BÀI BÁO KHOA HỌC

THE VARIATIONS OF HEAVY RAINFALL IN THE NORTHERN REGION OF VIETNAM UNDER THE GLOBAL WARMING: A CASE STUDY OF HEAVY RAINFALL EVENT FROM 30 OCTOBER TO 05 NOVEMBER, 2008

Tran Quoc Lap[1]

Abstract: *In this paper, a heavy rainfall event in the northern region of Vietnam in August 2008 was selected for simulation, using a Weather Research and Forecast (WRF) model and combining with ensemble simulation method. Rainfall variability in future climate scenarios was investigated using numerical simulations based on pseudo global warming conditions, constructed using fifth-phase results of Coupled Model Intercomparison Project multi-model global warming experiments. The simulation results of maximum six-hourly rainfall in northern Vietnam will slightly decrease under the climate change conditions, whereas, total precipitation would increase significantly in all three global climate models in the future. The spatial distribution of heavy rain would tend to shift to the northern mountainous regions of Vietnam. Simulation results suggest that global warming may correlate with a significant increase in total rainfall.*

Keywords: heavy rainfall, pseudo global warming, ensemble simulation,

1. INTRODUCTION

The science of climatic extremes is important and critical in terms of modeling, socioeconomic impacts, damages, and adaptation. Occurrences of rainfall extremes are expected to increase in changing climate (Goswami B. N et al. 2006, IPCC 2012) and hence, proper scientific understanding of extremes is crucial. Though there are significant research advancements in the last two decades in the science of extremes (Cavazos 2008, IPCC 2012, Wheater H.P 2002, Young 2002) to minimize the impacts, hazards, and losses,there are still a significant number of extreme events resulting in huge human and economic losses.

Heavy rains are the consequence of convective instabilities in moist air in small spatial location (Goswami B. N et al. 2006). Although the fraction of extreme rain events is caused by synoptic disturbances (Francis 2006), a large number of extremes are caused by processes like thunderstorms and are more uniformly distributed with space and time. Extremely rainfall is difficult to predict and continue to be a challenge to operational and research community (Das 2008, Li 2017).

Located along the east coast of the Indochina Peninsula with a substantial latitudinal extent on the northwest Pacific Ocean, Vietnam is one of the countries heavily affected by climate change in the world. Heavy rainfall is one of the major severe weathers over the northern region of Vietnam producing devastating flood in the delta and flood flash in the mountainous areas, and consequently having caused a number of fatalities and a tremendous amount of property damage. Heavy rainfall usually results from individual mesoscale storms or mesoscale convective systems (MCSs) embedded in synoptic-scale disturbances (Lee 1998). We need high-resolution observations and numerical modeling techniques to better predict heavy rainfall events and understand the evolution and development mechanisms of mesoscale convection and storms responsible for heavy rainfall.

In this study, the pseudo-global warming (PGW) downscaling approach (Sato, Kimura, and

[1] *Division of Water Resources Engineering, Thuyloi University*

Kitoh 2007) was applied to investigate the future variations in a heavy rainfall event in the northern region of Vietnam. So, we selected the heavy rain event from 30 October to 05 November 2008 and made hindcast and PGW simulations to investigate the changes in rainfall. The remainder of this paper is organised as follows. Section 2 presents an overview of the dataset, and the design of the dynamic downscaling (DDS) with PGW forcing data are provided In Section 3, the hindcast simulations of heavy rainfall are discussed, and the simulations of rainfall changes in future climate scenarios from the DDS are investigated with PGW conditions. Finally, a summary is given in the last section.

