Changes in climate extremes in Vietnam

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Abstract:

This study represents the observed and projected changes in climate extremes in the context of climate change. A linear regression method was used to identify trends and variations of climate extremes in the past, while projected changes in climate extremes were detected based on dynamical downscaling and compared with the baseline period (1986-2005). The results show that daily maximum and minimum surface air temperatures (Txx, Tnn) increased considerably with the highest value of about 0.9°C/decade during the period of 1961-2014. The number of hot days increased across most observed stations, especially in Central Vietnam. Trends of extreme precipitation varied among the regions: decreasing across most stations in the Northwest, Northeast and Red River Delta; and increasing at other stations. In Vietnam, over the period 1959-2015, there were no obvious changes in the frequency of tropical cyclones causing landfall events, including typhoons and tropical depressions. However, the rate of occurrence of the very strongest typhoons are currently on the increase. In recent years, typhoon seasons tend to end later than in the past, and typhoons occur more frequently in Southern regions. Predicted results of climate extremes in the future for the periods 2046-2065 and 2080-2099, compared with the baseline period of 1986-2005 under the medium and high scenario (RCP 4.5 and RCP 8.5) show that temperature extremes will likely increase considerably in the future. The number of hot days will likely increase in both frequency and intensity, while the number of extreme cold days will likely decrease at most stations in the North. A maximum 1-day rainfall will also likely increase across all regions in Vietnam. Results from models show that the number of strong typhoons will likely increase in the mid- and late-century.

Keywords: ***climate change, climate extreme.***

Classification number: ***6.2***

Introduction

Vietnam is one of the countries most affected by natural disasters and climate change. Storms and floods are the most frequent of severe natural disasters affecting Vietnam. Annually, extreme disasters cause negative effects on the natural environment, habitat and socio-economic development of Vietnam. Recent studies show that climate extreme events are likely adding more complexity to future issues of climate change [e.g. 1-5]. Climate change is leading to increases in surface temperatures, causing the occurrence of unusual climate extreme events (e.g. increase in drought) [1, 6, 7]. In addition, climate change is one cause of altering climate variations, resulting in extreme events. For instance, the increased rainfall in the rainy season may cause heavy rainfalls.

It is difficult to observe the extreme events caused by changes in climate variations; therefore, these have been defined by their thresholds. The identity of thresholds for extreme events depends on the consequences of their changes; thus, the thresholds differentiate among their respective regions [8]. To identify and quantify extreme events, a climate extreme index (CEI) was introduced in the United States in 1996. Since then, the CEI has been adapted and used by various regions around the world, especially in tropical regions [7]. Besides that, in the IPCC's fourth assessment report (AR4-2007) and fifth assessment report (AR5-2013) [9], the special reports about the managing risks of extreme events and disasters in order to advance climate change adaptation (SREX-2012), showed that the CEI was applied to assess climate extreme events on a global scale [e.g. 5]. In 2009, the world meteorological organization (WMO) announced a guide document designed for use to analyze and evaluate climate extreme events. Based on this guide document, many countries have built climate extreme indexes which are consistent with local climactic conditions. In Vietnam, Nguyen Thi Binh Minh et al. 2015 has proposed climate extreme indexes for monitoring and assessing climate change in Vietnam [10].

A large number of studies of the changes in climate variations and climate extremes have been conducted of Vietnam [1, 2, 4, 6, 9]. In general, these studies have given details and shown the assessment of climate extreme events based on meteorological data gathered up to 2010. These studies exhibited the impacts of climate change on future climate extreme events based on special report on emission scenarios issued by intergovernmental panel on climate change (IPCC). In this study, we focus on the state-of-the-art assessment of recent changes in climate extremes in Vietnam for the period of 1961-2014, and future changes

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in some climate extremes in the context of global warming. The results from this study would benefit Vietnam to improve environment management, socio-economic development, and decision-making. This study has been a source of reliable information for the national report "*Updating on climate change and sea level rise scenarios for Vietnam*".

Methodology

Data

In order to identify trends, long-term data is required for analysis and assessment. To analyze the climate extreme events occurring on short temporal and spatial scales, we generally need daily- or hourly-observed data, long term enough to detect any trends. In Vietnam, there are 174 meteorological observation stations; however, at a majority of those stations in the South, observed data is only available beginning in 1975 and is discontinuous. Therefore, we have only used observed data from stations which meet three criteria: (1) any data missing for a month cannot exceed five consecutive days; (2) across one year, all months must be completed as the first criterion; and (3) for a long-term series that is equal to or more than 65% of the time series, will be completed for years as the second criterion. After evaluating the observed data, 82 stations were chosen to submit data with time series from 1961 to 2014. In addition, the observed data for tropical cyclones derived from the national center for hydro-meteorological forecasting (NCHMF) until 2015 were also used for the assessment.

To assess the changes of climate extremes in the future, the simulated data from numerical model were used including: (i) the atmospheric general circulation (AGC) model of meteorological research institute (MRI) derived from the Japan meteorological agency (JMA), (ii) the providing regional climates for impact studies (PRECIS) model derived from the met office hadley centre - United Kingdom, (iii) the CCAM model derived from the cCommonwealth scientific and industrial research organization (CSIRO) - Australia, (iv) RegCM models derived from the international centre for theoretical physics (ICTP) - Italy and the clWRF model derived from the santander meteorology group - Spain.

