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**VIETNAM INSTITUTE OF
METEOROLOGY, HYDROLOGY AND CLIMATE CHANGE**

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ASSESSMENT AND PROJECTION FOR THE VARIABILITY OF VIETNAM SUMMER MONSOON CHARACTERISTICS

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LIST OF AUTHOR’S PUBLICATIONS
RELATED TO THE THESIS

1. Nguyen Dang Mau, Nguyen Van Thang, 2018. Definition of new summer monsoon index for Vietnam region. Vietnam Journal of Science,Technology and Engineering. Vol 60 No 1 (2018)

2. Nguyen Dang Mau, Nguyen Van Thang, Mai Van Khiem, 2017. Variability of the Vietnam summer monsoon for the 21st century: Projection of PRECIS model under RCP4.5 and RCP8.5 scenarios. Journal of Climate change science, No4, 2017.

3. Nguyen Dang Mau, Nguyen Van Thang, 2017. Interannual Variability (IAV) of Vietnam Summer Monsoon Characteristics. Scientific and Technical Hydro-Meteorological Journal, 10/2017.

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5. Nguyen Dang Mau, Nguyen Minh Truong, Hidetaka Sasaki, Izuru Takayabu, 2017. Changes in seasonal rainfall in Vietnam by the end of 21^{st}. Scientific and Technical Hydro-Meteorological Journal, 1/2017.

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INTRODUCTION

1. The urgency

Vietnam is located in the interaction area of the three Asia-Pacific summer monsoon system (Wang, B. et al., 2004). As a result, the variability of the Vietnam summer monsoon (VSM) is related to the variability of these three summer monsoon systems. During summer, above the ground level, the wind direction and stream flow are southwest in the South (SVN) and south or southeast in the North (NVN). The prevailing air currents are equatorial and tropical air, originating from the Southern Hemisphere and the tropical sea originating from the northern Pacific subtropical high pressure (Nguyen Duc Ngu, Nguyen Trong Hieu, 2004). In addition, during the pre-onset and summer, the westly winds originated from South Asian low pressure (Nguyen Duc Ngu, Nguyen Trong Hieu, 2004) and extratropical region (Wang, B. et al., 2004) also effect on the NVN.

Due to the impacts of mountainous terrain conditions in the NVN and Truong Son Mountains lying along Vietnam and Laos's boundary, the Vietnam climate and VSM weather have significant spatial distribution. In addition, El Nino - Southern Oscillator (ENSO) is also considered to be the main cause of annual variability of VSM (Nguyen Duc Ngu, Nguyen Trong Hieu, 2004, Nguyen Thi Hien Thuan, 2008).

VSM is a major factor in leading weather, climate and extreme events during the summer months. The variability of VSM and its weathers resulted affect the socio-economic activities and people. Especially in the context of global warming, the information about the variability of VSM projected is important for the response to climate change. As a result, PhD candidate chosen to undertake a doctoral dissertation on "**Assessment and projection for the variability of Vietnam summer monsoon characteristics**".

2. The objective:

(1) Results of assessing the variability of the VSM characteristics;

(2) Based on the climate scenarios, the variability of VSM characteristics due to effects of climate change are projected.

3. Subjects and area of research:

- Subjects:

+ The summer monsoon index

+ The variability of VSM

- Area of research:

+ Investigating the summer monsoon index: Investigation and calculation are implemented across the area of 60-160^{o}E and 15 - 40^{o}S.

+ Assessment and projections of variability are implemented across the area of 100-110^{o}E and 5 -15^{o}N.

+ Variability of rainfall due to VSM is implemented in the Central Highlands and the South regions.

4. New contributions

(1) Result of research proposed the new summer monsoon index for Vietnam region (VSMI) defined by averaging 850hPa zonal wind (U850hPa) over the area of 5-15^{o}N and 100-110^{o}E using the 1981-2010 CFSR reanalysis data. The VSMI index can reflect well the inter-annual variability of both low and high broad-scale circulation of the summer monsoon as well as its rainfall resulted.

