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RESEARCH THE IMPACT OF GLOBAL CLIMATE CHANGE TO SOME CLIMATE EXTREMES AND EXTREME CLIMATE EVENTS IN VIET NAM

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SUMMARY OF DOCTORAL DISSERTATION

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INTRODUCTION

1. General justification for the dissert

Climate change (CC) has occurred globally, but its manifestations are different in every nation and region of the world. Global temperature is growing and weather events as well as climate extremes tend to increase with more complicated changes. In addition, because continental temperature has tendency to rise more rapidly than ocean temperature, monsoon, atmospheric pressure centers,… may be changed in their intensity and operating range.

Meanwhile, Vietnam is located in the tropical monsoon zone and influenced by both the South Asian monsoon system and the East Asian monsoon system. Thus, global CC affects not only Ts directly but also the volatility of climate extremes and extreme climate events (ECEs) through the variation of the circulation system indirectly. This may be intensifying the extremeness of weather and climate events that have occurred in each subregion.

The effects of global CC on each region have been demonstrated by a number of authors through the variation tendency of climate elements and events in those subregions in the world and Vietnam so far. The changes of monsoon, some atmospheric pressure centers and their impacts on regional weather and climate have also been mentioned by several worldwide authors. Nonetheless, most of the studies only assess variation levels and trends of climate elements and events in specific subregions without explaining those changes in Vietnam.

In fact, weather and climate conditions, especially ECEs have changed in an unusual and complex way in recent years. So, are these changes related to global warming? If any, how is the relationship between them shown? Solving this problem will make contribution to elucidating multiple scientific aspects in the studies of CC and providing useful information for finding solutions to improve quality of weather forecast news, contributing impact mitigation of CC and the effectiveness improvement of natural disaster prevention and mitigation. Therefore, we have selected and implemented the dissertation titled ***"Researching the impacts of global climate change on some climate extremes and extreme climate events in Vietnam"*** in the aim of explaining partial causes of climate extremes and ECEs in Vietnam.

2. Objectives of the dissertation

- Indicating the level and trend of changing of some climate extremes and ECEs in Vietnam,
- Assessing the impact of global climate change to that climate extremes and extreme climate events

3. Object and scope of study

- Object of study:

Climate extremes: monthly maximum temperature (TXx), monthly minimum temperature (TNn); daily maximum temperature equal to the 90^{th} percentile (TX90); daily minimum temperature equal to the 10^{th} percentile (TN10); the number of days with minimum temperature less than the 10^{th} percentile (TN10p); the number of days with maximum temperature greater than the 90^{th} percentile (TX90p); maximum daily rainfall (RXx); daily rainfall equal to the 95^{th} percentile (RX95). Extreme climate events: cold weather, damaging cold weather, hot weather, intensive hot weather and heavy rain. Surface air temperature (Ts) and main atmospheric pressure centers have affected Vietnam and the region.

- Scope of study: Regions 50^0S - 70^0N; 40^0E - 140^0W and the territory of Vietnam.

4. New academic contributions of the dissertation

- The dissertation has identified the variation of intensity and operating range of main atmospheric pressure centers, playing an important role in weather conditions and formation of Vietnam's climate as well as the relationship between the variation of some climate extremes and ECEs in Viet Nam's climate subregions and global warming.

- The dissertation has put forward several explanations related to the impacts of global CC on the variation of some climate extremes and ECEs in Vietnam.

5. Scientific and practical significance of the dissertation

- The dissertation has made contribution to elucidating the relationship between global CC and the change in intensity and position of main atmospheric pressure centers. This affects Vietnam's climate and weather as well as variation trends of climate extremes and ECEs in the territory of Vietnam.

- The dissertation's results can be used for the assessment of CC and a basis for assessing the impacts of CC in Vietnam.

6. Structure of the dissertation

Chapter 1: Overview

Chapter 2: Data and method of study

Chapter 3: Variation of some atmospheric pressure centers, climate extremes and extreme climate events in Vietnam

Chapter 4: Relationship between global climate change and some climate extremes, extreme climate events in Vietnam

CHAPTER 1: OVERVIEW

1.1 Basic concepts

1.1.1 Climate extremes

A set of minimum or maximum values of each atmospheric variable for a certain period such as a day, a month or a year is the extreme values of that variable. Thus, the set of extreme values of each atmospheric variable will constitute a series of data and is considered as climate extremes of that variable over the years.

In terms of climate, variables of TNn, TXx, RXx, absolute minimum temperature (TN), absolute maximum temperature (TX), absolute maximum daily rainfall (Rx) in a month and year have been identified.

Besides, values x_M of daily maximum temperature (Tx) equal to the 90th percentile (TX90), daily rainfall (R) equal to the 95th percentile (RX95) and minimum temperature (Tn) equal to the 10th percentile (TN10) are considered as climate extremes of each atmospheric variable.