Method

In this study, linear regression was used to identify the trends and variations of climate extremes over a month, season or year based on daily observed data. Linear regression of a prediction and (x) at time (t) can be described as follows:

$$x(t) = a_0 + a_1 t \quad (1)$$

$$a_0 = \bar{x} - a_1 \bar{t} \quad (2)$$

$$a_1 = r\frac{s_x}{s_t} \quad (3)$$

in which $\bar{x}$, $\bar{t}$ are means, and s_x, s_t are standard deviations of x and t, respectively; r is linear correlation coefficient between x and t. The increased and decreased trends of $x(t)$ are identified by the slope a_1. Predictors were identified by the climate extreme indices as shown in Table 1.

Table 1. Climate extremes indices.

Indices	Definition	Unit
Number of very hot days (SU39)	Count of days with daily maximum temperature ≥ 39°C	days
Number of hot days (SU35)	Count of days with daily maximum temperature ≥ 35°C	days
Highest maximum temperature (Txx)	Maximum value of daily maximum temperature	°C
Lowest minimum temperature (Tnn)	Minimum value of daily minimum temperature	°C
Number of cold days (CD15)	Count of days with daily mean temperature ≤ 15°C	days
Number of extreme cold days (CD13)	Count of days with daily mean temperature ≤ 13°C	days
Number of heavy rainfall days (R100)	Count of days with daily precipitation > 100 mm	days
Maximum 1-day rainfall (Rx1day)	Maximum value of daily precipitation	mm
Maximum 5-day rainfall (Rx5day)	Maximum value of 5-day accumulated daily precipitation	mm

For the future, we have used simulated models to assess the changes of climate extremes. The changes of climate extremes were assessed by comparing the future trends and variations of climate variables (2046-2065, 2080-2099) with the trends and the variations in the reference period (1986-2005) (referred to as baseline).

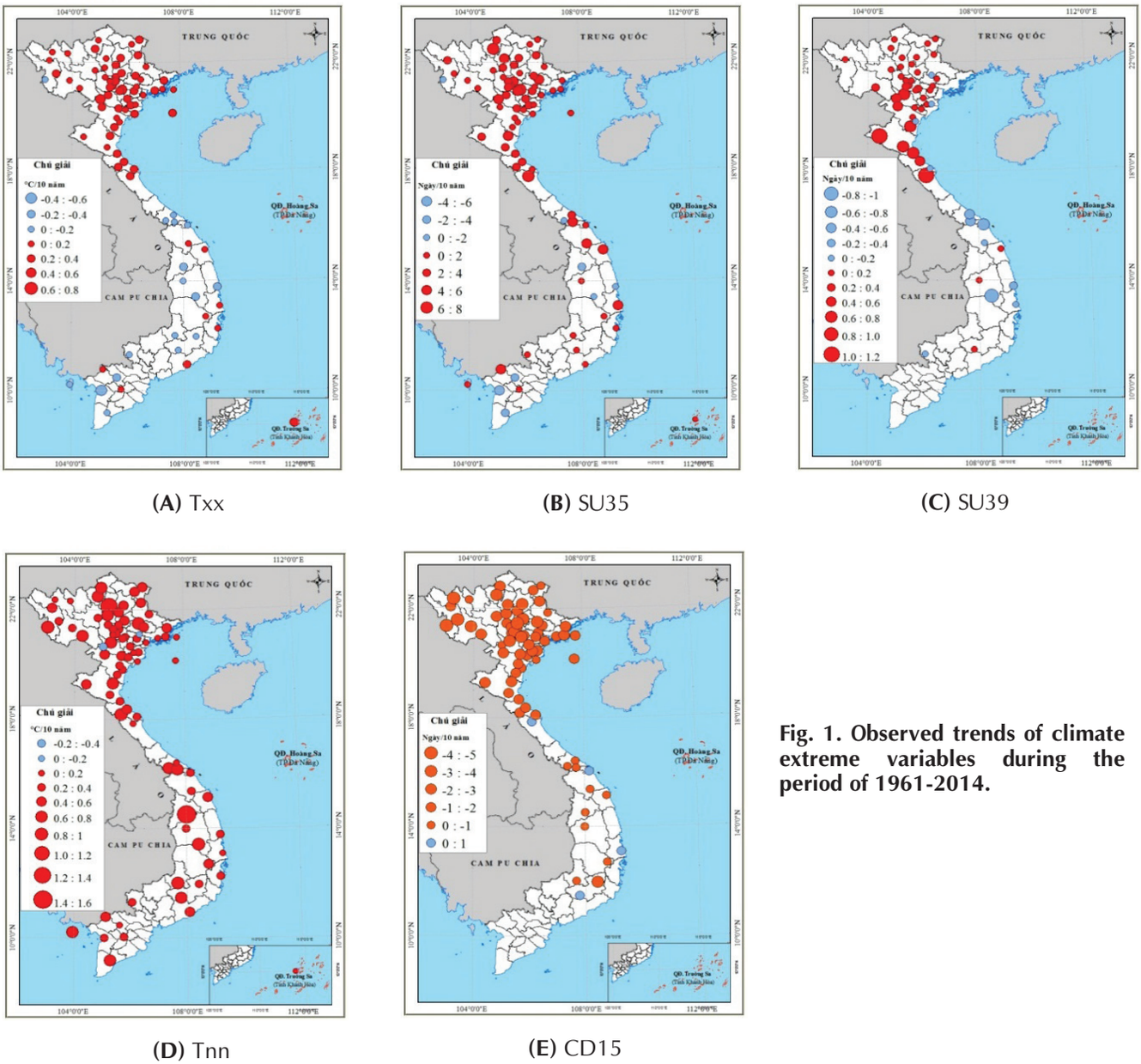
Results and discussion

Observation

Temperature extremes:

