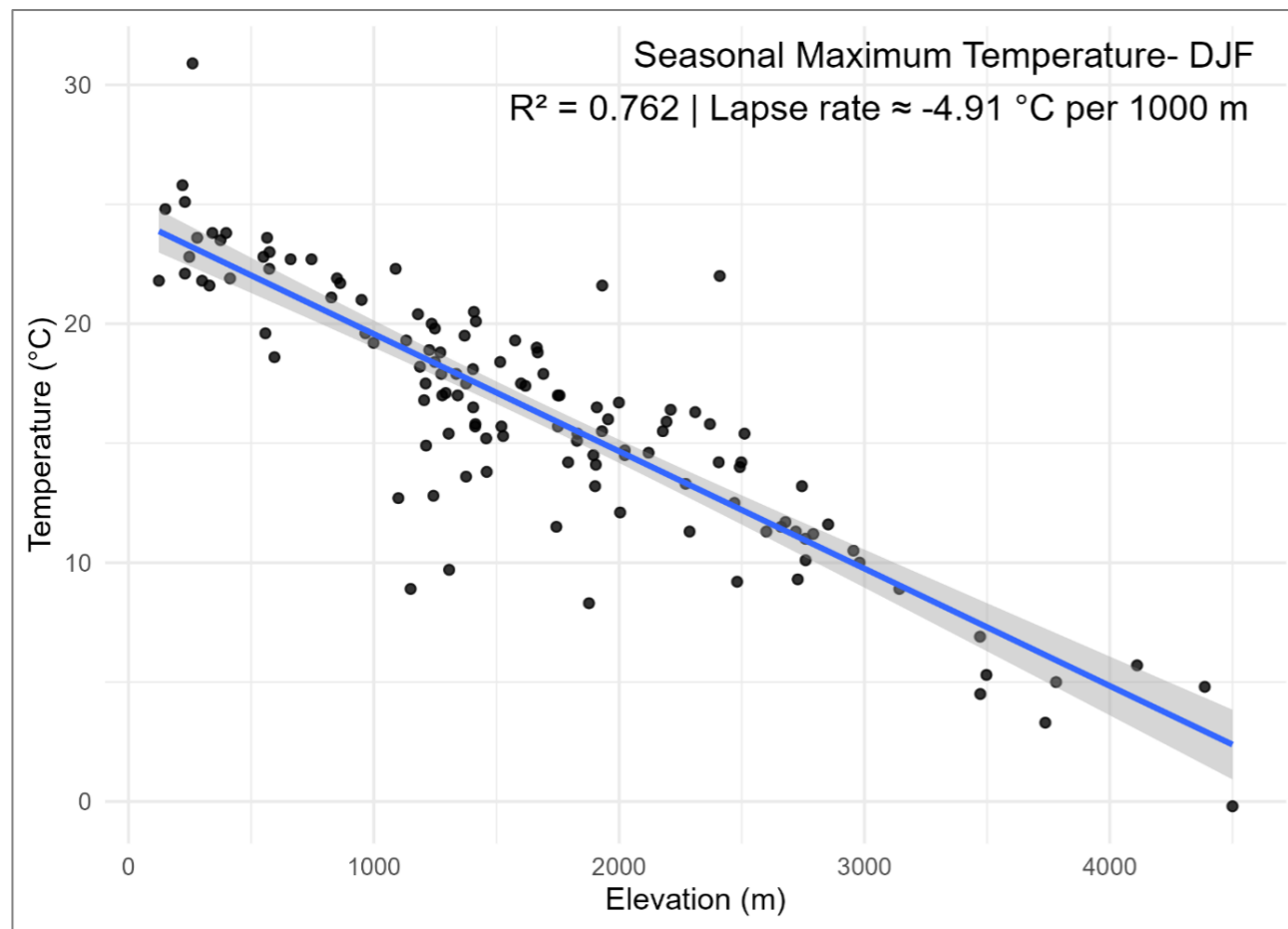


Figure 16: Relationship between elevation and seasonal maximum temperature

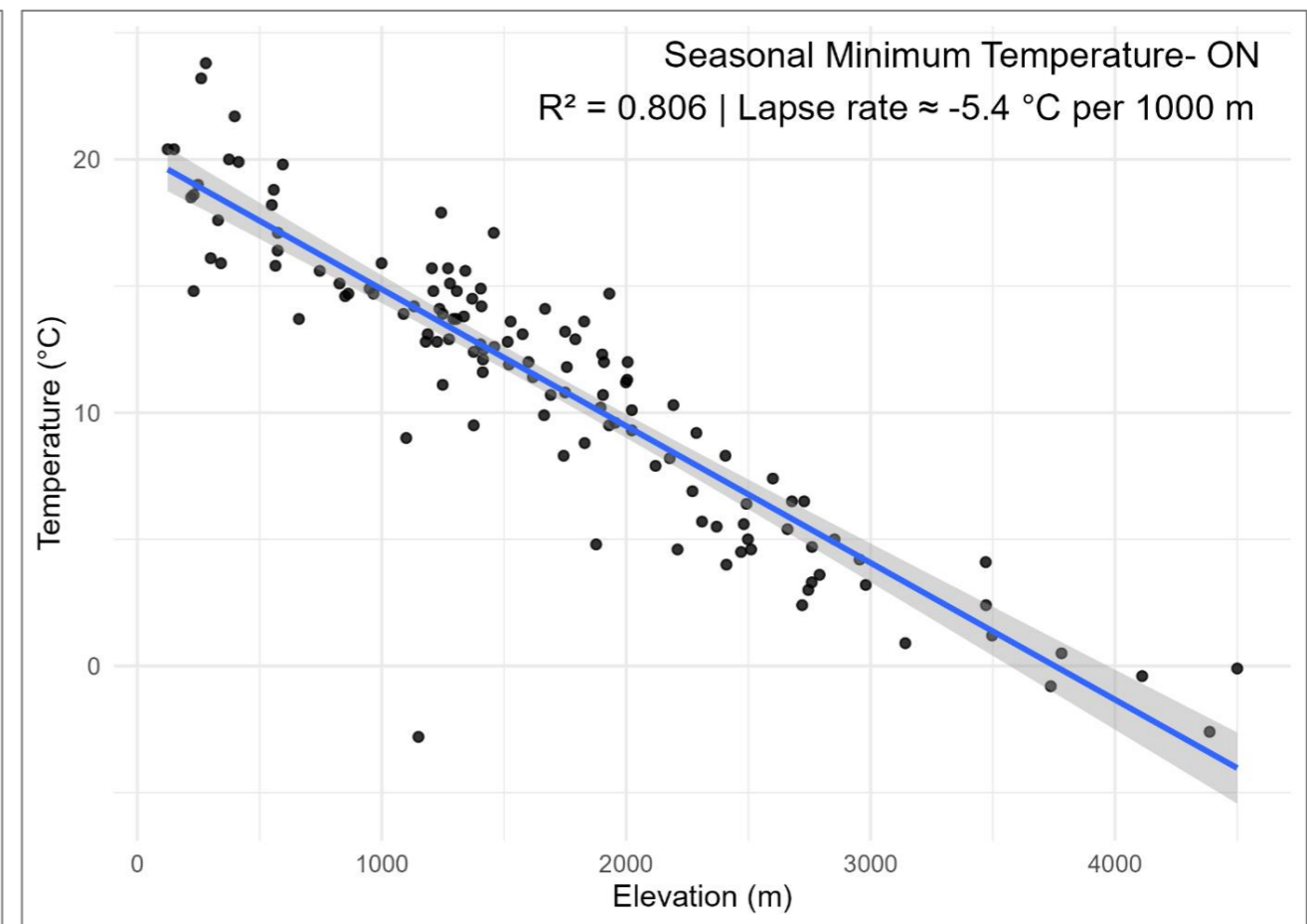
