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Numerical Simulation of Extreme Temperature (Heat Wave) in Bangladesh Using WRF-ARW Model

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Authors' contributions

This work was carried out in collaboration among all authors. Authors MAA and MAKM designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MAS and MRH managed the analyses of the study. Author MNUB managed the literature searches. All authors read and approved the final manuscript.

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Abstract

Every year Bangladesh experiences different types of natural hazards and heat wave is one of them. In the present study, an advanced high-resolution Weather Research and Forecasting (WRF-ARW) numerical mesoscale model is used to simulate a severe heat wave event occurred during April 2016 over Bangladesh and eastern part of India. The model is integrated for 6 days starting from 0000UTC of 19 April to 0000UTC of 24 April 2016, on a single domain of 10 km horizontal resolution. For validation of the model performance, the model simulated results of temperature at 2 m height, relative humidity (RH), mean sea level pressure (MSLP) at 0900UTC of 6 days are compared with the BMD observed data. And the results indicate that the model is able to simulate the occurrence of the heat wave event with 6 days over Bangladesh.

Keywords: Extreme temperature; heat wave; relative humidity; MSLP; mesoscale models.

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Nomenclatures

^0C → Celsius
^0N → Refer to latitude
^0E → Refer to longitude
% → Percentage
hPa → Hectopascal
UTC→ Universal Time Coordinated
m → Metre unit of length

1 Introduction

Almost every year, Bangladesh experiences different types of natural hazards which include cyclones, severe thunderstorm, flood, heavy rainfall, heat wave, cold wave etc. Among them Heat Wave (HW) is one of the lethal types of whether phenomena in Bangladesh. In 2015, the position of HW as the deadliest natural disasters were four out of ten and HWs ranking of South Asian was third UNSDR, [1]; Nissan et al. [2]. In Kuwait the extreme sea surface temperature reached 37.6°C, as a result several fish kill incidents were recorded Yosiri, et al. [3]. More than 70,000 people died as a result of the 2003 European heat wave Robine, et al. [4]. 26 people died over Bangladesh as HW in 2007. 2003 European heat wave Robine, et al. [4] In April and May 2016, Indian HW was a major HW and as a result about 160 people died when national record high temperature was 51.0℃ Tharoor, [5] Heat Wave has no universal definition and generally its definition is based on the area, location and time period You, et al. [6]. Generally, regression equations are used to define HW which are to relate a combination between whether parameters and human cognition Tharoor, [5]. Heat wave is also defined as different temperature thresholds for different geographical regions. For example, Kysely [7] defined Heat Wave for Check Republic that the definition consists of three requirements imposed on a period to be treated as a heat wave: (i) T_{MAX} (daily maximum air temperature) $\geq T_1$ in at least 3 days; (ii) mean T_{MAX} over the whole period $\geq T_1$; and (iii) $T_{MAX} \geq T_2$ in each day. The threshold values were set to T_1 = 30℃, T_2 = 25℃, in accordance with a climatological practice commonly applied in the Czech Republic which refers to the days with TMAX reaching or exceeding 30℃ and 25℃ as tropical and summer days, respectively. According to the Australian Bureau of Meteorology HW occurs when three consecutive days or more of maximum or minimum temperatures are unusual for the location. The World Meteorological Organization (WMO) defined heat wave as when the daily maximum temperature of more than five consecutive days exceeds the average maximum temperature. No such definition has been developed for Bangladesh, but Bangladesh Meteorological Department (BMD) defines various types of heat waves as: when maximum temperature $36 - 38$℃ → Mild Heat Wave; when maximum temperature $38 - 40$℃ → Moderate Heat Wave; when maximum temperature $40 - 42$℃ → Severe Heat Wave; when maximum temperature 42℃ → Extreme Heat Wave.

Study and experiment both theoretical and practical on the climatology of heat wave conditions has become a topic of great interest in scientific research since the last century. Yan et al. [8] analyzed and found from the longest (1741-1998) observational daily temperature series that the number of warm days are increasing and cold days are decreasing in China and Europe since 1961. The linear trends of mean daily minimum temperature and maximum temperature reached 0.41°C/10 yr and 0.18°C/10 yr, respectively over the eastern and central Tibetan Plateau during the period 1961-2003 Liu et al. [9]. Wenhui Xu et al. [10] studied the homogenizes time series of daily maximum and minimum temperatures over China and concluded that the diurnal temperature range was found to have significantly decreased at 49% and increases only at 3% of the 825 sites. The warming of IGP hotspot over South Asia with regard to temperature indices is seen much higher over Nepal, Bangladesh, the tropical region of India, compared with Pakistan and the Greater Himalayan region Sheikh et al. [11]. Das and Hunt [12] studied variability of climate change in India and they showed that the trends of temperature was increasing over the past quarter century, but significant variations in these trends during different seasons and over different regions of India. Some organizations and researchers research about climate changes on Bangladesh like as Rakib [13], Mahtab [14], Pramanik

[15], BCAS [16], BUP [17] etc. and all have concluded that Bangladesh is one of the topmost countries to the unpleasant effects of global warming. Islam et al. [18] and Shahid et al. [19] reported that temperature will increase through 2071 in Bangladesh.

