Current and projected climate change in the Mekong Delta

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Abstract:

This article evaluates trends in past and projected future climate change at the Mekong Delta. The study is based on updated observation data gathered up to 2014, and the latest climate change scenarios published by the Ministry of Natural Resources and Environment (MONRE). The results show that the mean annual temperature increased by 0.3 to 0.9°C, and annual rainfall increased by 5 basis points to 20% at most observation stations during the years 1958-2014. In comparison to the baseline (1986-2005), temperatures were projected to increase by between 1.3 to 1.4°C in the middle of the century and by between 1.7 to 1.9°C at the end of the century, under the medium scenario (RCP4.5). According to the high scenario of RCP8.5, temperatures likely increased by 1.8 to 2°C in the middle of the century and 3.4 to 3.6°C at the end of the century. Annual rainfall is expected to increase from 10 to 20% in the mid-21st century under both RCP4.5 and RCP8.5 scenarios; increase of 30% in a part of the northern Mekong Delta under the RCP8.5 scenario.

Keywords: ***climate change, Mekong Delta, projected climate, rainfall, temperature.***

Classification number: *6.2*

Introduction

The Mekong Delta is the largest river delta in Vietnam, located in the Mekong River Basin with a total natural area of about 3.96 million ha. This delta has a coastline ranging over 700 km, contiguous to Cambodia in the northwest, to South Vietnam in the east, to the East Sea in the northeast, to the Pacific Ocean in the south, and to the Gulf of Thailand in the west [1]. This region is favourable to marine economic development, exploitation, aquaculture, and consumption and export. The Mekong Delta is the largest agricultural development area in the country, contributing considerably to the region's total food production. However, due to its low elevation and flat terrain, as well as its location within tropical monsoon climates, this area is vulnerable to climate change [1].

In addition to this, freshwater resources in the Mekong Delta are strongly influenced by hydropower dams in the Mekong River System, especially during the dry season. Typically, severe droughts and saltwater intrusion from late 2015 to early 2016 in the Mekong Delta was caused by a prolonged El Nino phenomenon. According to the Intergovernmental Panel on Climate Change (IPCC), the Mekong Delta is one of three deltas classified to have extreme vulnerability of impact from sea level rise caused by climate change; this list also includes the Ganges River Delta of the Brahmaputra River (Bangladesh) and Nile River (Egypt) [2].

There have been a number of studies into the effects of climate change in the Mekong Delta since the 1990s [3, 4]. In recent years, the assessment of the impact of climate change, as well as its consequences, has been investigated by many authors [2, 5-15]. However, most of these studies assess the impact of climate change according to national scales, and the Mekong Delta is the only part of the assessments. In general, most research is primarily based on the IPCC's Greenhouse Gas Emission Scenario, published in 2007 [5, 6, 11, 12, 14]. In 2016, MONRE has updated the impact assessment of climate change and climate change projections at the national scale based on updated data (till 2014) and a new approach from Representative Concentration Pathways - RCPs announced by IPCC in 2013 [7].

The purpose of this study is to calculate, analyse, and evaluate trends in climate change ranging from the past to projected impacts at the Mekong Delta, based on the latest climate change studies from MONRE and IPCC. This study will update important information about climate change for use to assess the impact and vulnerability of the Mekong Delta to climate change.

Data and methodology

Data

Observation data:

Observation data includes datasets of climatic variables gathered from 1958-2014 at 11 stations in the Mekong Delta: Moc Hoa, My Tho, Cao Lanh, Ba Tri, Cang Long, Chau Doc, Can Tho, Soc Trang, Rach Gia, Bac Lieu, and Ca Mau.

Model data:

The models used for constructing climate change scenarios include: (i) the AGCM/MRI model of Meteorological Research Institute in Japan, (ii) the PRECIS model of Met Office Hadley Centre in UK, (iii) the CCAM model of the Commonwealth Scientific and

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Industrial Research Organization (CSIRO) in Australia, (iv) the RegCM model of the Abdus Salam International Centre for Theoretical Physics (ICTP) in Italia, (v) and the clWRF model of National Centers for Environmental Prediction (NCEP) in USA. These models were used to simulate the regional climate in the baseline period (1986-2005) and projected regional climate at the middle (2046-2065), and at the end (2080-2099) of the 21st century (Table 1).

