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Research Article

Evaluation Rainfall Characteristics over Vietnam Simulated by the Non–Hydrostatic Regional Climate Model – NHRCM during the 1981–2001 period

Ha Pham-Thanh[1]*, Hang Vu-Thanh[1], Truong Nguyen-Minh [1]

[1] VNU Hanoi University of Science, 334 Nguyen Trai, Thanh Xuan, Hanoi, Vietnam; phamthanhha.k56@hus.edu.vn; hangvt@vnu.edu.vn; truongnm@vnu.edu.vn

***Correspondence: phamthanhha.k56@hus.edu.vn; Tel.: +84–972355393**

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Abstract: This study aims to evaluating characteristics of rainfall simulated by Non–Hydrostatic Regional Climate Model (NHRCM) over seven sub–regions of Vietnam during the 1981–2001 period. Features such as seasonal cycle of monthly average daily rainfall, maximum daily rainfall, and frequencies at different thresholds are compared with observations. Statistical evaluations of errors and correlation coefficient are also examined to see the differences between model results and observations. The results show that NHRCM captured well the seasonal cycle of the simulated monthly average daily rainfall, but magnitudes are underestimated in all sub–regions except South Central Vietnam (N1). Generally, underestimations of the simulated daily rainfall are observed in almost all months and sub–regions, higher differences are found in rainy months and the most underestimation of rainfall is observed in South Vietnam (N3). Correlation coefficients over 0.6 are found in North West Vietnam (B1) and South Vietnam (N3). Monthly absolute maxima of the observed daily rainfall are found in North Central (B4) in transition months when the model usually underestimated significantly. In addition, NHRCM tends to simulate cases with rainfall amounts below 16 mm/day or above 50 mm/day with higher frequencies compared with the observations. In contrast, frequencies detected by NHRCM seem to be lower than those of the observations for rainfall amount in 16 – 50 mm/day, especially in sub–regions N2 and N3. These results are supportive for applying the Regional Climate Model in simulating rainfall characteristics over Vietnam, especially for Non–Hydrostatic version.

Keywords: NHRCM model; Rainfall; Vietnam.

1. Introduction

Southeast Asia including Vietnam is a monsoon region where extreme events frequently occur, especially associated with precipitation. Precipitation is an essential component of the earth's climate system affecting the eco–system and socio–economy activities [1]. Numerical experiments of Regional Climate Models (RCM) have been implemented so far by many authors such as [2–7]. Along with the development of science and technology in recent years, super computers have been able to run much finer grid RCMs that help to well reproduce extreme events such as heavy rain and intense heat [8]. It is well known that precipitation simulations of RCMs are biased due to limited understanding of atmospheric physical processes or insufficient spatial resolution [9]. Therefore, a major important thing is that output of RCMs should be evaluated with historical observations [10]. There are several studies [8–13] investigated the skill of the Non–Hydrostatic Regional Climate Model

