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Future climate projections for Vietnam: temperature and precipitation changes under SSP2-4.5 and SSP5-8.5 scenarios

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ABSTRACT

The IPCC's 6th Assessment Report in 2023 highlights Vietnam's undeniable vulnerability to climate change, ranking it among the most severely impacted countries. In response, experts developed the CMIP6-VN dataset, offering high-resolution downscaled temperature and precipitation data tailored for Vietnam using the CMIP6 GCMs model. This study aims to analyze climate projections for Vietnam throughout the 21st century, incorporating data from 25 models to provide valuable insights into potential future climate scenarios. The investigation compares projected temperature and precipitation changes for the mid-term (2040÷2059) and long-term (2080÷2099) periods relative to the historical period (1980÷2014) in the six sub-climatic regions of the country. The results show a consistent upward trend in average temperature, projecting an average of 2.3⁰C (SSP2-4.5) and 4.3⁰C (SSP5-8.5) increases by the end of the century. The Northern regions, especially the Northwest, are experiencing the most significant temperature rise, while moving towards lower latitudes, the temperature increase becomes less severe. The Southern regions, on the other hand, are experiencing a relatively lowest temperature increase. Rainfall variability indicates a slight increase across Vietnam by the century's end, aligned with rising temperatures, though not as pronounced as the temperature changes. This study emphasizes temperature disparities between the Northern and Southern regions, with the Northwest showing the highest increase and the Southern region displaying the least prominent rise. Policymakers and stakeholders can use these research insights to devise effective adaptation and mitigation strategies in addressing climate change challenges in Vietnam. Continued monitoring and further research are essential to enhance the accuracy and reliability of climate projections in the region, enabling Vietnam to better prepare and respond to the inevitable impacts of climate change.

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1. Introduction

Climate change presents one of the most urgent challenges on a global scale in our time, with far-reaching implications for the environment, economies, and public health (IPCC, 2023a). The IPCC's fifth Assessment Report (AR5), released in 2014, unequivocally identified Vietnam as one of the countries most vulnerable to the impacts of climate change and global warming (IPCC, 2014). In recent years, Vietnam has experienced a marked increase in the frequency and severity of climate extremes, such as tropical storms, heatwaves, floods, and droughts, resulting in significant economic losses and endangering public well-being (Espagne et al., 2021; Espagne & Magacho, 2022).

In 2021, the Intergovernmental Panel on Climate Change (IPCC) released its sixth Assessment Report (AR6), which presents a comprehensive and cutting-edge analysis of the current global climate, along with vital projections for the future (IPCC, 2023b). The report's alarming findings act as a clear warning, showing that global warming is happening faster than previously thought, leaving no doubt about the urgent nature of the climate crisis. AR6 reaffirms Vietnam's vulnerable status as a country highly susceptible to the impacts of climate change, underscoring the urgent need for immediate action. It emphasizes the critical importance of addressing the increasing threats posed by climate change to Vietnam's environment, economy, and public well-being.

To comprehensively address the implications of climate change in Vietnam, it is crucial to analyze the nation's future climate conditions using the latest scientific data from the IPCC. Despite numerous climate change and adaptation studies in Vietnam, the recently released IPCC 6th Assessment Report has not been fully integrated into these investigations. Many existing studies have relied on the IPCC CMIP5 dataset, including the most recent National climate change and sea-level rise scenario for Vietnam 2020, issued by the Vietnam Ministry of Natural Resources and Environment (MONRE, 2020). However, these national scenarios may now be outdated and do not meet the expected standards of confidence and accuracy. With the introduction of the new CMIP6 dataset, offering more precise climate projections and updated information on the Earth system over the past decade, it becomes imperative to promptly update Vietnam's climate scenarios using the latest scientific findings from the IPCC.

While some researchers have started utilizing the IPCC CMIP6 dataset, their main emphasis has centered on validating General Circulation Model (GCM) models specific to the Vietnam domain or forecasting large-scale climate and ocean circulations (Desmet and Ngo-Duc, 2022; Nguyen-Duy et al, 2023; Tran-Anh et al, 2023). However, the applicability of their findings for policymaking is limited, and their resolution may not offer the regional specificity necessary for effective decision-making.

To comprehensively understand and address the implications of climate change in Vietnam, it is crucial to conduct studies that specifically focus on the country's regional climate patterns, impacts, and adaptation strategies. Utilizing high-resolution data and advanced modeling techniques will be instrumental in providing accurate and localized projections. Additionally, integrating the findings of the IPCC 6th Assessment Report into such research would enhance the credibility and relevance of the results. This study aims to bridge these existing gaps by utilizing the most updated high-resolution dataset for Vietnam, known as CMIP6-VN (Tran-Anh et al., 2023), developed based on the CMIP6 dataset. By leveraging this advanced dataset, the objective is to investigate the mid-term and long-term trends of temperature and precipitation in Vietnam, enabling more precise and localized climate projections for the country. Through this research, valuable insights will be provided, empowering policymakers and stakeholders to devise effective strategies for adapting to and mitigating the impacts of climate change in Vietnam, thereby fostering a more resilient and sustainable future.