2. DATA AND METHODOLOGY

2.1 Data

2.1.1. Japanese 55-year Reanalysis (JRA-55)

The Japanese 55-year reanalysis product (JRA-55) by the Japan Meteorological Agency (JMA) was used for simulations of the heavy rain event in 2008. JRA-55 is produced by a system based on the low-resolution (TL319) version of JMA's operational data assimilation system, which has been extensively improved since the previous reanalysis (JRA-25). The atmospheric component of JRA-55 is based on the incremental four-dimensional variational method. Newly available and improved past observations are used for JRA-55. Major problems in JRA-25 (cold bias in the lower stratosphere and dry bias in the Amazon) have been resolved in JRA-55; therefore, the temporal consistency of temperature is improved. Further details are available in Kobayashi et al. (Kobayashi 2015).

2.1.2. Climate Model Intercomparision Project (CMIP5)

Global warming experiments Climate projections of the fifth phase of the Climate Model Intercomparison Project (CMIP5) were used for the preparation of the PGW conditions. In CMIP5 (Taylor K.E. 2012), simulations of climate projections are conducted according to several greenhouse gas emission scenarios, i.e., representative concentration pathways (RCPs). For example, in the RCP4.5 scenario, the radiative forcing of the Earth becomes 4.5 W/m^2 by the end of the 21 st century. In this study, projections based on the RCP4.5 scenario were used, details of which are presented in Table 1.

Table 1. List of the CMIP5 models used in our research

CMIP5_ID	Institute	Country
1 ACCES1-0	Commonwealth Scientific and Industrial Research and Organization.	Australia
2 CNRM_CM5	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique	France
3 GFDL-CM3	Geophysical Fluid Dynamics Laboratory, USA	United State

2.1.3. The sea surface temperature (SST)

For SST in the simulations, we used the National Oceanic and Atmospheric Administration Optimum Interpolation 1/4 Degree Daily Sea Surface Temperature Analysis (NOAA OI SST) (Reynolds 2007). The NOAA OI SST data set has a grid resolution of 0.25° and a temporal resolution of one day. The product uses Advanced Very High-Resolution Radiometer infrared satellite SST data. Advanced Microwave Scanning Radiometer SST data were used after June 2002. In situ data from ships and buoys were also used for large-scale adjustment of satellite biases.

2.1.4. Land-surface Conditions

For the land-surface condition in the numerical simulations (volumetric soil moisture, soil temperature, soil type, and vegetation type), we used National Centers for Environmental Prediction (NCEP) Final Operational Global Analysis (NCEP FNL) data. NCEP FNL data are produced on a 6-hourly basis by the NCEP global data analysis system from July 1999 to the near present. Data spatial resolution is 1.0° × 1.0° (NCEP 2000).

2.1.5. Rainfall Data for Verification

As rainfall data for verification of the heavy rain event in 2008, we used in-situ observation data from fourteen rain gauge stations in the northern region of Vietnam. The locations of weather stations are shown in Fig 1 (b). In Vietnam, weather radar stations over the whole territory are fairly sparse. Hence, to examine the detailed spatial distribution of precipitation in the northern region of Vietnam, simulated results were compared with the spatial distribution of heavy rainfall rate by Tropical Rainfall Measuring Mission Microwave Imager (TRMM/TMI) measured microwave energy emitted by the Earth and its atmosphere to quantify the water vapor, the cloud water, and the rainfall intensity in the atmosphere. TRMM precipitation measurements have made critical inputs to numerical weather prediction, and precipitation climatologies.

2.1.6. Heavy rainfall event in 2008

From 30 October to 1 November 2008, the extremely heavy rains are recorded with the total amount of over 500 – 600 mm during the three days in Hanoi area. The rain in Hanoi was concentrated in a short period with the highest intensity over the past 100 years.

2.2. Pseudo-Global Warming and dynamical downscaling method

In recent years, there have been a number of research works related to the affecting of global warming and the climate sciences usually use the simulation output from coupled atmosphere-ocean global climate models (AOGCMs) for present and future predicted (Lee 2006, Von Storch 2008). However, the spatial resolution of AOGCM models are usually too coarse (generally several hundreds of kilometer per grid), so it is too difficult to investigate future variations of local-scale hydrologic, atmospheric and meteorological conditions, and extreme weather events.