In the past half-century (1961-2014), there was an increasing trend in the highest maximum temperature (Txx) at most stations in the North and a decreasing trend in most stations in the South. The highest increasing rates of about 0.9°C/decade (Fig. 1A) were observed in some stations in Northwestern and Northeastern Vietnam. The highest decreasing rates of about 0.8°C/decade were found in some stations in the North Central Vietnam. The increasing trends of SU35 were observed in most stations of Northern Vietnam (North, North Central Coast, and Mid Central Coast) with a regular increase of about 2-6 days/decade. Whereas, the decreasing trends were found in most stations of the Southern Vietnam (South Central Coast, Central Highlands and Mekong River Delta) with a regular decrease of about 2-4 days/decade (Fig. 1B). In most stations in Northern Vietnam (Northwest, Northeast, Red River Delta and North Central Coast), SU39 had increasing trends with regular increases of about 0.2-0.6 days/decade. Decreasing trends were found in most stations of Southern Vietnam with a regular decrease of about 0.4-0.8 days/decade (Fig. 1C).

The trend of the lowest minimum temperature (Tnn)



(A) Txx **(B)** SU35 **(C)** SU39

(D) Tnn **(E)** CD15

Fig. 1. Observed trends of climate extreme variables during the period of 1961-2014.

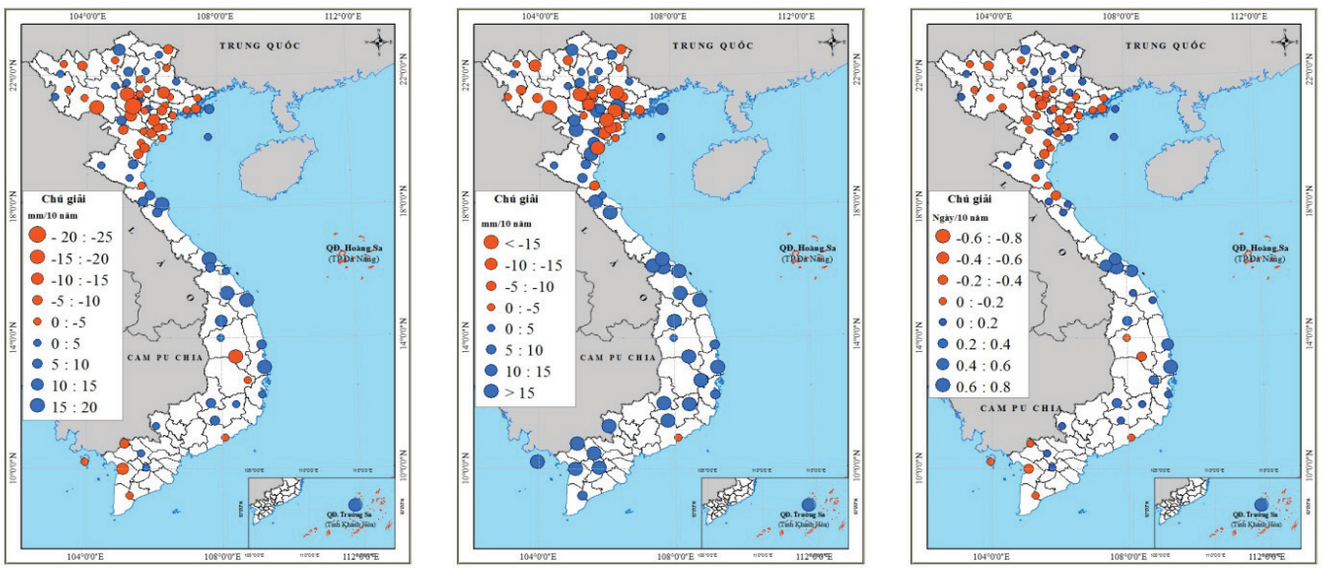
increases in most stations over the country, except Chi Linh, Mai Chau station. A regular increase was in a range of 0.4 to 0.8°C/decade. An increase of about 1.2°C occurred in some stations North of Thanh Hoa Province and the Central Highlands (Fig. 1D). In general, the increasing rate of Tnn was faster and more significant than that of Txx. The number of cold days (CD15) had an obviously decreasing trend at the stations in Northern Vietnam, and the Central Highlands had regular decreases of about 2-4 days/decade. The number of cold days over four days was observed at some stations of Northwest (Fig. 1E).

Rainfall extremes:

Over the past 54 years, rainfall extremes had contradictory trends between regions. However, the observed data exhibited an obvious relation of these trends within a climate region. In general, the trends of the Rx1day, Rx5day and R100 were decreasing at most stations in Northern Vietnam, especially at the Red River Delta; and increasing in most stations in Central Vietnam (Fig. 2).

Storms and tropical depressions:

Over the past half-century (1959-2015), trends of tropical



(A) Rx1day **(B)** Rx5day **(C)** R100

Fig. 2. Changes in extreme events related to rainfall during the period of 1961-2014.

cyclones affecting and occurring in Vietnam had no significant changes (Fig. 3A). However, the number of strong typhoons (over level 12) had a slightly increasing trend in recent years (1990-2015) (Fig. 3B).