Table 1. Models used for constructing climate change scenarios.

No.	Models	GCMs	Resolution	Available Data Period			
				Baseline	*RCP4.5*	*RCP6.0*	*RCP8.5*
1	CCAM	ACCESS1-0	10 km	1970-2005	2006-2099	x	2006-2099
2		CCSM4					
3		CNRM-CM5					
4		GFDL-CM3					
5		MPI-ESM-LR					
6		NorESM1-M					
7	RegCM	ACCESS1-0	20 km	1980-2000	2046-2065 2080-2099	x	2046-2065 2080-2099
8		NorESM1-M					
9	Precis	HadGEM2-ES	25 km	1960-2005	2006-2099	x	2006-2099
10	CLWRF	GFDL-CM3	30 km	1980-2005	2006-2099	x	2006-2099
11		CNRM-CM5					
12		NorESM1-M					
13	MRI-20km_A	NCAR-SST	20 km	1984-2003	x	x	2080-2099
14	MRI-20km_B	HadGEM2- SST					
15	MRI-20km_C	GFDL - SST					
16	MRI-20km_D	SST					

x: No data.

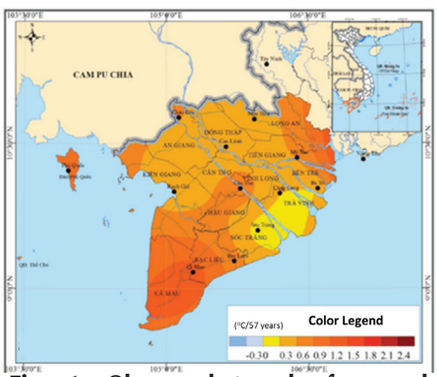

Fig. 1. Observed trend of annual temperature (°C) during the period of 1961-2014.

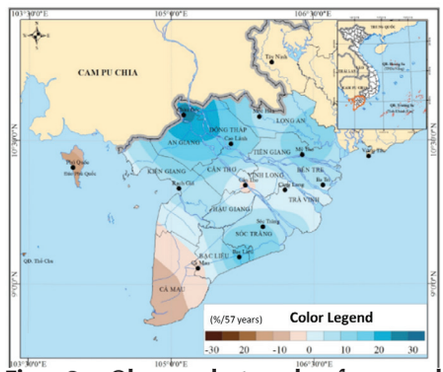

Fig. 2. Observed trend of annual rainfall (%) during the period of 1961-2014.

Methodology

Identify the trends of climate change in the past:

In this study, linear regression was used to identify the trends in climate variables during the period of 1961-2014. Linear regression of a predicted (y) at time (t) can be described as follows:

$$y = a_o + a_1 t$$

$$a_o = \bar{y} - a_1 \bar{t},\ a_1 = r_{yt} \frac{s_y}{s_t}$$

$$s_y = \sqrt{\sum_{i=1}^{n} (y_i - \bar{y})^2},\ s_t = \sqrt{\sum_{i=1}^{n} (t_i - \bar{t})^2}$$

In which $\bar{y}$, $\bar{t}$ are means, and S_y, S_t are standard deviations of y and t, respectively; r is linear correlation coefficient between y and t. The increased and decreased trends of *y(t)* are identified by the slope a_1.

Climate change projections:

Projected climate change was calculated based on the ensemble method of 16 members derived from 16 models in Table 1. The variability of variables was defined as follows:

- Determine the magnitude of changes in temperature (°C):

$$\Delta T_{future} = T^*_{future} - \overline{T^*_{1986\text{-}2005}}$$

- Determine the magnitude of changes in rainfall (mm):

$$\Delta R_{future} = \frac{\left(R^*_{future} - \overline{R^*_{1986\text{-}2005}}\right)}{R^*_{1986\text{-}2005}} * 100$$

In which: ΔT_{future} is the difference between future temperature and the temperature taken at the baseline period (°C), T^*_{future} is the future temperature (°C), $T^*_{1986\text{-}2005}$ is the average temperature of the baseline period (°C); ΔR_{future} is the difference between the rainfall in the future and the rainfall at the baseline period (%), R^*_{future} is the future rainfall (mm), $R^*_{1986\text{-}2005}$ is the rainfall in the baseline period (mm).