2. Data and Methods

2.1. Study domain

Vietnam's unique geographical location in the eastern side of the Indochina Peninsula contributes to its diverse topography. Around three-quarters of the country's territory is marked by mountainous regions, while the lowland areas are mainly concentrated in the eastern coastal zones and the two major deltas, the Red River and the Mekong deltas. To better understand Vietnam's climate, climate experts have classified it into seven distinct climatic sub-regions, each with its own characteristics based on factors such as radiation, temperature, and rainfall. These sub-regions are identified as follows: (1) Northwest (NW), (2) Northeast (NE), (3) Red River Delta (RRD), (4) North Central (NC), (5) South Central (SC), (6) Central Highland (CH), and (7) South (S) (Nguyen & Nguyen, 2004) (Figure 1).

2.2. Model data and scenarios

In this study, we examine the historical and projected daily rainfall (R) and 2-meter temperatures (T2m) for Vietnam using the CMIP6-VN dataset, which comprises data from 25 downscaled models (Tran-Anh et al., 2023). The CMIP6-VN dataset offers a high-resolution climate representation specifically tailored for Vietnam's mainland territory. To create this dataset, CMIP6-GCM data was subjected to the bias correction and spatial disaggregation (BCSD) downscaling method. The BCSD method is well-known and widely used in downscaling climate variables, ensuring improved accuracy in the localized climate projections (Wood et al, 2004; Maurer, 2007; Rasmusen et al, 2016; Tran-Anh et al, 2022).

To establish a robust framework for assessing future climate change, we utilize historical simulations from the period 1980 to 2014 as the reference baseline. This reference period allows us to calculate and analyze the anticipated changes in the forthcoming climate. Subsequently, we project climate changes for both mid-term (2040÷2059) and long-term (2080÷2099) periods, considering two distinct Shared Socioeconomic Pathways (SSPs): SSP2-4.5 (Middle of the Road) and SSP5-8.5 (Fossil-fuel Development) scenarios (IPCC, 2023b).

The SSP2-4.5 and SSP5 scenarios in the Intergovernmental Panel on Climate Change (IPCC) 6th Assessment Report (AR6) are equivalent to the RCP4.5 and RCP8.5 scenarios from the IPCC 5th Assessment Report (AR5).

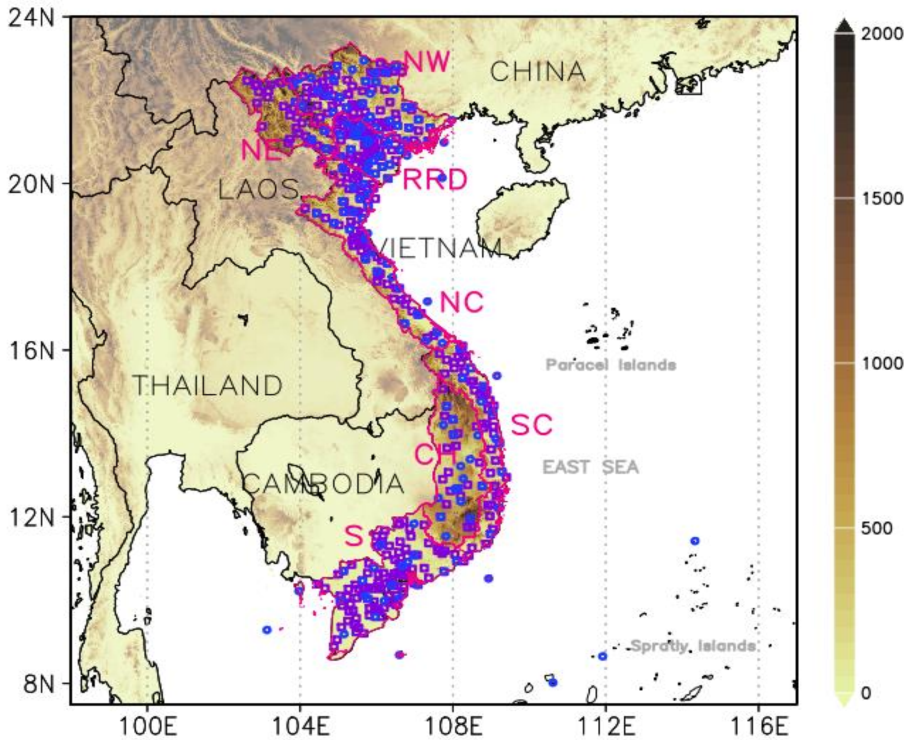

Figure 1. Geographic distribution of the seven climatic subregions in Vietnam, overlaid on a topography map derived from the Hydroshed Dataset. The purple squares and blue dots on the map represent the respective locations of precipitation and temperature stations utilized in this research.