In this paper, control simulations of the heavy rainfall events (CTL) from 30 October to 05 November 2008 were performed with initial and boundary conditions prepared from JRA-55, NCEP FNL and NOAA 0.25 interpolated OI SST. In addition to CTL, we performed simulations with pseudo global warming forcing prepared using different CMIP5 data. Pseudo Global Warming conditions of the heavy rainfall event were calculated from future and present climate conditions. The future weather conditions were obtained from the 10-year monthly mean from 2091 to 2100. Present climatic conditions were obtained from the 10-year monthly mean from 1991 to 2000 in 20C3M. Then, anomalies of global warming were calculated as the difference between future and present climatic conditions and added to JRA-55. Thus, a set of PGW conditions was constructed for the wind, atmospheric temperature, geopotential height, surface pressure, and specific humidity. For relative humidity, the original values in JRA-55 were retained in three CMIP5 models conditions, and specific humidity in these conditions was defined from the relative humidity and the modified atmospheric temperature of the future climate. To prepare SST for the PGW condition, the SST anomaly obtained from future and present climate conditions in the CIMP5 output was added to the NOAA SST.

Design of Numerical Simulations

In this study, weather research and forecasting model (WRF) version 3.6.1 were adopted for the CTL and PGW simulations. A two-way nesting grid system was used, as shown in Figure 1 (a). The coarsest domain (D01) had a 30-km horizontal resolution and the higher resolution domain D02 had a 6-km horizontal resolution. The Betts–Miller–Janjic microphysics and Lin ice cumulus parameterization schemes (Lin 1983) were used to calculate precipitation in the model. Planetary boundary layer processes were calculated using the Total Energy - Mass Flux (TEMF) scheme. For longwave and shortwave radiation, the rapid radiative transfer model with the New Goddard scheme was used. For D01, a spectral nudging method was used for atmospheric temperature, zonal wind, meridional wind, and geopotential height every six hours at altitudes above 6–7 km. An outline of the model settings is given in Table 2

Errors in initial conditions and in model physics result in forecast uncertainties. One approach for reducing these uncertainties is the use of ensemble forecasting Ensemble simulations with different initial conditions were performed for the CTL and each PGW condition. Ensemble simulations enable stochastic analysis of differences between CTL and PGW runs. Therefore, it could be determined whether differences were attributable to the effects of global warming or chaotic behaviors in the numerical weather model. For more details of this methodology, refer to Tran and Taniguchi (2016) (Tran and Taniguchi 2016).

3. RESULTS

3.1. Results of the CTL run

Figure 2 shows the results of total precipitation at 14 rain gauge stations in the northern region of Vietnam. From the results of total rainfall amount from 06:00 UTC 30 October to 00:00 UTC 05 November 2008 we can see that the average heavy rainfall from nineteen ensemble members at the most of rain gauge stations is close with observation data. Except for the results from Ha Dong station, precipitation tends to be underestimated in CTL runs, the mean simulation result is approximately 500 mm when compared with over 800 mm. The average simulation results of nineteen ensemble members at Ba Vi, Hung Yen, Van Ly, and Thai Binh rain gauge stations are higher than the observed data.

The correlation coefficient (CC), and root mean square errors (RMSE) between CTL runs and observation data are 0.8 and 132 mm respectively. It means that the simulation results are good correlate with the observed data.

