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Changes in weather conditions in the near futureon the Cau River basin in Northern Vietnam using a Downscaling Method

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ABSTRACT
A complete and appropriate set of historical and future climate data is a necessary condition to research the impacts of climate change on a specific basin. In this study, daily temperature and precipitation data for the near future (up to 2040) were obtained using the BCSD downscaling method based on CMIP6-SSPs global forecast model scenarios. Overall, the results imply that the basin will be hotter and drier in the near term, which could cause potential problems related to agricultural activities and water consumption. At the same time, these findings can provide further information and support for further investigations leading to practical adaptation strategies in the context of the climate emergency.
Keywords: *BCDS Method, CMIP6, SSPs, The Cau River Basin*

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I. INTRODUCTION

The earth is getting warmer. The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) indicates that the global average surface temperature has increased by 0.85°C between 1880 and 2012. To assess the impacts of global warming on natural and human systems as well as prepare for climate change adaptation and mitigation measures, information on future climate in developing countries is needed. different spatial scales, including local and regional.

The Coupled Model Intercomparison Project (CMIP) is an international experimental procedure coordinated by the World Climate Research Program (WCRP) to study the output of atmospheric general circulation models. -ocean combined. In CMIP6, a large number of climate models and projections are available for a historical simulation and four future scenarios of SSP representing different socio-economic pathways of land use and emissions. greenhouse based on estimated future radiation through the end of the 2100th century.

Global climate models (GCMs) are powerful tools that provide future climate scenarios to quantitatively assess the impacts of climate change. The information produced by GCMs can effectively explain climate processes and interactions within and between different components of the climate system. However, for local to regional scale needs, GCM output is generally insufficient to provide accurate information due to inadequate horizontal resolution (typically at 100-300 km). Although the quality of GCMs continues to improve with advances in climate science and technology over time, their spatial resolution is still often too coarse. Downscaling is an attempt to bridge the gap between local and global information by overlaying local-scale data onto coarse-scale GCM. Such an attempt can be made using various techniques, including dynamic and statistical types of downscaling. With the increasing availability of GCM families, the use of statistical downscaling across climate model ensembles has become widespread. Previous studies have shown that statistical methods are not only easily implemented but also very ingenious, comparable to kinetic downscaling methods. Among those methods, the bias-corrected spatial disaggregation method is considered one of the most reliable and effective methods for downscaling high-resolution temperature and precipitation data. BCSD has been widely applied in climate-related impact assessment studies in many parts of the world.

Admittedly, there are no studies on the use of downscaling tools (e.g., SDSM) to generate climate change scenarios in the Cau River basin as well as other river basins in Vietnam. It should be noted that most hydrological and hydrological modeling tools, for example, SWAT, IHACRES, Precipitation Runoff Modeling System (PRMS), Integrated Catchment Modeling (CATCHMOD), River analysis by Hydrological Engineering Center (HEC-RAS), MIKE, etc. , historical and future climate data are needed as key inputs to assess the impacts of climate change on water resources at the river basin scale. Therefore, there is an urgent need to construct future daily climate data at individual meteorological stations by applying a downscaling approach.

II. MATERIAL AND METHODS

2.1 Study area

The Cau River Basin (CRB) of the Thai Binh River system is one of the longest rivers in Northern Vietnam and is also one of the important river basins with a special geographical location as well as unique and diverse. resource diversity and the history of socio-economic development of localities in the region. The basin is limited by geographical coordinates: 21007' - 22018'N, 105028' - 106008'E. Cau River is the most important tributary of the Thai Binh river system - the second largest river system in the North of Vietnam after the Red River system. The river flows in the North-South direction starting from the high mountain area of Bac Kan province, then passing through the provinces of Thai Nguyen, Bac Giang, Bac Ninh, Vinh Phuc, and the North of Hanoi downstream.

The terrain in the basin varies from an altitude of approximately 1,000 m in the surrounding mountain ranges in the West, North, and Northeast regions to the plains in the central and southern regions with elevations of less than 10 m, alternating with The hills are 200 to 400m above sea level.

The river basin has the basic characteristics of the tropical monsoon climate of Northern Vietnam, which is considered the key characteristic that regulates the development direction of the ecosystem. On the other hand, cold winters are an anomaly that has disrupted the typicality of tropical climates, leading to limitations in the development of pure tropical ecosystems. However, on the other hand, it contributes to creating climate diversity and is a premise for the development of a rich ecosystem that typical tropical or temperate regions often do not have.