Notably, these scenarios have been adopted in the Vietnam National Report on Climate Change and Sea Level Rise.

2.3. Observation of rainfall and temperature

For this research, we collected near-surface daily average, temperature (T2m), and precipitation (pr) data for the period 1980-2014, sourced from the Vietnam Meteorological and Hydrological Administration (VMHA). The dataset comprises 147 temperature stations and 481 rain gauges, distributed across Vietnam's territory (Figure 1).

After collecting station data, we created a gridded dataset with a 10 km resolution, covering the entire inland territory of Vietnam, using the interpolation method adopted in the research by Tran-Anh et al. (2023). The implementation of their interpolation method is described here in parallel with their paper. We adopted two distinct interpolation techniques to address temperature and rainfall data. For temperature, we applied the Kriging interpolation technique, which has been well-established as an effective method for estimating continuous spatial variables like temperature (Wu & Li, 2013). On the other hand, for rainfall data, we utilized the Sphere map interpolation technique, which was chosen based on previous research by Nguyen-Xuan et al. (2016). Their study demonstrated the superiority of the Sphere map technique in generating a reliable gridded rainfall dataset for Vietnam when compared to various other interpolation methods such as Cressman (1959), Inverse Distance Weighted (Shepard, 1968), or Kriging (Switzer, 2014).

3. Results and Discussion

3.1. Future projection

3.1.1. Temperature

The figure (Figure 2a) clearly illustrates the prominent upward trend in average temperature for Vietnam's future compared to the reference period. Projections indicate an increase of

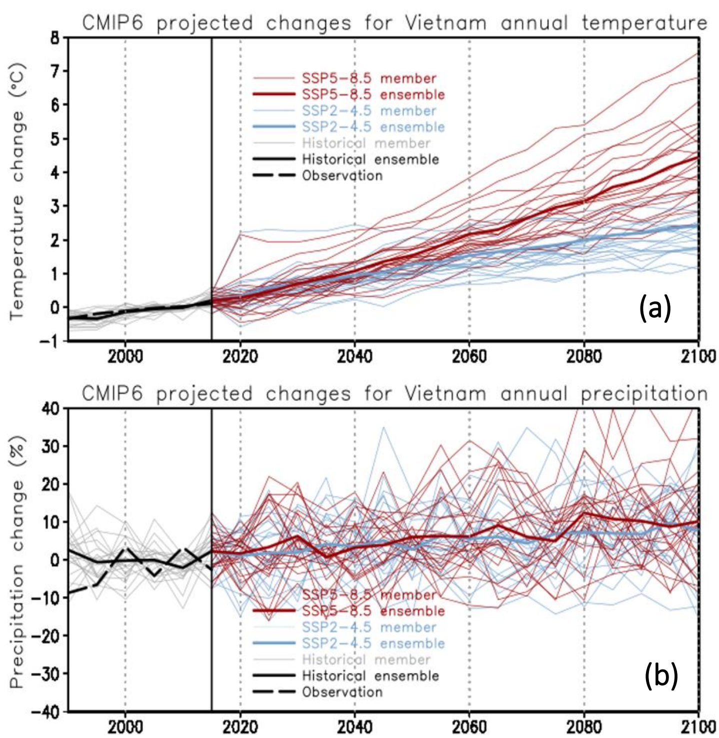

Figure 2. Projected changes in (a) temperature and (b) average rainfall for Vietnam during the reference period (1980-2014) and the future period (2015-2100) based on the CMIP6-VN dataset. The solid black, blue, and red lines represent the ensemble mean values for Historical, SSP2-4.5, and SSP5-8.5 scenarios, respectively. The corresponding shaded lines in the same colors represent the individual model components. The observed values for the reference period are shown by the dashed black line.

2.3°±0.8° under the SSP2-4.5 scenario and 4.3°±2.1° under the SSP5-8.5 scenario. Throughout the reference period, the simulated temperature data from the CMIP6-VN ensemble closely matches observational data. While the models show relatively low uncertainty during this historical period, the future projections suggest a gradual rise in model uncertainty, peaking towards the end of the century. The warming of average temperature becomes evident under the high emission scenario SSP5-8.5 and the moderate emission scenario SSP2-4.5, starting from the mid-21st century onwards. In the period 2040÷2059, the SSP5-8.5 scenario suggests a temperature difference of 0.4÷0.6^0 higher than SSP2-4.5. This difference increases to 1.7÷2.2^0 degrees in the period 2080÷2099.