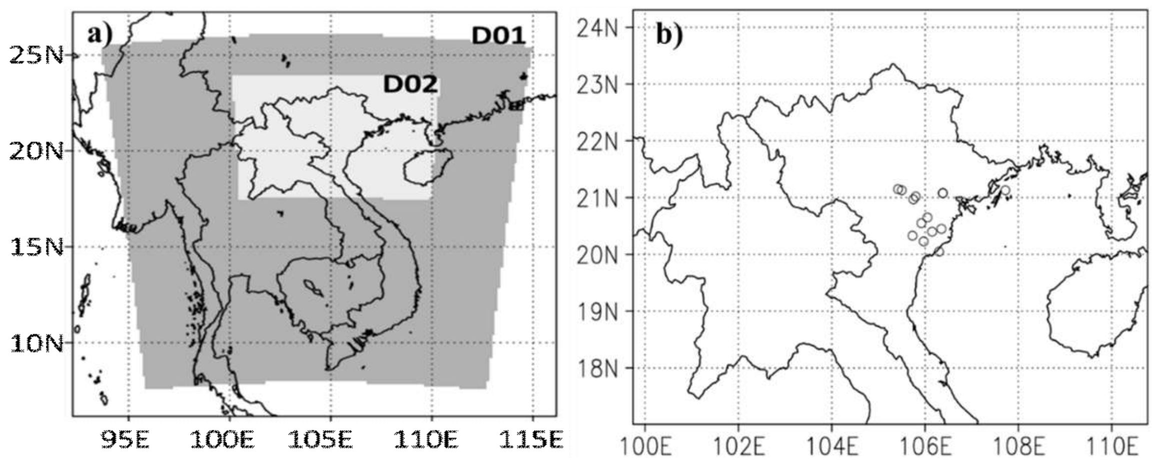

Figure 1. a) Two domains using in this study D01, D02 are coarse and fine domains respectively, b) The open circles are the locations of 14 rain gauge stations.

Table 2. The settings in Weather Research and Forecasting model

Version of model	V 3.6.1
Number of domain	Two
Horizontal grid distance	30 km (coarse domain); 6 km (fine domain)
Cloud microphysics	Lin et al. method (Lin, Farley,and Orville (1983, JCAM))
Cumulus parameterization	Betts-Miller-Janjic scheme cumulus parameterization
Longwave radiation	New Goddard scheme
Shortwave radiation	New Goddard scheme
Sf_sfclay_physics	TEMF (ARW only)
Land surface scheme	unified Noah land-surface model
Planetary boundary layer scheme	Total Energy - Mass Flux (TEMF) scheme
Setting of spectral nudging	A spectral nudging method was used for atmospheric temperature, zonal wind, meridional wind, and geopotential height every six hours, at altitudes above 6-7 km.

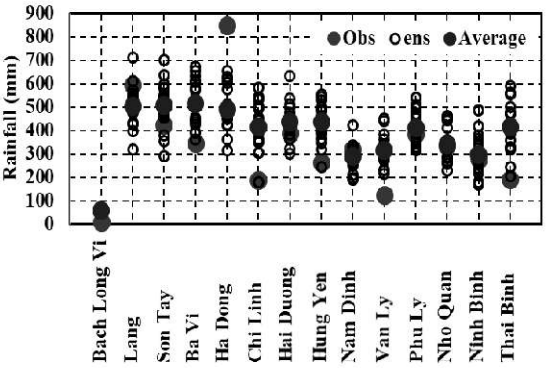

Figure 2. Rainfall at 14 rain gauge stations. Large blue solid circles and open small circles are average rainfall simulation results and rainfall simulation results for each ensemble member respectively. Large red solid circles are observation rainfall data at 14 rain gauge stations.

Figure 3 (a) and (b) show the spatial distribution of rainfall from 03 UTC to 04 UTC 31 October 2008 of Tropical Rainfall Measuring Mission Microwave Imager (TRMM/TMI), and ensemble mean results of CTL runs. The simulation result captures the heavy rain events through the intensity and distribution of rainfall. The simulation results seem to concentrate in the Northwest region, spread from 20°N to 22°N latitude and 103.5°E to 105°E longitude, the heavy rainfall area is to move to the northern area when compared with spatial distribution rainfall of TRMM/TMI. The heavy rainfall area in one hour greater than 30 (mm/h) is larger than the results fromTRMM/TMI.