(2) The ISV and IAV variability of the VSM characteristics are clearly assessed. The ISV of the VSM is broadly falling in the range of 35–85 days and showing two peak times at the pentad of 36th and 40th. The VSM has strong IAV and significantly depended on the

ENSO phases. In the El Nino summer, the VSN has the later onset and earlier withdrawal date, shorter season duration and fewer break spell as well as stronger intensity compared with annual mean. In contrast to La Nina summer, the VSM has the earlier onset and later withdrawal data, longer season duration and more break spell as well as weaker intensity compared with annual mean.

(3) Initially, the IAV results of the VSM for mid-21st (2046-2065) and end-21st century (2080-2099) from the PRECIS model projections are implemented. The IAV of the onset date is projected to decrease slightly in the mid-21st and end-21st century. In contrast, other characteristics (withdrawal, season duration, break spell, intensity as well as rainfall resulted in the CHVN and SVN) are projected to increase in the mid-21st and end-21st century.

5. Scientific arguments for protection

(1) The new VSMI index can perform the activity of the VSM.

(2) VSM characteristics are characterized by both intra-seasonal variability (ISV) and inter-annual variability (IAV).

(3) The increase in GHG concentrations (RCP4.5 and RCP8.5) in the future have impacts on the variability of the VSM characteristics.

6. Scientific and practical significance

(1) The new VSMI index reflects well the activity of the Vietnam summer monsoon.

(2) The new VSMI index can be applied to operational monitoring and forecasting of Vietnam summer monsoon.

(3) Results of variability provide scientific information for VSM forecasts.

(4) Strengthening the scientific basis on the potential impact of climate change on the variability of the VSM

7. Thesis structure

Excluding the Introduction, Conclusion and recommendation, References and Annexes; the final thesis is divided into 4 chapters:

Chapter 1. Overview of the assessment and projection of the summer monsoon variability

Chapter 2. Methodology and data

Chapter 3. Variability assessment for Vietnam summer monsoon characteristics

Chapter 4. Variability projection for Vietnam summer monsoon characteristics

CHAPTER 1:
OVERVIEW OF THE ASSESSMENT AND PROJECTION OF THE SUMMER MONSOON VARIABILITY

1.1. Overview of the summer monsoon

The Asia-Pacific region (TBD) is divided into three summer monsoon systems in India, East Asia and the Pacific Northwest (Wang, B. et al., 2004). According to this division, Vietnam is located in the interaction region of the Asia-Pacific summer monsoon systems.

In the summer months, the wind and stream flow near the ground are southwest to south and south or southeast to north. The air flow prevailing in Vietnam is equatorial and tropical, originating from the southern hemisphere and the tropical sea originating from the North Pacific high pressure (Nguyen Duc Ngu, Nguyen Trong Hieu, 2004). The westly winds originated from South Asia (Nguyen Duc Ngu, Nguyen Trong Hieu, 2004) and extratropical region (Wang, B. et al., 2004) also affect the NVN.

The mountains of the West, particularly the Truong Son mountain and the mountains of Laos, are responsible for the Foehn effects losing the wet-hot of the southwest monsoon from the Bay of Bengal when hit Vietnam (Nguyen Duc Ngu, Nguyen Trong Hieu, 2004). El Nino - South Ossetia (ENSO) is also considered to be the main cause of annual monsoon variability in Vietnam (Nguyen Duc Ngu et al., 2003, Nguyen Thi Hien Thuan, 2008).

1.2. International researches

1.2.1. Assessment of summer monsoon variability

The variability is defined by World Meteorological Organization (WMO) as "variations in the mean state and other statistics of the climate on all temporal and spatial scales, beyond individual weather events".

Summer monsoon variability is subject that attracts a lot of meteorological scientists around the world. One of the first studies was done in 1686 by Hadley. Number of research on summer monsoon variability has been growing since 1970s.