3.1.2. Precipitation

As for rainfall variability, although not as distinct as temperature changes, there is a general tendency for a slight increase in rainfall towards the end of the century, corresponding to the degree of warming (Figure 2b). The simulation results for rainfall variability exhibit higher model uncertainty compared to temperature, both in historical simulations and future projections. Near the century's end, model uncertainty increases, but the rate of additional uncertainty is not clearly evident. Both the SSP2-4.5 and SSP5-8.5 scenarios project a marginal increase in rainfall by approximately 3÷4% under SSP2-4.5 and 3÷6% under SSP5-8.5 as we approach the latter part of the century. However, the differences between the two scenarios are not distinctly discernible.

In Figure 3, the projected temperature variability towards the far future is depicted in comparison to the reference period for each model under the SSP2-4.5 and SSP5-8.5 scenarios. The results show a consistent and significant temperature increase across all models as we approach the century's end. Under the SSP2-4.5 scenario, the average temperature warming ranges from 1.2^0 (MPI-ESM1-2-HR) to 3.32^0 (HadGEM3-GC31-LL), while the corresponding range under the SSP5-8.5 scenario is 2.31^0 (INM-CM5-0) to 6.26^0 (HadGEM3-GC31-LL). Notably, the SSP5-8.5 scenario exhibits a higher level of warming in average temperature compared to the SSP2-4.5 scenario, with ensemble mean temperatures of 3.96^0 and 2.16^0, respectively. Projected temperature increases are expected across all regions in Vietnam towards the end of the century. The northern regions, especially the Northwest, are projected to experience the most significant temperature rise, followed by a decreasing trend towards lower latitudes, with the southern regions showing the least prominent increase. The most extreme projections from certain models, such as HadGEM3-GC31-LL and CIESM, suggest that the temperature in Northern Vietnam could potentially rise by over 7 degrees by the end of the century. The projected temperature increases in this study are consistent with other studies showing significant warming across Vietnam by the end of the century. For example, Tran-Anh et al. (2022) used multiple climate models and found mean temperature increases ranging from 1.0÷3.5^{0}C by 2080÷2099 across Vietnam under RCP4.5 and RCP8.5. Similarly, Kieu et al. (2018) projected an ensemble mean warming of 2.8^{0}C by 2071÷2100 across Vietnam in their study. The larger warming projected for northern Vietnam is also a robust result seen in other studies like Phan et al. (2018).

At the end of the century, both scenarios project an increase in average rainfall across the entire region of Vietnam in response to rising average temperatures (see Figure 4). However, the magnitude of the rainfall increase is not as significant as that of the temperature. The ensemble mean for the SSP5-8.5 scenario indicates a higher rise in rainfall compared to the SSP2-4.5 scenario, with a percentage increase of 9.85% versus 7.51%, respectively. While the overall rainfall in Vietnam is expected to experience a slight increase, its distribution will be uneven among different climatic subregions. The Northern region and the South Central Coast are anticipated to undergo a more substantial increase in rainfall compared to other regions.

The projected modest increases in total rainfall align with some previous studies, though the range is wide. For example, Kieu et al. (2018) projected changes in mean rainfall from -2÷+13% across models by 2071÷2100 under RCP8.5 for Vietnam, while Chand et al. (2020) found projections ranging from -10÷+20% for central Vietnam by 2050. The higher rainfall increases