(NHRCM) of the Meteorological Research Institute (MRI) in simulating the present climate, including heavy precipitation as well as in producing climate projection over Japan and Southeast Asia. Five–year integration from 2001 to 2006 was carried out continuously in the study [8] to evaluate reproducibility of the present climate over Japan using the double–nesting NHRCM with the analysis data. The simulated results of the 4–km grid spacing NHRCM showed that the average annual precipitation was overestimated by only 8% compared to the Automated Meteorological Data Acquisition System (AMeDAS) observations. NHRCM simulated reasonable frequency distribution of precipitation intensity, with a little higher value for the frequency of heavy precipitation than that observed by the AMeDAS [8]. A 20–year–integration of NHRCM of the present climate using an inner nested grid with a spacing of 5 km showed that the model performance fluctuated significantly among regions over Japan. In particular, the model tended to give underestimated precipitation from 20% to 40% along the coast of the Japan Sea and the Nansei Archipelago and overestimated precipitation by more than 40% at some inland locations when compared with observed amounts. However, the model well reproduced the spatial and temporal distributions of the annual mean temperature and precipitation [11]. The study of [12] evaluated the accuracy of four RCMs, including NHRCM, through daily precipitation indices during the period 1985–2004 over Japan at 20–km grid interval. The results indicated that for most indices, such as mean precipitation, number of wet days, mean amount per wet day, 90th percentile of daily precipitation, number of days with precipitation ≥90th percentile of daily precipitation, are often produced well by NHRCM model. However, the accuracy varies depending on the indices, seasons and aspects. The study also highlighted that higher–resolution dynamical models derive a better representation of most daily precipitation indices than reanalysis data, especially in areas with complex terrain and land–sea distribution. The present climate over Southeast Asia, from 1989 to 2008, was simulated by NHRCM with 25–km resolution and 50 vertical levels [13]. It is shown that the model can capture well the topographic effect on rainfall, but the simulated values can be wet (dry) biases in the windward (leeward) side of mountains compared to APHRODITE. In terms of both seasonality and daily distribution of rainfall, the NHRCM model tends to underestimate the number of wet days during the respective wet season of the sub–regions and to overestimate daily rainfall intensity. There are many researches on RCM performance assessment such as RegCM, MM5, WRF… over Vietnam especially on examining rainfall simulation. The study of [14] used RegCM3 to analyze the simulations of surface temperature and precipitation over the Red River Delta of Vietnam. Model results are compared with observations at the 17 meteorological sites in Red River Delta during the 1980–1999 baseline period. They conclude that temperature is underestimated systematically as well as precipitation has cold bias during summer and autumn while is well reproduced in winter and spring. Besides that, the ability simulations of the climate regional non–hydrostatic NHRCM and hydrostatic RegCM4.2 models from 1985–2007 showed in the study of [15]. It can be found that surface temperatures simulated by NHRCM have warm biases while vice versa of RegCM compared with observations. Rainfall simulations of NHRCM have a better agreement with observations than those of RegCM4.2, especially NHRCM can reproduce some heavy rainfall centers. In the study [16], clWRF model is used to simulate the rainfall amount in the period of (1981–2000). The results show that the model simulations are often overestimated comparing to observations especially in rainy season and in southern surface meteorological stations. The performance of simulation and projection of rainfall and tropical cyclone activity over Vietnam was investigated in [17]. The simulated results showed that climatic heavy rainfall centers are well captured in the seasonal cycle. However, the model overestimates rainfall in comparison with the APHRODITE data. In addition, NHRCM underestimates rainfall in North Vietnam but overestimates rainfall in South Vietnam in June–July–August compared to the rain gauge data. The model also overestimates rainfall in September but underestimates in October–November in Central Vietnam.

The purpose of this paper is to evaluate rainfall simulation of NHRCM over Vietnam as well as to analyze its characteristics in the present climate from 1981 to 2001. Main features including seasonal cycle of monthly average daily rainfall, maximum daily rainfall, and frequencies at different thresholds are compared directly with observations. The rest of this work is organized as follows. Section 2 will provide details of model experiment and data. Section 3 describes results and discussions. Concluding remarks are given in Section 4.

2. Data and Methods

2.1. Data

In this study, daily rain gauge data observed at 127 selected meteorological stations, as shown in Figure 1, are used to estimate the seasonal march of the simulated rainfall in seven sub–regions of Vietnam during the 1981–2001 period. The ERA–Interim reanalysis (hereafter denoted as ERA) is a global atmospheric reanalysis dataset developed by the European Centre for Medium–Range Weather Forecasts (ECMWF), which covers from January 1989 onward and is continuously updated in near–real time [18]. In this study, the ERA data for precipitation and the wind field on the 850mb pressure level for the period 1981–2001 are used to evaluate the performance of the NHRCM model in capturing the features of wind across a year.

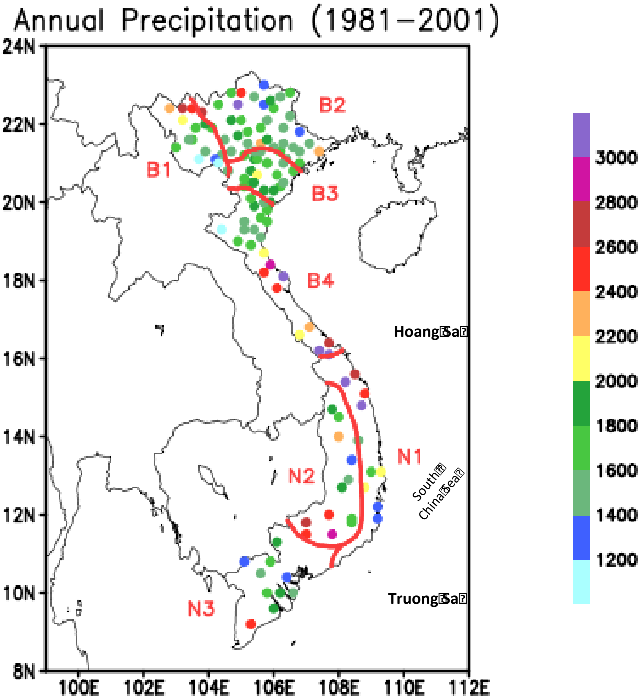


Figure 1. Colors indicate average annual precipitation (mm) over seven sub–regions of Vietnam during the 1981–2001 period. Circles show meteorological observation sites and lines display the boundaries of seven sub–regions.