Prediction

Temperature extremes:

Under the RCP4.5 scenario, changes in the multi-model mean maximum temperature (Fig. 4A) shows increases of 1.7÷2.7°C by the end of the century, with the greatest increases of mean maximum temperatures to be in the Northeast and Northern Delta region of Vietnam, and with the largest increases at over 2.5°C. The smallest increases will be about 1.4°C, observed in the South and South Central Vietnam. The changes of multi-model mean minimum temperature (Fig. 4B) shows increases of 1,8÷2,2°C by the end of the century. Similar to maximum temperatures, there will be the greatest increases of mean minimum temperatures in the Northeast and Northern Delta region of Vietnam. Under the RCP8.5 scenario (not shown), mean maximum temperature will increase at 3.0÷4.8°C and mean minimum temperature will increase at 3.0÷4.0°C by the end of the century.

Heat waves will likely increase in the future when compared to the baseline. SU35 will increase by about 25÷35 days for the RCP4.5 scenario and 35÷45 days for the RCP8.5 scenario (Fig. 5 and Fig. 6). By the end of the 21st

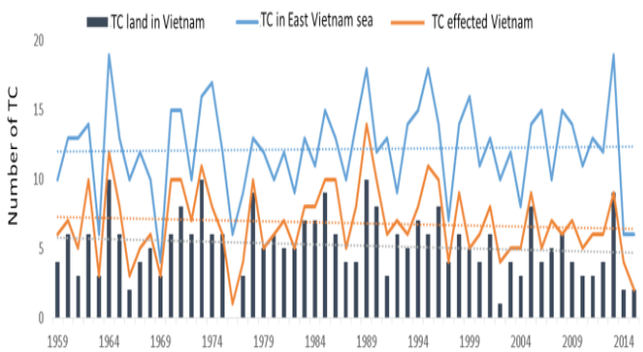


Fig. 3A. The number of tropical cyclones in the period of 1959-2014.

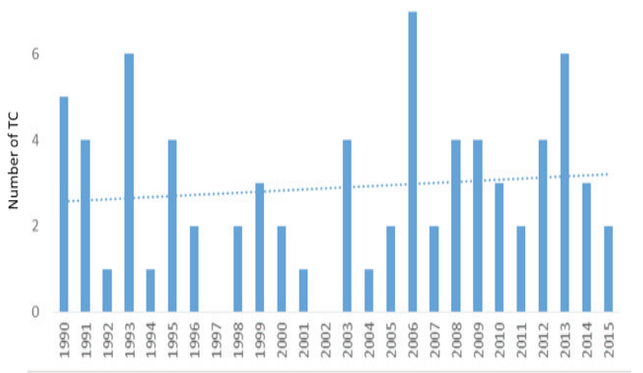
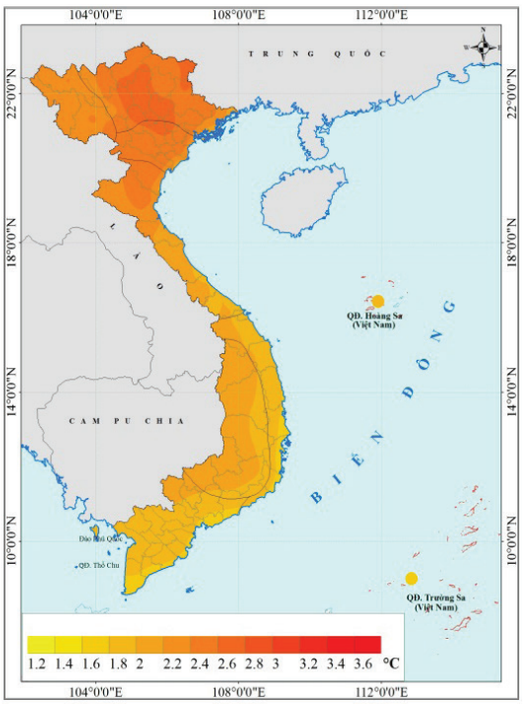


Fig. 3B. The number of typhoons over level 12 in the East Sea in the period of 1990-2015.



(A) Maximum temperature

(B) Minimum temperature

Fig. 4. Predicted changes in annual mean maximum temperature (A) and minimum temperature (B) at the end of the 21st century compared to the baseline period under the RCP4.5 scenario from an ensemble of models.

century, according to the RCP4.5 scenario, the largest increase in SU35 will likely be above 50 days in Central Vietnam, and the smallest increase of SU35 will likely be in the Central Highlands and Southern Vietnam (Fig. 5B). According to the RCP8.5 scenario, the largest increase of SU35 will likely be above 100 days in the Northeast, South Central and Southern Vietnam (Fig. 6B).

According to the RCP4.5 scenario, by the mid-21st century, trends from the CD15 and the CD13 tend to decrease by about 5÷10 days across most provinces in the North when compared to the baseline. The highest decrease will likely be above 15 days in the Northwest and Northeast; the lowest decrease (under five days) will likely be in North Central Vietnam. By the end of the 21st century, the number of extreme cold days and dangerously cold days tends to decrease from 10 to 20 days, with the highest decrease likely being at some stations in the Northwest and Northeast (above 20 days), and the lowest decrease will likely be less than 10 days in North Central Vietnam (Table 2 and Table 3).

Table 2. Changes of the CD15 compared with the baseline.

