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Study on Heat Wave and its Thermodynamic features over Bangladesh using Numerical Weather Prediction Model (NWPM)

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Abstract:

In this study, an attempt has been made to simulate the Heat Wave conditions in temperature range of ≥ 36ºC and its associated thermodynamic features over Bangladesh from 19 may to 25 May, 2017, using Advanced Research and Forecasting Model (WRF-ARW) - version 4.0. The WRF model was run for 6 days on a single domain of 10 km. horizontal resolution, using 6 hourly GFS datasets from 0000 UTC of each starting day of the required events as initial and lateral boundary conditions. For simulation, Kessler Scheme (KF) for microphysics, Yonsei University Scheme (YUS) for Planetary Boundary Layer (PBL) parametrization, Rapid Radiative Transfer Model (RRTM) for long wave radiation, and Dudhia Scheme (DS) for short wave radiation and Kain- Fritsch (KF) scheme for cumulus parametrization were used. The models have been analyzed numerically using several meteorological parameters such as Mean Sea Level Pressure, Relative Humidity, Temperature, Wind Pattern, Rainfall and Latent Heat, and the output is visualized by Grid Analysis and Display System (GrADS) and surfer. To validate the model performance, model-simulated values of Relative Humidity, Temperature (maximum) and Mean Sea Level Pressure were compared with observed data (Bangladesh Meteorological Department). From the analysis it is clear that the performance of the model is reasonably well to the observations, so that for the up-coming events for extreme temperature conditions the model can be used for the prediction which will bring social and economic benefits.

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1. Introduction

Bangladesh has a monsoon climate, characterized by three distinct seasons: cool, dry winters (approximately from mid-October to late February); hot pre monsoon summers (March–May/early June); and a rainy monsoon season (June–late September/early October). Continental heating increases throughout the pre monsoon period, producing a low-pressure monsoon trough, which is anchored by the Tibetan Plateau and the Himalaya extending the heating throughout the troposphere. The resulting cross-equatorial pressure gradient, reinforced by convective activity over the region, triggers the arrival of the monsoon in southeastern Bangladesh in early June. The monsoon progresses towards the northwest later in the month and retreats from the northeast to the southwest in late September or early October (Ahmed & Karmakar, 1993). Quite a few researches have been made on Bangladesh's climate condition by Mahtab (1989), Pramanik (1983), BCAS (1994), BUP (1994), Bangladesh Climate Change Country Study Program (1997) etc. and all of them have the same view that Bangladesh is one of the foremost countries which are extremely susceptible to the detrimental effects of global warming. According to the collected data of Bangladesh Meteorological Department, the mean and maximum annual temperature is increasing exceedingly, resulting in a definite rise in Bay of Bengal. The average annual temperature of Bangladesh is expected to increase by 1.4 ± 0.6°C by 2050 (IPCC 2007; MoEF 2008).The BUP-CEARS-CRU (1994) study reported a 0.5°C to 2.0°C rise in temperature by the year 2030 under business as usual 'scenario of IPCC. It was reported by ADB (1994) that, for 2010 the temperature would rise by 0.3°C and for 2070, the corresponding rise would be 1.5°C.

Table 1.1: Various kinds of HW by BMD

Types of Heat Wave (HW)	Corresponding Temperature (°C)
Mild HW	36-38
Moderate HW	38-40
Severe HW	40-42
Extreme HW	> 42

Yan et al. (Yan et al. 2002) found that the number of cold days in China is gradually reducing over the 20th century and the number of warm days is increasing, and this has been happening only since 1961. Heat Index combines air temperature and relative humidity to determine how hot it feels. It is also known as apparent temperature. The human body naturally cools itself by perspiration, or sweating, in which the water in the sweat evaporates and carries heat away from the body. However, when the relative humidity is high, the evaporation rate of water is reduced. This results in heat being removed from the body at a lower rate, causing it to retain more heat than it would in dry air (Ogunsote 2002).

2. Methodology

2.1 Data Collection

Numerous types of weather-related data, collected by various weather observatories and meteorological departments around the world and then reanalyzed by different models, are available for simulation and NWP. In this study, the GFS data from 19 May to 24 May 2017 and 19 April to 24 April 2016, each starting from 0000 UTC and ending on the last day at 0000 UTC (produced by NCEP), are used as the initial and lateral boundary condition. The GFS model is a spectral model with an approximate horizontal resolution of 13 km for the first 10 days and 27 km from 240 to 384 hours (16 days).