Results and discussions

Climate change in the past

Temperature:

The annual average temperature had an increasing trend across the Mekong Delta, with increases of 0.3 to 0.9°C during the period of 1958-2014. The increasing trend in temperature at the southern areas increased faster than that of the areas in the north, except for a portion in the northeast region of the Mekong Delta (Fig. 1).

Rainfall:

Annual rainfall increased by 5 to 20% in the period from 1958 to 2014 in the majority area of the Mekong Delta. As well, there was a decrease of less than 10% in rainfall over the southern

region (Can Tho and Ca Mau, Fig. 2).

Climate extremes:

Daily maximum temperature (TXx) has been seen to vary heterogeneously, and some stations had a slightly increasing trend, while others had a decreasing trend (Soc Trang, Can Tho, Cao Lanh, Rach Gia, and Ca Mau). In contrast, daily minimum temperature (TNn) increased at most of the stations, with increases at a range from of 0.01°C/10 years (at My Tho station) to 1.36°C/10 years (at Chau Doc station). Along with a decreasing trend at TXx, the number of days with the high temperatures of over 35°C (SU35) decreased at most stations in the Mekong Delta. Heavy rainfall increased more than average rainfall. The maximum 1-day rainfall (Rx1day), the maximum 5-day rainfall (Rx5day), and the number of days with precipitation exceeding 95% (R95P) had increases in most localities. Dry conditions appeared more and more often, especially during the dry season.

Climate change projections

Changes in the mean values of climate variables:

Changes in average temperature at the middle and the end of the century, in comparison to those of the baseline period, are presented in Fig. 3 and 4. The figures exhibit the most likely increases in temperature across the whole Mekong Delta. The increasing temperatures seen in the provinces of the Mekong Delta are quite similar to each other; however, the increasing rate of temperatures is slightly higher in the parts of the northeastern and southern Mekong Delta.

- Temperature:

According to the RCP4.5 scenario, the annual average temperature likely increases by 1.3 to 1.4^{0}C in the middle of the century (Fig. 3A) and 1.7 to 1.8^{0}C at the end of the century (Fig. 3B) in comparison to the baseline period.

Under the RCP8.5 scenario, compared with the baseline period, the annual average temperature likely increases by 1.8 to 2.0^{0}C in the middle of the century (Fig. 4A) and 3.4 to 3.6^{0}C at the end of the century (Fig. 4B).

- Rainfall:

According to the RCP4.5 scenario: When compared to the baseline period, annual rainfall at the mid-21st century will likely increase by 0 to 20% with increases in rainfall over the Northern Delta (e.g. Long An, Dong Thap, Tien Giang, and Ben Tre, seen in Fig. 5A). At the end of the 21st century, an increase in rainfall is typically 10 to 20%; and the

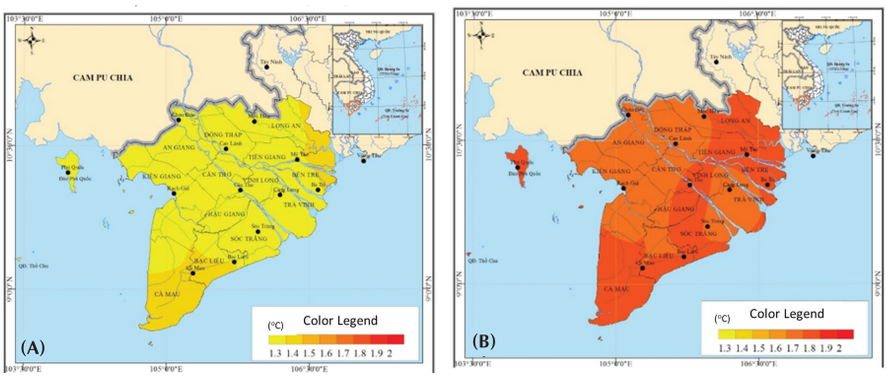

Fig. 3. Projected changes in annual temperature (°C) for the middle (A) and the end (B) of 21st century compared to the baseline period under RCP4.5 scenario from an ensemble of models.