The major objective of this study to simulate HW events in all divisions of Bangladesh on 19 - 25 April 2016 using WRF model and to compare the model simulated result with the BMD observed data for validity of the model.

2 Data Used and Methodology

The Advanced Research WRF (ARW) dynamic core was developed and maintained by NCAR of Weather Research and Forecasting (WRF) model Version 3.9 has been used during the present study. WRF Model is a next-generation mesoscale numerical weather prediction model which schematic for both atmospheric research and operational forecasting applications. The other dynamic core of the WRF model is the NMM (Nonhydrostatic Mesoscale Model) was developed by the National Centers for Environmental Prediction (NCEP). In this study, the Global Forecast System (GFS) data produced by NCEP which are used from 19 - 25 April 2016 with 0000 UTC as the initial and lateral boundary condition.

The WRF model was run on a single domain at 10 km resolution using Microphysics scheme namely Kessler scheme Kessler, [20]. Although the coverage area of model domain is $12-30^0N$ and $80-100^0E$, Bangladesh (center$23°N, 90°E$) is the main focus area of this study. To simulate a weather phenomenon, WRF model has several components and the major components are (i) WRF Preprocessing System (WPS), (ii) ARW solver, (iii) Post-processing & Visualization tools. The physical parameterization schemes used in this study are Yonsei University (YSU) scheme Hong et al. [21] for planetary boundary layer (PBL) parameterization, Revised MM5 scheme Paulson, [22] for surface layer physics, Kain-Fritsch (KF) scheme Kain, [23] for cumulus parameterization, Dudhia scheme Dudhia, [24] for shortwave radiation and Rapid Radiative Transfer Model (RRTM) scheme Mlawer, et al. [25] for longwave radiation. Three hourly outputs produced by the model have been analyzed numerically and graphically using Grid Analysis and Display System (GrADS). Details of WRF model configuration are given in Table 1. For validation of model, the comparison of BMD observed data and the model simulated data is also analyzed.

Table 1. WRF model and domain configuration

Dynamics	**Non-hydrostatic**
Number of domains	1
Central point of the domain	$23^0N, 90^0E$
Grid size	$251 \times 251 \times 38$
Map projection	Mercator
Integration time step	$45s$
Vertical coordinates	Pressure coordinate
Time integration scheme	3rd order Runge-Kutta
Spatial differencing scheme	6th order centered difference
Microphysics	Kessler scheme
PBL Parameterization	Yonsei University (YSU) scheme
Land-surface model	Unified Noah LSM
Short wave radiation	Dudhia scheme

3 Results and Discussion

According to Bangladesh Meteorological Department (BMD), Bangladesh experienced a major HW event during 19 April to 30 April in 2016. The maximum temperature was 41.2℃ and relative humidity was 40%, recorded by BMD, on 29 April 2016 at Rajshahi and according to the heat index chart the feeling temperature was 48°C.

This event is simulated by WRF model with evaluating different meteorological parameters are described briefly in the following subsections.

3.1 Analysis of Relative Humidity (RH) at 2 m height

Model simulated results of RH for 6 days based on the initial conditions 0000 UTC of 19 April 2016 are presented in Fig. 1(a-f). From the analysis of relative humidity, it is found that the strong southwesterly flow transports a high amount of moisture of the order $70 - 90\%$ to the plain of central and northeastern part of Bangladesh and adjoining areas of the Bay of Bengal, on 19 April. But most of the region of Bangladesh has about $30 - 60\%$ moisture.