The variability is defined by the fluctuation around the average without causing the long-term average itself to change. In particular, previous studies focused primarily on the major types of GMMH variability (Wang, B., 2006): (1) Intra-seasonal Variability (ISV); (2) Inter-annual Variability (IAV); and (3) Interdecadal Variability (IDV). In which, the ISV is characterized by the fluctuation range compared to the seasonal mean. The IAV is the range of climate compared to its annual mean. The IDV fluctuations are often considered for a long time, up to hundreds of years.

1.2.2. Projection of summer monsoon variability

IPCC (2013) projections shown the summer monsoon expected to be stronger. These projections also shown the ealier onset and latter withdrawal date which leading to be longer rainy season. In recent years, many studies have mentioned the impact of the increase of GHG concentration on the summer monsoon variability. However, the very high uncertainty projections under scenarios for summer monsoon variability are found in studies.

1.3. Researches in Vietnam

1.3.1. Assessment of VSM variability

The impact of ENSO on the onset date and rainfall summer monsoon in Vietnam mentioned in the study of Nguyen Duc Ngu et al (2003). Based on the CSHL index for the SVN, Nguyen Thi Hien

Thuan (2008) assessed the IAV of the summer monsoon and its rainfall resulted in the SVN region due to the ENSO phases. Based on the SCSSM index, Tran Quang Duc (2011) evaluated the trend of VSM characteristics during 1950-2010.

1.3.2. Projection of Vietnam summer monsoon variability

Research of projection for VSM variability is still void study in Vietnam. One of the first study is focused on the projection of the onset date based on the CCAM model's projections under RCP8.5 scenario (Katzfey et al., 2014). The onset date is defined by the U850hPa combined with the rainfall observed. Based on the rainfall index, projections under the RCP8.5 scenario from the PRECIS model indicate that the onset date of the VSM expected to be earlier in the mid-21st and end-21st century (Mai Van Khiem et al., 2016).

1.4. Overview of the summer monsoon index

In the Asia-Pacific monsoon region, much summer monsoon index has been researched and proposed. In East Vietnam sea area, the SCSSM index defined by U850hPa (110-120oE; 5-15oN) was proposed (Wang, B. et al., 2004). The CSHL and CSDL were proposed for SVN summer monsoon variability (Nguyen Thi Hien Thuan, 2008). In particular, CSHL is calculated by U850hPa (2.5^{o}N - 12.5^{o}N, 90^{o}E -110^{o}E) - U850hPa (20.0^{o}N - 27.5^{o}N, 105^{o}E - 120^{o}E); and the CSDL is calculated by -1xΔOLR (5-15^{o}N, 100-115^{o}E). Recently, the new index called as NRM was proposed for defining the summer monsoon variability (Nguyen Dang Quang et al., 2014). This NRW is defined by the sign (U850) x abs (MSLP x U850).

1.5. Commendations of Chapter 1

Variability of the Asia-Pacific summer monsoon is a subject that much scientists in the world are interested. Much researches focused mainly on the India, East Asia and Northwestern Pacific regions. Variability of summer monsoon normally characterized by ISV, IAV and IDV.

In recent decades, much researches have been focused on the impacts of the increase in GHG concentration on the fluctuation of summer monsoon characteristics. However, projections of the change in summer monsoon in the 21st century are highly uncertain.

In Vietnam, based on the CSHL index, the impact of ENSO on the SVN summer monsoon variability was assessed. In addition, evaluation of the trend of most key summer monsoon characters was implemented based on the SCSSM index. However, these two-summer monsoon index have not yet been identified as representative of VSM variability. In the term of the summer monsoon projection, this is a new issue and only a part of the onset summer monsoon is considered.

Monsoon index is a simple and effective tool in reflecting summer monsoon activities. As a result, many indices have been researched and proposed for the Asia-Pacific monsoon regions. In Vietnam, summer monsoon indices have been proposed for the South and the new NRM index for summer monsoon rainfall variability study. For building the representative index for VSM, the assessment of the suitable index is suggested.