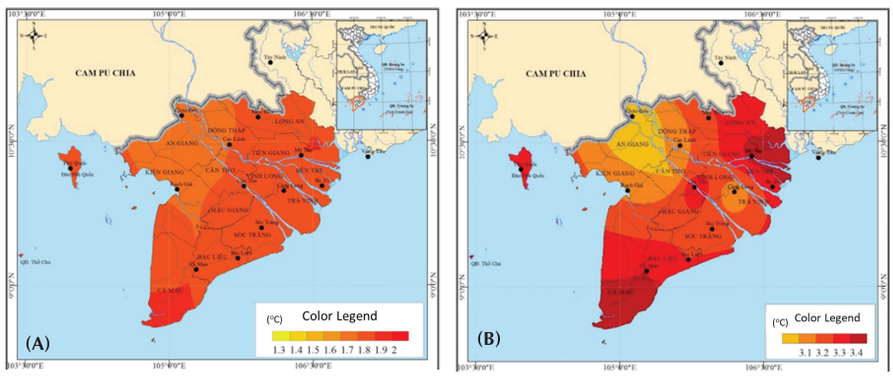

Fig. 4. Projected changes in annual temperature (°C) for the middle (A) and the end (B) of 21st century compared to the baseline period under RCP8.5 scenario from an ensemble of models.

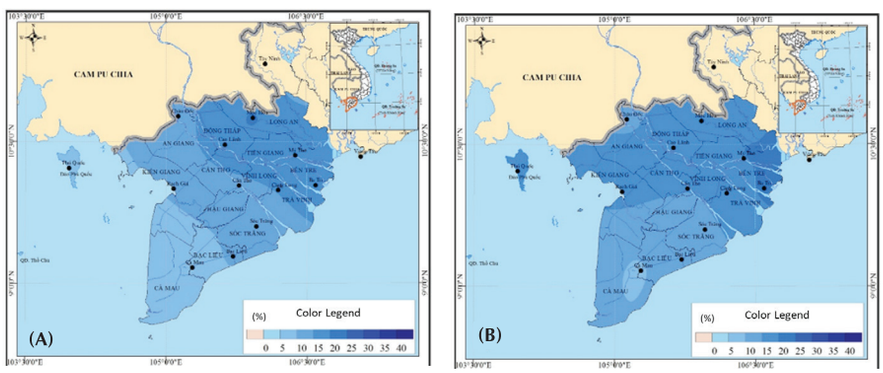

Fig. 5. Projected changes in annual rainfall (%) for the middle (A) and the end (B) of 21st century compared to the baseline period under RCP4.5 scenario from an ensemble of models.

Northern provinces will have a higher increase in rainfall (Fig. 5B).

According to the RCP8.5 scenario: Compared to the baseline, rainfall in the mid-21st century will likely increase by 10-20% (Fig. 6A). By the end of the 21st century, annual rainfall will likely increase higher than that of the mid-century, with a typical increase of 10 to 30% (Fig. 6B).

Changes in climate extremes:

- Extreme temperature:

Changes in average maximum temperature at the end of the 21st century:

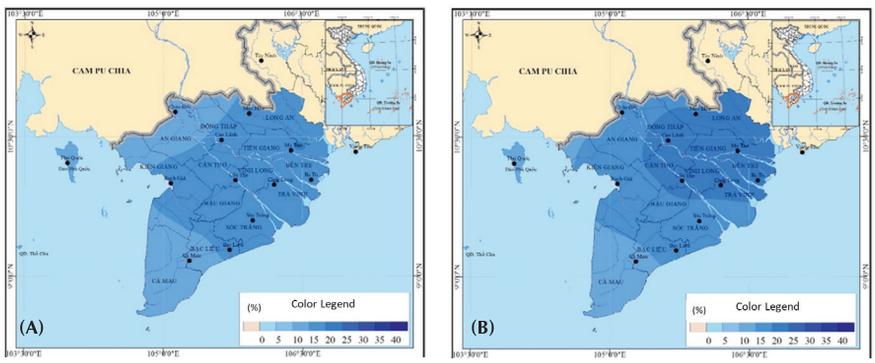

Fig. 6. Projected changes in annual rainfall (%) for the middle (A) and the end (B) of 21st century compared to the baseline period under RCP8.5 scenario from an ensemble of models.