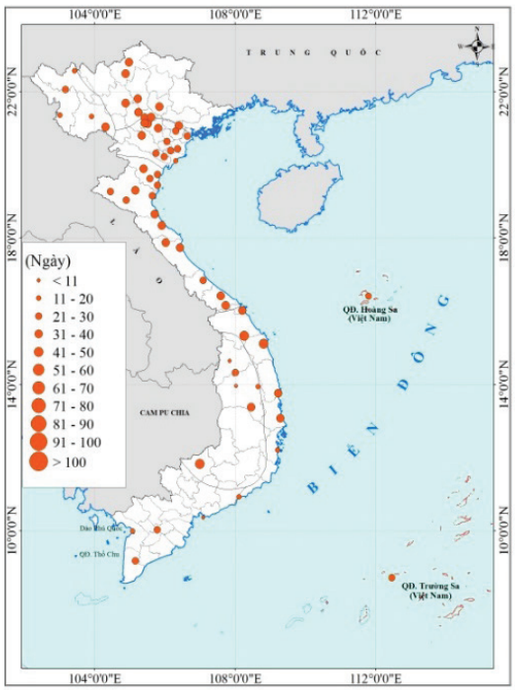
Region	RCP4.5 scenario			RCP8.5 scenario		
	2016-2035	*2046-2065*	*2080-2099*	*2016-2035*	*2046-2065*	*2080-2099*
Northwest	-13.1 ÷ -1.8	-30.9 ÷ -2.6	-38.7 ÷ -2.8	-20.4 ÷ -2.3	-37.1 ÷ -3.0	-61.0 ÷ -3.2
Northeast	-13.2 ÷ -1.2	-28.3 ÷ -2.1	-35.1 ÷ -2.7	-18.9 ÷ -1.6	-34.6 ÷ -2.5	-58.1 ÷ -3.1
Red River Delta	-3 ÷ -1.9	-7.1 ÷ -5.2	-10.0 ÷ -7.2	-5.2 ÷ -3.5	-9.0 ÷ -6.3	-11.2 ÷ -7.9
North Central Coast	-2.0 ÷ -0.1	-4.1 ÷ -0.1	-5.2 ÷ -0.1	-3.2 ÷ -0.1	-4.9 ÷ -0.1	-5.7 ÷ -0.1

Table 3. Changes of the CD13 compared with the baseline.

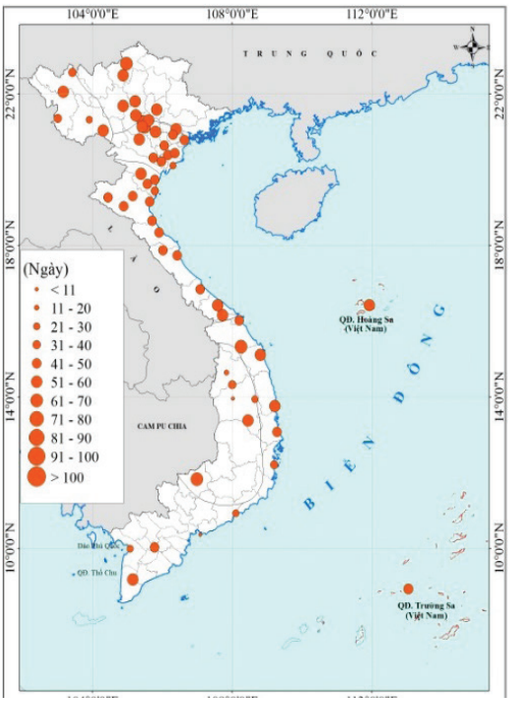
Region	RCP4.5 scenario			RCP8.5 scenario		
	2016-2035	*2046-2065*	*2080-2099*	*2016-2035*	*2046-2065*	*2080-2099*
Northwest	-14.0 ÷ -5.2	-32.6 ÷ -8.3	-42.8 ÷ -10.3	-22.5 ÷ -7.0	-40.6 ÷ -9.8	-71.1 ÷ -12.3
Northeast	-14.2 ÷ -2.4	-31.6 ÷ -4.5	-40.3 ÷ -6.5	-20.9 ÷ -3.6	-39.3 ÷ -5.5	-66.4 ÷ -7.8
Red River Delta	-5 ÷ -3.2	-13.1 ÷ -9.5	-17.9 ÷ -13.2	-10.5 ÷ -7.1	-16.5 ÷ -11.9	-23.9 ÷ -17.3
North Central Coast	-4.4 ÷ -0.7	-9.8 ÷ -0.9	-13.5 ÷ -1.1	-7.7 ÷ -0.6	-12.1 ÷ -1.2	-16.9 ÷ -1.5

Rainfall extremes:

According to the RCP4.5 and the RCP8.5 scenario, maximum 1-day Rainfall (Rx1day) tends to increase within a range of 10 to 70% over the country in the middle of the 21st