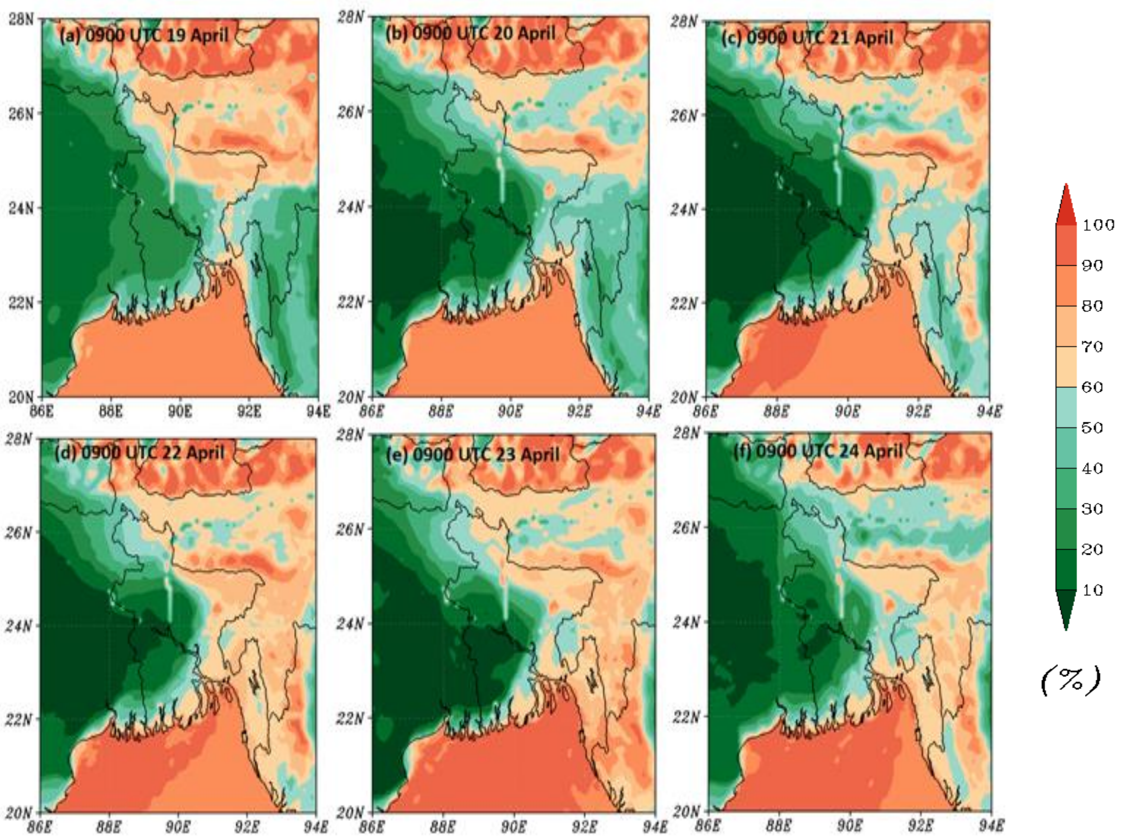


Fig. 1(a-f). Model derived RH at 2m height of 19 April to 24 April

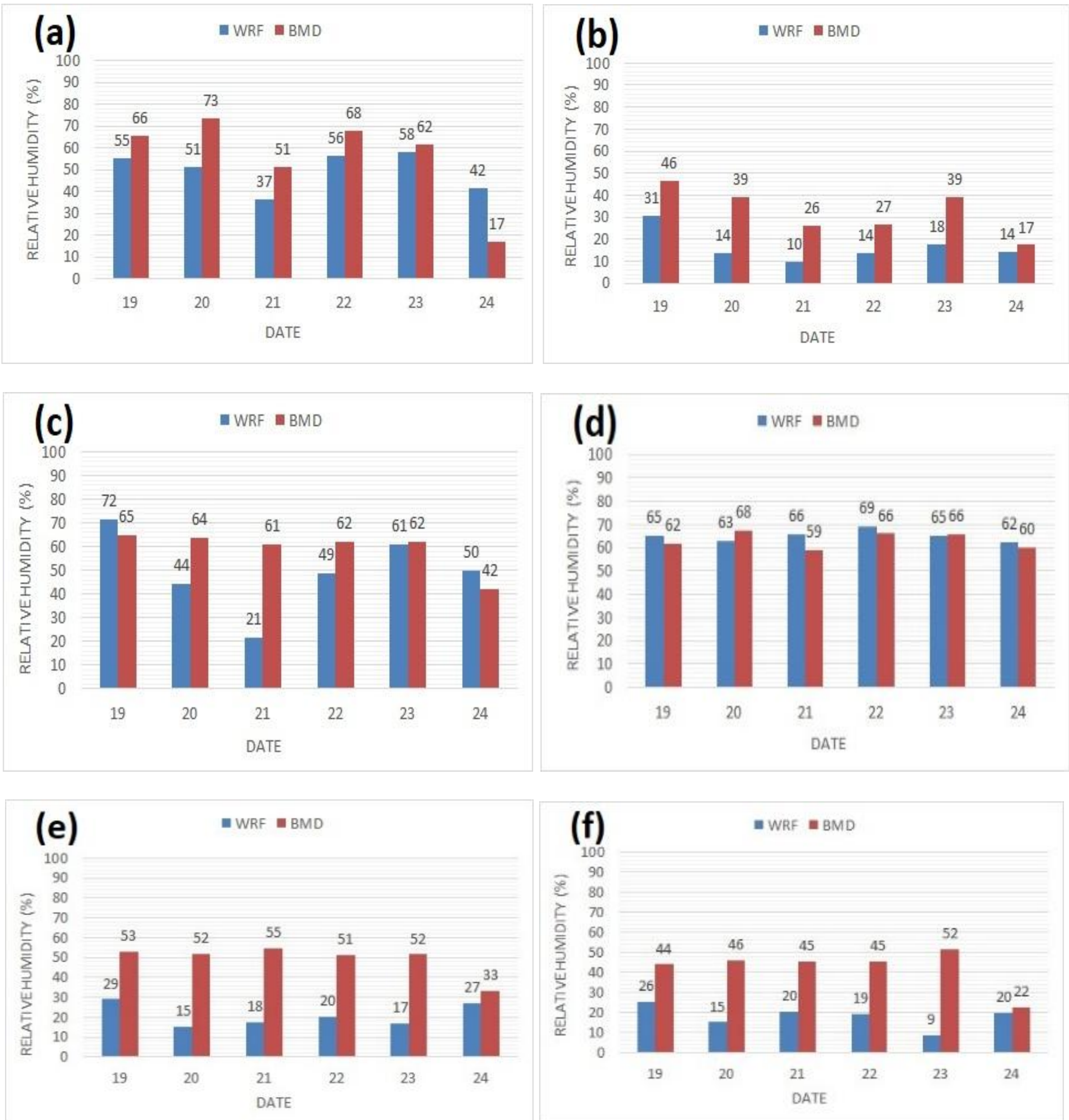
For the validity of the model performance, simulated RH using WRF model at 0900 UTC of 19 April to 24 April 2016 were compared with the observed values recorded by BMD. Fig. 2 (a-h) shows the division-wise comparisons of relative humidity of Bangladesh. From these comparisons, the model predicted RH is found to be always less than the BMD observed data except at Chittagong and Sylhet division of Bangladesh.