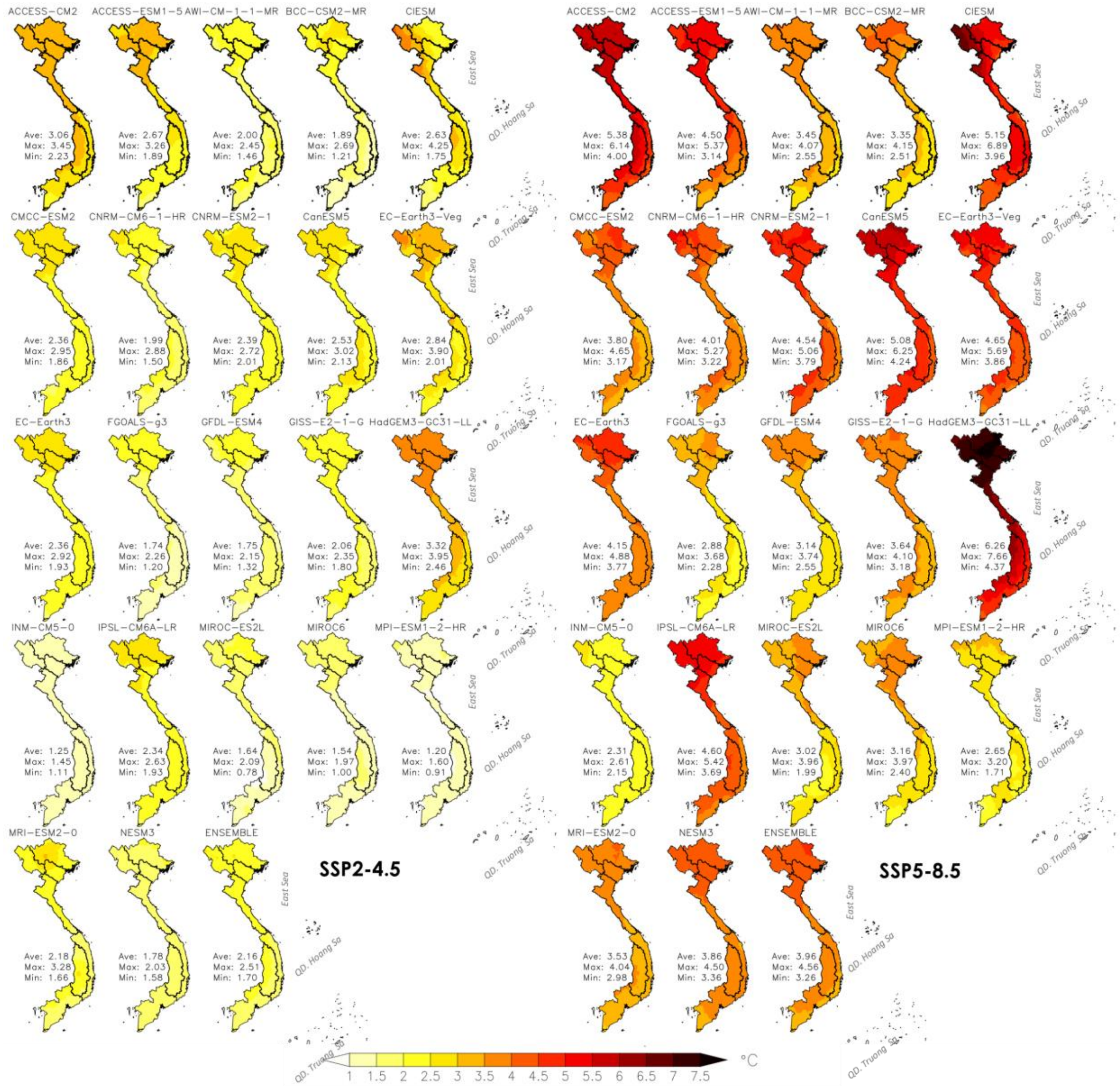

Figure 3. Projected changes in average temperature for the period 2080-2099 compared to the reference period 1996-2014 under the SSP2-4.5 (left) and SSP5-8.5 (right) scenarios using the CMIP6-VN dataset. The average, maximum, and minimum temperature changes for each individual model are illustrated on the left of the corresponding subplot.

is projected in the northern and south-central regions are consistent with spatial patterns found in other studies like Nguyen-Thi et al. (2018).

The wide variability observed among climate models in our projections for Vietnam is a common feature, indicative of the inherent uncertainties in such assessments, a point underscored by Kieu et al. (2018) and other studies employing multi-model methodologies. By considering both medium (SSP2-4.5) and high (SSP5-8.5) emissions scenarios, our analysis encompasses a significant spectrum of potential future outcomes. This approach aligns with research such as that conducted by Phan et al. (2018), which comprehensively incorporates both RCP4.5 and RCP8.5 scenarios, thus offering a robust framework for exploring the range of possible climatic trajectories.

3.2. Seasonal Variations of Temperature and Rainfall

Table 1 presents the projected distribution of average temperature increase across the seven