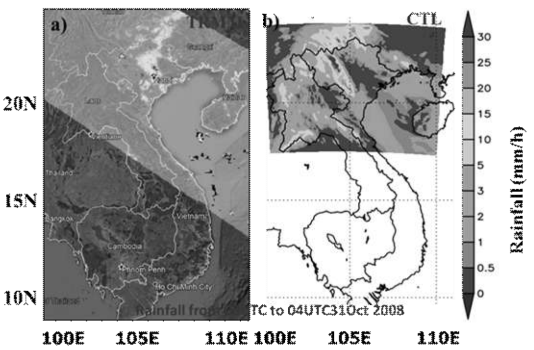

Figure 3. a) and b) the spatial distribution of heavy rainfall rate by Tropical Rainfall Measuring Mission Microwave Imager and the average simulation results of nineteen ensemble members from 03UTC to 04 UTC 31 October 2008 respectively.

3.2. The variation of heavy rainfall under the global warming

3.2.1. Maximum six-hourly rainfall amount and total rainfall amount.

Figure 4 displays the relationship between the maximum six hourly rainfall amount and total rainfall amount of CTL runs and three CMIP5 models. The simulation results of six-hourly rainfall from nineteen ensemble members of three CMIP5 models show slightly decrease when compared with CTL runs. The mean six-hourly rainfall of nineteen ensemble member of CTL runs is about 446 mm, whereas the values simulated by three CMIP5 models are from 412 (mm) and 433 (mm). However, when considering the results of total rainfall simulated by three CMIP5 models, the all simulation results of mean total rainfall from nineteen ensemble members increase from 15% to 28 % in all experiments. The highest increase in total precipitation (the average from nineteen ensemble members) is 1701 mm at ACCESS1-0 model, followed by CNRM-CM5, and GFDL-CM3 models with 1652.4 mm and 1527 mm, respectively when compared with 1326.7 mm of CTL runs. The heavy rainfall from each ensemble member is maximum value were found from the spatial distribution of rainfall in domain 2 with the simulated time of 6 hourly and total time (from 06UTC 30 October to 00UTC 05 November) respectively.

In this research, to assess the variation of total rainfall in the future, the author used empirical cumulative distribution curves (ECD). However, other CDF may give better fitting. The results are shown in Figure 5.

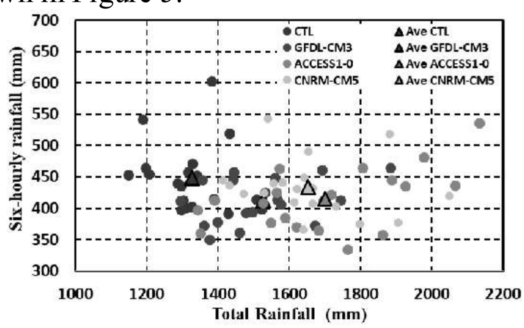

Figure 4. Maximum six-hourly rainfall amount and total rainfall amount (from 06UTC 30 October to 00UTC 05 November) for each simulation and ensemble mean result.

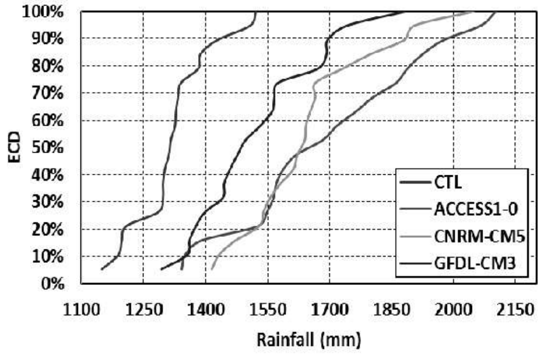

Figure 5. The Empirical Cumulative distribution curves of total rainfall simulated by three CMIP5 models and CTL runs

From Figure 5, it is clear that there is a significant increase in the amount of total rainfall in three models. For instance, an assumption that the probability of total heavy rainfall is 10% (the CDF is 90%), the highest increase in heavy rainfall would be ACCESS1-0 model, next is CNRM-CM5 and GFDL-CM3 models with respectively when compared with CTL run. It means that the total heavy rainfall similar to precipitation events in 2008 would tend to increase significantly in the future because of global warming.