CHAPTER 2:
METHODOLOGY AND DATA

2.1. Methodology

2.1.1. Proposing the Vietnam summer monsoon index

a) Approach recommends the summer monsoon index:

To develop and propose a monsoon index, the most important point is to base its definition and physical nature. Therefore, the selection of elements and domain need to be carefully assessed. The VSM is characterized by the significant southwest winds. Moreover, due to the impact of the Truong Son and Hoang Lien Son mountains, summer monsoon's activities have created a hot and dry weather. Thus, besides reflecting large-scale circulation, the index suggested is considered suitable for reflecting its rainfall resulted.

b) Method of solving the problem proposing the monsoon index:

Suggested monsoon index is the VSMI defined by U850hPa (5 - 15^{o}N, 100 - 110^{o}E).

(1) Select the variable and domain

The selected variable based on the definition of VSM is the southwest monsoon developed at low level and represented by U850hPa.

The domain of index is selected based on analysis of U850hPa's performance during the period from May to September according to CFSR data. Orthogonal function (OEF) analyzes and 850hPa wind maps are performed to determine the domain.

(2) Assessment of the summer monsoon

The correlation with U at atmospheric levels (850hPa, 700hPa, 500hPa and 300hPa) is basic information for assessing the monsoon index in reflecting the broad-scale circulations.

The ability to reflect rainfall results is based on statistical relationships with the observed rainfall at 70 stations across Vietnam. In addition, the correlation coefficient with rainfall of VSMI index is also compared with its of the CSHL and SCSSM indices for suggesting the most suitable index.

2.1.2. Definition of the Vietnam summer monsoon characteristics

Summer monsoon characteristics defined by VSMI index:

- The onset date of the VSM is defined by the first after the pentad of 21st that satisfies the following two criteria: (1) In the onset pentad, VSMI>0m/s; (2) In the next at least two consecutive pentads (including the onset pentad), VSMI>0m/s.

- The withdrawal date is the pentad after the pentad of 50th that followed two criteria: (1) In the withdrawal pentad, VSMI<0m/s; (2) In the next at least three consecutive pentads (including the withdrawal pentad), VSMI<0m/s.

- The VSM duration is defined by the length calculated from the onset pentad to the pre-withdrawal pentad.

- The intensity of the VSM is defined by the value of the VSMI.

- A break period (event) is defined from the onset pentad to the pre-withdrawal pentad that followed criteria: VSMI < 0m/s during one or consecutive pentads.

Other characteristics:

- U850hPa.

- Summer monsoon rainfall in the CHVN and SVN.

2.1.3. Definition variability calculations

- **Statistical coefficients for variability**

(1) Anomaly ():

$$\Delta = x_t - \bar{x} \qquad (2.1)$$

$\bar{x}$ is long time mean value

(2) Standard deviation (STD)

$$SD_x = \sqrt{D_x} \qquad (2.2)$$

D is expected from Δ:

$$D_x = \frac{1}{n}\sum_{t=1}^{n}(x_t - \bar{x})^2 \qquad (2.3)$$

x_t, t=1...n is the time series data of the X.

- **Impacts of ENSO on variability**

The approach study is based on the comparison of statistical results for each ENSO phases.

- **Projection of the summer monsoon variability**

Periods of calculations:

- Baseline period: 1986-2005;

- Future periods: Mid-21st century (2046-2065) and end-21st century (2080-2099).

The projection of Vietnam summer monsoon variability is defined by the changes in STD of the future periods compared with the baseline period value under scenarios followed by equations (2.6) and (2.7).

$$\Delta X_{future} = \frac{\left(X_{future} - \bar{X}_{1986\text{-}2005}\right)}{\bar{X}_{1986\text{-}2005}} * 100 \qquad (2.6)$$

$$\Delta X_{future} = X_{future} - \bar{X}_{1986\text{-}2005} \qquad (2.7)$$

In which:

ΔX_{future} is the change in the future compared with baseline value.