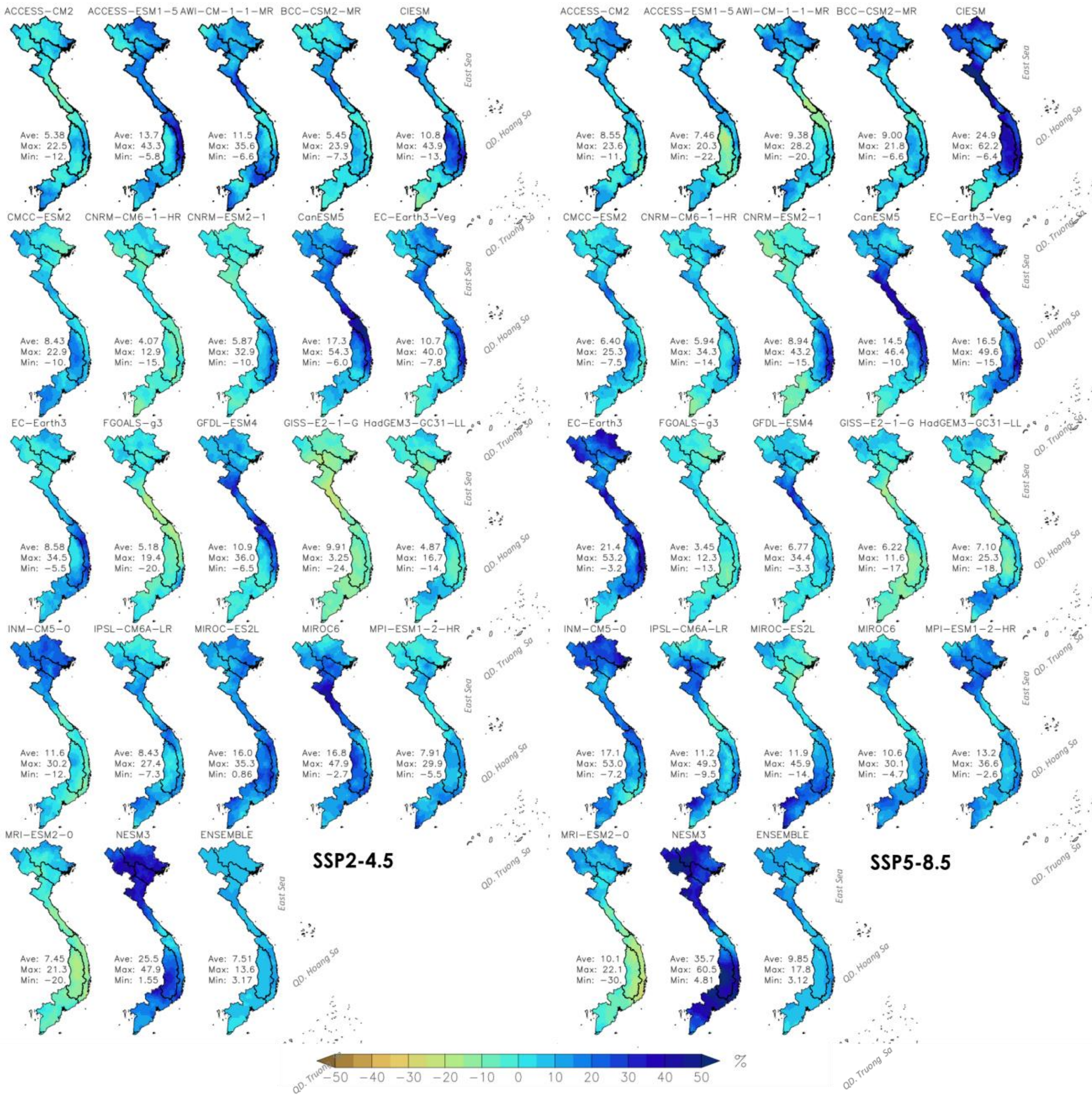

Figure 4. Projected changes in average precipitation for the period 2080÷2099 compared to the reference period 1996÷2014 under the SSP2-4.5 (left) and SSP5-8.5 (right) scenarios, notations similar to Figure 3.

climatic subregions in Vietnam during different seasons. Generally, the trend of temperature rise in the Northern regions surpasses that in the Southern regions, not only towards the end of the century but also during the mid-century period. The Northwest region experiences the highest temperatures in the country, with average temperature increases for each season during the periods 2040÷2059 and 2080÷2099, compared to the reference period, ranging from 1.2÷1.6^0 and 2.2÷2.6^0 under the SSP2-4.5 scenario, and 1.7÷2.0^0 and 4.1÷4.6^0 under the SSP5-8.5 scenario, respectively. Conversely, the Southern region exhibits the lowest level of temperature increase during the seasons, with values ranging from approximately 1.0÷1.1^0 (SSP2-4.5) and 1.7÷1.9^0 (SSP5-8.5) for the mentioned periods. In contrast to the regions from the South Central Coast to the Southern region, which show relatively consistent temperature increases across the seasons, with differences typically not exceeding 0.1^0, the regions from Northeast to North Central Coast display uneven temperature increases. For example, during the periods 2040÷2059 and 2080÷2099, the temperature increase is highest during DJF (winter) and lowest during SON (autumn), with values of 1.4÷1.6^0 and 2.5÷2.6^0 for DJF, and 1.2÷1.3^0 and 2.2÷2.3^0 for SON, respectively. Overall, the model uncertainty in temperature projections for the late 21st century (2080÷2099) is notably higher compared to the mid-century period (2040÷2059).

The analysis of Table 2 clearly indicates a consistent trend of reduced rainfall in most climatic subregions during DJF, while increased rainfall is observed in the other seasons under both the SSP2-4.5 and SSP5-8.5 scenarios during the mid-century period. Specifically, the DJF rainfall is projected to decrease by -2.4÷10.1% and -5.6÷0.4% under the SSP2-4.5 and SSP5-8.5 scenarios, respectively.