3.2.2. The spatial distribution of heavy rainfall

1. Spatial distribution of Six-hourly rainfall

Figure 6 shows the spatial distribution of maximum six-hourly rainfall from 06:00UTC 30 October to 00:00UTC 05 November and the difference heavy rainfall between three CMIP5 models and CTL runs. The average spatial distribution of heavy rainfall area from nineteen ensemble members seems to increase and shift to the north-northeast and the north central coast regions of Vietnam. Especially in CNRM-CM5 the heavy rainfall area increases from 18^{o}N to 22^{o}N latitude, 104^{o}E to 106^{o}E longitude, but the results of ACCESS1-0, the heavy rain band seems to concentrate in the middle part of northern Vietnam (104^{o}E to 106^{o}E longitude). The heavy rain band in the coastal regions of northern Vietnam would decrease in the future.

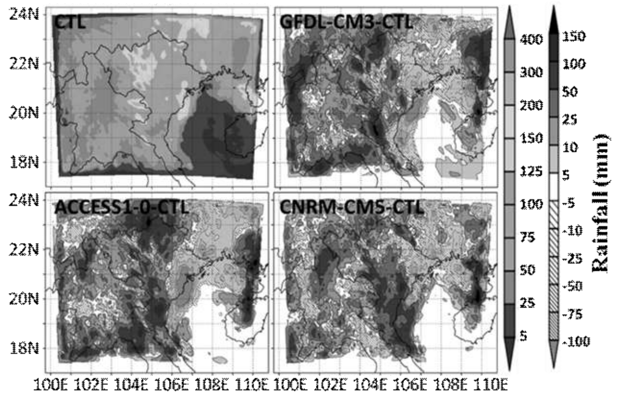

Figure 6. The spatial distribution of maximum six-hourly rainfall of CTL runs and the difference between three CMIP5 models and CTL runs. Left- and right-hand color bars are for the maximum six-hourly rainfall and the differences between three CMIP5 models and CTL (mm), respectively

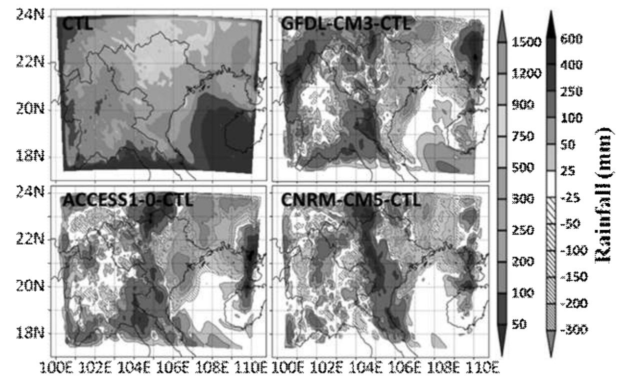

Figure 7. The spatial distribution of total rainfall of CTL runs and the difference between three CMIP5 models and CTL runs. Left and right-hand colorbars are for the maximum total rainfall and the differences between three CMIP5 models and CTL (mm), respectively.

2. Spatial distribution of total rainfall.

Figure 7 displays the spatial distribution of total rainfall of CTL runs and the difference between three CMIP5 models and CTL run. The simulation results of three models show an increase heavy rainfall in the west-northeast region of Vietnam, from longitude 104.5^{o}N to 106.5^{o}N, and 18^{o}E to 23^{o}E, especially in some provinces such as Ha Giang, Tuyen Quang, Phu Tho, Hoa Binh, and Thanh Hoa provinces. The total mean rainfall simulated by 3 PGW experiments increases to near 400 mm when compared with CTL runs. Meanwhile, the total rainfall seems to decrease to 200 mm in the Red River Delta and the north-northeast regions of Vietnam such as Hanoi, Ha Nam, Quang Ninh, and Thai Binh… provinces.