1.1.2 Extreme climate events

Extreme climate events have occurred for a certain period of the year such as a season and repeated for a number of years, called extreme climate events [22].

Cold-weather or damaging cold-weather events will occur at a weather station in Vietnam if average air temperature (Ttb) at that station is less than or equal to 15^0C or 13^0C. Similarly, NN or intensive hot-weather events will happen if daily maximum temperature (Tx) is greater than or equal to 35^0C or 37^0C. Heavy rain also occurs when daily rainfall is greater than or equal to 50 mm ($R \geq 50$ mm).

1.1.3 Extreme climate indices

Extreme climate indices are given by the IPCC, including 27 indices mostly used for analyzing and assessing the variation levels and trend of

ECEs in each subregion.

1.2 Climate change and atmospheric circulation

Temperature in each region of the Earth is increasing with different speeds, changing mean sea level pressure (Pmsl) on a large scale. For the period 1981-2000, air pressure reduced about 2 mb/decade in high and middle latitude regions of the Asia and the Aritic Sea but increased about 1 mb/decade in southwest Europe and from the Pacific Ocean to the East America; about 2 mb/decade in Tibetan Plateau (Gong D.Y and et) [36].

Furthermore, temperature in Siberia increased faster than growing rate of global average temperature (Hansen et al, 2012) [37]. Therefore, although the Siberian high was rising in the 60s but significiantly weakened in the 80s and early 90s. Specifically, intensity at this high center markedly degraded from the 70s to the 90s [36].

However, the Hadley circulation intensity also increased (Zhou Botao and Wang Huijun, 2008) [57]; Northwest Pacific high (ACTBD) tends to expand and move to the west for the period 1980-1999 (HeXuezhao et al, 2002 [37]; Zhao Tianjun et al, 2008 [99]; Zhao Tianjun et al, 2009 [58]). During the period 1958-2000, there were 7 years of strong winter monsoon (1967, 1969, 1976, 1980, 1983, 1984 and 1985) and 7 years of weak winter monsoon (1958, 1971, 1972, 1978, 1989, 1991 and 1997) (Ghap Jhun Jong and et, 2004) [35].

Meanwhile, the East Asian summer monsoon (EASM) was stronger for the period 1950-1964 (Gang Zeng et al, 2007) [34] and in late 70s and early 80s (QH Qian Qin A, 2008 [48]; Ning Liang and Oian Yongfu, 2009 [46]), but weakened for the period 1976-1997 [34].

The strengthened of North Pacific high for the period 1961-2000 made Ttb at some stations on the territory of Vietnam in January and February increase (Nguyen Viet Lanh, 2007) [15]. Additionally, reduced intensity of the Siberian high made the number of cold and very cold days in the northern climate subregions of Vietnam decrease (Vu Thanh Hang et al, 2010) [8]. Conversely, the Tn reduction on the South Central subregion (N1) for the period 1961-1990 is caused by the intensification of cold air for the decade 1981-1990 (Ho Thi Minh Ha et al, 2011) [39].

With respect to the effects of ENSO on monsoon, Nguyen Duc Ngu (2002), Pham Thi Thanh Huong (2002), Nguyen Thi Hien Thuan (2005), etc assumed that both the winter monsoon and the summer monsoon in East and Southeast Asia weakened for the El Nino years, but intensified for the La Nina years [10], [16], [27].

1.3 Climate change and some climate extremes, extreme climate events

According to the IPCC (2007), global average Ts rose about 0.74^0C (for the period 1906-2005) and increased 0.13^0C/decade (for 50 recent years). Ts in the winter grew faster than in the summer; on the continent faster than on the ocean; in the Northern Hemisphere (BBC) faster than in the Southern Hemisphere (NBC), in which the Asia is the place with the most dramatically increasing temperature [37], [41].

In mostly regions of the Asia, the number of hot day-time and warm night-time increases meanwhile the number of cold day-time and cold night-time decreases. Drought also have tendency to grow in East Asia. Heavy rains tend to vary inconsistently between the regions [42].

In many different regions of the world, extreme events also tend to increase. Specifically, the number of hot day and warm night increases meanwhile the number of cool day and cold night decreases over 15 countries in Southeast Asia and South Pacific (Manton MJ et al, 2000) [44]; 8 countries in South America (Vincent LA et al, 2005) [53]; and in the Indian northern regions (Dash S K et al, 2011) [30]. In mostly parts of Russia, the number of days with maximum temperature greater than the 95th percentile has increased meanwhile the number of days with minimum temperature less than the 5th percentile has decreased over the past six decades (Bulygina O . N et al, 2007) [29].