3.2 Analysis of temperature at 2 m height

The model simulated temperature (°C) at 2 m height valid for 0900 UTC of 19 April to 24 April 2016 of model simulation with their corresponding observed data for 6 days based on the initial conditions 0000

UTC of 19 April are presented in Fig. 3(a-f). From the temperature analysis it is observed that the model gives the temperature of about $(36 - 42)$℃ at eastern part of India and the western part of Bangladesh and also the nearest southern part, whereas it is about $(34 - 38)$℃ given from the observed data. Both of the model and observed simulation this temperature stays consecutively in 6 days, so the HW occurred in this region.

For validation of the model performance, simulated 6 days temperature values of 19 April to 24 April 2016 over eight divisions of Bangladesh were compared with the temperature records of BMD. The division-wise comparison between model data and BMD data are shown in Fig. 4(a-h). Over Barisal, Rangpur and Sylhet divisions, WRF captured the temperature reasonably well compared to Dhaka, Rajshahi and Khulna divisions. Also from these Figures the model simulated temperature values are overestimate the BMD observed data at Rajshahi, Dhaka and Khulna whereas at Chittagong it is underestimate the BMD data.



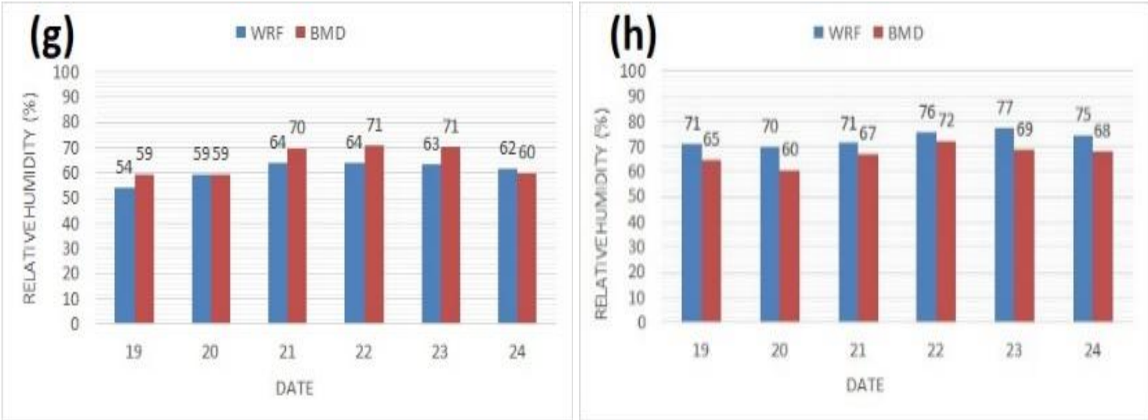


Fig. 2. Division wise comparison of RH (a) Rangpur, (b) Rajshahi, (c) Mymensingh, (d) Sylhet, (e) Dhaka, (f) Khulna, (g) Barisal and (h) Chittagong division