4. CONCLUSIONS

This study aims to perform a hindcast of heavy rainfall in the northern region of Vietnam from 30 October to 05 November 2008, and investigate the variations in torrential rain under global warming climate conditions using the PGW method. In the hindcast and the simulations using the PGW method, 19 ensemble members were prepared based on the LAF method.

In the hindcast, the torrential rains were underestimated in some regions when compared to observation data. In the future simulations, the six-hourly heavy rainfall amount slightly decreases, while, total rainfall increases significantly when compared with control run values in all models. The fluctuation of six-hourly and total rainfall was wide among ensemble members of CTL runs and three CMIP5 models. Torrential rains may occur over short periods and larger areas in future climate conditions. The spatial distribution of precipitation in three CMIP5 models would be larger than in the CTL runs. The cumulative distribution curves of the maximum total precipitation showed clear differences between current and future climate conditions. The results indicate that under the climate change condition, the heavy rainfall event similar to 2008 would be expected to increase significantly when compared with the current climate. This is because, under the global warming, saturated water vapour will increase and the warmer SST will provide more water vapour.

Only one heavy rainfall event was examined and the conclusions drawn about variations in heavy rainfall due to future global warming may include some uncertainty. It is thought that the results of this study are the first step in evaluating heavy rainfall, and investigation of other rainfall event, as well as the use of additional AOGCMs and climate change scenarios, will be indispensable for assessing changes in heavy rainfall due to climate change.

REFERENCES

Cavazos, T., Turrent, C., Lettenmaier, D.P. 2008. *"Extreme precipitation trends associated with tropical cyclones in the core of the North American monsoon."* Geophys Res Lett no. 35:L21703.

Das, S., Ashrit, R., Iyengar, G. R., Mohandas, S., Gupta, M. D., George, J. P., Rajagopal, E., and Dutta, S. K. 2008. *"Skills of different mesoscale models over Indian region during monsoon season: Forecast errors." J.* Earth Syst. Sci no. 117:603-620.

Francis, P.A; Gadgil S. 2006. *"Intense rainfall events over the west coast of India."* Meteorol Atmos Phys no. 94:27-42.

Goswami B. N, Venugopal V, Sengupta D, Madhusoodanan M. S, and Xavier P. K. 2006. *"Increasing trend of extreme rain events over India in a warming environment."* Science no. 314 (5804):1442-5. doi: 10.1126/science.1132027.

IPCC. 2012. *"Managing the risks of extreme events and disasters to advance climate change adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. In: Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner G-K, Allen SK, Tignor M, Midgley PM (eds)."* Cambridge University Press, Cambridge 582 pp.

Kobayashi, S., Y. Ota, Y. Harada, A. Ebita, M. Moriya, H. Onoda, K. Onogi, H. Kamahori, C. Kobayashi, H. Endo, K. Miyaoka, and K. Takahashi. 2015. *"The JRA-55 Reanalysis: General specifications and basic characteristics."* J. Meteor. Soc. Japan no. 93:5-48.

Lee, D. K., H. R. Kim, and S. Y. Hong. 1998. *"Heavy rainfall over Korea during 1980–1990." Kor. J. Atmos. Soc* no. 1:32-50.

Lee, T. C. K., F. C. Zwiers., X. Zhang., M. Tsao. 2006. "*Evidence of decadal prediction skill resulting from changes in anthropogenic forcing.*" J. Climate no. 19:5305–5318.