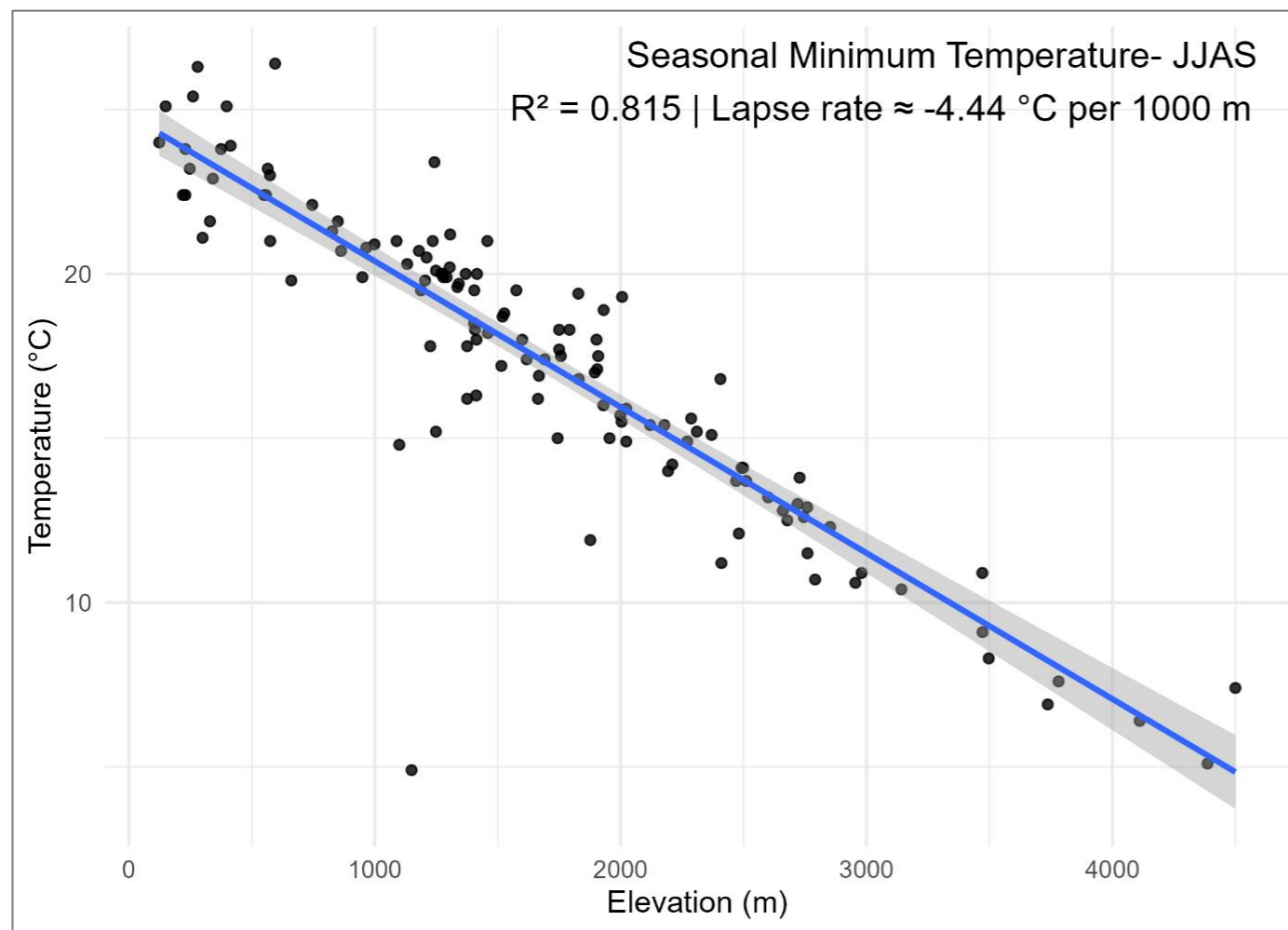
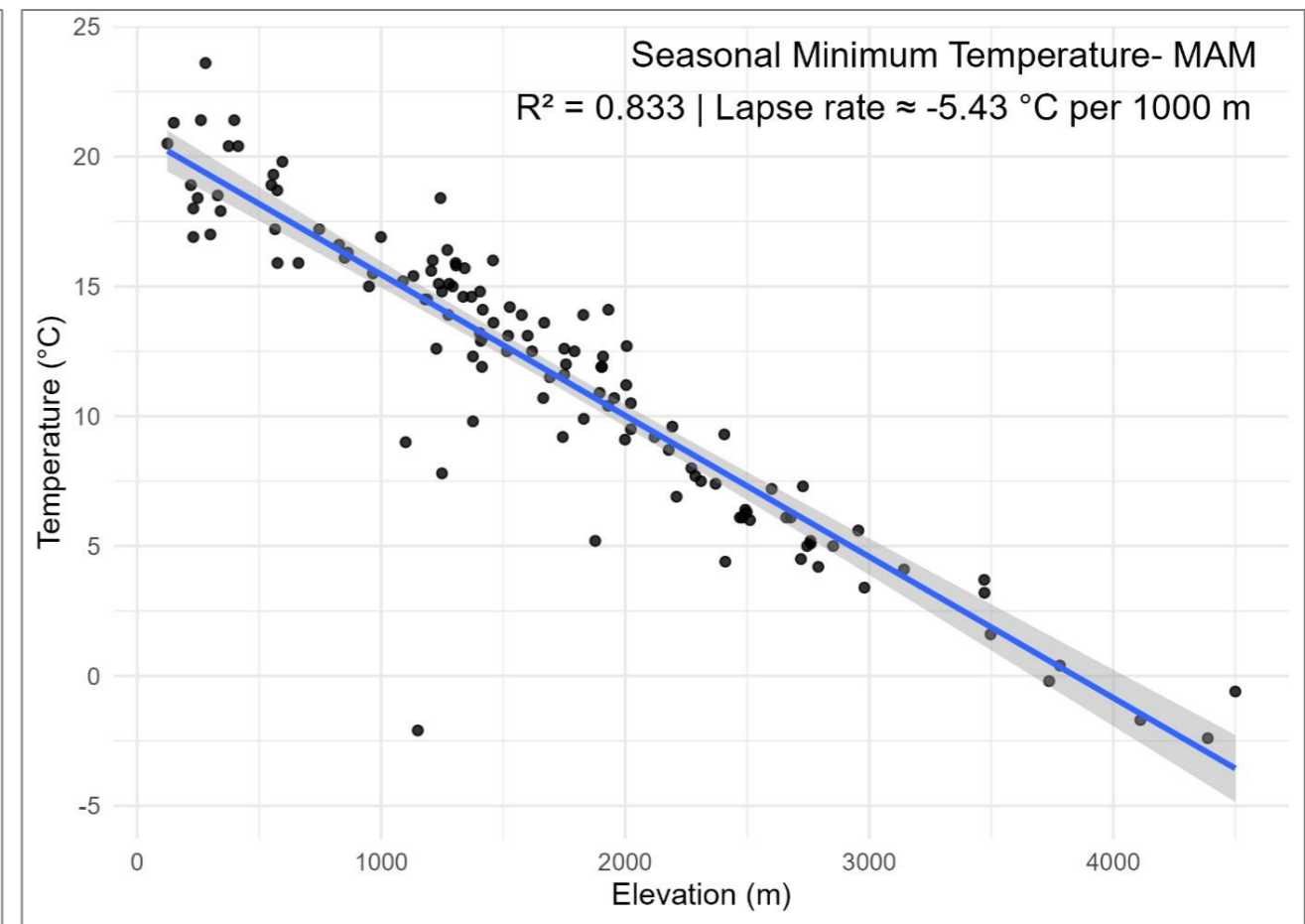
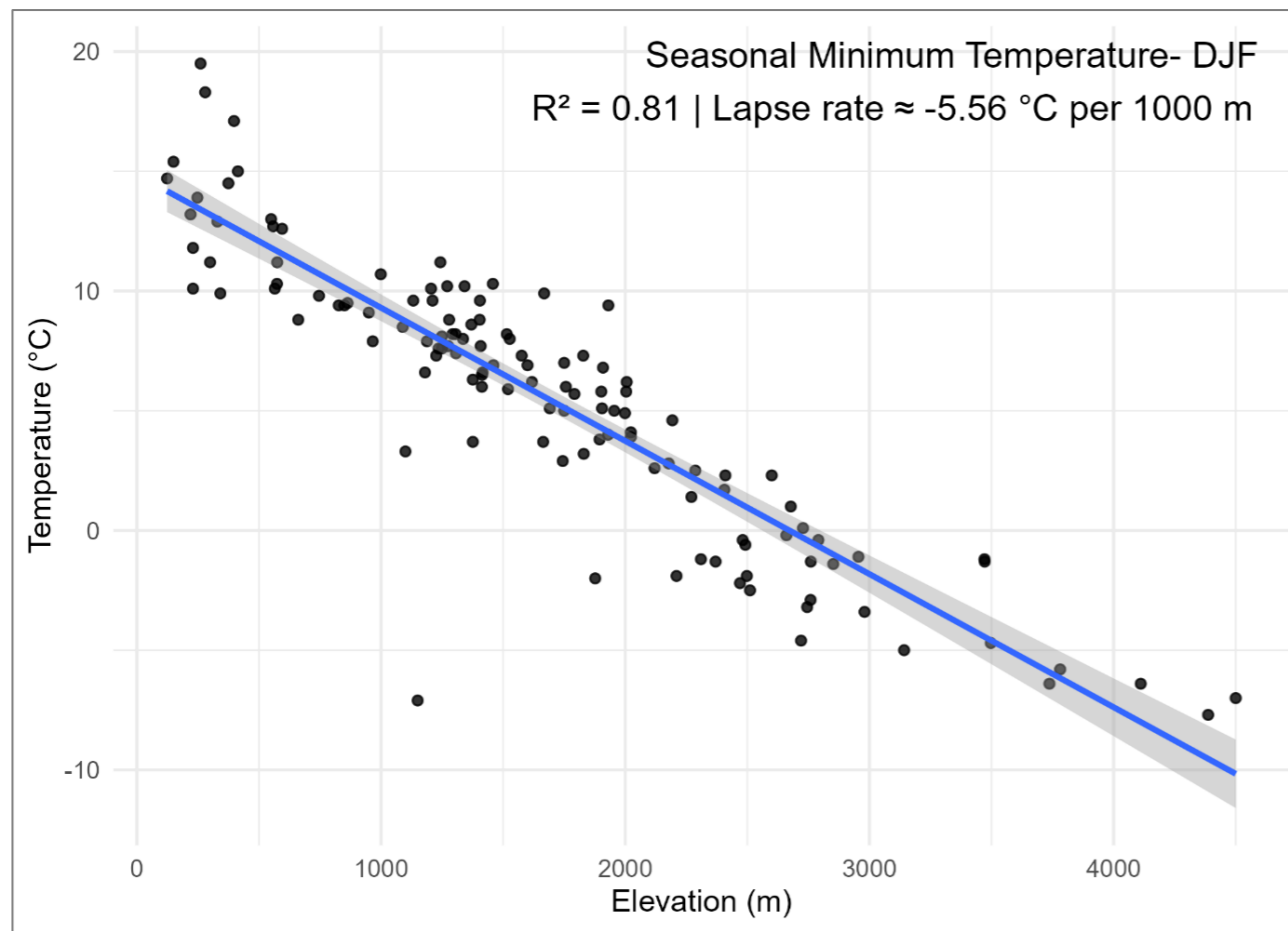