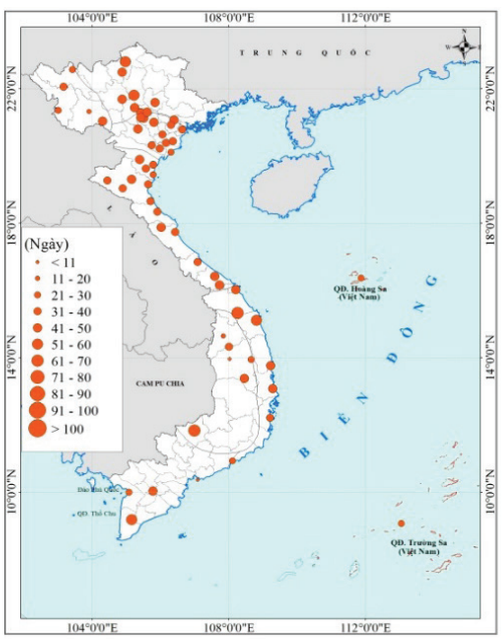


(A) The mid-21st century

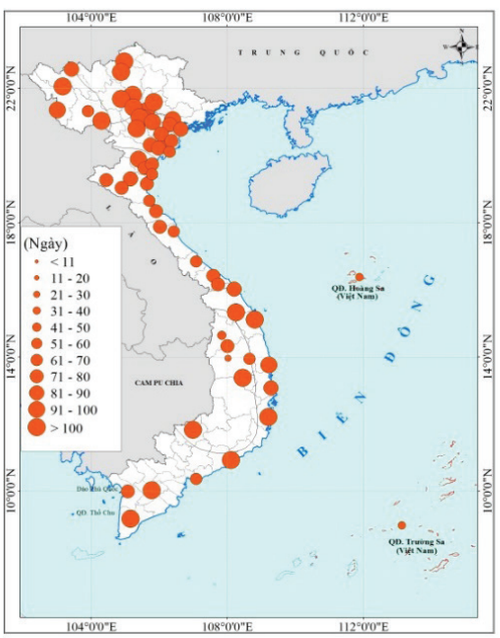


(B) The end of the 21st century

Fig. 5. Predicted changes in SU35 for the middle (A) and the end (B) of the 21st century compared to the baseline period according to the RCP4.5 scenario from an ensemble of models.

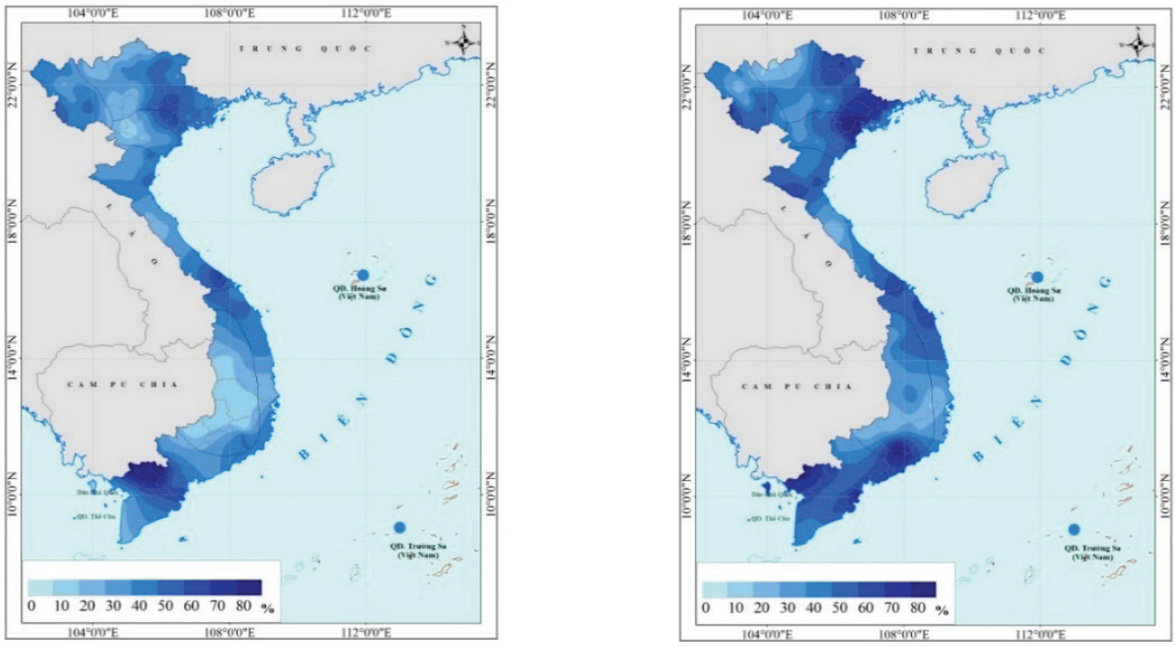


(A) The mid-21st century



(B) The end of the 21st century

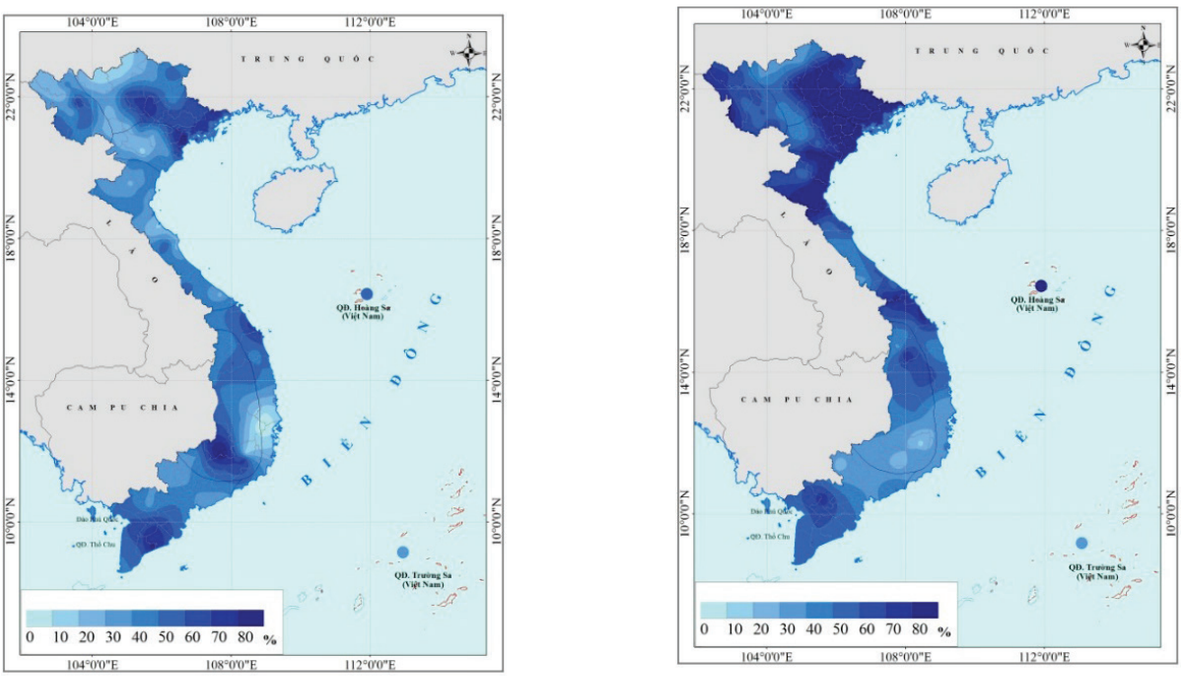
Fig. 6. Predicted changes in the number of SU35 for the middle (A) and the end (B) of the 21st century compared to the baseline period according to the RCP8.5 scenario from an ensemble of models.