To validate the model's performance, model-simulated values of RH, maximum and minimum temperature, and MSLP were compared with observational data obtained from Bangladesh Meteorological Department (BMD).

2.2 Model Configuration

To simulate a weather phenomenon, WRF model has several components that need to be configured in a successive manner.

2.2.1 Configuration of WPS

The WRF Preprocessing System (WPS) is a set of three programs whose collective role is to prepare input for the real program for real-data simulations (WPS, n.d.; Scamarock, 2008).The work of vertically interpolating meteorological fields to WRF eta levels is performed within the real program. Data flow between the programs of WPS is shown in Figure 2.1

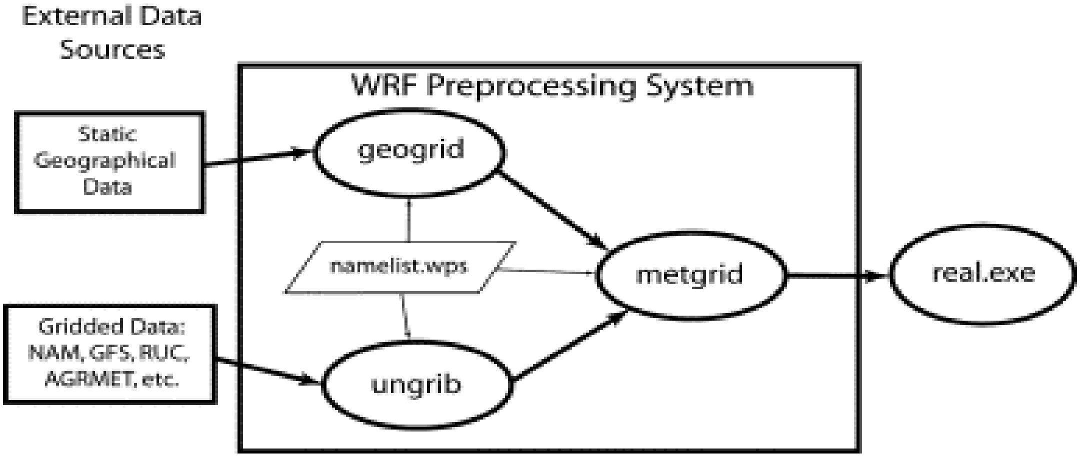


Figure 2.1: WRF Preprocessing System

2.2.2 Configuration of ARW solver

The output files produced by 'metgrid' are linked to the 'run' directory, after completing the running process of WPS. This program is used to initialize the model for real data case.

2.2.3 Post-processing & Visualization

In this study, the ARW post package is used as the post-processing tool with the Grid Analysis and Display System (GrADS) as the visualization tool. The Grid Analysis and Display System (GrADS) is an interactive desktop tool that is used for easy access, manipulation, and visualization of earth science data.

2.3 WRF Model

The Weather Research and Forecasting (WRF) Model is a next generation mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting applications. The model serves a wide range of meteorological applications across scales from tens of meters to thousands of kilometers. The effort to develop WRF began in the latter part of the 1990's and was a collaborative partnership of the National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration represented by the National Centers for Environmental Prediction (NCEP) and the Forecast Systems Laboratory (FSL), the Air Force Weather Agency (AFWA), THE Naval Research Laboratory, the University of Oklahoma, and the Federal Aviation Administration (FAA), with the participation of university scientists (Skamarock et al 2005). The principle components of the WRF system are delineated in Figure-2.2. The model was installed on an Intel CoreTM i3 Personal Computer (PC) with Ubuntu 16.04 Operating System (OS) by the help of Bangladesh Meteorological Department (BMD) (see Figure 2.2).