Figure 17: Relationship between elevation and seasonal minimum temperature

Rainfall Climatology

Annual Total Mean Rainfall
Bhutan | Baseline climatology | Unit: mm

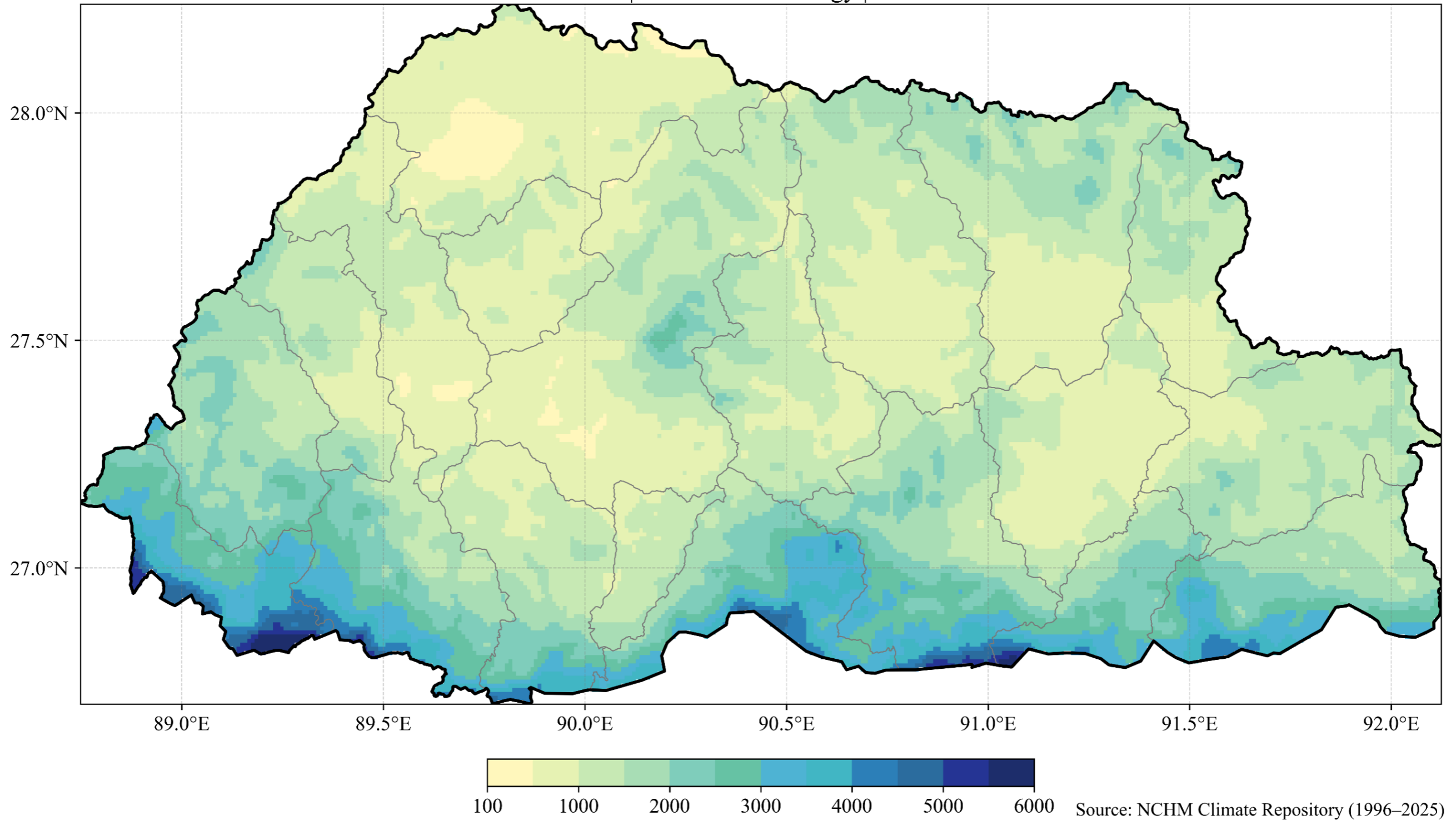
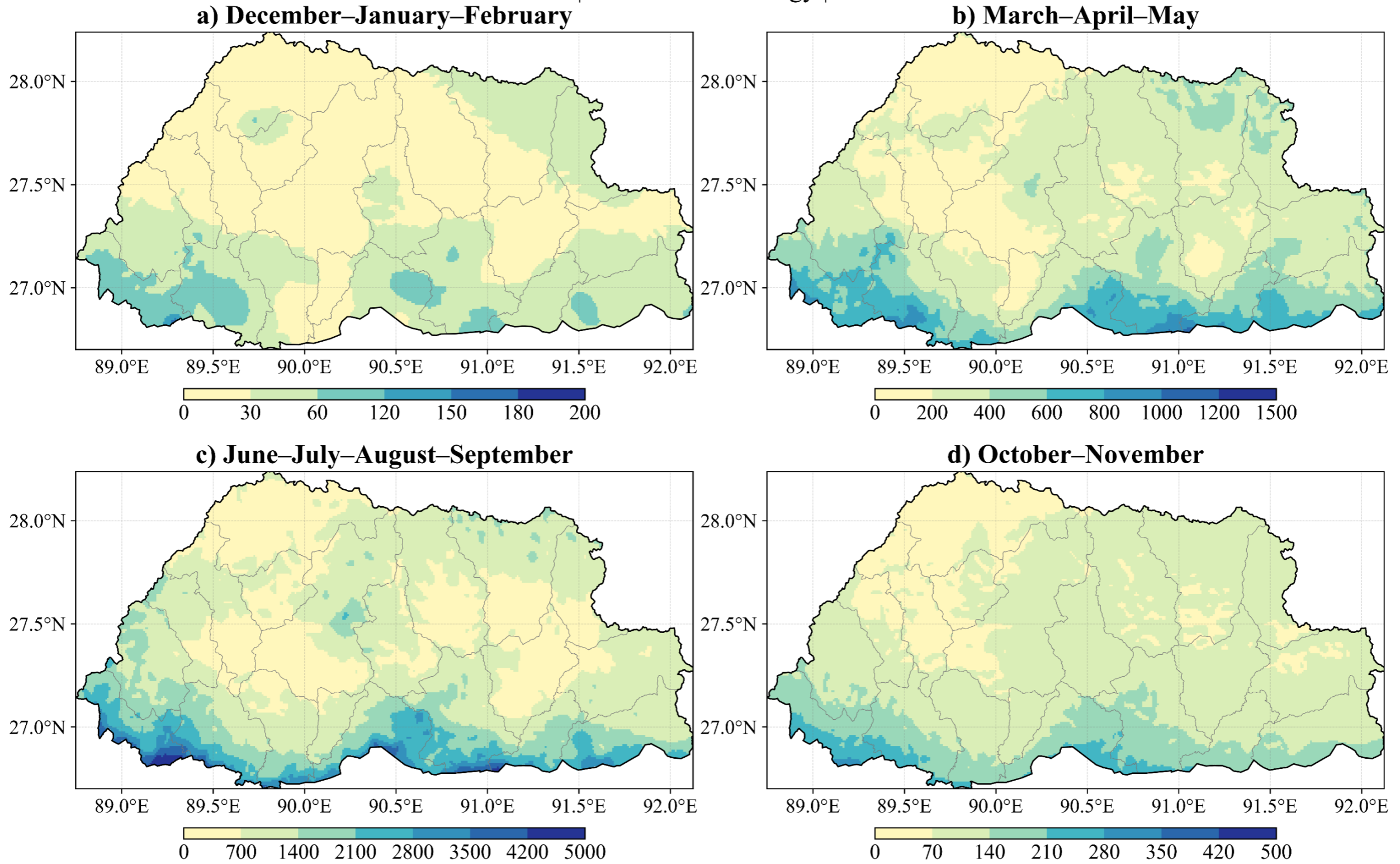


Figure 18: Spatial distribution of annual total mean rainfall of Bhutan (1996- 2025)

The spatial distribution of annual total mean rainfall of Bhutan (1996- 2025) shows a distinguished south to north gradient, with the highest rainfall of 4000-6000 concentrated towards the southern low foothills of the country, which are mostly driven by the summer monsoon. As the elevation increases towards the central and northern regions, rainfall gradually decreases with central parts receiving rainfall of 1000- 3000 mm. The northern high- altitude regions receive comparatively lower rainfall.