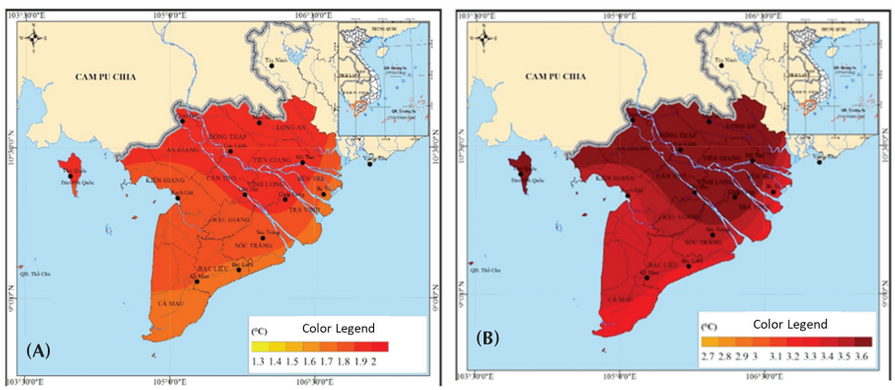

Fig. 7. Projected changes in annual mean maximum temperature (°C) for the end of 21st century compared to the baseline period according to RCP4.5 (A) and RCP8.5 (B) scenarios from an ensemble of models.

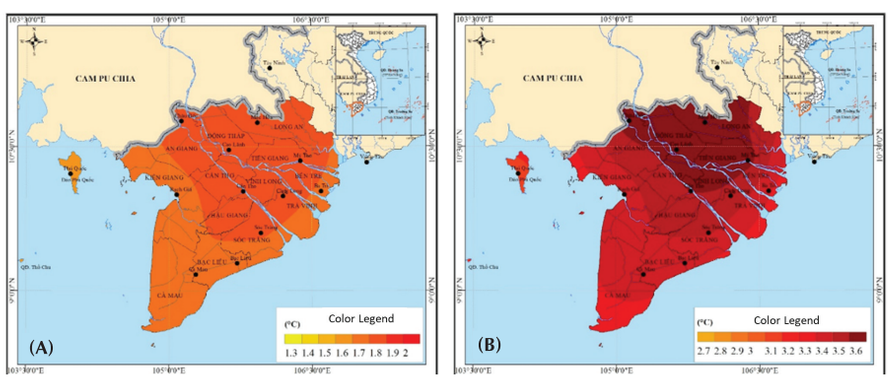

Fig. 8. Projected changes in annual mean minimum temperature (°C) for the end of 21st century compared to the baseline period according to RCP4.5 (A) and RCP8.5 (B) scenarios from an ensemble of models.

Compared to the baseline period, the average maximum temperature will likely increase by 1.8 to 2°C as seen with the RCP4.5 scenario (Fig. 7A), and by 3.5 to 3.8° C as seen with the RCP8.5 scenario (Fig. 7B). Accompanied with an increase of maximum temperature, the number of hot days is likely to increase by 10 to 20 days as predicted by the RCP4.5 scenario or by 20 to 40 days as based on the RCP8.5 scenario by the end of the 21st century.

Change in average minimum temperature at the end of the 21st century: Compared to the baseline period, the average minimum temperature will likely increase by 1.8 to 1.9°C as seen with the RCP4.5 scenario (Fig. 8A) and by 3.4 to 3.6°C as seen with the RCP8.5 scenario (Fig. 8B).