Li, L., Gochis, D. J., Sobolowski, S., and Mesquita, M. D. 2017. *"Evaluating the present annual water budget of a Himalayan headwater river basin using a high‐resolution atmosphere‐hydrology model." J. Geophys. Res. [Atmos.]* no. 122:4786-4807.

Lin, Y.-L., Farley, R. D., and Orville, H. D. 1983. *"Bulk parameterization of the snow field in a cloud model."* J. Climate Appl. Meteor no. 22:1065–1092.

NCEP. 2000. *"NCEP FNL Operational model global tropospheric analyses, continuing from July 1999."* Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory. Boulder*, CO,*. doi: http://dx.doi.org/10.5065/D6M043C6.

Reynolds, R. W., T. M. Smith, C. Liu, K. S. Casey, and M. G. Schlax. 2007. *"Daily high-resolution blended analysis for sea surface temperature."* J. Climate no. 20:5473-5496.

Sato, T., F. Kimura, and A. Kitoh. 2007. *"Projection of global warming onto regional precipitation over Mongolia using a regional climate model."* J. Hydrol no. 333:144-154.

Taylor K.E., Stouffer R.J., Meehl G.A. 2012. *"An Overview of CMIP5 and the experiment design." Bull.* Amer. Meteor. Soc. no. 93:4.

Tran, L.Q, and K. Taniguchi. 2016. *"Simulations of Heavy Rainfall from a Tropical Cyclone in Coastal Regions of Vietnam under the Global Warming."* Journal of Climate change no. 2 (2):25–34.

Von Storch, J-S. 2008. *"Toward climate prediction: Interannual predictability due to an increase in CO2 concentration as diagnosed from an ensemble of AO GCM integrations."* J. Climate.

Wheater H.P. 2002. *"Progress in and prospects for fluvial flood modelling."* Philos Trans R Soc London, Ser A no. 360:1409–1431.

Young, P. C. 2002. *"Advances in real-time flood forecasting."* Philos Trans A Math Phys Eng Sci no. 360 (1796):1433-50. doi: 10.1098/rsta.2002.1008.

Tóm tắt:

THAY ĐỔI CỦA MƯA LỚN TRONG KHU VỰC PHÍA BẮC CỦA VIỆT NAM DƯỚI TÁC ĐỘNG CỦA SỰ NÓNG LÊN TOÀN CẦU: MỘT NGHIÊN CỨU CỦA TRẬN MƯA TỪ 30 THÁNG 10 ĐẾN 05 THÁNG 11 NĂM 2008

Trong bài báo này, mưa lớn ở khu vực phía Bắc của Việt Nam từ ngày 30 tháng tới ngày 05 tháng 11 năm 2008 được lựa chọn để mô phỏng, dự báo, sử dụng mô hình nghiên cứu và dự báo thời tiết (WRF) kết hợp với phương pháp mô phỏng tổ hợp. Dự báo sự thay đổi lượng mưa trong tương lai sử dụng mô phỏng số học dựa trên các điều kiện giả định sự nóng lên toàn cầu dựa trên 3 mô hình khí tượng toàn cầu GCM trong bộ mô hình CMIP5. Các kết quả mô phỏng lượng mưa 6 giờ lớn nhất cho thấy có sự giảm nhẹ về cường độ trong vùng phía Bắc của Việt Nam, trong khi đó, tổng lượng mưa của trận mưa tăng lên đáng kể trong tất cả 3 mô hình lựa chọn mô phỏng trong tương lai. Sự phân bố của mưa lớn có xu hướng dịch chuyển lên vùng núi phía Bắc của Việt Nam. Kết quả mô phỏng chỉ ra rằng sự nóng lên toàn cầu có tương quan lớn với sự gia tăng của lượng mưa trong tương lai.

Từ khoá: lượng mưa lớn, sự nóng lên toàn cầu, mô phỏng tổ hợp

Ngày nhận bài: 24/7/2019

Ngày chấp nhận đăng: 29/8/2019