In the regions of southwest Norway and southern Spain, record values of rainfall occurred in the 20th century and was unprecedented for the past 500 years (Matti C. et al, 2009) [45]. In mostly regions of China, rainfall tended to rise suddenly in the late 70s and early 80s (QH Qian et al, 2008) [48]. Heavy rains in the summer have also increased in south China since 1990 (Ning Liang et al, 2009) [46].

In Vietnam, a number of authors such as Nguyen Viet Lanh (2007) Nguyen Duc Ngu, et al (2008, 2009), Vu Thanh Hang, et al (2009, 2010), Chu Thi Thu Huong, et al (2010), Nguyen Van Thang, et al (2010), Phan Van Tan, et al (2010, 2011), Ho Thi Minh Ha et al (2009, 2011), Nguyen Trong Hieu, et al (2011), Tran Thuc et al (2012), Ngo Duc Thanh et al (2012), Hoang Duc Cuong (2013), Nguyen Dang Quang, et al (2013), etc have studied the changing tendency of average temperature and rainfall, climate extremes and ECEs in each region or the whole territory. The results show that, average temperature for the past 50 years has increased to 0.5 - 0.7^{0}C and temperature in the winter have risen more rapidly than that in the summer in the territory of Vietnam. Moreover, Tn, Tx, daily maximum temperature equal to the 95th percentile (TX95), daily minimum temperature equal to the 5th percentile (TN5) and the number of hot days (SNNN) have the tendency to increase, but Tn and TN5 has increased much faster than Tx and TX95. The number of cold air waves and cold days (SNRD) decreases although the abnormalities of cold air has occured more frequently. Total annual rainfall in the northern climate zones also tends to decrease but rise in the southern climate zones. Daily rainfall (R), RX95 and the number of heavy rain days tend to increase in mostly climate subregions, especially in the Central Subregion. Frequency of tropical cyclones is not clear, but the number of strong storms is increasing. Maximum wind velocity (VXx) in a month and year tends to go down in the subregions; whereas, frequency of droughts is growing [2], [4], [6], [7], [8], [9], [12], [13], [15], [19], [20], [21], [22], [25], [26], [31], [39].

Thus, beside the changing tendency of climate elements and events, that of some atmospheric pressure centers or monsoon circulation as well as the relationship between them have been mentioned by many worldwide authors. Nevertheless, the studies only determine the changing tendency of some climate extremes, climate indices and ECEs in Vietnam. Although the conclusions are given uniformly and consistently, more studies have hardly explained causes of those changes. Therefore, to assess the impacts of CC on climate extremes and ECEs in Vietnam, the correlation between them and global and regional average Ts, as well as intensity of the atmospheric pressure centers has been analyzed so as to explain partial causes of those changes.

CHAPTER 2: DATA AND METHOD OF STUDY

2.1 Data

2.1.1 Observed data from the station network in the territory of Vietnam

A set of observed data related to temperature and daily rainfall (Tx, Tn, Ttb and R) of 70 stations characterized by 7 climate subregions in the territory of Vietnam for the period 1961- 2010 or 1976-2010 (at several southern stations) was used in the dissertation.

2.2.2 Re-analysized data

Source of monthly average data of Pmsl, Ts and geopotential height (HGT) is determined at the standard isobaric levels. The source of data is defined on the grid at a resolution of 2.0 x 2.0 degrees longitude/latitude for the period 1961-2010. In addition, the standard deviation of global and regional average Ts for the period 1880-2010 has been used.

2.2 Methods of study

2.2.1 Method of analyzing the changing levels and trends of climate extremes and extreme climate events

The changing tendency of global average Ts, climate extremes, ECEs and intensity of atmospheric pressure centers are determined by Sen coefficient (Q). Besides, reliability of the trend is evaluated by Mann – Kendall testing. Sen coefficient also serves as the a_1 coefficient in a single-variable linear equation, but it can eliminate the influence of raw errors in a series of data. Therefore, the Sen coefficient has been increasingly used by a number of authors such as Draple K. et al (2011) [32], Phan Van Tan et al (2010) [22], Ngo Duc Thanh et al (2012) [25], Nguyen Dang Quang et al (2013) [31], etc.