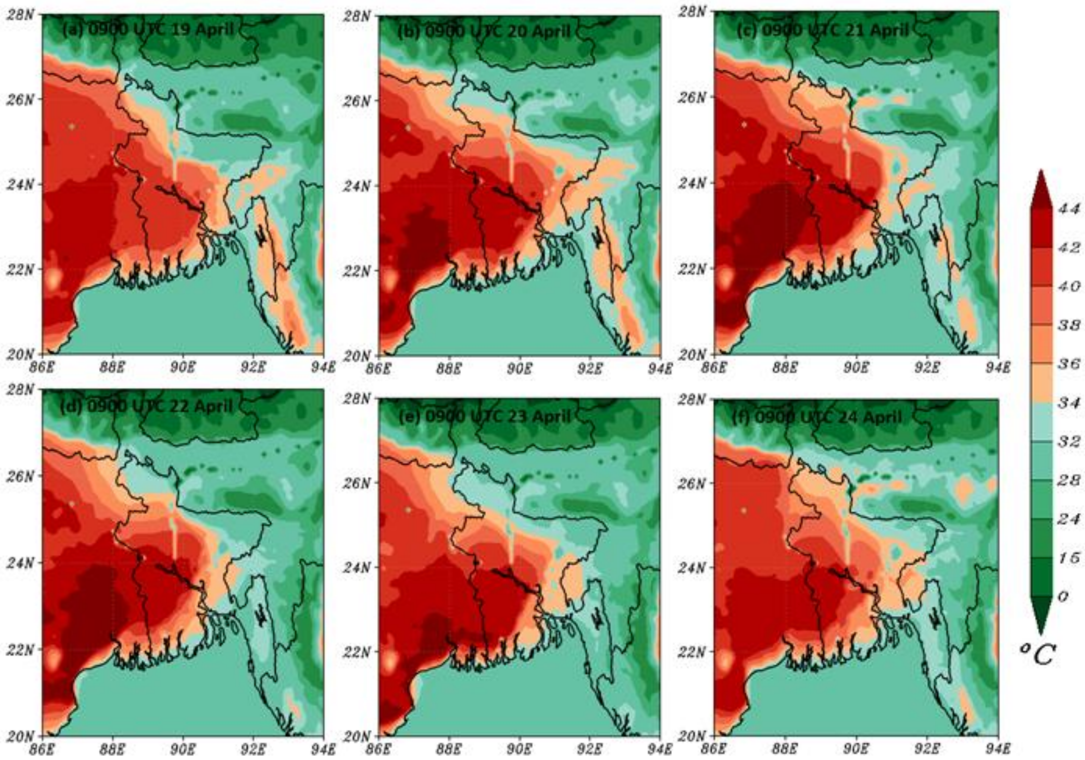
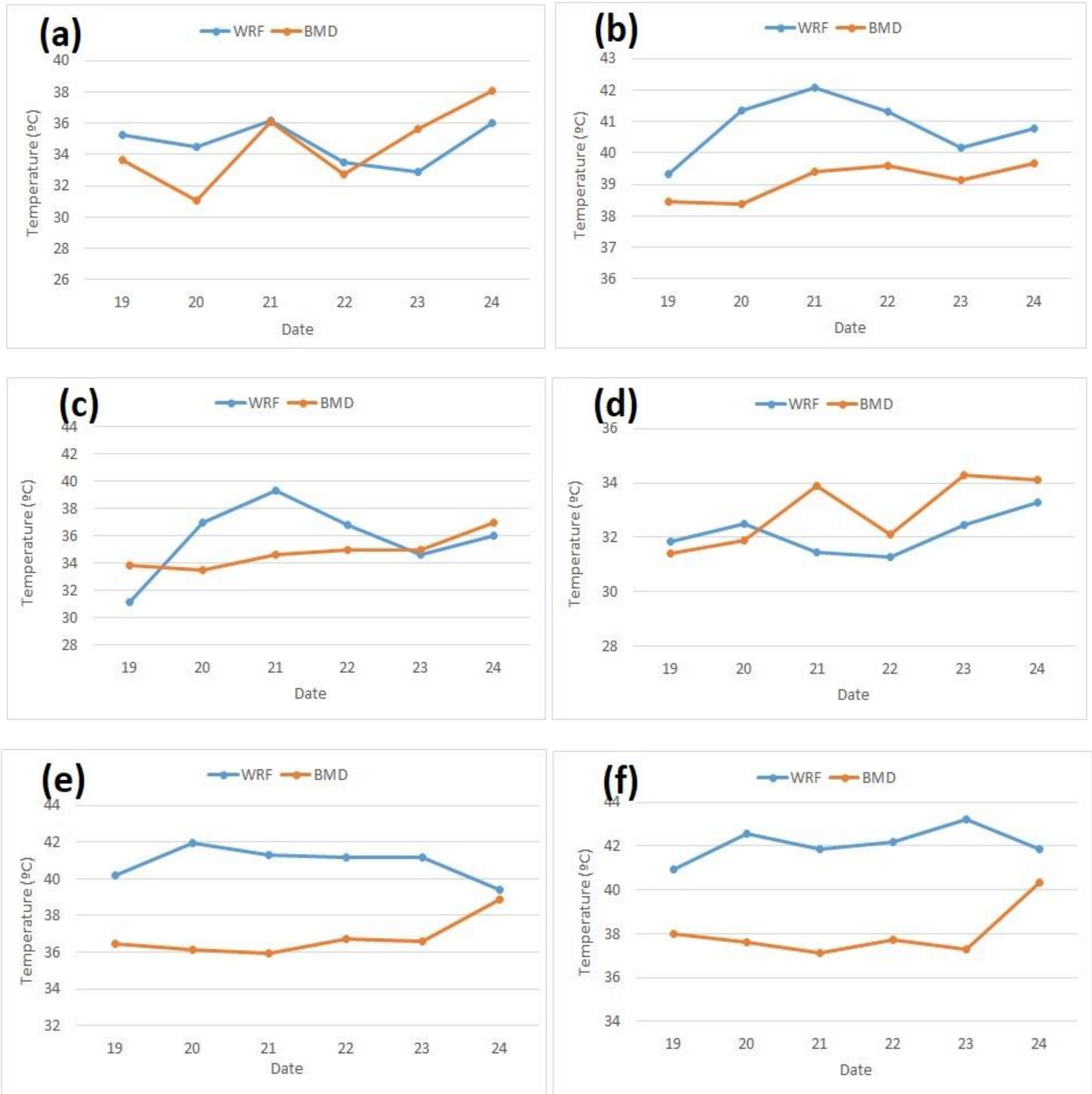