- The annual air temperature of the river basin ranges from 18 - 230C on average, Tam Dao and Cho Don regions have the lowest temperature at 18 - 200C, and the downstream areas of Vinh Yen, Bac Giang, Hiep Hoa, Tan Yen,... are areas with high temperatures from 23 - 240C.

Table 1. Monthly average, maximum, and minimum air temperature during the observation period at meteorological stations in the basin (unit ^{0}C)

	Station	Factor	Month											
			I	II	II	IV	V	VI	VII	VIII	IX	X	XI	XII
1	Bac Kan	Tmax	19.1	20	23.2	27.3	31.1	32.3	32.4	32.4	31.4	28.7	25.1	21.7
		Tmin	12.1	13.7	17	20.3	22.7	24.2	24.4	24.1	22.5	19.7	15.9	12.6
2	Dinh Hoa	Tmax	19.5	20.1	23.2	27.1	31.3	32.7	32.7	32.5	31.7	28.9	25.3	21.9
		Tmin	13	14.3	17.5	21	23.5	25.2	25.2	24.7	23.3	20.5	16.5	13.3
3	Thai Nguyen	Tmax	19.7	20.3	22.9	27	31.3	32.7	32.4	32.4	31.6	29.1	25.7	22.2
		Tmin	13.7	15	17.8	21.3	21	25.5	25.2	25.2	24.1	21.3	17.6	14.6
4	Bac Ninh	Tmax	19.4	20.1	22.9	26.7	31	32.5	21.7	31.7	30.7	28.5	25.1	21.8
		Tmin	13.7	15.3	18.2	21.4	24.3	26.1	25.9	25.9	24.8	22	17.8	15.1

- The average air humidity measured over many years in areas located in the basin ranges from about 81 - 87%, in mountainous areas where there are many trees and forests, and when there is a lot of rain, the humidity is higher.

- Circulation: The Cau River basin belongs to a region with a tropical monsoon climate, the year is divided into two very distinct seasons: summer is hot, humid, and has a lot of rain, winter is cold, dry, and rarely rains. rainy.

- Rainfall: The average annual rainfall in the Cau River basin is average, fluctuating between 1,700 - 2,000mm. Rainfall distribution in the basin is uneven and divided into two distinct seasons: May to October is the most obvious rainy season, and the basin's rainfall accounts for 75 - 80% of the total rainfall of the year.

In the basin, the main river tributaries are distributed quite evenly along the direction of the mainstream of the Cau River, however relatively large tributaries are all located on the right bank of the basin such as the rivers: Cho Chu, Du River, Cong River, Ca Lo,... In the entire basin, there are 68 rivers and streams with a length of 19km or more with a total length of about 1,600km, there are 13 rivers and streams with a length of about 15km or more, and 20 rivers and streams with large areas more than 100km2. The Cau River is the mainstream of the Thai Binh river system, flowing through the provinces of Bac Kan, Thai Nguyen, Bac Giang, Bac Ninh and then flowing into the Thai Binh river at Pha Lai. The length of the main river up to Pha Lai is 288.5 km.

2. Methods of use

2.1 The BCSD method

The bias correction and spatial distribution (BCSD) technique, originally developed by Wood et al. (2002) has been widely used to produce high-resolution precipitation and temperature data while effectively reducing climate biases in GCMs. In the study, the author applied the BCSD method to obtain daily climate data sets over the Cau River basin from the output of GCM-CMIP6.

The BCSD downscaling process can be divided into two main stages, which are bias correction and spatial disaggregation. In the first stage, biases in the monthly output of the GCM, which were gridded to the same 1° × 1° intermediate resolution, were corrected by mapping the quantiles to the same probability from the GCM simulation data into the OBS data set data. In the second stage, spatial decomposition was adopted to spatially translate the BC-GCM data from an intermediate resolution of 1° × 1° to a targeted high resolution of 0.1° × 0.1°.