2.2.2 Determining the variation of atmospheric pressure centers

a. Determining intensity

Intensity of the Siberian high (regional average Pmsl: 40 – 60^0N, 70 – 120^0E); the Aleutian low (regional average Pmsl: 40 – 60^0N, 160^0E – 160^0W); the South Asian low (regional average Pmsl: 20 – 35^0N, 60 – 90^0E); Equatorial low pressure trough (regional average Pmsl: 5^0S – 15^0N, 90^0E – 160^0E); the Australian high (regional average Pmsl: 36^0S-24^0S; 122-152^0E); the Mascarene high (regional average Pmsl: 36^0S-26^0S; 50-80^0E); the North Pacific high (ACTBD) (regional average HGT: 20-35^0N; 140^0E-160^0W above 500 hPa level) and intensity at the western edge of ACTBD (regional average HGT: 20^0N – 25^0N, 125^0E – 140^0E).

b. Determining the operating range

The change in the operating range of atmospheric pressure centers is determined based on the shift, expansion or narrowing of an isobaric contour or contour with the same geopotential height in each decade. Specifically, the 1016 hPa (the Siberian high), 1010 hPa (Aleutian low and equatorial low pressure trough), 1005 hPa (the South Asian low), 1020 hPa (the Australian and Mascarene high) isobaric contours and the 586 dam contour above 500 hPa level (ACTBD).

2.2.3 Determining the impacts of global climate change on climate extremes and extreme climate events

The impacts of global CC on climate extremes and ECEs are determined based on the correlation between them and global and regional average Ts, Pmsl and HGT on each grid point or on average in a subregion.

The magnitude of correlation coefficient is tested under the Student distribution. With a set of 50-year data, the gained correlation coefficients with the 0.05 significance level (or the 95% level of reliability) and the 0.01 significance level (or the 99% level of reliability) will be 0.273 and 0.352, respectively.

CHAPTER 3
CHANGE OF SOME ATMOSPHERIC PRESSURE CENTERS, CLIMATE EXTREMES AND EXTREME CLIMATE EVENTS IN VIETNAM

3.1 Change of global average Ts

In the dissertation, a year is divided into 4 seasons of 3 months each: spring – March, April and May, summer – June, July and August, autumn – September, October, November; and winter – December, January and February.

During the two periods 1880-2010 and 1961-2010, global and regional average Ts were on a upward trend, but Ts for the period 1961-2010, Ts increased nearly 10 times faster than that for the period 1880-2010. The growth rate of global and ocean average Ts is relatively uniform but on the continents, especially the Northern Hemisphere continents, there are striking differences.

Similar to the previous studies, the growth rate of Ts on the Northern Hemisphere continent is faster than that on the Southern Hemisphere continent, on the continent faster than on the ocean, in the winter and spring faster than in the summer and autumn. This may lead to the change of intensity and operating range of some atmospheric pressure centers, significantly affecting the climate characteristics of each region.

3.2 Variation of atmospheric pressure centers affecting Vietnam

3.2.1 Intensity

In the winter, intensity of the Siberian high has tended to decrease in mostly months, including the sharpest decrease in Febuary with the Pmsl decrease in about 0.6 hPa/decade at the central of Siberian high. Intensity of the high has witnessed a reduction in 0.2 - 0.3 hPa/decade (in the fall), slower reduction (in the spring) and even increase in 0.08 hPa/decade in May.

Meanwhile, the Aleutian low has increased its intensity in mostly months and seasons (except for March and May). Especially, with more than 90% level of reliability, intensity of the Aleutian low undergoes the most dramatic increase in December and April. During this time, Pmsl at the central of the Aleutian low has decreased about 0.9 hPa/decade. For the remaining months, intensity of the Aleutian low increases or decreases more slowly (about 0.2 hPa/decade).

With more than 90% level of reliability in mostly months, intensity at the central zone and the western edge of ACTBD has the tendency to increase for all the months. The trend of the strongest increases occurs in the winter months, especially January and February, in which intensity of the high goes up about 0.5 hPa/decade. Intensity at the western edge of ACTBD also increases about 0.3 hPa/decade in the fall. However, intensity at the western edge of ACTBD rises slowly, even intensity at the central of this high tends to go down slowly in May.

Intensity of equatorial low pressure trough is also on an upward trend for all the months and seasons with the mostly significance levels of 10%. Pmsl at the central of equatorial low pressure trough has decreased about 0.1 hPa/decade and even up to 0.2 hPa/decade (in November).

Intensity of the South Asian low tends upwards in March, April, June and July, and downwards in August and September, but changes a little in May.

Intensity of the Australian and Mascarene high tends to increase for all the months with the 90% level of reliability. The trend of sharp increases occurs in April, May, June and August with the Pmsl increase in about 0.3 hPa/decade at the central region.

3.2.2 Operating range

The operating range of the Siberian high has also tended to be narrowed over the decades. Although, in December for the decade 1981 – 1990, this high has tended to expand southwards compared to that for the previous decades, but for the decade 2001-2010, the Siberian high has tended to be narrowed northwards.

The operating range of the Aleutian low over the decades has hardly changed in the winter months. However, in the early and late winter, this low has tended to expand more westwards, especially for the two last decades (1991-2010).

Meanwhile, the operating range of ACTBD has been expanded westwards, especially for the two decades 1991-2000 and 2001-2010.