2.2. Methods

The regional climate model NHRCM is the extended version of an operational Non–Hydrostatic Model (NHM) developed by the Meteorological Research Institute (MRI) and the Numerical Prediction Division of the Japan Meteorological Agency (NPD/JMA). The detail descriptions of NHM can be found in [19]. The Kain–Fritsch scheme [20] is used in this study for cumulus convective parameterization. The soil model is replaced by

MRI/JMA– Simple Biosphere model (MJ–SiB, [21]) and lateral boundary conditions are replaced by spectral nudging boundary conditions.

Simulations have been done over a domain of (6.4° – 25.2°N; 98.4° – 112.5°E) as shown in Figure 2. The time steps for the model configured with 5–km horizontal resolution and 50 vertical levels. Initial and boundary conditions for NHRCM are provided by a simulation performed by an atmospheric general circulation model with a 20–km horizontal grid spacing (AGCM20; [22]). Lateral boundary conditions are updated every 6 hours. The sea surface temperature is given by the Hadley Centre Sea surface temperature data set version 1 (HadISST1) four times a day [23]. Time integration was implemented continuously from January 1981 to December 2000. For each year, the simulation began at 00 UTC 20 November and ended 00 UTC 31 December. The first 42 days of the simulation were regarded as the model spin–up and discarded.

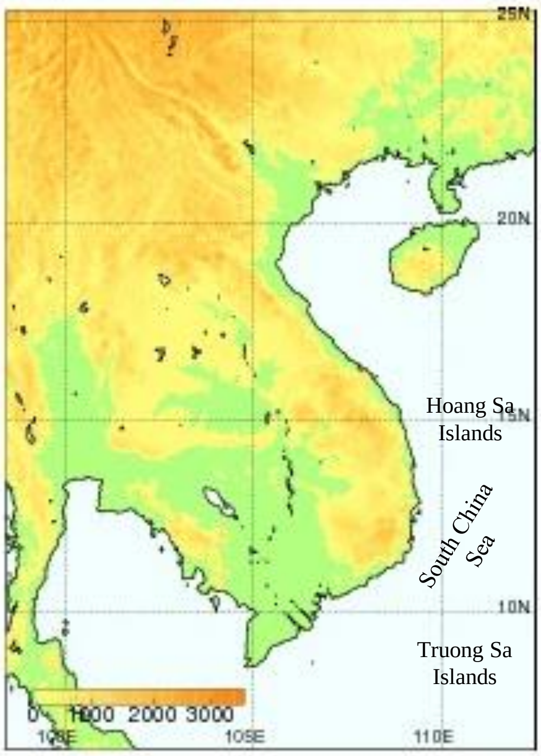


Figure 2. Model domain and topography.

3. Results and discussions

Figure 3 shows the mean 850–hPa wind patterns in March–April–May (MAM), June–July–August (JJA), September–October–November (SON) and December–January–February (DJF) of NHRCM and ERA during 1981–2001. In general, the spatial and temporal variability of the prevailing 850–hPa winds are simulated well by NHRCM compared with ERA for the whole Vietnam region. However, the values of NHRCM are a little higher than those of ERA. During MAM, the mean 850–hPa winds are southwesterly over North and North Central Vietnam, while they are easterly and northeasterly over South Central and South Vietnam. In JJA, the prevailing 850–hPa winds are westerly almost all over Vietnam, however, they change to northeasterly and easterly in Central and South Vietnam while southeasterly and southerly in North Vietnam in SON and DJF. The effects of interactions, especially the interaction between circulations and topography, result in the seasonal cycle of rainfall over each sub–region as illustrated in Figure 4.