Fig. 3(a-f). Model derived temperature at 2m height for 0900 UTC of 19 April to 24 April

3.3 Analysis of Mean Sea Level Pressure (MSLP)

Air pressure plays a great role in the evolution of the weather and it is known that the whole earth surface is covered with low air pressure and high air pressure. Bangladesh is situated at the head of the Bay of Bengal. MSLP is affected by temperature. Hot air is lighter than cold air and also hot region has low pressure and which creates unstable weather condition like rain, storm, cyclone etc. The model simulated MSLP for 6 days based on the initial conditions 0000 UTC of 19 April 2016 are shown in Fig. 5(a-f). From figure, it is found that on 19 April, a trough of westerly low of $1002 - 1004hPa$ is simulated over West Bengal, Bihar, Sikkim, Meghalaya, and western and north-west part of Bangladesh while the MSLP of the eastern part of Bangladesh including Sylhet and southeast part was comparatively higher with $1004 - 1010hPa$. The trough of low moved farther to east and on 20 April, a convergence zone of low MSLP with $998 - 1002hPa$ is simulated over West Bengal and adjoining part of Rajshahi. The model simulated that this zone spread with time and next three days, it covered larger part of Rajshahi, Dhaka and small area of Khulna division, while MSLP over Sylhet is found to fall down to $1002 - 1004hPa$. From Fig. 5(f) at 0900 UTC, simulation shows that MSLP continued to fall down to $1000 - 1002hPa$ in Rajshahi and Rangpur division whereas in Dhaka and adjoining part of Khulna it is found to be same as before.

The division-wise comparisons of MSLP between model simulated values and observed values by BMD for 0900UTC of 19 April to 24 April are shown in Fig. 6(a-h). From these Figures the MSLP is continued to fall down from 19 to 24 April for all divisons in both BMD and WRF model data. Also from Fig. 6 it is found that almost there is no difference of MSLP between model simulated data and BMD observed data, that is the WRF model is capable to capture the MSLP for this region is reasonably well.



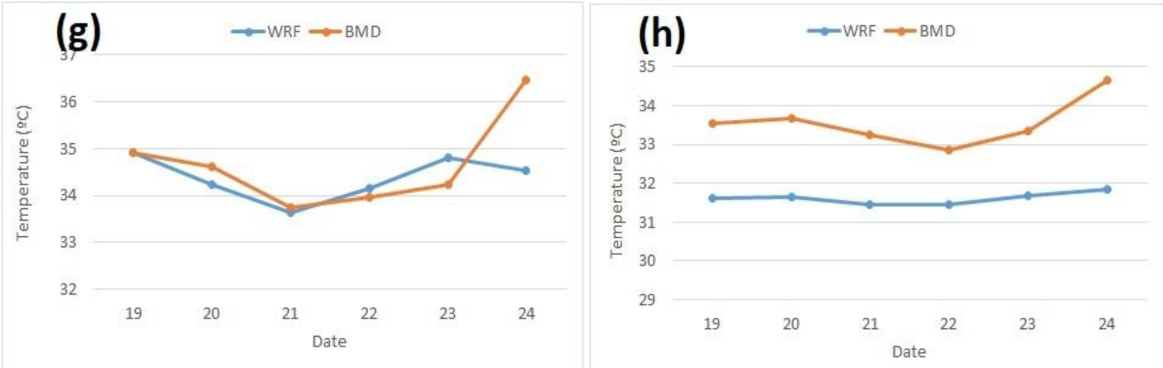


Fig. 4. Division wise comparison of temperature (a) Rangpur, (b) Rajshahi, (c) Mymensingh, (d) Sylhet, (e) Dhaka, (f) Khulna, (g) Barisal and (h) Chittagong division