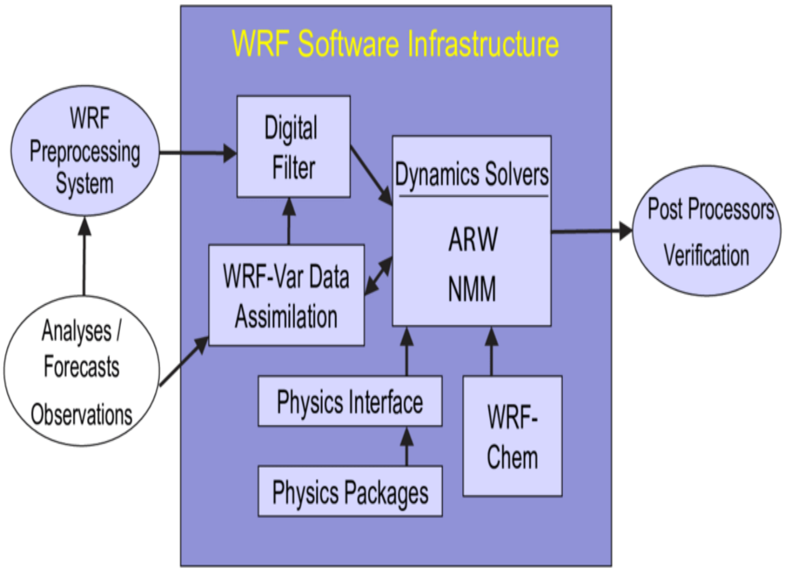


Figure 2.2: WRF Systems Components (Source: https://www.researchgate.net/publication/306154004)

3. Results and Discussion

The simulation of HW events over Bangladesh, on 19 May to 24 May 2017 and 19 April to 24 April 2016 are analyzed. To simulate these cases, the WRF-ARW model was run with cumulus physics scheme. Namely Kain-Fritsch (KF), using NCEP-GFS 6-hourly data from 0000 UTC of 19 May to 0000 UTC of 26 May 2017 and 0000 UTC of 19 April 2016 to 0000 UTC of 26 April 2016 as initial and lateral boundary conditions for each run, analyzed and discussed these cases. From the analysis of relative humidity, on 19 May, (10-40)% RH is found over West

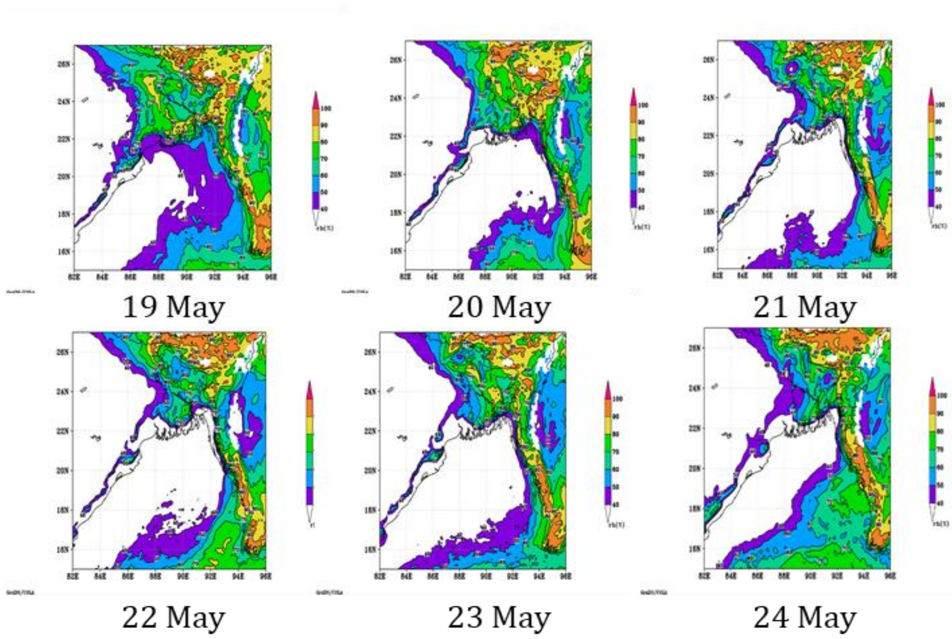


Figure 3.1: Model-simulated RH (%) at 2m height valid for 0900 UTC from 19 to 24 May 2017, for 6 days respectively.

Bengal and Bihar, and (40-60)% RH is found over western and central parts of Bangladesh, while the RH of Sylhet is about (60-70)% and the adjoining part of Meghalaya is about (60-90)%. The RH at the north and northwest part of Bangladesh i.e. Rangpur, Mymensingh and Sylhet division, is about (60-70) %, whereas it is about (40-60) % in the central area, on 20 May. From these Figures, model RH at 0900 UTC from 19 to 24 May is (80-100) % in Bay of Bengal.