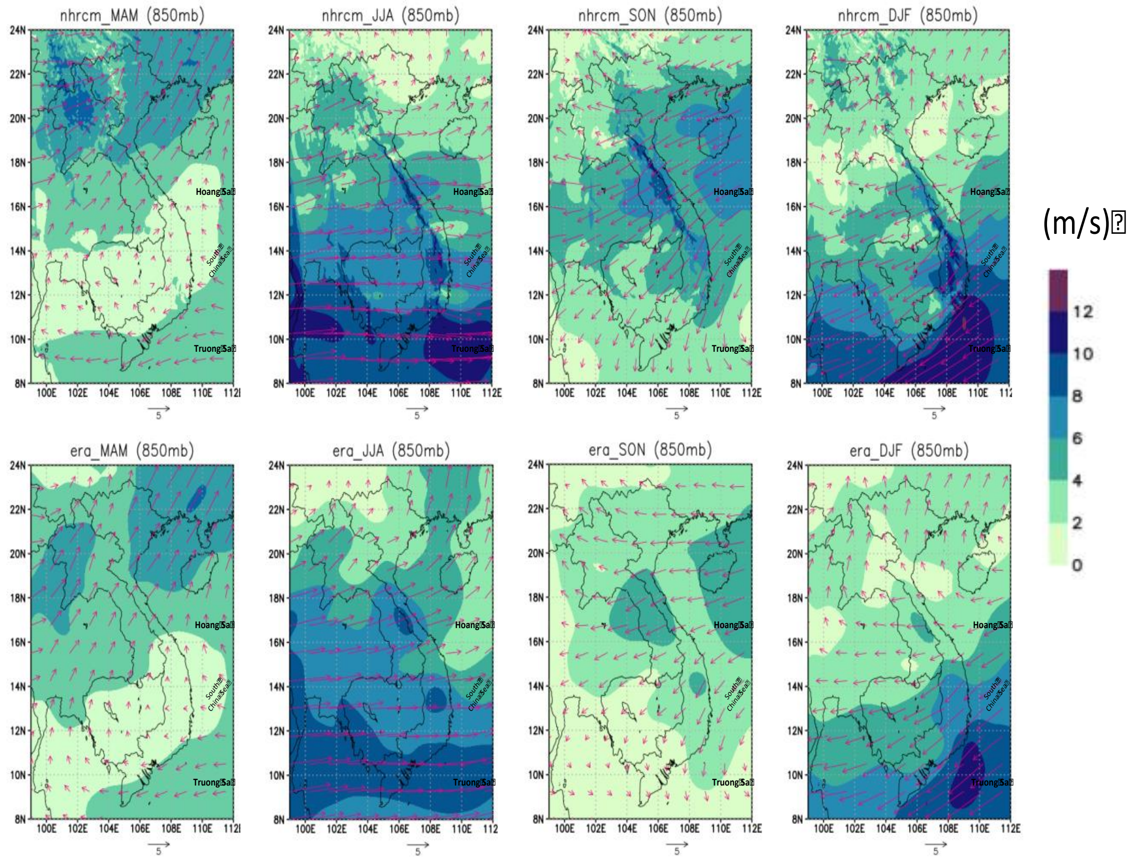
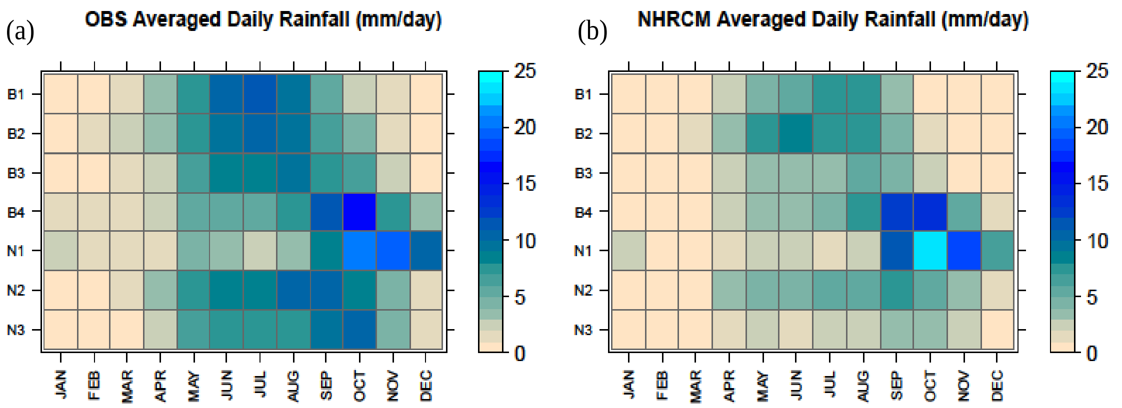


Figure 3. Mean winds at 850–hPa during the 1981–2001 period in (a) MAM, (b) JJA, (c) SON and (d) DJF of NHRCM (upper) and ERA (lower).