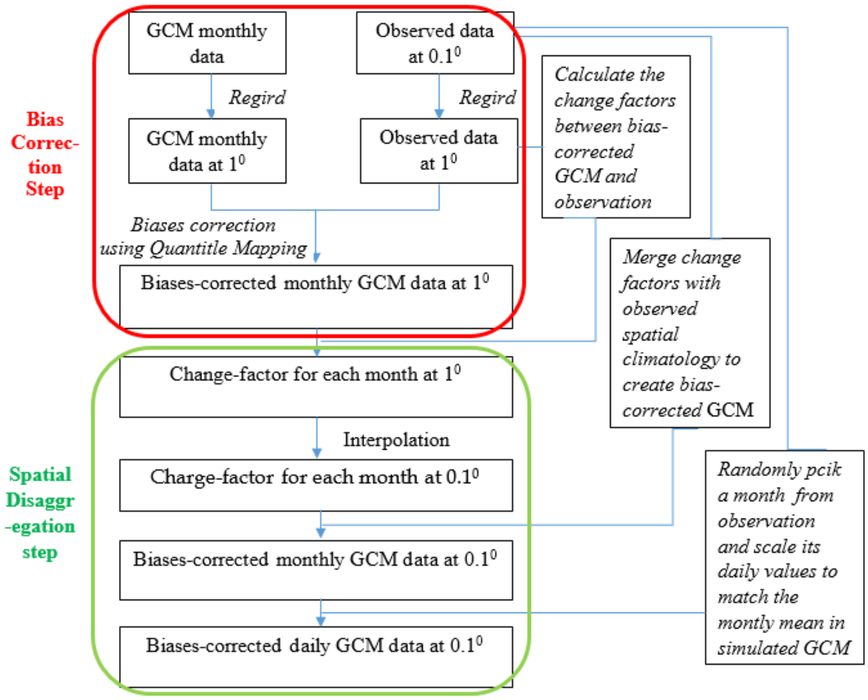

Figure 1. The major steps of BCSD downscaling

2.2.2 Performance Evaluation Index

Satellite weather data (including temperature and precipitation) obtained from downscaled GCM models need to be checked for accuracy. For evaluation, the statistical index correlation coefficient (CC) was used. The calculation formula of this index is as follows:

$$CC = \frac{\sum_{i=1}^{n}(O_i - \bar{O})(G_i - \bar{G})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}\sqrt{\sum_{i=1}^{n}(G_i - \bar{G})^2}}$$

where Gi and Oi are the marked and observed temperature (or precipitation), respectively; and mean G are mean temperature and observed temperature (or precipitation), respectively; "i" represents each measurement; and "n" is the number of measurements.

For climate data, weather data series from 1985 to 2014 including daily air temperature (maximum, minimum), average daily precipitation collected at 5 rain gauge stations, 4 air stations (Bac Kan, Dinh Hoa, Thai Nguyen, and Bac Ninh) in the basin. In addition, data on daily temperature and precipitation according to two SSPs (SSP2-4.5, 5.85 corresponding to the two average and highest threshold scenarios) in the short term (up to

2040) are taken at the stations. In this case, 5 additional grid points through the use of the BCSD method and a set of GCM-based predictors are retrieved from these grid points. Weather data files are classified into weather variables: precipitation, and air temperature. Then, the author creates a location table and data table for each weather variable. As for flow data, due to limited data, the study only collected time series of daily flow data from 1997 to 2013 at Gia Bay hydrological station.

Table 2. Information on the GCM-CMIP6, and SSPs availability used in this study

Models	Institute	Spatial resolution (degree)	Emission Scenarios	Variable	Historical-Future period
CNRM-ESM2-1	National Institute of Meteorology, France	0.5×0.5	SSP4.5 and 8.5	Pr, T2m, Tmax, Tmin	1985-2014; 2021-2100
EC-Earth3	EC-Earth consortium, Europe	0.375×0.375	SSP4.5 and 8.5	Pr, T2m, Tmax, Tmin	1985-2014; 2021-2100
GFDL-ESM4	NOAA/Geophysical Fluid Dynamics Laboratory	1.0×1.0	SSP4.5 and 8.5	Pr, T2m, Tmax, Tmin	1985-2014; 2021-2100
HadGEM3-GC3-1-LL	Met Office Hadley Center	2.0×1.125	SSP4.5 and 8.5	Pr, T2m, Tmax, Tmin	1985-2014; 2021-2100
MPI-ESM1-2-HR	Max Planck Meteorological Institute, Germany	1.0×1.0	SSP4.5 and 8.5	Pr, T2m, Tmax, Tmin	1985-2014; 2021-2100

III. RESEARCH RESULTS

3.1 Relationship between GCM and in situ observational data

To limit possible errors between GCMs and in situ ground data (such as monthly precipitation and temperature), GCM results are first compiled using the BCSD method, and then compared with the data. Data from local climate stations during the period 1985-2014.