As we progress towards the end of the century, the Southern regions continue to experience a significant decreasing trend in DJF rainfall, whereas the Northern regions show a slight increase. For instance, the DJF rainfall is forecasted to decrease by -15.5% (SSP2-4.5) and

Table 1. Projected temperature change (^{0}C) for the seven climatic sub regions by CMIP6-VN model ensemble.

Region	DJF		MAM		JJA		SON	
	2040÷2059	2080÷2099	2040÷2059	2080÷2099	2040÷2059	2080÷2099	2040÷2059	2080÷2099
SSP2-4.5								
Northwest	1.6 ± 1.6	2.6 ± 1.6	1.3 ± 0.9	2.3 ± 1	1.4 ± 1.4	2.4 ± 1.3	1.2 ± 1.9	2.2 ± 1.9
Northeast	1.5 ± 1.7	2.5 ± 1.7	1.2 ± 0.8	2.2 ± 1	1.4 ± 1.2	2.4 ± 1.3	1.3 ± 2.1	2.3 ± 2.2
Red River Delta	1.4 ± 1.6	2.5 ± 1.7	1.2 ± 0.8	2.2 ± 1	1.3 ± 1.2	2.3 ± 1.3	1.3 ± 2.1	2.2 ± 2.1
North Central	1.4 ± 1.7	2.4 ± 1.8	1.2 ± 0.9	2.1 ± 1.1	1.2 ± 1.2	2.1 ± 1.2	1.2 ± 2	2 ± 2
South Central	1.1 ± 1	1.9 ± 1.1	1.1 ± 0.8	1.9 ± 1	1.1 ± 0.8	1.8 ± 0.8	1 ± 1.2	1.7 ± 1.2
Central Highland	1.2 ± 0.9	2.1 ± 1.2	1.1 ± 0.8	1.9 ± 0.9	1.1 ± 0.8	1.8 ± 0.8	1.1 ± 1.1	1.8 ± 1.2
South	1.1 ± 0.8	1.9 ± 1	1 ± 0.6	1.7 ± 0.7	1 ± 0.7	1.7 ± 0.7	1.1 ± 0.9	1.7 ± 1
SSP5-8.5								
Northwest	2 ± 1.6	4.6 ± 2.1	1.8 ± 0.9	4.1 ± 1.4	1.9 ± 1.3	4.4 ± 1.6	1.7 ± 1.9	4.1 ± 2.1
Northeast	1.9 ± 1.7	4.5 ± 2.1	1.8 ± 0.9	4.1 ± 1.4	1.9 ± 1.2	4.4 ± 1.6	1.8 ± 2.1	4.2 ± 2.3
Red River Delta	1.9 ± 1.7	4.4 ± 2.1	1.7 ± 0.9	4.1 ± 1.4	1.8 ± 1.2	4.3 ± 1.6	1.8 ± 2.1	4.1 ± 2.3
North Central	1.8 ± 1.7	4.2 ± 2.1	1.7 ± 1	3.9 ± 1.4	1.7 ± 1.2	4 ± 1.5	1.7 ± 2	3.7 ± 2.2
South Central	1.4 ± 1	3.4 ± 1.3	1.4 ± 0.8	3.5 ± 1.3	1.4 ± 0.8	3.3 ± 1.1	1.4 ± 1.2	3 ± 1.4
Central Highland	1.6 ± 1	3.8 ± 1.5	1.5 ± 0.8	3.6 ± 1.3	1.5 ± 0.8	3.5 ± 1.1	1.5 ± 1.2	3.4 ± 1.4
South	1.4 ± 0.8	3.5 ± 1.2	1.3 ± 0.7	3.3 ± 1	1.3 ± 0.6	3.2 ± 1	1.5 ± 0.9	3.3 ± 1.2

Table 2. Projected precipitation change (%) for the seven climatic sub regions by CMIP6-VN model ensemble