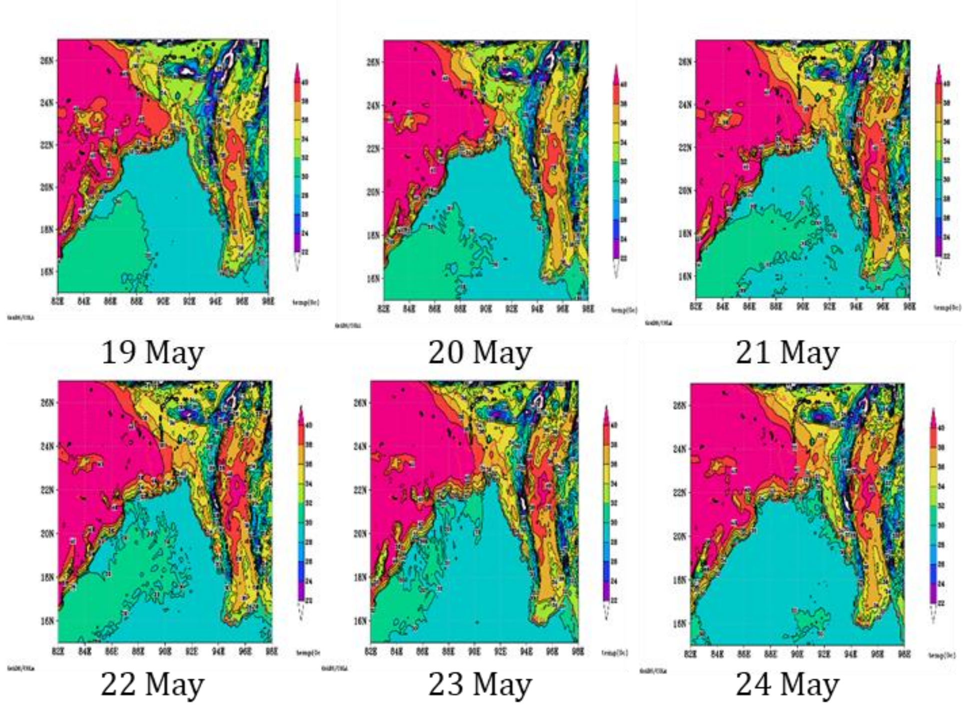


Figure 3.2: Temperature (°C) at 2m height valid for 0900 UTC from 19 to 24 May 2017, for 6 days respectively.

From the temperature analysis it is observed that on 19 May 2017, a temperature of about (34-38)° C is simulated by the model over the western and central parts of Bangladesh i.e. over the Rajshahi, Dhaka and Khulna Divisions and also a small part over the adjoining areas of the Chittagong division at 0900 UTC. Also on 19 May at 0900 UTC, (28-32)° C temperature is found over Sylhet and the Bay Of Bengal and nearest region of Chittagong division. On 20 May at the same time i.e. 0900 UTC, the temperature is about (38-40)° C in the Dhaka division and also the nearest region in Khulna and during (21-24) May, the temperature is about (40-42)°C, which is simulated by a model and (36-38)°C is simulated by observed data over West Bengal and adjoining western parts of Bangladesh; The Rajshahi and Khulna division and a small part of the Dhaka division. For the inspection of the model's performance, simulated maximum temperatures over 6 days from 19 May to 24 May 2017 at 0900 UTC were compare with the values observed by BMD.