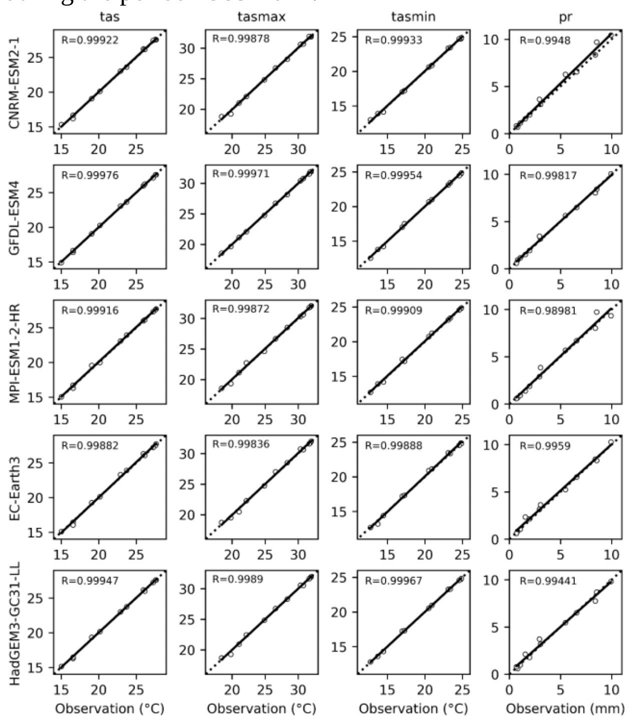

Figure 2. GCMs monthly mean temperature and accumulated precipitation from 1985 to 2014 at the Thai Nguyen climate station

Based on the locations of all points on the scatter plot, it can be seen that the BCSD method produces similar mean monthly temperature and mean monthly precipitation output at all GCMs at the observing station in the basin. Performance results of all applied GCMs (CNRM-ESM2-1, EC-Earth3, GFDL-ESM4, HadGEM-GC31-LL, MPI-ESM1-2-HR) show relatively higher correlations with observational data on average monthly temperatures. The GCM accuracy is mostly greater than 0.99 over the selected period 1985-2014, showing identical accuracy in both mean temperature, Tmax and Tmin. However, in most GCM tests, the R2 value of average temperature and Tmin is slightly higher than Tmax (except for Tmax in GFDL-ESM4 which is higher than Tmin but still lower than the average temperature). average), which implies that the amplitude of the BCSD variation of Tmax is slightly wider than that observed at the measuring station.

The correlation results of all GCMs applied in the Cau River basin show that the uncertainty of precipitation is larger than that of temperature. The correlation coefficient of cumulative observed monthly precipitation (mm/day) and GCMs data shows values between 0.994 and 0.998 during this period. Overall, the R2 coefficient shows that the synthesis of BCSD-corrected GCMs shows that this approach produces approximately similar and reasonable results for each climate variable at a sample of midpoint observations. basin.

3.2 Changes in annual temperature and precipitation

Future scenarios were downgraded for three climate variables (rainfall, Tmax, and Tmin) to detect the general trend for the period 1985-2040 in the Cau River basin as shown in Figures 3 and 4. Overall, the observations found in both SSP2-4.5 and SSP5-8.5 recorded a significant increase in mean maximum and maximum temperatures over the whole period. However, future SSP2-4.5 has an increasing trend for Tmax and Tmin, while SSP5-8.5 has a decreasing trend. The same thing happened for the average annual rainfall, with an increasing trend for SSP2-4.5 and a slightly decreasing trend for SSP5-8.5 over the whole period.

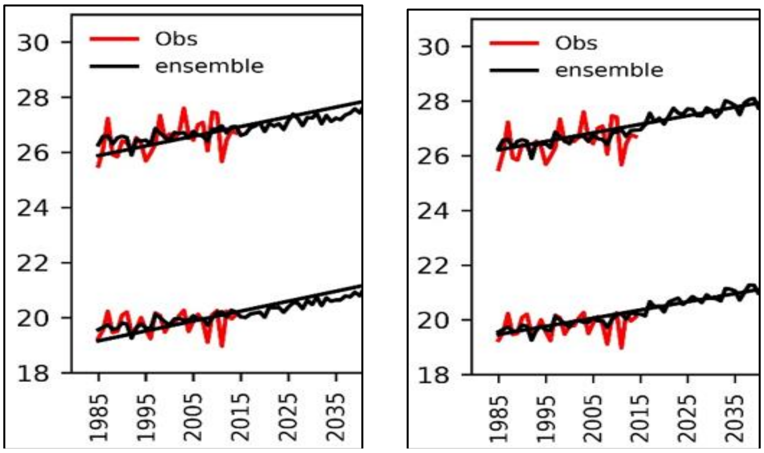

Figure 3. Future trends of (a) SSP2-4.5 and (b) SSP5-8.5 Tmax and Tmin mean annual temperatures