Region	DJF		MAM		JJA		SON	
	2040÷2059	2080÷2099	2040÷2059	2080÷2099	2040÷2059	2080÷2099	2040÷2059	2080÷2099
SSP2-4.5								
Northwest	-4.4 ± 2.6	-0.4 ± 2.6	6.2 ± 4.8	8.7 ± 5.1	11.5 ± 2.7	9.9 ± 2.5	-4.4 ± 1.2	5.8 ± 1.3
Northeast	-2.4 ± 2.8	3.2 ± 2.9	4.5 ± 5.1	7.6 ± 5.2	10 ± 3.6	12.2 ± 3.5	-0.1 ± 1.3	7.1 ± 1.3
Red River Delta	-4.6 ± 2.3	0.5 ± 2.5	2.9 ± 4.4	6.3 ± 4.6	8.8 ± 5.5	13.6 ± 5.4	2.4 ± 1	9.2 ± 1
North Central	-5 ± 2.3	-1.8 ± 2.5	4 ± 4.4	7.3 ± 4.6	10.5 ± 9.6	14.9 ± 9.8	4.2 ± 1.7	8.7 ± 1.7
South Central	-4.9 ± 2.5	-6.3 ± 2.7	4 ± 2.7	5.4 ± 2.8	8.2 ± 11.5	10.2 ± 12	8 ± 4.1	28.4 ± 5.4
Central Highland	-7.8 ± 2.5	-7 ± 2.8	5.8 ± 4.4	8 ± 4.5	12.1 ± 5.9	15.5 ± 6.1	10.8 ± 1.6	30.7 ± 2
South	-10.1 ± 2.4	-15.5 ± 2.5	5.4 ± 3.4	7.4 ± 3.6	8.4 ± 3.6	10.5 ± 3.8	4.5 ± 1.1	24.6 ± 1.3
SSP5-8.5								
Northwest	-5.4 ± 2.6	3.4 ± 2.8	6.2 ± 5	13.6 ± 5.7	14.5 ± 2.7	18.7 ± 2.9	2.6 ± 1.3	-0.5 ± 1.3
Northeast	-2 ± 2.8	5.2 ± 3	5.2 ± 5.1	10.8 ± 5.9	14.2 ± 3.6	21.7 ± 4	10.4 ± 1.5	-0.4 ± 1.3
Red River Delta	-3.1 ± 2.4	2.8 ± 2.6	3.9 ± 4.6	7.5 ± 5.1	15.6 ± 5.6	27.1 ± 6.3	15.7 ± 1.2	-1.1 ± 1
North Central	-5.6 ± 2.4	-3 ± 2.5	2.3 ± 4.4	7.6 ± 4.9	13.6 ± 9.7	23.8 ± 10.8	10.2 ± 1.7	0.1 ± 1.7
South Central	0.4 ± 2.9	-12.8 ± 2.5	-2.5 ± 2.7	2.5 ± 3	5.5 ± 10.9	10.3 ± 12.1	12.7 ± 4.5	8.8 ± 4.9
Central Highland	-1.1 ± 2.8	-12.6 ± 2.8	2.6 ± 4.3	9.3 ± 4.8	14.1 ± 5.8	22.2 ± 6.5	18.2 ± 1.8	11.4 ± 1.9
South	-5.4 ± 2.6	-20.6 ± 2.6	3 ± 3.5	7.6 ± 3.9	9 ± 3.6	14.3 ± 4.1	19.2 ± 1.2	-1.7 ± 1.1

-20.6% (SSP5-8.5) in the Southern regions, while simultaneously increasing by 3.2% (SSP2-4.5) and 5.2% (SSP5-8.5) in the Northeast region. In contrast, the trend of increasing rainfall is quite distinct for the other seasons during both the mid and late-century periods. Among these seasons, JJA exhibits the most substantial increase in rainfall, followed by MAM, and finally SON. Notably, Central Coast and Central Highland emerge as two regions with the most pronounced prediction increase in rainfall towards the end of the century, with rainfall projected to rise by 30.7% and 28.4% in SON under the SSP2-4.5 scenario, respectively.

4. Conclusion

This study uses high-resolution temperature and precipitation data from 25 models in the CMIP6-VN dataset to investigate climate changes in Vietnam during the mid and late 21st century. The findings reveal a consistent trend of increasing average temperature, with projections showing an average rise of 2.3^0 (SSP2-4.5) and 4.3^0 (SSP5-8.5) by the end of the century. The models closely match observational data during the reference period, displaying relatively low historical uncertainty but increasing uncertainty towards the end of the century. Temperature warming becomes evident from the mid-21st century onwards, with the Northern regions, particularly the Northwest, experiencing the most significant increase. Rainfall variability also rises towards the end of the century, although not as prominently as temperature. The study emphasizes temperature differences between Northern and Southern regions, with the Northwest experiencing the highest temperature rise and the Southern region the least. Regarding rainfall, a reduction is observed during DJF and an increase in other seasons during the mid-century period. The research provides valuable insights for policymakers addressing the impacts of climate change in Vietnam, highlighting the need for continued monitoring and further research to improve climate projections.

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Contributions of authors

Quan Anh Tran - Conceptualize the research, organise the research works, run simulation, writing manuscript, review & editing; Ngoc Hong Thi Nguyen - write methodology & discuss the results; Hai Thi Do - doing paperworks, discuss the results; Huong Thu Thi Tran - writing & revision. All authors have thoroughly reviewed and approved the final manuscript

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