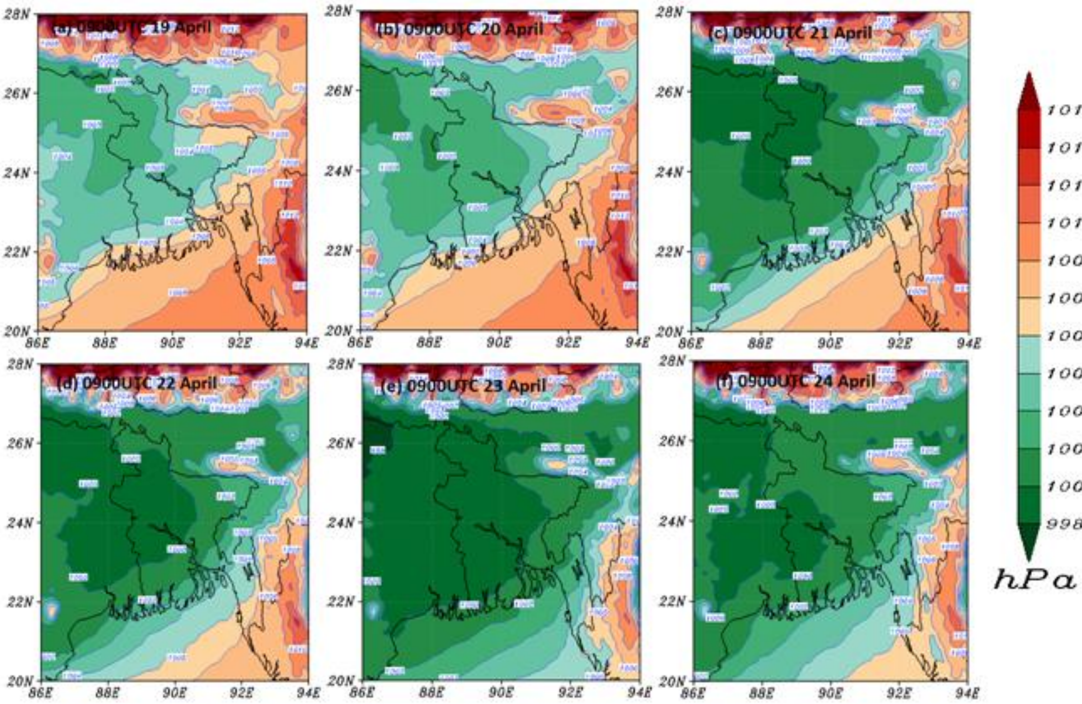
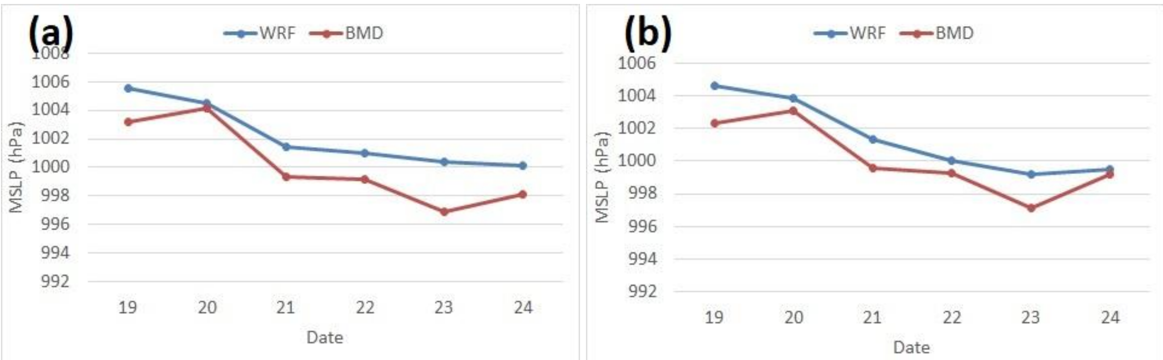