Seasonal Total Mean Rainfall

Bhutan | Baseline climatology | Unit: mm

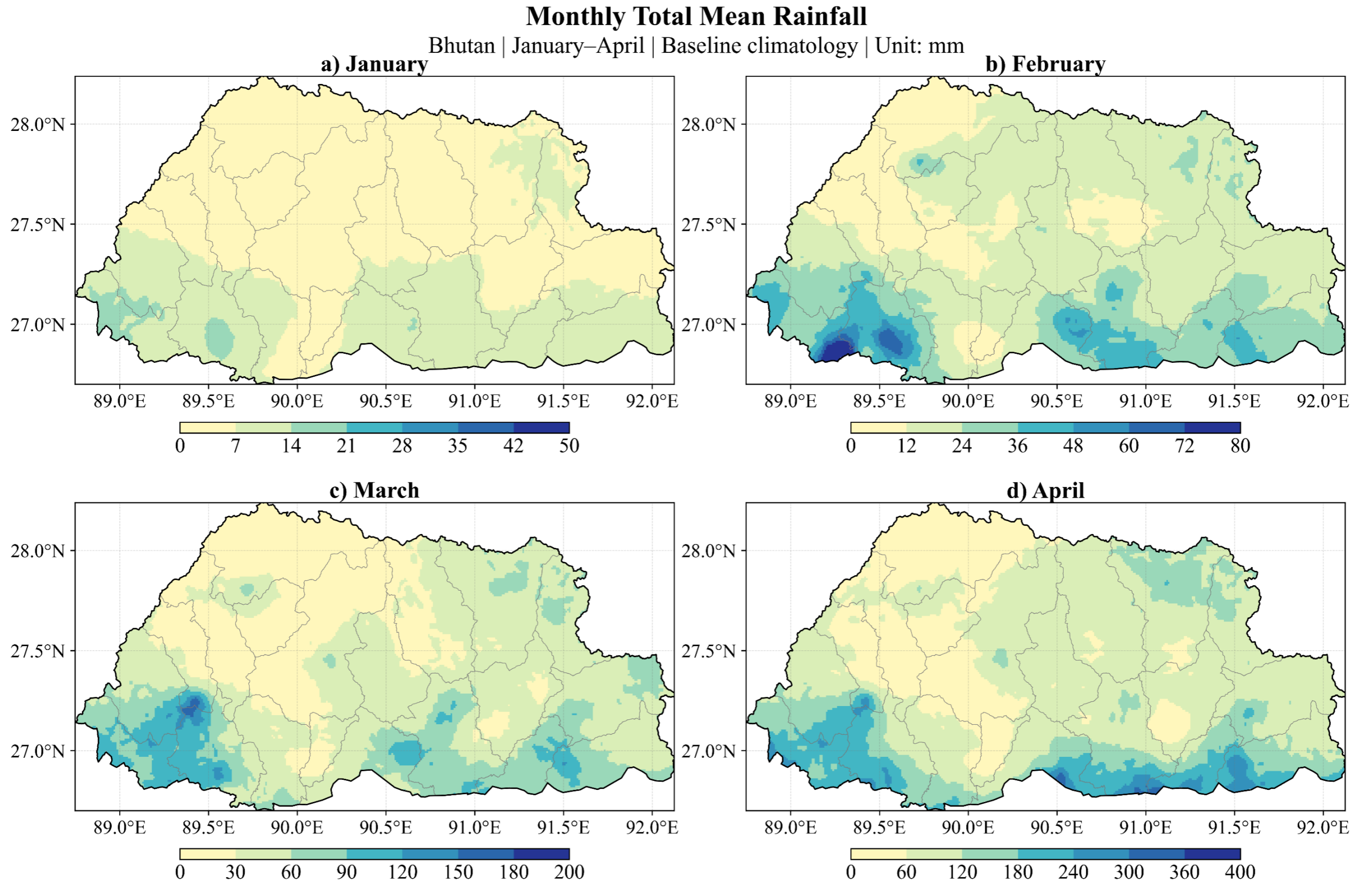


Source: NCHM Climate Repository (1996–2025)

Figure 19: Spatial distribution of seasonal total mean rainfall in Bhutan (1996- 2025)

The seasonal distribution of total mean rainfall across the country from 1996- 2025 shows strong seasonal variability driven by the monsoon system. During the winter season of December, January and February, the rainfall is less across most of the country, with slightly higher amounts in the southern

parts. Pre- monsoon months from March to May show gradual increase in rainfall particularly in the southern and southwestern parts of the country. The monsoon season of June to September contributes the majority of the annual rainfall. The same is showing in the monthly total mean rainfall as follows.

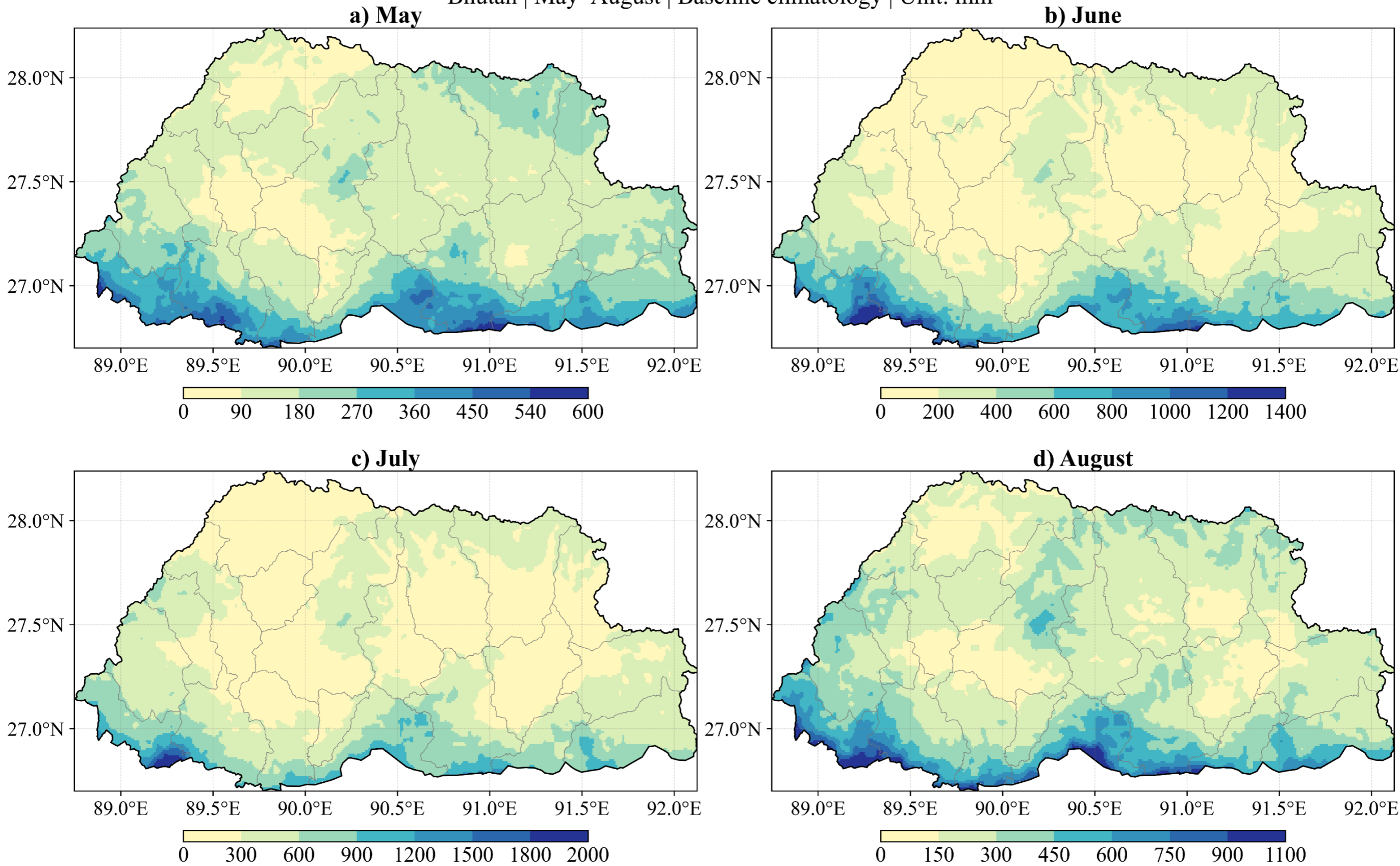


Source: NCHM Climate Repository (1996–2025)

Figure 20: Spatial distribution of monthly total mean rainfall in Bhutan (1996- 2025)- a) January, b) February, c) March, d) April

Monthly Total Mean Rainfall

Bhutan | May–August | Baseline climatology | Unit: mm



Source: NCHM Climate Repository (1996–2025)