Similar to ACTBD, the Australian and Mascarene high also have the expanded operating range over the decades, especially for the three lasting decades (1981-2010). The operating range expansion of the Australian high in April, May, June and August, combined with the strengthened of both the high may have enhanced the activity of southwest monsoon.

However, the operating range of equatorial low pressure trough and the South Asian low in the months has hardly changed over the decades. Particularly, in the early summer months, the South Asian low pressure has tended to expand more for the decade 2001-2010.

Thus, not only intensity increases but also the operating range of ACTBD, the Mascarene and Australian high also tend to expand increasingly in each decade. Moreover, although the operating range of the Aleutian and South Asian low and equatorial low pressure trough have changed a little over the decades, but their intensity in mostly months has tended to increase. Whereas, the operating range of the Siberian high has been narrowed to northward and its intensity has tended to decrease in the winter. This shows that, intensity of the winter monsoon (WM) maybe tends to weaken, but the summer monsoon (SM) tends to strengthen.

3.3 Change of some climate extremes

3.3.1 Minimum temperature

TNn and TN10 on each region have tended to change similarly in the seasons and months. The biggest upward trend occurs in the winter with the speed of about 0.5°C/decade (in the Northwest climate (B1), the Highlands climate (N2) and Southern climate (N3) subregions), 0.2- 0.3°C/decade (in the Northeast climate (B2), the Northern Plains climate (B3) and the North Central climate (B4) subregions) and 0.05°C/decade (in the South Central climate (N1) subregion). Compared to other subregions of the territory, TNn and TN10 in the N2 subregion have undergone the most rapid upward trend; whereas, the N1 subregion has tended to increase most slowly, even decrease slowly in the fall. In the northern subregions, TNn and Tn10 have the tendency to increase faster in the mid-winter and mid-summer months, but increase or decrease more slowly in April, May and November. This result is consistent with the upward trend of Ts in the seasons and the changing tendency of the intensity of the Siberian high, the Aleutian low, the South Asian low and ACTBD in April and May.

Annual TNn has the upward trend from 0.2 to 0.6°C/decade at all the stations with the nearly 90% level of reliability. The stronger upward trend often occurs at the mountainous stations such as Dien Bien, Yen Chau, Tuyen Quang, Hoa Binh, Ha Giang, Tam Dao, Bao Loc, Phan Thiet, Dak Nong, Kon Tum, Ayunpa, etc with the increasing speed of over 0.6°C/decade.

3.3.2 Maximum temperature

In the northern subregions, TXx and TX90 have increased in mostly months, but faster in January, February, March and April with the speed from 0.3 to 0.6°C/decade (in the B2, B3 and B4 regions). Nonetheless, TXx and TX90 have increased very little, even had the downward trend in May. Annual TXx also has the upward trend from 0.2 to 0.3°C/decade at the stations. However, TXx at almost the southern stations has tended to insignificantly decrease or increase.

Similar to TNn and TN10, TXx and TX90 in the N2 and N1 subregions have the fastest and slowest growth rate, respectively. Despite to the reduced rate or little changes for the six last months of the year, TXx and TX90 in the N1 subregion increases about 0.4°C/decade in the spring. Whereas, in the N3 subregion, TXx and TX90 decreases from January to May and increases from June to December with the rate of 0.1-0.2°C/decade. Particularly, in the N2 subregion, TXx and TX90 increases in all months with the growth rate of about 0.5°C/decade.

3.3.3. Maximum daily rainfall

RXx and RX95 have tended to increase from 2 to 4 mm/decade in the B4, N1 and N2 subregions in all the seasons. The most dramatic upward trend occurs in the N1 subregion in the fall with the rate of 14 mm/decade and 8.5 mm/decade respectively. Meanwhile, in the northern and southern subregions, RXx and RX95 have tended to decrease about 2mm/decade. The most dramatic downward trend occurs in the fall but in the B3 region with the rate of about 4 mm/decade. In the N1 and N2 subregions, RXx tends to increase in almost the months, especially more sharply in the months of rainy seasons. Specially, RXx has increased up to 15 mm/decade in October and November.

Although annual RXx has tended to decrease about 10mm/decade at almost the northern stations, it has the tendency to increase about 2 mm/decade at several stations of the northern mountainous subregions such as Lai Chau, Dien Bien, Lang Son, Tuyen Quang, Yen Bai, etc. Especially, at Bac Quang station, RXx has also increased with the rate of more than 8 mm/decade.

3.4 Change of some extreme climate events

3.4.1 The phenomenon of hot and very hot

The number of hot days (SNNN) and very hot days (NNGG) often has positive standard deviation during or after the El Nino years, but the negative standard deviation not only during (1971, 1999) and after the La NiNa period (1974, 1989, 2000, 2008) but also before the LaNina period (1984), even during (1963, 1991) and before the El Nino period (2004).