(A) The mid-21st century

(B) The end of the 21st century

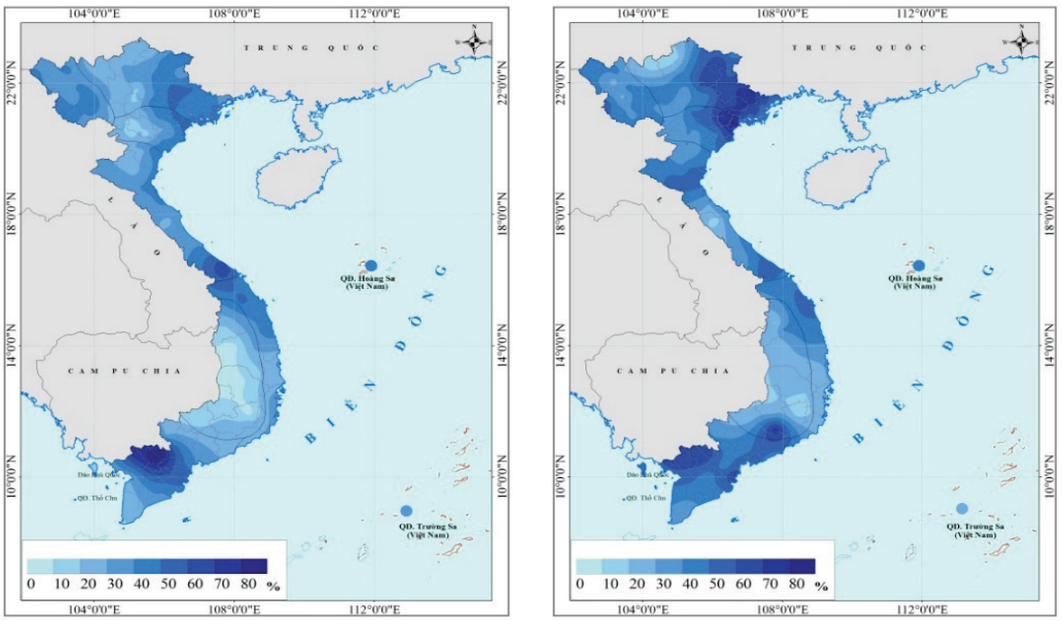
Fig. 7. Predicted changes in the Rx1day (mm) by the middle (A) and the end (B) of the 21st century compared to the baseline period according to the RCP4.5 scenario.



(A) The mid-21st century

(B) The end of the 21st century

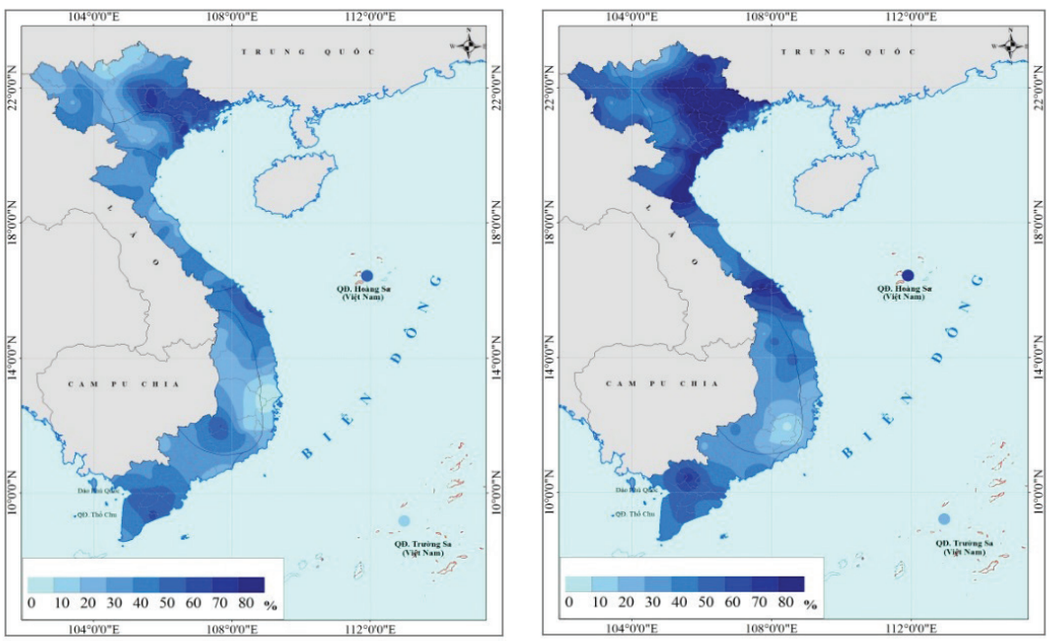
Fig. 8. Predicted changes in the Rx1day (mm) by the middle (A) and the end (B) of the 21st century compared to the baseline period according to the RCP8.5 scenario.