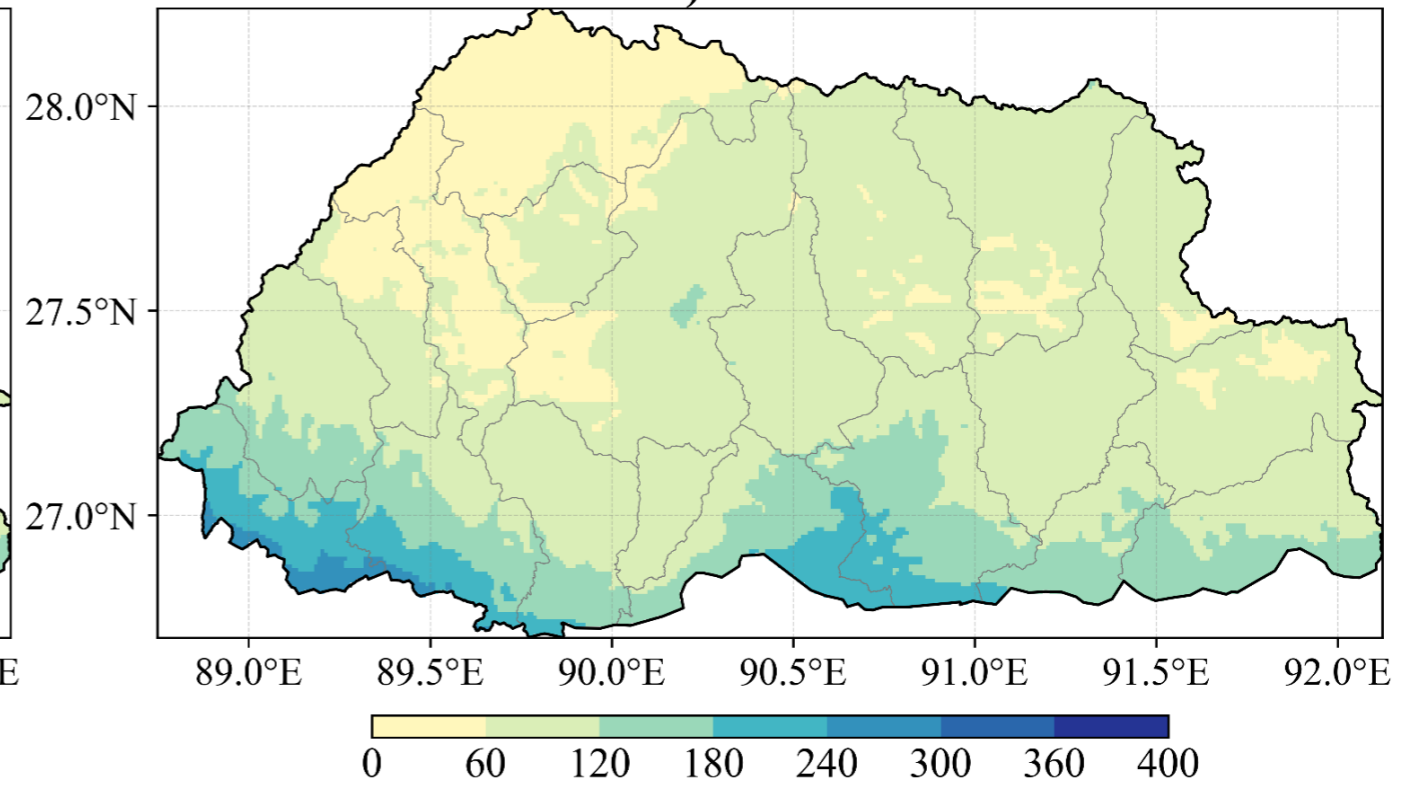
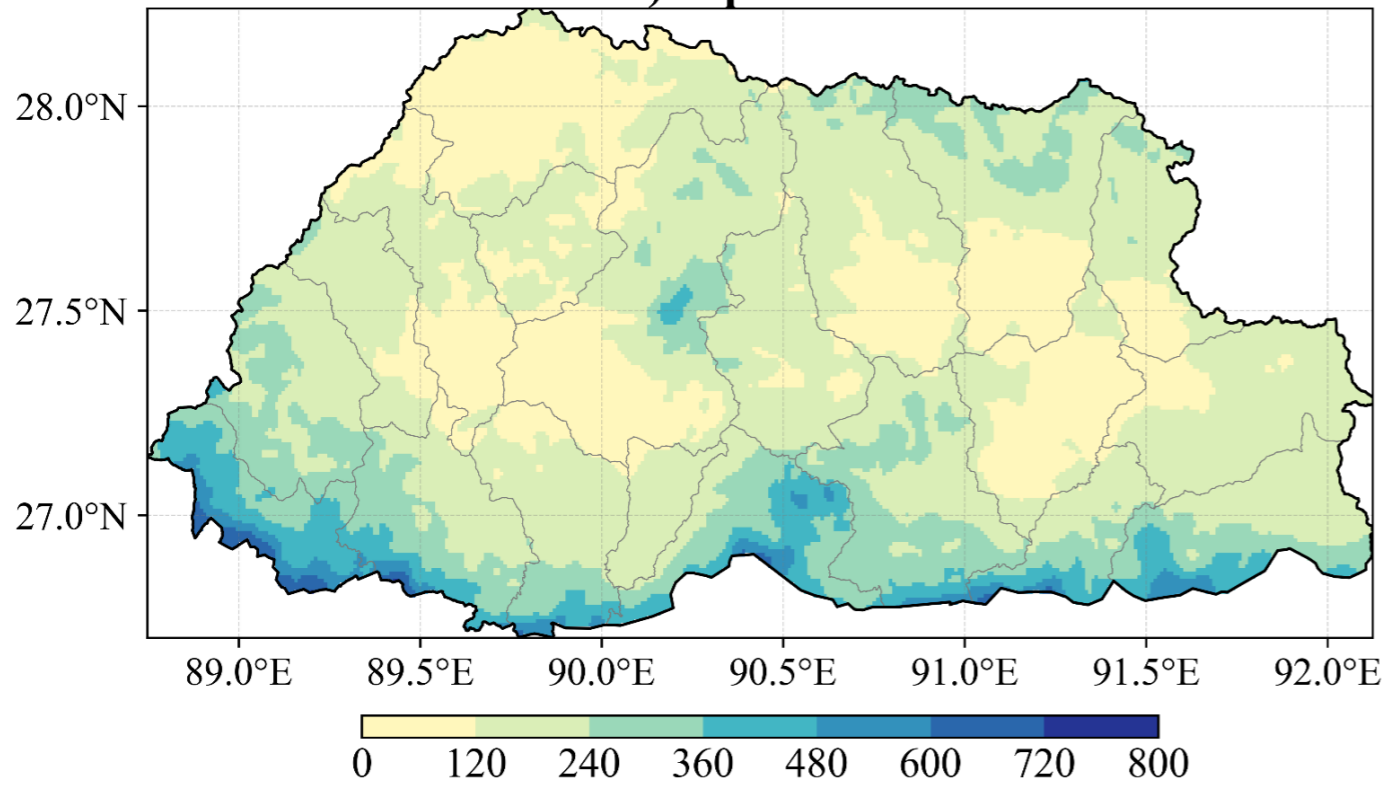
Figure 21: Spatial distribution of monthly total mean rainfall in Bhutan (1996- 2025)- a) May, b) June, c) July, d) August