Fig. 5(a-f). Model simulated MSLP for 0900 UTC of 19 April to 24 April



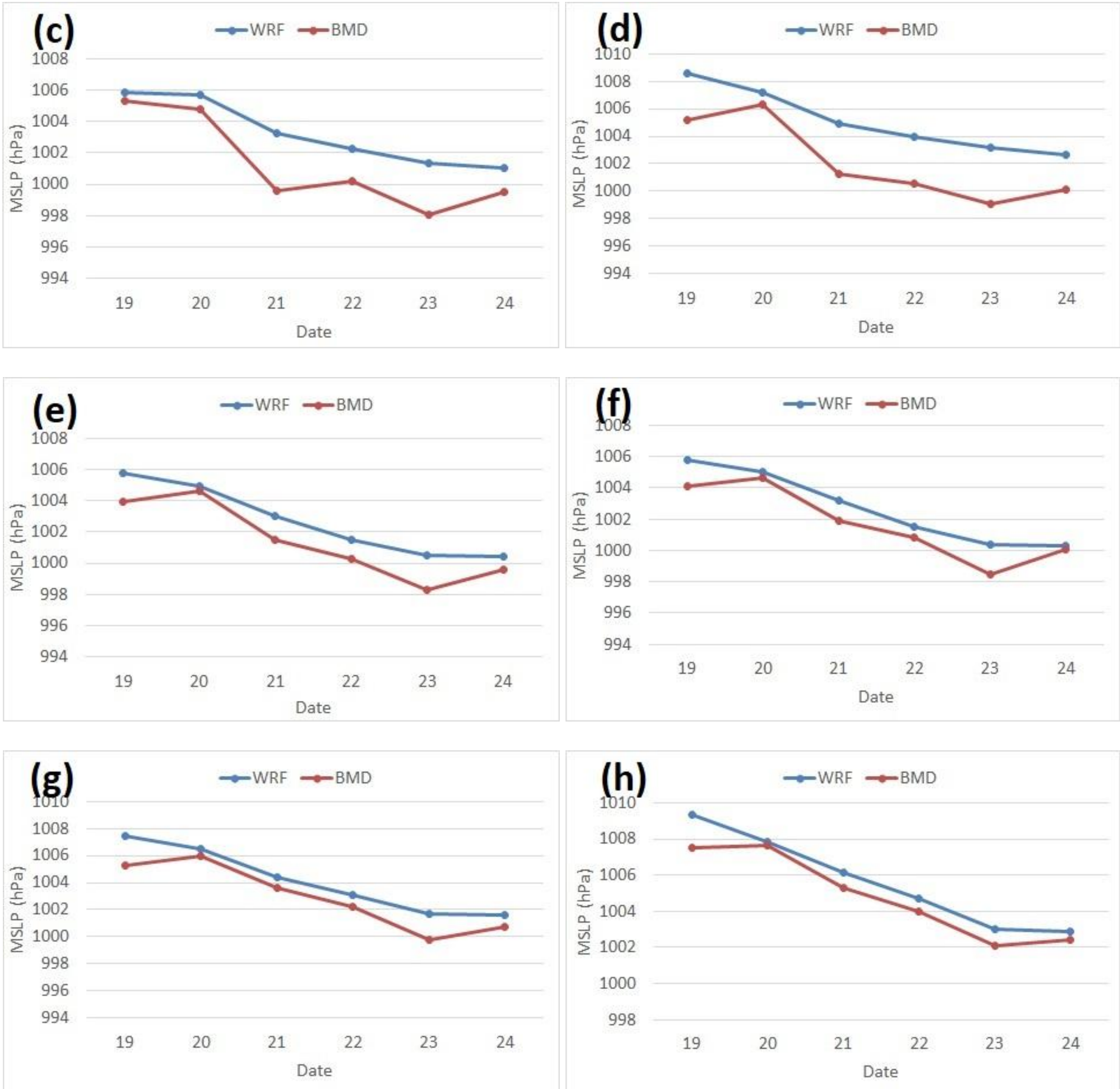


Fig. 6. Division wise comparison of MSLP (a) Rangpur, (b) Rajshahi, (c) Mymensingh, (d) Sylhet, (e) Dhaka, (f) Khulna, (g) Barisal and (h) Chittagong division

4 Conclusions

On the basis of the present study, the following conclusions can be drawn:

i. The model predicted RH is found always less than the BMD observed data except at Chittagong and Sylhet divisions.
ii. The model captured the values of RH for consecutively 6 days. Moisture availability is played a crucial role in controlling the relative humidity in Bangladesh.
iii. The results also highlight that the vital components of the formation of heat wave i.e. temperature consecutively 6 days is captured by the model. And from the division wise comparisons of maximum temperature between model data and BMD observed data, the temperature is about $(36-42)^{\circ}C$ at eastern part of India and the western part of Bangladesh and also the nearest southern part of Bangladesh.

iv. The model simulated and observed MSLP continued to fall down to $1000 - 1002hPa$ in Rajshahi and Rangpur division whereas in Dhaka and adjoining part of Khulna it is found to be same as before.

v. The model simulated temperature, RH and MSLP values of associated areas are sensibly well compared with the data observed by Bangladesh Meteorological Department (BMD). So, for forecasting the heat wave event of any part of the Bangladesh the model can be used for the upcoming heat wave events.

Competing Interests

Authors have declared that no competing interests exist.

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