Figure 4 describes the monthly average daily rainfall in seven sub–regions of Vietnam of the reanalysis (ERA), model (NHRCM), and observation (OBS) data. It is clear that the maximum average daily rainfall occurs in autumn in B4, N1, and N3 sub–regions while in summer in other sub–regions. The delay of the rainy season in B4 and N1 is due to the barrier effect of topography on prevailing winds during SON, causing heavy rainfall on the windward side of Truong Son Mountains (Figure 3c). According to the observations, the daily rainfall is commonly from 10 mm/day to 15 mm/day in almost all sub–regions, however, rainfall amounts can frequently reach 20 mm/day in B4 and N1 sub–regions (Figure 4a). The average daily rainfall is well captured in terms of the evolution but a little underestimated by NHRCM in all sub–regions except for N1 (Figure 4b). Figure 4c shows that the ERA average daily rainfall also has a good agreement with the observations in the annual march but is much overestimated in all sub–regions.



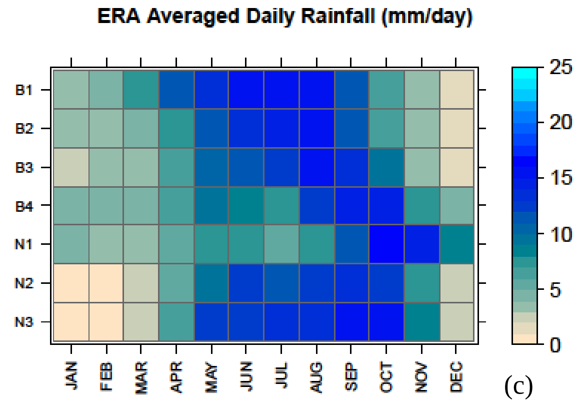


Figure 4. Monthly average daily rainfall in seven sub–regions of Vietnam of (a) observation, (b) NHRCM and (c) ERA during the 1981–2001 period.

The differences in the monthly average daily rainfall between the ERA and NHRCM data and the observations in seven sub–regions are displayed in Figure 5. Accordingly, positive differences between ERA and the observations are found in almost all sub–regions except in October–November for B4, and in October–December for N1. In general, these differences tend to be higher in the rainy season, and the highest ones of 8 mm/day between ERA and the observations can be seen in B1. Conversely, negative differences are detected in almost all sub–regions when comparing the NHRCM and observation data. It is clear that higher differences occurred in higher rainfall months, and the most underestimated rainfall area is N3.

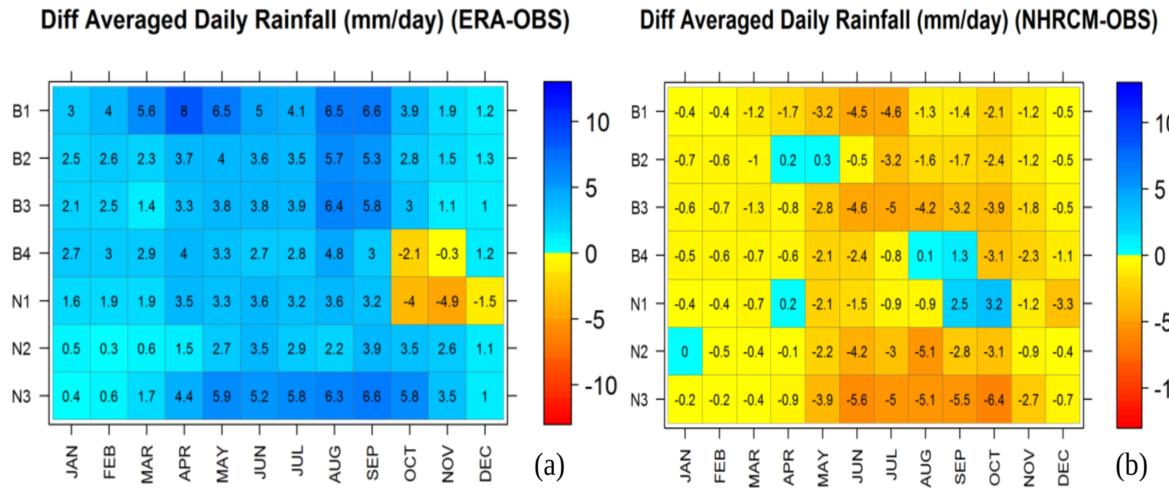


Figure 5. Monthly average daily rainfall differences between (a) ERA and (b) NHRCM and the observations in seven sub–regions of Vietnam during the 1981–2001 period.