Monthly Total Mean Rainfall

Bhutan | September–December | Baseline climatology | Unit: mm

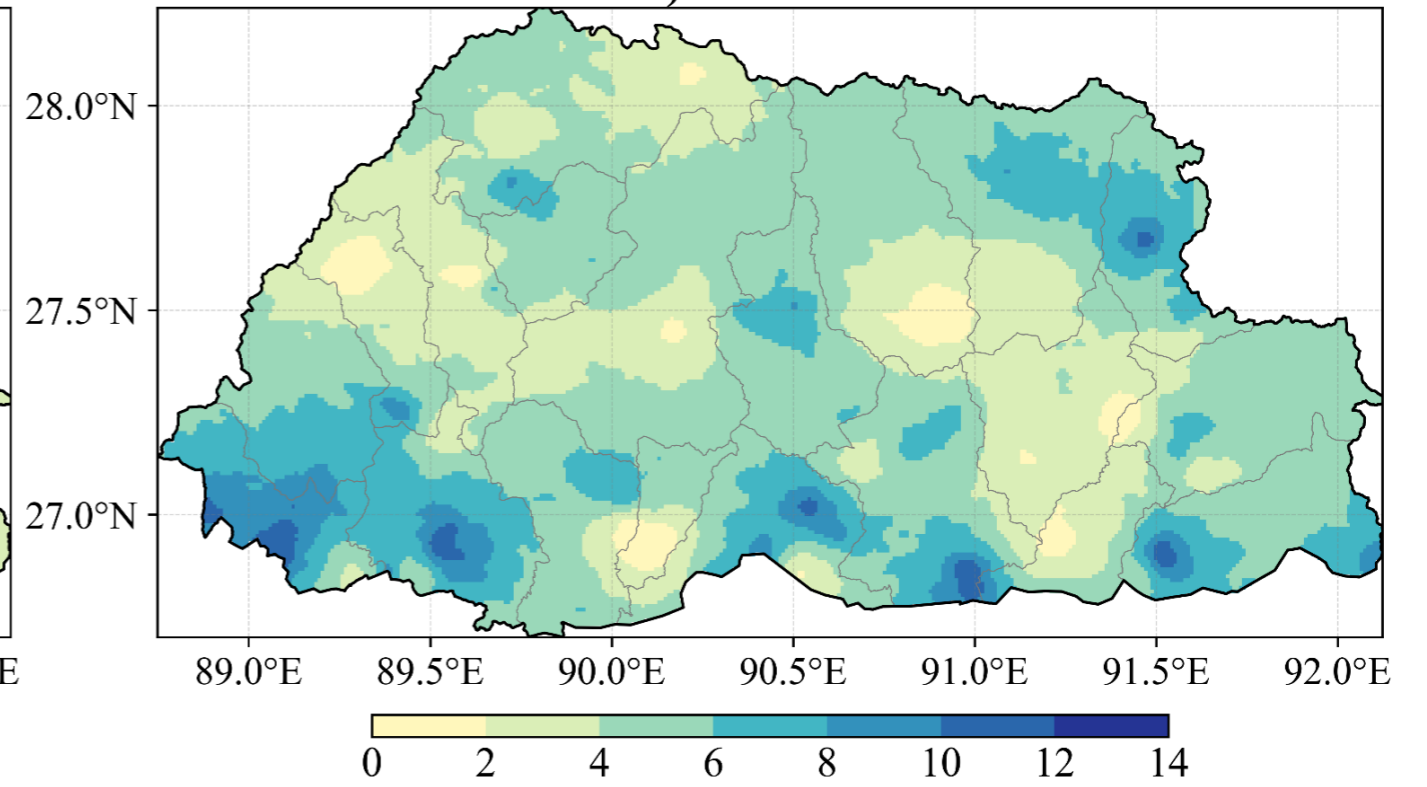
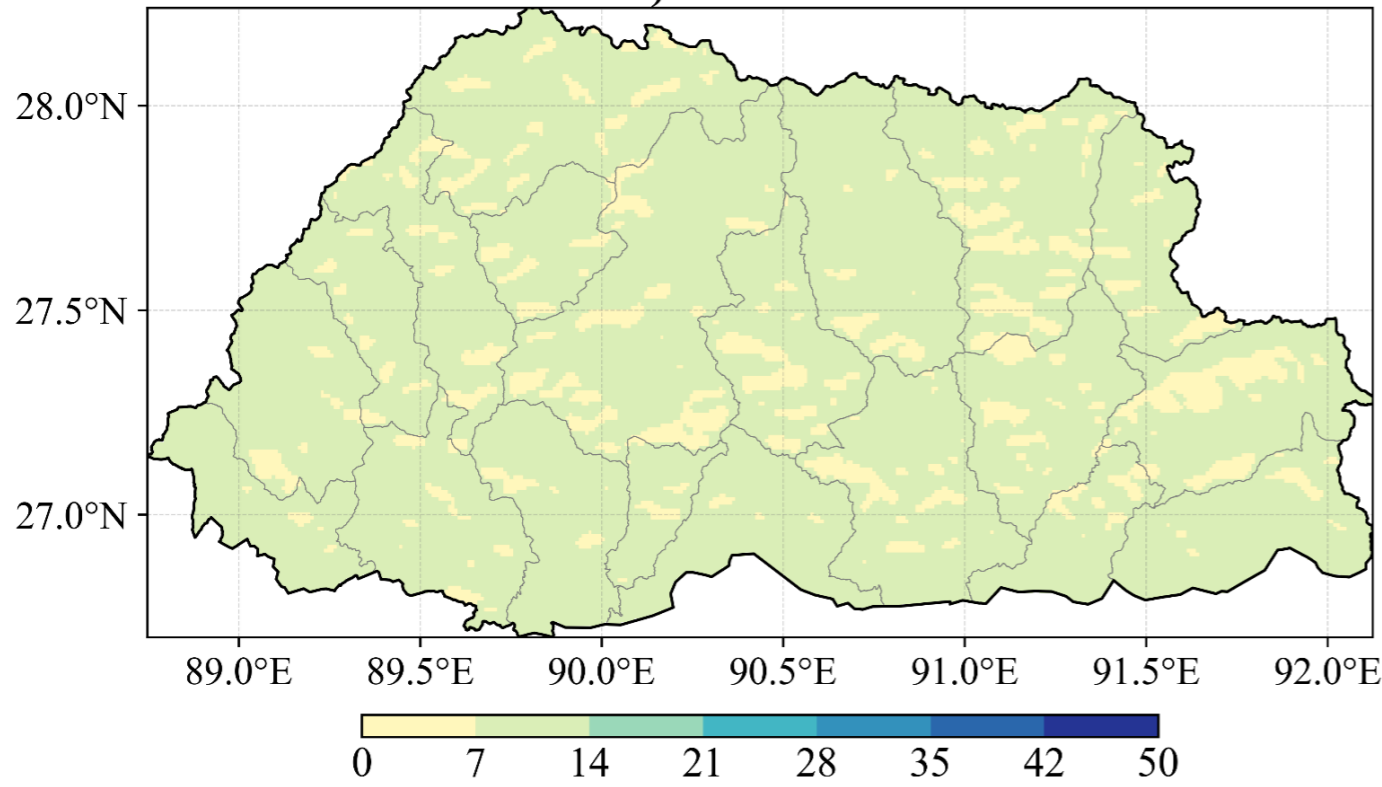
a) September

b) October



c) November

d) December



Source: NCHM Climate Repository (1996–2025)

Figure 22: Spatial distribution of monthly total mean rainfall in Bhutan (1996–2025)- a) September, b) October, c) November, d) December

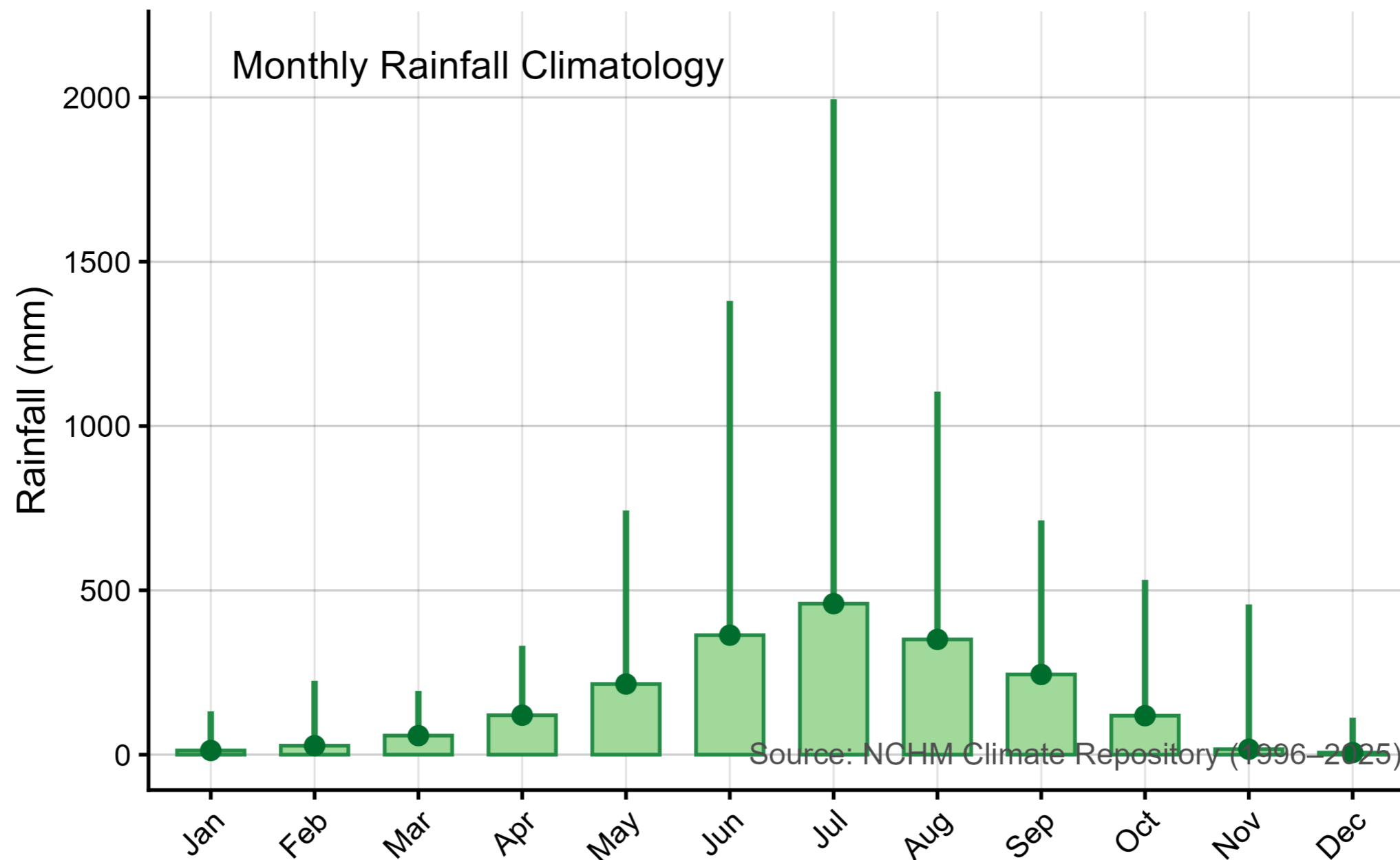
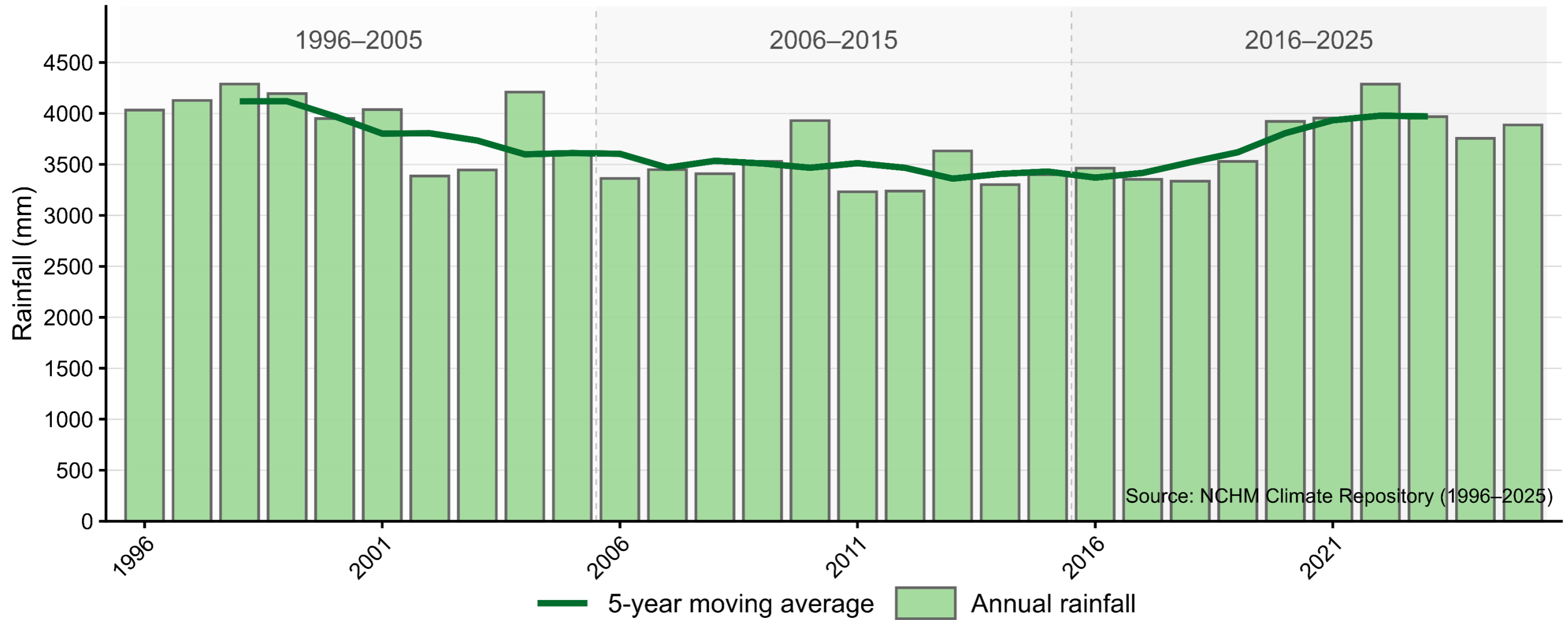