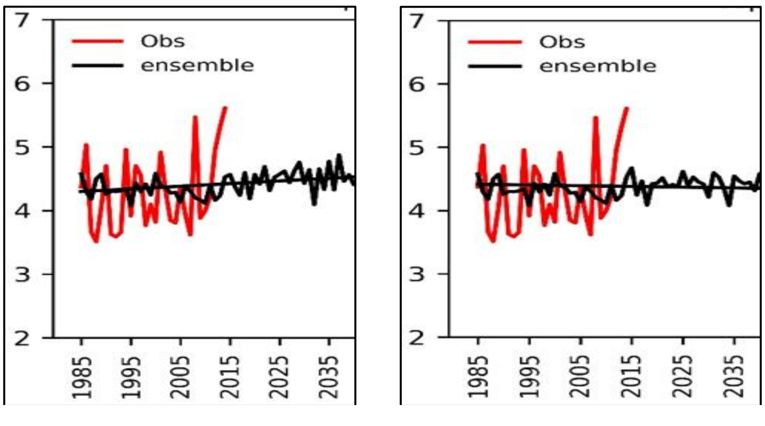

Figure 4. Future trends of (a) SSP4.5 and (b) SSP8.5 total mean annual rainfall (1985-2040)

In contrast to Tmax and Tmin, some differences were detected in the annual precipitation forecasts at the corresponding stations in the SSP. The results shown in Figure 4 show an increasing trend at all stations in the basin shortly (2030s) and mid-future (2060s) and the final future (2080s). Significant increases of 2.1-4% and 7.8% for the years 2030 and 2060, respectively, are found in the SSP2-4.5 scenarios at most stations, while SSP5-8.5 shows the opposite trend . The general trend shows a decline in average annual precipitation in the far future period (the 2080s) with a decrease of 4.6%, 3.3%, 3.8%, and 4% over the period. References in Bac Kan, Dinh Hoa, Thai Nguyen, and Bac Ninh. Therefore, the characteristics of the future precipitation forecast for SSP2-4.5 show a steady increase over time, while SSP5-8.5 tends to make less difference until mid-century but low rainfall forecast in the future period. It is noteworthy that several previous studies indicate an increasing trend in annual rainfall over the Cau River basin by applying bias correction methods, different from those found in this study. To a certain extent, these findings reflect differences in future daily precipitation forecasts.

Overall, uncertainty in climate projections is mainly due to internal climate variability, downscaling methods and tools, and the input data used (including variables). observations and forecasts based on GCM). This study uses a set of predictors derived from the SSP2-4.5 and SSP5-8.5 models. Other scaling methods (e.g., bias correction, LARS-WG, ASD, or artificial intelligence approaches) should also be applied in conjunction with BCSD. Another suggestion is to use more than one set of potential forecasts for each climate variable at individual stations to obtain the range of climate variability that may occur in future periods.

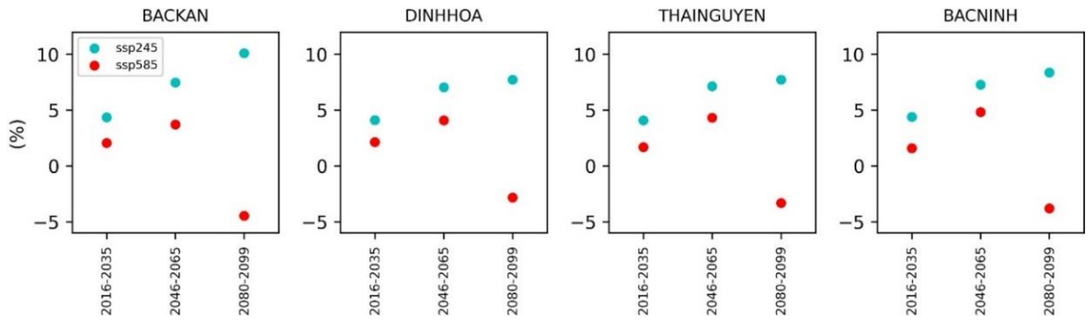

Figure 5. Projected change in average annual rainfall in the 2030s (representing the near future period 2015-2040) when compared with the period between the middle (2060) and the end of the 21st century (2080) according to the SSP scenario

IV. DISCUSSION

According to climate change scenarios, in the future, the Cau River basin will decrease overall rainfall and increase temperature in all time periods under the two SSP scenarios. These conditions can cause problems such as water shortages across the basin. In addition, there will be a significant impact of climate change on the water balance of the basin. The resulting processes tend to decrease over time and the scenarios are evapotranspiration, surface runoff, baseflow and water yield.

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