Scatter plots of the average daily rainfall of the observations and NHRCM in seven sub–regions and the whole of Vietnam during 1981–2001 are depicted in Figure 6. Accordingly, the correlations of B1 and N3 sub–regions are over 0.6 while the others are over 0.4. The correlation coefficient of the whole of Vietnam is 0.46. It is clear that rainfall amounts of 25–50 mm/day are often observed in B2 sub–region, however, such amounts are normally underestimated by NHRCM. The daily rainfall values of NHRCM in other sub–regions are overestimated compared with the observations.

Maxima and means of the monthly maximum daily rainfall of the observations and NHRCM over seven sub–regions of Vietnam from 1981 to 2001 are shown in Fig. 7. In general, the monthly mean variations of NHRCM well follow those of the observations, however, a clear underestimation is found in N3. Besides, the maxima of the NHRCM maximum daily rainfall are underestimated compared with the observations in late autumn and early winter and vice versa in late spring and summer in almost all sub–regions.

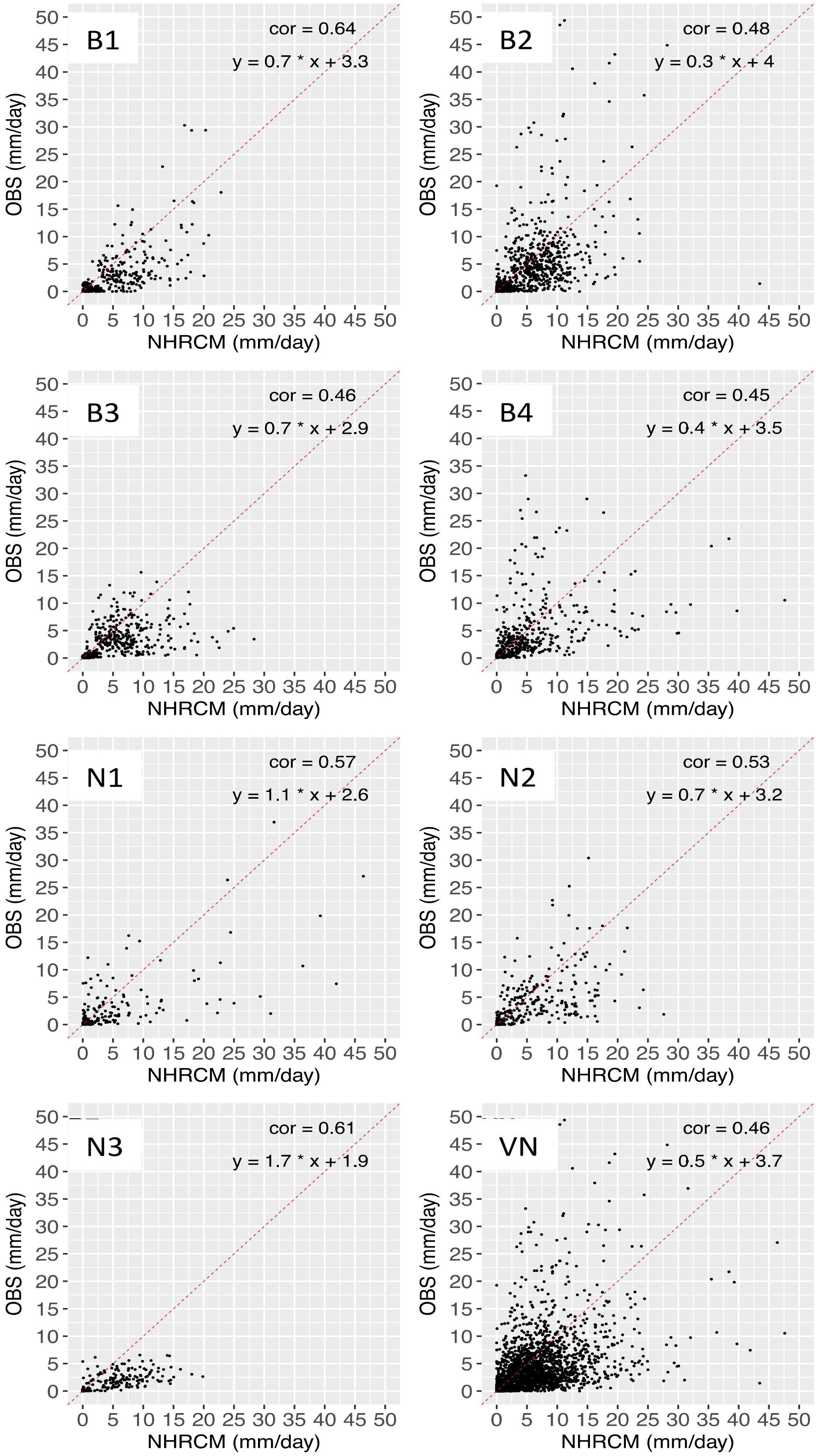


Figure 6. Scatter plots of the average daily rainfall (mm/day) of the observations and NHRCM in seven sub–regions and the whole of Vietnam during the 1981–2001 period.