With more than 90% level of reliability, the number of monthly average hot days in the northern subregions of Vietnam has the upward trend in all the months from March to September (except for May) with the rate of about 0.3 day/decade. In the N1 and N2 subregions, SNNN has tended to increase, especially more sharply in April, May and June with the growth rate of about 1 day/decade. Nevertheless, in the N3 subregion, SNNN in March, April and May has tended to decrease from 0.2 to 0.9 day/decade. Therefore, total number of annual hot days has also increased from 2 to 4 days/decade in almost all the stations of B3 and B4 subregions as well as several stations of the N1 subregion. Specially, at some stations such as Bac Quang, Ha Noi, Tuyen Hoa, Tra My and Quy Nhơn, total number of annual hot days has increased up to 5 days/decade, even approximately 9 days/decade at Tuyen Hoa station. Whereas, at several stations such as Da Nang, Nha Trang, Kon Tum, Can Tho and Rach Gia, SNNN tends to decrease slowly.

3.4.2 The phenomenon of cold and very cold

The number of cold days (SNRD) and very cold days (SNRH) has large positive standard deviation during the La Nina period but the negative standard deviation during the El Nino period. SNRĐ in the northern subregions of Vietnam has the downward trend in all the winter months. Total SNRD in the winter in each subregion has tended to decrease from 2 to 3 days/decade with confidence level more than 90%. To be more specific, SNRD in the B2 subregion has the most dramatic downward trend but the least dramatic downward trend in the B4 subregion. SNRD và SNRH has decreased from 3 to 4 days/decade (at almost all the stations of B1, B2 and B3 subregions), but only from 1 to 2 days/decade (in the B4 subregion and some coastal stations of the Northern subregions).

3.4.3 Heavy rain

Similar to the changing tendency of RXx and RX95, the number of heavy rain days (SNML) is on an upward trend in the B4, N1 and N2 subregions and a downward trend in the northern and southern subregions in all the seasons. SNML may increase faster in the N1 subregion with the rate of about 1 day/decade in the fall. Particularly, at some stations such as Ba To, Tra My, Nam Dong and A Luoi, SNML increases up to 2 days/decade. Whereas, in almost the stations of the northern and southern subregions, SNML has tended to decrease about 0.3 - 0.5 day/decade.

In summary, the change of global average Ts has influenced intensity as well as position of atmospheric pressure centers and varied climate elements and events in Vietnam. Meanwhile, the variation of atmospheric pressure centers can indirectly affect these climate elements and events, making them change more strikingly and extremely.

CHAPTER 4
RELATIONSHIP BETWEEN GLOBAL CLIMATE CHANGE AND SOME CLIMATE EXTREMES, EXTREME CLIMATE EVENTS IN VIETNAM

4.1. Impacts of global average Ts

Obviously, the increase in global average Ts have strengthened TXx, the number of hot days, TNn and reduced the number of cold days on the whole Vietnam's territory. In terms of TXx, the subregion having the highest correlation with Ts is N2, in which correlation coefficients (HSTQ) reaches 0.45 all time. Specially, in the summer, HSTQ in this subregion even reaches 0.7. In terms of the number of hot days, HSTQ in the N1 and N2 subregions are considerably high, especially in the summer months and on N2 subregion. However, in the northern and southern subregions, most of the HSTQ are less than 0.5 and at least 50% of the months with HSTQ do not reach the 95% level of reliability.

Furthermore, Ts has the high HSTQ with TNn in all months and seasons in both N2 and N3 subregions. Specially, in the spring and summer, most of the HSTQ are over 0.7. Even in the spring, HSTQ between TNn in the N3 subregion and Ts reaches 0.82. In the northern regions, HSTQ only gets the 5% significance level in the summer months.

4.2. Impacts of surface air temperature in the areas

Increasing surface air temperature in the V2 (10^0S-10^0N, 60-100^0E) and V1 (0-20^0N, 100-120^0E) subregions makes TXx, TNn and the number of hot days in the Northern and Highland climate subregions rise and vice versa. In particular, the Central Highlands is influenced most strongly by the increased temperature on two seas, with HSTQ by 0.7. Besides, increasing average Ts in the N3 subregion (15^0 - 40^0N; 100^0E - 120^0E) increased TNn and decreased the SNRD in the northern climate subregions. Absolute values of HSTQ between average Ts in the V3 region and TNn as well as SNRD in the B2, B3 and B4 subregions are more than 0.6. In particular, with SNRD in February, HSTQ reaches up to -0.8, even -0.91 and -0.89 on B2 and B3 subregions.

In contrast, RXx and the number of heavy rain days in the subregions are hardly affected by global and regional average Ts.