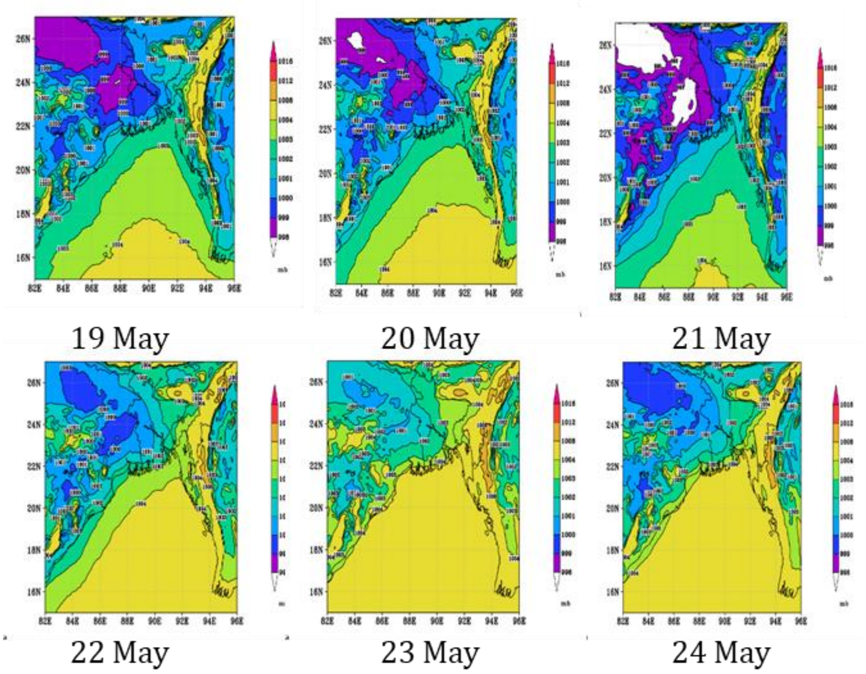
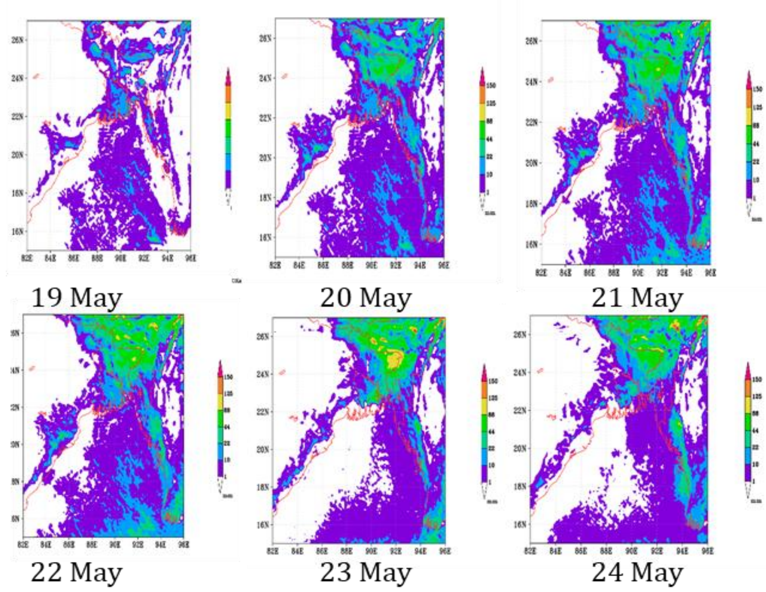


Figure 3.4: Model simulated daily rainfall based on 0900 UTC from 19 to 24 May 2017, for 6 days respectively.

No significant rainfall amount is simulated over Bangladesh on 19 May, (10-20) mm rainfall is simulated over Sylhet during this period. In the next day, (20-40) mm rainfall is found over Sylhet and (10-30) mm over Dhaka and Rajshahi. From (21-22) May at 0900 UTC, (30-60) mm rainfall is simulated over Sylhet and (10-40) mm is found in Dhaka and in adjoining parts of Khulna. During the next two days, the rainfall over Rajshahi, Rangpur, Dhaka and adjoining parts of Khulna is (10-30) mm while it is (40-60) mm over Sylhet and (40-125) mm over Meghalaya. As very low amount of rainfall occurred over Bangladesh in the required time-period, it is an important argument for HW continuation.



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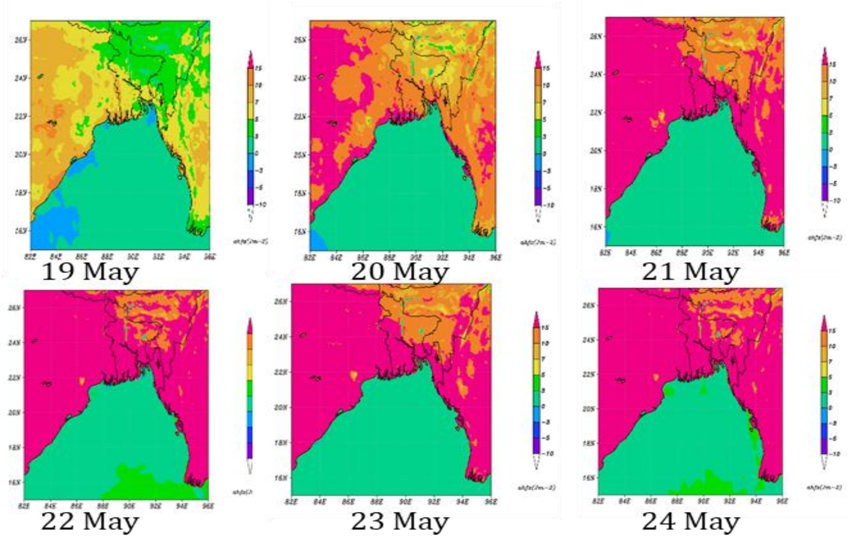
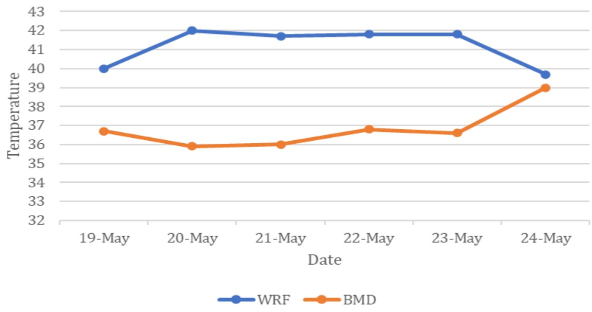
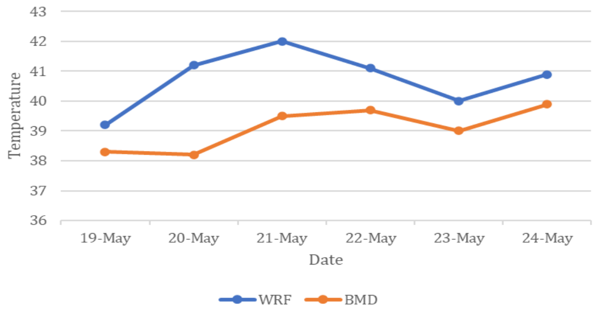