X_{future} and $\bar{X}_{1986\text{-}2005}$ are the value of future projection and baseline simulation, respectively.

2.2. Data used in the research

2.2.1. Re-analysis and observation data

Data used is 1981-2010 of reanalysis and observation:

- Re-analysis data: CFSR, ONI index

- Observation: Daily rainfall data at 70 meteorological stations

2.2.2. Projection data from PRECIS model

The U850hPa and rainfall simulated by PRECIS model for baseline (1986-2005) and future (2046-2065 and 2080-2099) under RCP4.5 and RCP8.5 scenarios are used.

2.3. Commendations of Chapter 2

Research methodology:

The major method of proposing summer monsoon index is based on the definition of the VSM that is the southwest monsoon in low atmospheric level. In order to validate the monsoon index, calculations of the ability to reflect broad-scale circulation of atmospheric levels, as well as its rain resulted.

The summer monsoon variability is the range of the fluctuation compared to its mean value (seasonal mean or annual mean). The estimation of the summer monsoon variability, statistical coefficients such as standard deviation as well as anomaly are used. In addition, assessment of summer monsoon variability is also implemented.

Projections of the summer monsoon variability are the changes in the future variability compared with the present variability. To do this, calculations of changes in future STD index compared to the present STD index are implemented under RCP4.5 and RCP8.5 scenarios.

Data used:

Historical data includes the following types of data: (1) CFSR data; (2) ONI; (3) Daily rainfall at 70 stations.

Climate data from PRECIS model: Simulations (1986-2005) and projections (2046-2065 and 2080-2099) data under scenarios RCP4.5 and RCP8.5 are used.

CHAPTER 3:
VARIABILITY ASSESSMENT FOR VIETNAM SUMMER MONSOON CHARACTERISTICS

3.1. The new Vietnam summer monsoon index

3.1.1. Definition of the variable and domain for summer monsoon index

The variable chosen is U850hPa.

The domain definition of the VSM: 5^oN-15^oN, 100^oE-110^oE

The equation for calculating VSMI index:

$$\mathbf{VSMI = U850hPa\ (5^oN - 15^oN;\ 100^oE - 110^oE)}$$

3.1.2. Validating the performance of the VSMI index

3.1.2.1. Performance in describing the broad-scale circulation

The VSMI is highly correlated with the broad-scale summer monsoon in low and high layers on the inter-annual timescales. During 1981-2010, the correlations between VSMI with U wind (850-500hPa) are higher than 0.35 in the Southwest monsoon region. The correlation coefficients are at the 95% confidence level. In the 300hPa, the correlation between the VSMI with U300hPa is smaller than -0.35 and at the 95% confidence level. This suggests that the VSMI can reflect the inter-annual variations of broad-scale summer monsoon circulations in layers of atmosphere.

3.1.2.2. Performance in describing summer monsoon rainfall

The VSMI, SCSSM and CSHL indices are significantly correlated with rainfall in the CHVN and the SVN. However, the summer monsoon rainfall is reflected more clearly by the VSMI and SCSSM indices than the CSHL. In while, the CSHL tend to describe the positive correlations with rainfall which is not only rainfall from summer monsoon. Comparison of three indices, the VSMI reflect more clearly summer monsoon rainfall than other two indices.

3.2. Intra-seasonal variability of Vietnam summer monsoon

3.2.1. Variability of the broad-scale circulation

The intra-seasonal variation of the VSM is known to consist of fluctuations on time scales broadly falling in the range of 35–85 days. The intensity of the VSM is found to consist of two peak times at the pentad of 36th and 40th.

3.2.2. Broad-scale circulation during the onset and withdrawal date

The prominent feature during the onset and withdrawal of VSM is a shift of the Ridge of high pressure in the North Pacific. During the onset period, the ridge shift of high pressure is rapid eastward. However, during the withdrawal period, the ridge shift of high pressure is slow westward.