4.3. Impacts of atmospheric pressure centers

TXx and SNNN in the northern climate and N2 subregions have negative correlation with atmospheric pressure at the southern edge of the Siberian high, but positive correlation with the southwestern edge of ACTBD and the southeastern trough of South Asia low with absolute values of HSTQ ranging from 0.4-0.6. Probably, strengthening of the South Asia low is also the development period of the south west monsoon, thereby monsoon rains can reduce temperature in the regions. Furthermore, what the South Asia low weakens and backs to the west will facilitate ACTBD to expand westwards and affect Vietnam. Accordingly, TXx and SNNN on the territory will increase. This is shown through HSTQ between total SNNN on Vietnam’s climate subregions per year and Pmsl as well as average HGT at the western edge of ACTBD on the levels mostly reaching 95% reliability. Moreover, the study results show that, SNNN in the B4 subregion dramatically rises for the years when ACTBD enhances and expand westwards.

Obviously, the strengthening of ACTBD also increases TNn and decreases SNRD in mostly subregions on the Vietnam’s territory (except for N1 and N3 subregions). In particular, HSTQ between HGT at the edge of ACTBD and TNn in the N2 subregion in the fall and winter months reach up to 0.6.

Furthermore, TNn and SNRD in the northern climate subregions are primarily influenced by Siberian high with absolute values of HSTQ in the winter months greater than 0.5. The gained HSTQ in February and the winter is up to 0.7.

Besides, Aleutian low and East Asia low pressure trough are considered as an element to enhance cold air.

During the wet season months, HSTQ between Pmsl and RXx and the number of heavy rain days (SNML) in the climate subregions get the 95% level of reliability with values ranging from -0.4 to -0.6. It can be explained by the air convergence from the edge of Siberian high and ACTBD (in April). The operation of the South west monsoon develops and affects B1, B4, N1, N2 and N3 subregions in May. The activity of equatorial low pressure trough is clearly demonstrated through intertropical convergence zone (ITCZ), thereby increasing rainfall in the B2 and B3 subregions in July. Heavy rain in the B4, N1 and N2 subregions in October and November is mostly caused by the operation of ITCZ or combined impacts of cold air and ITCZ.

Thus, for the active period of the winter monsoon, TXx, TNn, SNNN and SNRĐ in the northern subregions are influenced by the Siberian high. Additionally, Aleutian low and East Asia low pressure trough are considered as an element to strengthen cold air. During the summer months, ACTBD affects TXx and SNNN in mostly subregions (except for N3 subregion). The combination of cold air and south east monsoon (in April) or operation of the south west monsoon (in May) or operation of ITCZ (in July) and its combination with cold air (in October and November) is one of the factors increasing rainfall in general or RXx and SNML in particular in the regions.

CONCLUSIONS

For the purpose of assessing the impact of global climate change on climate extremes and ECEs in Vietnam, the thesis has used sets of observed data at 70 meteorological stations in the territory of Vietnam; global re-analyzed data and some other sources of data mainly in the period 1961-2010. Since then, the thesis has determined the level and trend of change of some climate extremes and ECEs in Vietnam; the interrelationship between Ts, intensity of atmospheric pressure centers (factors indicating global climate change) and climate extremes, ECEs in the climate subregions in each month and season.

Besides, variation trends of Ts, climate extremes and ECEs as well as intensity of atmospheric pressure centers in each month and season has been determined based on Sen's slope estimator and Mann Kendall test. The gained results lead to several comments as follows:

1. Variation trends of several main atmospheric pressure centers affecting Vietnam for the period 1961 - 2010:

- Siberian high has decreased intensity and its scope is narrowed and backed northwards in the winter. The intensities of Aleutian low, South Asia low and equatorial low pressure trough are on a upward trend in mostly months of activity despite he scope of their activities less change over each decade.

- Other impact centers such as ACTBD, Mascarene and Australia high have the tendency to increase intensity and increasingly expand over the decades.

- The strengthened South Asia low, equatorial low pressure trough, ACTBD and the weakened Siberian high may be consequences of global warming.

2. Variation trends of several climate extremes and extreme climate events in Vietnam

- During the seasons, TNn and TN10 tend to increase from 0.2-0.6^{0}C/decade, more dramatically in the winter, typically in N2, N3 subregions and some stations in mountain areas. TNn and TN10 tend to rise or reduce slowly in the northern subregions for the transition months (April, May and November). Except for N3 subregion, TXx and TX90 tend to increase by 0.1-0.4^{0}C/decade, with the fastest growing speed in N2 subregion.

- Except for the N3 region, SNNN and the number of very hot days (NNGG) tend to rise in mostly summer months, in which total yearly SNNN at a number of stations increases by about 2-4 days/decade. In particular, SNNN/NNGG often increases remarkably in the summer after the El Nino cycle and decreases after the La Nina cycle. SNRD and the number of very cold days (SNRH) have the tendency to decrease faster in the B1, B2 and B3 subregions (about 3-4 days/decade). SNRD and SNRH has also decreased for the El Nino years, but increased for the La Nina years.