Figure 23: Monthly mean rainfall in Bhutan (1996- 2025) showing the highest monthly rainfall

The annual cycle of monthly mean rainfall in the country from 1996- 2025 clearly highlights the seasonal distribution and variability of rainfall throughout the year. Rainfall remains relatively low during the winter season of December to January with values less than 30 mm, indicating mostly dry conditions. Pre- monsoon rainfall gradually rises from March to May, reflecting the transition towards the summer monsoon. June to September received the majority of the annual rainfall in the country, with the highest mean rainfall observed in July with 459.3 mm, and highest maximum rainfall of 1994.3 mm. Rainfall starts to decline towards the post- monsoon season of October and November transiting back to drier conditions.

The vertical lines represent the range between the minimum and maximum monthly rainfall, indicating considerable interannual variability during the summer months compared to the low rainfall winter months. It highlights the strong seasonal concentration of rainfall during the summer monsoon.

Interannual Variability of Annual Total Rainfall (1996–2025)



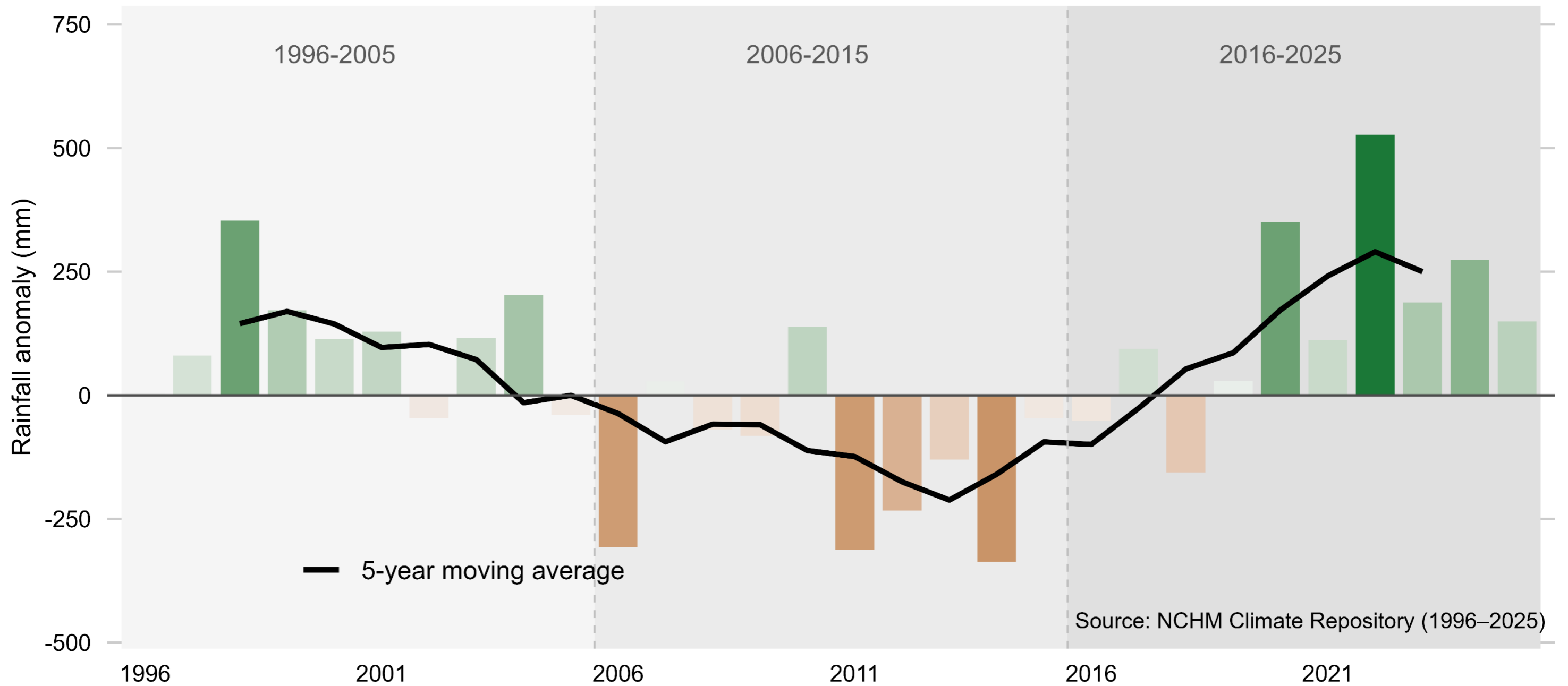
Source: NCHM Climate Repository (1996–2025)

Figure 24: Interannual variation of annual total rainfall (1996- 2025)

The annual total rainfall shows clear year- to- year fluctuations in rainfall amounts over the decades ranging from 3200- 4300 mm. Rainfall was generally greater during the late 1990s and early 2000s, with several years exceeding 4000 mm of rainfall. It was then followed by a drier condition from the mid-2000s to mid- 2010s, with rainfall less than 3000- 3500 mm. Recovery of the rainfall is seen towards the recent decades.

The 5- year moving average clearly shows the fall in the total annual rainfall in the late 1990s and the recovery in the recent years. It indicates clear year- to- year rainfall variability with recent years suggesting wetter conditions.

Annual Rainfall Anomaly Relative to 1996-2020 climatological baseline



Source: NCHM Climate Repository (1996–2025)

Figure 25: Annual rainfall anomaly

The annual rainfall anomaly was computed relative to baseline 1996- 2020, shows substantial year- to- year variability in total annual rainfall over the years. Wetter than average years are seen in the parts of the late 1990s and early 2000s, followed by drier conditions from the mid- 2000s to mid- 2010s where years recorded negative anomalies.

The black line showing the 5- year moving average emphasizes this shift by showing decline from wetter conditions to dry phase, followed by recovery after 2017. In the recent decade, the rainfall anomalies have become mostly positive, indicating a tendency towards wetter conditions than average.

Conclusion

The Climate Atlas of Bhutan (1996- 2025): Climatology of Temperature and Rainfall provide a comprehensive analysis of temperature and rainfall pattern across Bhutan based of three decades of observation data. It provides long- term climatological averages, seasonal variations, and spatial distributions through maps and visual analyses into the country's climate system.

The spatial distribution of annual, seasonal, and monthly mean maximum and minimum highlights the influence of elevation and terrain of the country. Warmer conditions are seen over the southern low foothills with maximum and minimum temperature ranging from 25- 30 °C, and 15- 20°C respectively, with colder towards the northern high- altitudes of the country, with less than 10 °C and below freezing for maximum and minimum temperatures respectively. The influence of the terrain is further supported by the clear negative relationship between elevation. The lapse rate is approximately -4.76°C and - 5.13°C per 1000 m for daytime temperatures and nighttime temperatures.