3.2.3. Variability of summer monsoon rainfall

In the CHVN: The ISV of the summer monsoon rainfall is found by the anomaly pentad rainfall in the range of -2.4 to 2.62 mm/day. The ISV can be found in the consist of fluctuations on time scales falling in the range of 70-80 days.

In the SVN: The ISV of the summer monsoon rainfall is found by the anomaly pentad rainfall (mm/day) in the range of -1.93 to 3.13 mm/day. The ISV can be found in the consist of fluctuations on time scales falling in the range of 40-100 days.

3.3. Inter-annual variability of the Vietnam summer monsoon

3.3.1. The relationship of characteristics

Some characteristics are clearly related (above 95% confidence level) such as the correlation of onset and withdrawal date with the seasonal length, correlation coefficients are -0.73 and 0.74, respectively. The intensity of VSM has the good correlation with the withdrawal date, break spells as well as the seasonal length, with correlation coefficients as -0.56, -0.71 and -0.51, respectively.

3.3.2. Inter-annual variability of characteristics defined by VSMI index

3.3.2.1. Variability of onset date

During 1981-2010, the onset date has IAV with anomaly ranged from -4.1 to 4.9 pentad and 1.9 pentad of STD. The onset date usually comes later in the El Nino summer; conversely, early in the summer La Nina.

3.3.2.2. Variability of withdrawal date

During 1981-2010, the withdrawal date has IAV with anomaly ranged from -5.7 to 3.3 pentad and 2.4 pentad of STD. In the El Nino and neutral-warm summer, the withdrawal date usually comes early; the opposite occurs in the summer of La Nina and neutral - cold phase.

3.3.2.3. Variability of the seasonal length

Mean value of the period 1981-2010, the length of the VSM is remaining in about 30 pentads (around 150 days). The seasonal length has IAV with anomaly ranged from -6 to 8 pentads and 3.4 pentad of STD. In almost La Nina season (85.7%), the seasonal length usually lasts longer; Conversely, shorter in summer El Nino (87.5%).

3.3.2.4. Variability of the break spell

The break spell has IAV with anomaly varied from -1.5 to 2.5 times and 1.3 times of STD. The number of break spell is to be less in the El Nino summer; Conversely, higher in La Nina summer.

3.3.2.5. Variability of the intensity

The intensity of VSM has IAV with anomaly ranged from -2.7 m/s to 1.6 m/s and 1.1 m/s of STD (Cv index is 21.9%). In the El Nino

(85.6%) and neutral-warm summer (77.8%), stronger intensity is found; Conversely, weaker in the La Nina (85.6%) and neutral - cold summer (57.1%).

3.3.2.6. Decade trend of the GMMH

The IAV variation has changed over the decades, with the tendency of decreasing in variability.

3.3.3. Inter-annual variability of summer monsoon rainfall in the CHVN and SVN

In the period 1981-2010, the summer monsoon rainfall in the CHVN varies with anomaly ranged from -2 to 2 mm/day and 1.45 mm/day of STD (Cv index is 18, 06%).

In the period of 1981-2010, the summer monsoon rainfall in the SVN varies with anomaly ranged from -1.6 to 1.7 mm/day and 1.27 mm/day of STD (Cv index is 16.24%).

3.4. Commendations of the Chapter 3

(1) The VSMI reflects well on large-scale circulation in atmospheric levels (850, 700, 500 and 300hPa) and its rainfall resulted in the VSM season. Thus, the VSMI is perfectly suited for the study of summer monsoon variability in Vietnam.

(2) The ISV of the summer monsoon: The VSM has fluctuations in range of 35-85 days and twice reached peak at the pentad of 36^{th} and 44^{th}. The summer monsoon rainfall in the CHVN and SVN fluctuates strongly depending on spatial distribution. The strongest fluctuations are at less rainfall stations; Conversely, in the higher rainfall stations.