- Annual RXx and the number of heavy rain days are on a downward trend in mostly stations of B1, B2, B3 and N3 subregions with the respective rate of reduction from 5-10 mm/decade and from 0.3-0.5 day/decade. Especially in some stations such as Bac Quang and Truong Sa, RXx tends to increase. In B4, N1 and N2 subregions, RXx, RX95 and the number of heavy rain days tend to raise about 10-30mm/decade and 0.5-1 day/decade, respectively with the most dramatic growth in the autumn and in N1 subregion.

3. Impacts of global climate change on climate extremes and extreme climate events in Vietnam:

- Increasing average Ts in V1 (0^0 – 20^0N; 100^0E – 120^0E) and V2 (10^0S - 10^0N, 60^0-100^0E) subregions may reduce the number of damaging cold-weather days in the northern climate subregions and grow TNn, TXx and the number of hot days in mostly climate subregions (except for N1 and N3 regions).

- The weakened Siberian high in combination with the increased Ts in V3 region (15^0 - 40^0N; 100^0E - 120^0E) are related to the increase in TNn and decrease the number of very cold days in the northern climate subregions. However, the strengthened of this high pressure and the weakened South Asia low and ACTBD in May has reduced TX90 and the number of hot days in these subregions.

- The strengthening of ACTBD is consistent with an increase in TNn, TXx and the number of hot days in the northern climate subregions and N2 subregion. Especially, for the years when ACTBD enhances and dramatically expands westwards, the number of hot days in the B4 subregion considerably increases. This shows that, the role of ACTBD is closely associated with hot weather in Vietnam.

- The increase in RXx and the number of heavy rain days in the N1 subregion in the fall is also consistent with the strengthening of equatorial low pressure trough as the reason why TXx, TX90, TNn and TN10 tend to reduce for this period.

In summary, probably the most evident indication of global climate change is the increase in global average temperature, leading to the variation of atmospheric circulation system characterized by atmospheric pressure centers. Its consequences are the effects on climate extremes and extreme climate events globally in general and Vietnam in particular. The relationship has been demonstrated partly through this thesis. However, due to the complexity of the climate system, to fully explain the physical mechanism of the relationship between the change of climate extremes and extreme climate events in Vietnam and global warming that is studied further in the future. Despite this, in the implementation process of the dissertation, several scientific issues have been opened but exceeding framework of the dissertation. Nonetheless, those topics will continue to be studied more intensively as follows:

1) Increase in the number of heavy rainy days in the southern climate subregions, especially the Central South climate region may be related to the temporal and spatial transition of heavy rain causing system such as storms, tropical depressions, intertropical convergence zone and their interaction between them and the deeper penetration of cold air.

2) The transformation of climate extremes may be associated with the changes in the ENSO cycle as well as regional psychometric transport mechanism. Clarifying the relationship may contribute to explaining causes of the variation of climate extremes and extreme climate events in Vietnam.

3) Vietnam is in the region of the Asian monsoon. The variation of climate extremes and extreme climate events in Vietnam is closely related to the operating mode variation of these systems. This is maybe the crucially important and interesting mathematical problem needed to study more intensively.

However, due to the complexity of climate system, fully explaining physical mechanism of the relationship between the variation of climate extremes and extreme climate events in Vietnam and global warming is not an easy issue.

LIST OF AUTHOR'S PUBLICATIONS RELATED TO THE THESIS

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2. Chu Thi Thu Huong, Phan Van Tan, Vu Thanh Hang (2010), *Variation levels and trends of maximum wind velocity in Vietnam for the period 1961-2007*, Journal of Hydrometeorology, No.597, pp. 32-41.

3. Chu Thi Thu Huong, Phan Van Tan, Pham Thi Le Hang, Vu Thanh Hang (2010), *Variation levels and trends of hot weather in Vietnam for the period 1961-2007, Journal of Science under Vietnam National University, Hanoi*, Natural Sciences and Technology, Volume 26, No.3S, pp. 370-383.

4. Chu Thi Thu Huong, Phan Van Tan (2010), *Activities of the Siberian high and temperature in the northern region of Vietnam*, Journal of Hydrometeorology, No.599, pp. 30-38.

5. Chu Thi Thu Huong, Phan Van Tan (2012), *Relationship between hot weather and cold weather in Vietnam and outgoing longwave radiation*, Journal of Hydrometeorology, No.614, February/2012 , pp. 8-14.

6. Chu Thi Thu Huong (2013), *Transformation of intensity and position of Pacific high,* Journal of Hydrometeorology, No.635, November/2013, pp. 35-42.