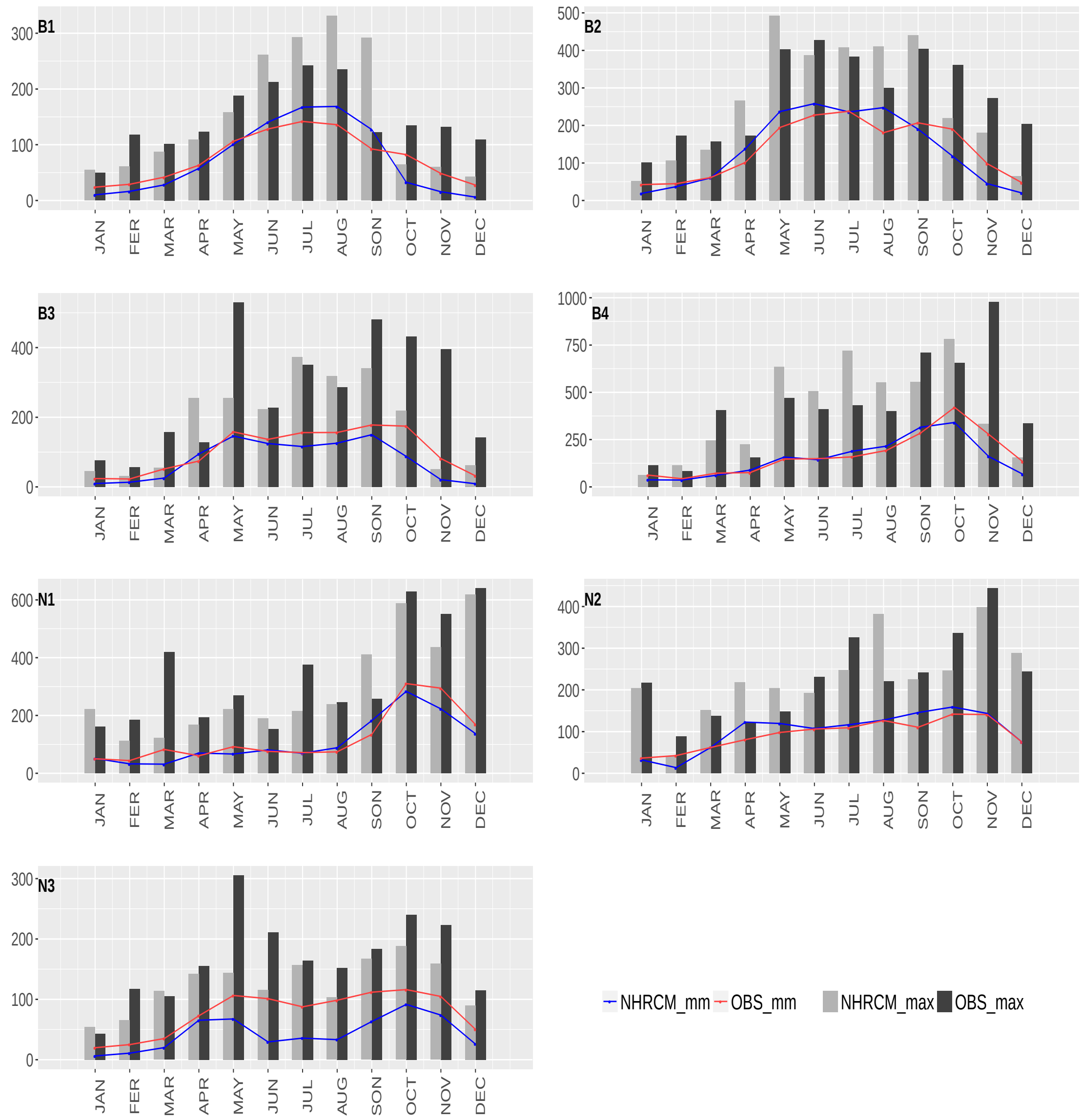


Figure 7. Maxima (columns) and means (lines) of the monthly maximum daily rainfall of the observations and NHRCM over seven sub–regions of Vietnam during the 1981–2001 period.

Frequencies of the daily rainfall at different thresholds of the observations and NHRCM over seven sub–regions of Vietnam during the 1981–2001 period are illustrated in Fig. 8. Accordingly, frequency distribution of the observed daily rainfall is captured well by NHRCM. However, NHRCM tends to simulate cases with rainfall thresholds of below 16 mm/day or above 50 mm/day with higher frequencies compared with the observations. In contrast, frequencies given by NHRCM seem to be lower than the observations for rainfall thresholds from 16 mm/day to 50 mm/day, especially in sub–regions N2 and N3.

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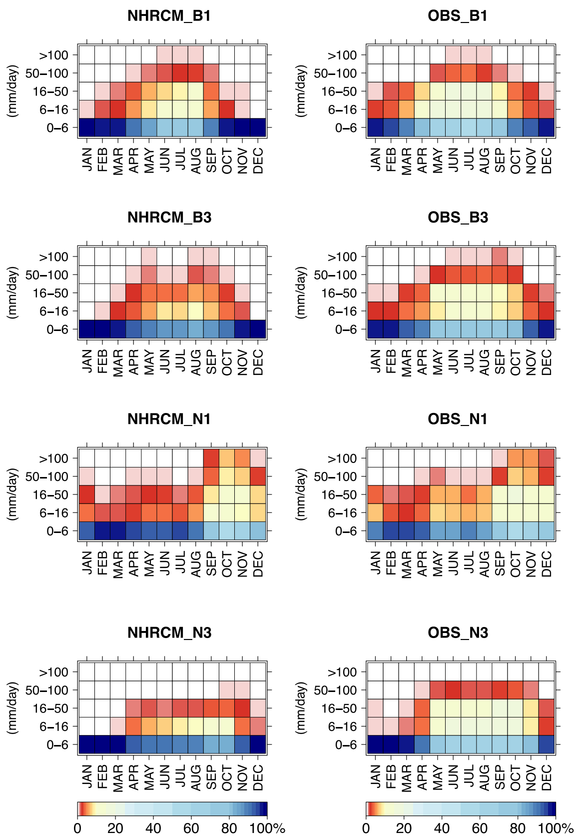

Figure 8. Frequencies of the daily rainfall at different thresholds of the observations and NHRCM over seven sub–regions of Vietnam during the 1981–2001 period.

4. Conclusions

The main goal of this paper is to evaluate the rainfall simulation of NHRCM over Vietnam and analyze its characteristics in the present climate from 1981 to 2001. The results show that the observed seasonal cycle of rainfall is captured well by NHRCM for all sub–regions, but magnitudes are underestimated in all sub–regions except South Central Vietnam (N1). Generally, higher differences are found in rainy months, and the most underestimation of rainfall is observed in South Vietnam (N3). However, correlation coefficients of the average daily rainfall between the observations and NHRCM are over 0.4 for all sub–regions and are higher in North West Vietnam (B1, about 0.64) and South Vietnam (N3, about 0.61). The monthly absolute maxima of the observed daily rainfall are found in North Central (B4) in transition months when the model is underestimated significantly. Besides, NHRCM tends to simulate cases with rainfall thresholds of below 16 mm/day or above 50 mm/day with higher frequencies compared with the observations. Conversely, frequencies found in the NHRCM rainfall data seem to be lower than the observations for cases with rainfall thresholds ranging from 16 mm/day to 50 mm/day, especially in sub–regions N2 and N3. These results have inspired a further study to examine statistical or bias correction for the rainfall simulations and projections of NHRCM over Vietnam.

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