(3) THE IAV of VSM characteristics:

The VSM characteristics fluctuate from year to year and in ENSO phases such as following as:

- The IAV of onset date is defined by anomaly varying ranged from -4.1 to 4.9 pentad and 1.9 pentad of STD (around 9.5 days). In most of La Nina summer (57.1%) and neutral - cold phase (85.7%), the onset date usually comes earlier; Conversely, it arrives later in the El Nino summer and neutral - warm phase.

- The withdrawal date has inter-annual fluctuation with standard deviation ranged from -5.7 to 3.3 pentad and 2.4 pentad of STD (around 12 days). In most of La Nina (71.4%) and neutral-cold (57.1%) summer, the withdrawal date is later; Conversely, its earlier in the El Nino and neutral - warm phase summer.

- The seasonal length has IAV with the anomaly ranged from -6 (30 days) to 8 pentads (40 days) and 3.4 pentad of STD (17 days). In the La Nina and neutral - cold summer, the length of VSM is usually longer; Conversely, shorter in summer El Nino and neutral – warm summer.

- The number of break spell has IAV with anomaly ranged from -1.5 to 2.5 times and 1.3 times of STD (Cv index 83.9%). In the La Nina summer, the number of break spell is more frequent; Conversely, less frequent in the El Nino summer.

- The intensity has IAV with anomaly ranged from -2.7 to 1.6 m/s and 1.1 m/s of STD (Cv index is 21.9%). In most of El Nino summer (85.6%) and neutral - warm (77.8%), stronger intensity; Conversely, the weakest intensity coincides with La Nina.

- The summer monsoon rainfall in the CHVN and SVN is higher in La Nina summer; Conversely, lower in the El Nino summer.

CHAPTER 4:
VARIABILITY PROJECTION FOR VIETNAM SUMMER MONSOON CHARACTERISTICS

4.1. Simulation of the PRECIS model for summer monsoon characteristics in Vietnam

The earlier onset date and later withdrawal date is simulated by the PRECIS-CNRM model. In contrast, PRECIS-GFDL tends to simulate later onset and withdrawal date.

GMMH late and finish earlier than CFSR. The intensity of GMMs in the simulation models using the PRECIS model has a stronger tendency than the CFSR.

4.2. Projection of the U850hPa variability

4.2.1. For the mid-21st century

The projected scenarios show an increase in U850hPa fluctuations in the North Central Coast and adjacent ocean. However, there is a heterogeneity in the U850hPa's fluctuations in other regions, especially in the North.

4.2.2. For the end-21st century

The U850hPa variability in the end-21st century is similar to the mid-21st century. However, the uniformity of the U850hPa's increased variability in the south is more evident, especially under the RCP4.5 scenario.

4.3. Projection of the VSMI's characteristics variability

4.3.1. Variability of the onset date

Variability of the onset date is projected to decrease in the mid and end-21st century compared to the base period. The reduction of the STD in ensemble results projected by from 18.4% (RCP8.5) to 24.8%

(RCP4.5) in the mid-21st century and from 13.2% (RCP8.5) to 19, 7 (RCP4.5) in the end-21st century.

4.3.2. Variability of the withdrawal date

By the mid and end-21st century, the variability of the withdrawal date is expected to increase in most cases (accounting for 66.7%) compared with the baseline value, with an increase in the STD ranged from 25 to 47.8%.

4.3.3. Variability of the seasonal length

Projections show an increase of variability in the mid and decrease of variability in the end-21st century.

4.3.4. Variability of the break spell

The increase in break spell variability in the 21st century is found in the PRECIS-GFDL's projections; Conversely, in the PRECIS-CNRM's projections.

4.3.5. Variability of the intensity

Most of projections show the increase in variability of the summer monsoon intensity, with the increase of STD ranged from 11.9 to 16.1% under the ensemble results.