The annual temperature indicates a moderate interannual variability with a gradual warming tendency in recent years, particularly after the mid- 2010s. Warmer than average years are seen in the late 1990s, with cooler conditions from the mid- 2000s to around 2020.

Annual, seasonal and monthly mean rainfall shows a distinct south to north gradient, with the highest rainfall over the south of 4000- 6000

mm. As the elevation rises, the rainfall gradually decreased, with northern parts of the country receiving the least rainfall. Rainfall shows a decreasing trend from the mid- 2000s to mid- 2010s, with recovery towards the recent decade indicating wetter conditions.

The Climate Atlas utilized 30- year of climatological dataset, which provides a standard climatological baseline, however a longer time series would allow for more robust detection of long- term trends in temperature and rainfall across the country. The limited temporal coverage may contain the ability to fully capture the climate variability and emerging climate change signals. Furthermore, the analysis focusses primarily on mean condition and a more details assessment of climatological extremes such as heatwaves, intense rainfall, drier conditions, would provide deeper understanding of climate variability and associated risks. Limited observation stations in the high- altitude and remote regions may also introduce uncertainties in representing localized climatic conditions due to data gaps and interpolation limitations.

Despite the limitations, this Atlas represents the first comprehensive efforts of its kind in Bhutan, providing a systematic analysis of temperature and rainfall over a period of 30- years. It serves as a critical foundation for future climatological studies, climate risk assessments, and evidence-based planning and research in the country.

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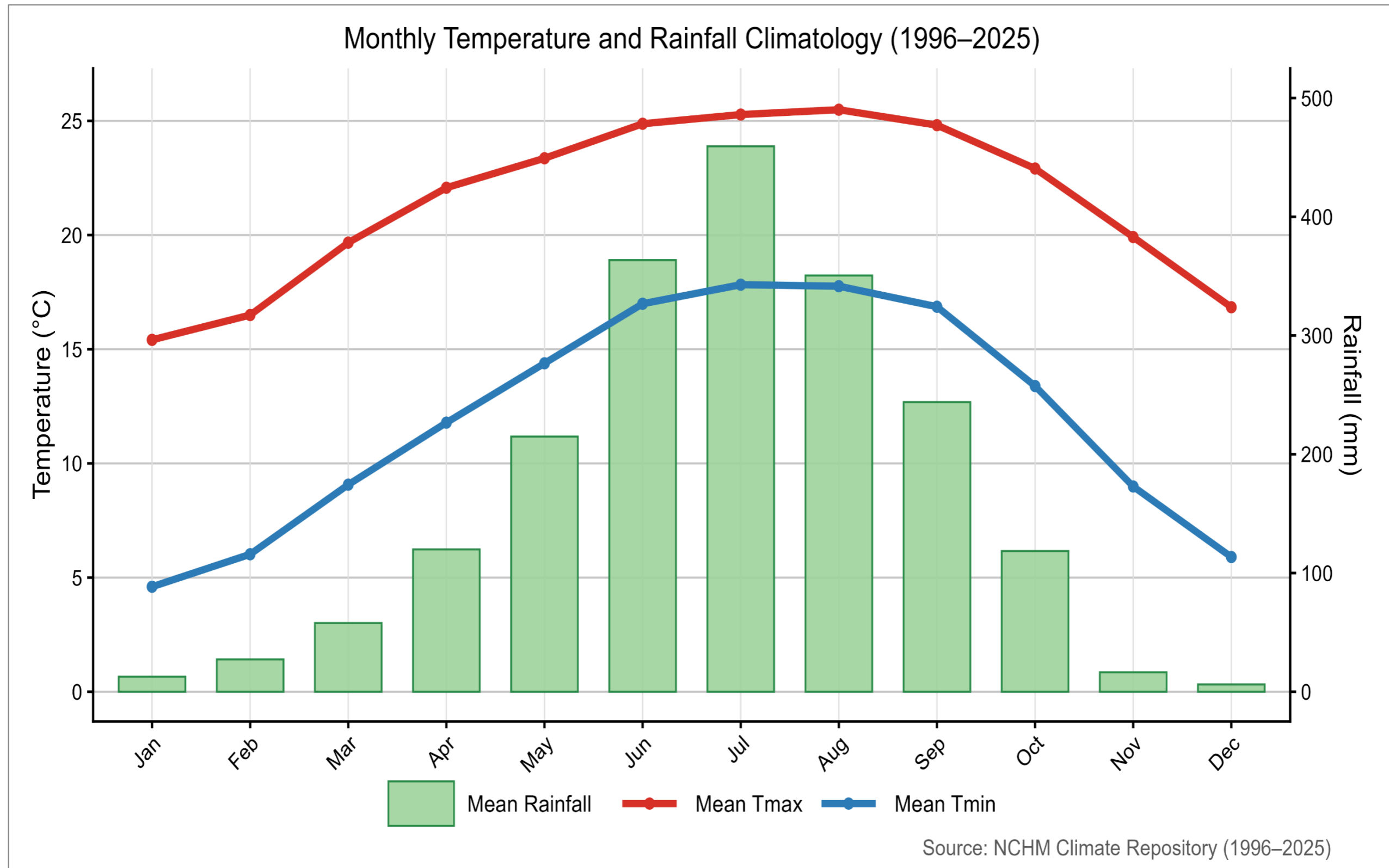
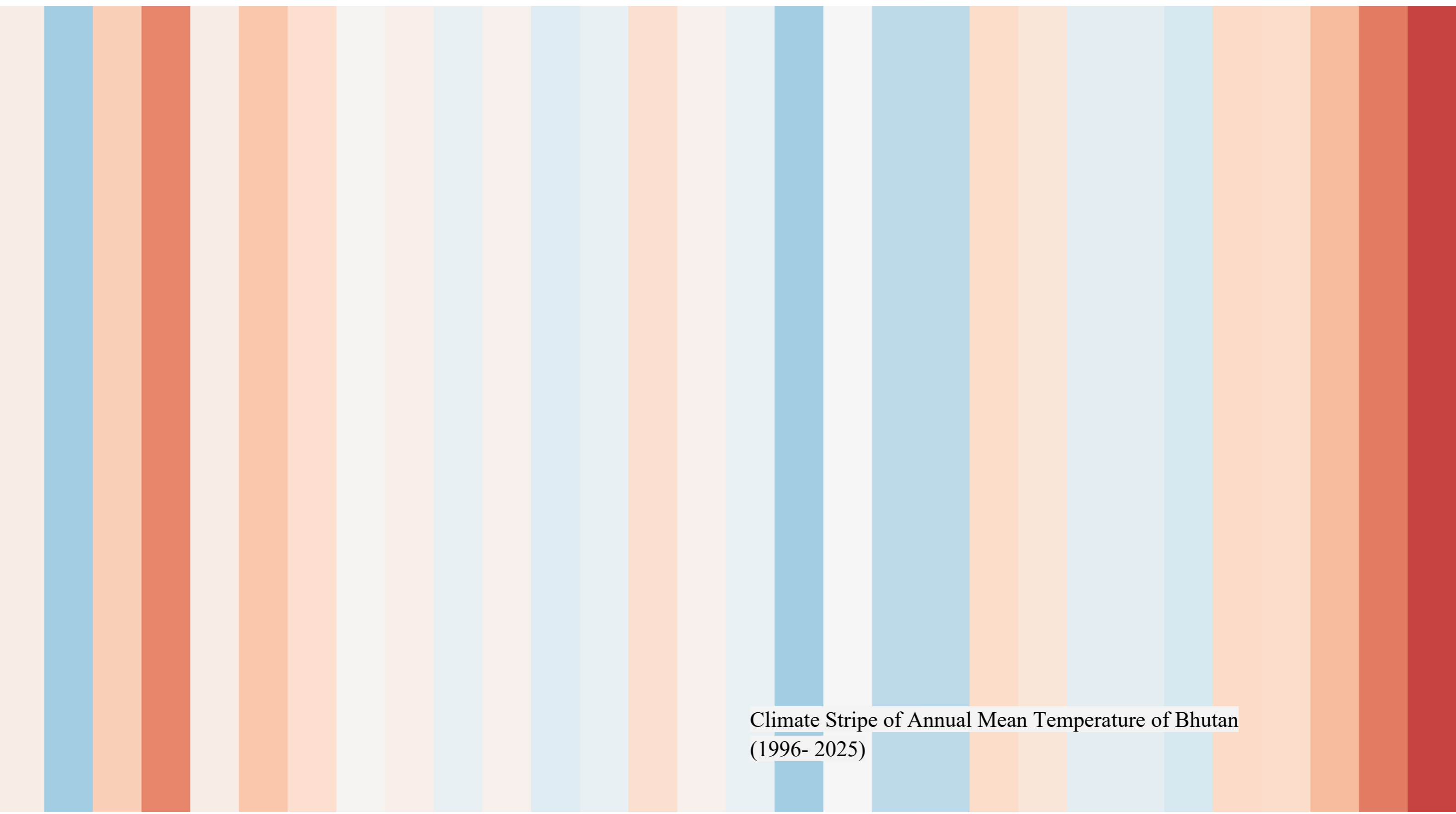


Figure 26: Monthly mean maximum and minimum temperature, with mean rainfall in Bhutan (1996- 2025)



Climate Stripe of Annual Mean Temperature of Bhutan
(1996- 2025)