- Extreme rainfall:

Compared to the baseline, the maximum 1-day rainfall (Rx1day) and the maximum 5-day rainfall (Rx5day) are expected to increase in the future. According to the RCP4.5 and RCP8.5 scenarios, Rx1day increased by 10 to

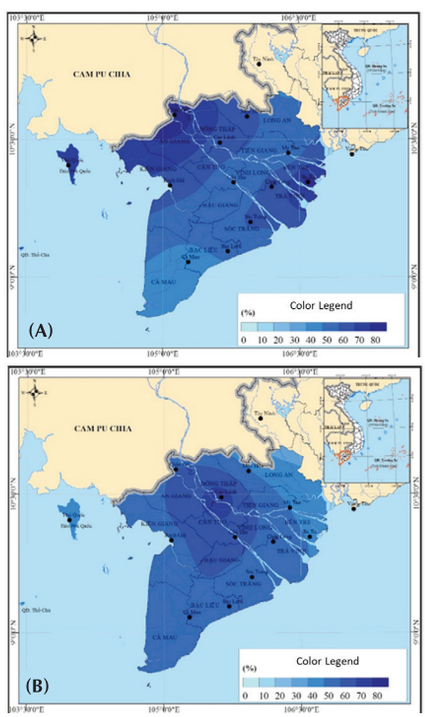

Fig. 9. Projected changes in Rx1day (mm) for the end of 21st century compared to the baseline period according to RCP4.5 (A) and RCP8.5 (B) scenarios from an ensemble of models.

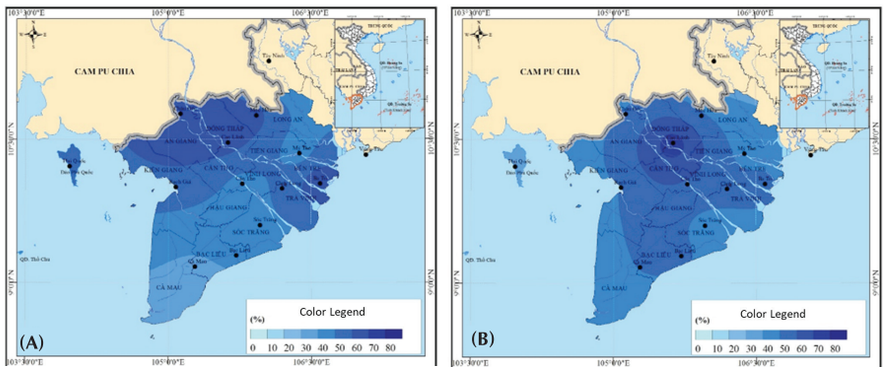

Fig. 10. Projected changes in Rx5day(mm) for the end of 21st century compared to the baseline period according to RCP4.5 (A) and RCP8.5 (B) scenarios from an ensemble of models.

40% and Rx5day increased by 20 to over 40% (Fig. 9 and 10) by the end of the 21st century.

Conclusions

This study presents the results of an assessment of past and projected impacts of climate on the Mekong Delta, based on updated data (up to 2014) and the latest climate change scenarios from the MONRE; the results show that:

1) The indicators of climate change in the Mekong Delta:

The annual average temperature in the Mekong Delta Region increased during the period of 1958-2014, with a typical increase within a range of 0.3 to 0.9°C. In which, the temperature increased higher in localities such as Long An, Hau Giang, Bac Lieu, Ca Mau, and Phu Quoc. Minimum temperature has obviously increasing trends at most stations.

Annual rainfall increased by 5-20% in most provinces of the Mekong Delta during the period of 1958-2014.

2) Climate change projections:

- Temperature: According to the RCP4.5 scenario, the average annual temperature will likely increase by 1.3 to 1.4°C in the mid-21st century and by 1.7 to 1.9°C at the end of the 21st century. According to the RCP8.5 scenario, the average annual temperature will likely increase by 1.8 to 2°C in the mid-21st century and 3.4 to 3.6 at the end of the 21st century. The average maximum temperature increases higher than the average minimum temperature and the increasing trend gradually reduces from northern to southern regions of the Mekong Delta.

- Rainfall: When compared to the baseline period, rainfall based on RCPs (RCP4.5 and RCP8.5) likely increases by 5 to 15% at the middle and at the end of the 21st century, in which the increase in the North is higher than in the Southern Delta. At the end of the century, Rx1day increased by 10 to 40%, while Rx5day increased by 20 to over 40%.

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