4.4. Projection of the summer monsoon rainfall in the Central Highlands and the South

Most results show an increase in rainfall variability in future periods compared to baseline in the CHVN and SVN. The increase in rainfall variability between the two climatic zones is quite similar. In particular, the general trend is that rainfall fluctuations increased more under the RCP8.5 scenario than RCP4.5 and increased more towards the end of the century than in the mid-21st century.

4.5. Commendations of Chapter 4

(1) Projections show the decrease of the onset date variability in the 21^{st} century compared with the baseline value, with the decrease ensembled of STD ranged from 13.2 to 24.8%.

(2) The withdrawal date variability is projected to increase in the 21^{st} century compared with the baseline value, with the increase ensembled of STD ranged from 25 to 47.8%.

(3) The seasonal length variability is projected to increase in the mid and decrease in end-21^{st} century.

(4) The variability of the break spell is projected as changes in STD ensembled in future compared with the baseline value ranged from -16.5 (RCP4.5) to 3.6% (RCP8.5) in the mid and from -0.6 (RCP8.5) to -0.2% (RCP4.5) in the end-21^{st} century.

(5) The intensity variability is projected to increase significantly in the mid and end-21^{st} century compared with the baseline value, with the STD ensembled in the range from -3.0 (RCP4.5) to 11.9% (RCP8.5) in mid and -5.4 (RCP8.5) to 16.1% (RCP4.5) in the end-21^{st} century.

(6) Changes in rainfall during GMMH season

Most of the projections show that the fluctuation of GMMH rainfall in the CHVN and the SVN in the mid and end-21^{st} century is higher than in the baseline period. In particular, the increase in rainfall variability is more significant under the RCP8.5 scenario than RCP4.5; at the end of the 21^{st} century compared to the mid of the century as well as in the SVN compared to the CHVN.

CONCLUSION AND RECOMMENDATION

1. Conclusion

Based on the results of the study on the assessment and projection of the VSM variability, some conclusions can be drawn:

(1) The new VSMI index is calculated by U850hPa (5^oN - 15^oN and 100^oE - 110^oE), reflecting well the VSM activities and large-scale circulation, as well as rain effected.

(2) VSM characteristics have clear ISV and IAV variability:

- The ISV of VSM characteristics: The intensity of VSM fluctuates in the range of 35-85 days and 1.9 m/s of STD (Cv index is 39.2%). Variability of summer rainfall is stronger at stations with high rainfall and vice versa at lower rainfall stations. The summer monsoon rainfall variation in the CHVN is in range of 70-80 days and in range of 40-110 days in the SVN.

- The IAV of VSM characteristics:

The VSM characteristics have strong IAV; the STD of the following characteristics such as onset date, withdrawal date, seasonal length, break spell and intensity respectively 1.9 pentad, 2.4 pentad, 3.1 pentad, 1.3 time and 1.1 m/s. ENSO has a strong impact on IAV of ISV. In the El Nino and neutral-warm summer, VSM features are defined as: later onset date, earlier withdrawal date, shorter length and less break spell as well as stronger intensity. In the La Nina and neutral - cold summer, VSM features are defined as: earlier onset date, later withdrawal date, longer season length and more break spell as well as decreased in intensity.

(3) The results projected by the PRECIS models show that the increase in GHG under RCP4.5 and RCP8.5 has an impact on the

fluctuation of GMMH characteristics in the mid-21st and end-21st century.

- The variability of the onset date is projected to decrease; Conversely, the increase in the variability of the withdrawal date. VSM season length is projected to change by little increase in the mid-21st and decrease in the end-21st century.

- By the mid and end-21st century, the variability of both summer monsoon intensity and summer monsoon rainfall (in the CHCN and the SVN) are projected to increase compared to the baseline values. In particular, projections show more increase under the RCP8.5 than RCP4.5 as well as more by the end-21st than mid-21st century.

2. Recommendation

Based on the results of the study, we propose the following research directions as: Variability projections of the summer monsoon based on considering more increase of climate models.