(A) The mid-21st century

(B) The end of the 21st century

Fig. 9. Predicted changes in the Rx5day (mm) by the middle (A) and the end (B) of the 21st century compared to the baseline period according to the RCP4.5 scenario.



(A) The mid-21st century

(B) The end of the 21st century

Fig. 10. Predicted changes in the Rx5day (mm) by the middle (A) and the end (B) of the 21st century compared to the baseline period according to the RCP8.5 scenario.

century, when compared to the baseline. By the end of the 21st century, the increasing trend of the Rx1day will be higher with similar patterns as compared to the trend observed in the mid-21st century (Fig. 7 and Fig. 8).

According to the RCP4.5 scenario, by the mid-21st century, the Rx5day tends to increase within a range of 10 to 50% across the country when compared to the baseline. The highest increase of about 80% will likely occur in the East of Southern Vietnam. By the end of the 21st century, the increasing trend will be higher with similar patterns than compared to the trend observed in the mid-21st century (Fig. 9). As shown through the RCP8.5 scenario, the Rx5day tends to increase within a range of 10 to 60% all over the country happening at the middle and the end of the 21st century. The highest increase of about 80% will likely be in the Northeast and North Central Coast at the end of the 21st century (Fig. 10).

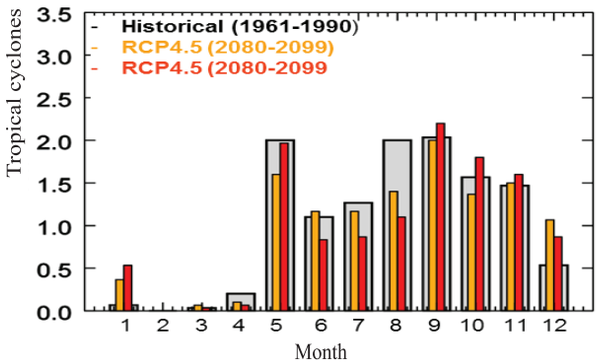


Fig. 11. The number of tropical cyclones at the end of the 21st century (PRECIS model).

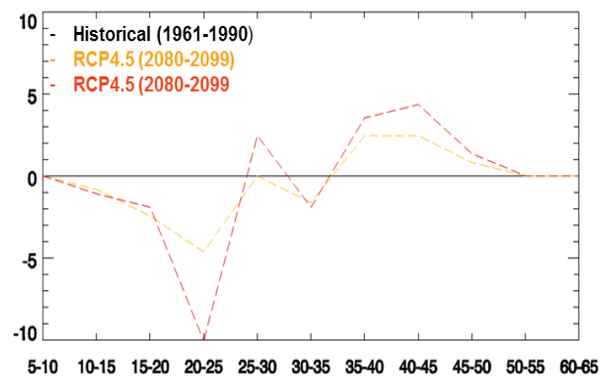


Fig. 12. The changes of tropical cyclones with different intensity at the end of the 21st century when compared with the baseline (PRECIS model).

Tropical cyclone:

According to the simulations derived from the PRECIS model, tropical cyclone activities tend to decrease early in the typhoon season (Jun-August) in the East Sea for both RCP4.5 and RCP8.5 scenarios. However, it is likely that tropical cyclone activities increased in the last typhoon season, especially based on the RCP8.5 scenario (Fig. 11). It can be seen that tropical cyclone activities will shift to the end of the typhoon season, which is the period at which typhoons occur mainly in the South. Figure 12 indicates that the number of weak and normal typhoons will decrease, while the number of strong typhoons will increase significantly by the end of the 21st century.

Conclusion

We investigate long-term changes of climate extremes over Vietnam for the period of 1961-2014 and future changes of some climate extremes in the context of global climate change. The resulting evidence shows obvious decreasing and increasing climate extreme trends across all regions of Vietnam.

Over the past half-century (1961-2014), the highest maximum temperatures had an increasing trend at most stations in the North and a decreasing trend at most stations in the South. The trend for lowest minimum temperatures was clearly decreasing across the whole country. The number of cold days had a decreasing trend at stations in the North and at the Central Highlands. The trends of the maximum 1-day and 5-days rainfall were decreasing at most stations in the North, whereas the trends were increasing at stations in the Central and the South. There was no obvious change in the frequency of tropical cyclones, including typhoons and tropical depressions causing landfalls. However, the rate of very strongest typhoons is on the increase. The typhoon season, at present, tends to end later than in the past, and typhoons occur more frequently in Southern regions.

Presented figures clearly show the predictions of changes in climate extremes across the country. By the end of the 21st century, the number of hot days will increase significantly for both scenarios (RCP4.5 and RCP8.5), according to simulated models. The number of cold days and extremely cold days will decrease across most provinces in the North and for the North Central Coast. The trends for the maximum 1-day and 5-days rainfalls will increase across the whole country. In general, other trends observed at the middle and the end of the century will stay at the same levels. However, any increasing trends observed at the end of the century will be more significant in values and patterns. Projected result show the number of tropical cyclones in the East Sea and their impacts on Vietnam do not show a clear trend and it is uncertain, but the number of strong typhoons will likely increase in the future.

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