Figure 3.5: Model simulated daily latent heat based on 0900 UTC from 19 to 24 May 2017, for 6 days respectively

From above figures, on 19 May, (300-400) wm^{-2} LH is simulated over Meghalaya and adjoining northern and northeastern parts of Bangladesh including the Rangpur, Mymensingh and Sylhet divisions at 0900 UTC. Also (100-300) wm^{-2} is simulated over West Bengal and adjacent south and southwestern parts of Bangladesh, which is over Rajshahi, Dhaka, Khulna and Barisal divisions. In the next day, the LH is (200-300) wm^{-2} is found over Rangpur and a small region of Sylhet, whereas it is unchanged over other regions for the next 4 days at the same time (0900 UTC), this LH is approximately stable over Rajshahi, Dhaka, Khulna, Rangpur, Barisal and where it is found in about (100-300) wm^{-2}, that means HW occurred in those regions and since LH has decreased over Sylhet, HW has not occurred there.



a. Dhaka



b. Rajshahi

From above these graphs, Dhaka and Rajshahi divisions are shown different conditions.

Table 4.1: Dhaka and Rajshahi divisions model-simulated results of 19-24 May 2017

Division	Parameter	Day	1	2	3	4	5	6
Dhaka	MSLP(*hPa*)	Model	1004	1004	1002	1002	1005	1004
		observed	1003	1001	1001	1003	1003	1003
	RH (%)	Model	55	48	37	39	38	37
		observed	65	68	69	67	66	66
	T2 (̊C)	Model	35	37	40	40	40	39
		observed	36	36	36	37	37	36
	LH (wm^-2)	Model	299	276	263	251	247	239
		observed	-	-	-	-	-	-
	Wind at 850 Lev(ms¯1)	Model	4	5	4	4	4	5
		observed	-	-	-	-	-	-
Rajshahi	MSLP(*hPa*)	Model	1003	1002	1000	1001	1003	1002
		observed	1003	1001	1001	1003	1002	1003
	RH (%)	Model	44	39	34	37	39	34
		observed	68	67	67	69	65	68
	T2 (̊C)	Model	37	38	41	40	40	40
		observed	36	36	35	36	36	36
	LH (wm^-2)	Model	220	212	165	154	153	186
		observed	-	-	-	-	-	-
	Wind at 850 Lev(ms¯1)	Model	2	3	2	3	3	5
		observed	-	-	-	-	-	-

4. Conclusion

Heat waves are a part of extreme weather events, which cause enormous losses in terms of lives and human discomfort and ailments arising as a result of it. So, the recasting of HW events over Bangladesh is important. Therefore, this study has made an attempt to simulate the weather for 19-24 May, 2017 for HW event using WRF models to predict the future events more effectively. The model simulated RH over all divisions underestimates the BMD observed RH. The difference between Dhaka and Rajshahi clearly illustrates the outcome of the research. MSLP values captured by model were appropriate indication of unstable atmosphere than that of the other parameters. The mode simulated temperature over all divisions overestimates the temperature compared to BMD observed temperature. The mode simulated temperature values and associated areas are sensibly well compared with the data observed by Bangladesh Meteorological Department (BMD). Thoroughly, the analysis showed that the model performed reasonably well in capturing these events in the face of some spatial and temporal preference. It can be concluded that the WRF-ARW is a reliable model, which may be used to forecast future HW events over Bangladesh.

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