Simulation of a Heat Wave Event using WRF model and Analysis of Heat Stress Index over Bangladesh

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Abstract

As a consequence of worldwide warming of atmosphere, heat waves are becoming more intense, frequent and widespread. Bangladesh, being a tropical country, is at a high risk of this extreme weather event. Heat waves have been accounted to significant rise in morbidity and mortality rates in recent years. For this reason, an attempt has been made to simulate a heat wave which occurred in the month of May, 2017 using Advanced Research WRF model. The WRF model was run for seven days on a single domain- of 10km horizontal resolution using six hourly GFS data. The model performance has been evaluated by analyzing temperature, relative humidity, wind speed and surface level pressure considering their sultriness on thermal stress. Analysis of observed human thermal stress during the heat wave event has also been made extensively for eight divisional stations spread across the country using bioclimatic index, Physiologically Equivalent Temperature (PET). Finally, a comparison between observed and model simulated PET has been made.

Key words: Heat wave, WRF, Heat stress and PET

1. Introduction

Climate change is an established fact and global warming is the most prominent impact of it. According to the report by IPCC, the 30-year period starting from 1983, was the most temperate period of the last 1400 years for the Northern Hemisphere [1]. It has been found in a study that an upward change occurred in daily maximum and minimum temperatures, as well as the amount of discomfort caused by excessive heat, throughout the monsoon and pre-monsoon seasons in Bangladesh [2]. In most parts of Bangladesh, an increase in monthly and seasonal (pre-monsoon) mean maximum temperatures has been found [3].

Owing to this augmentation in temperature, extreme weather events are on a rise, and heat wave is one of them. According to World Meteorological Organization (WMO), heat wave is the period of 5 or more consecutive days of extreme heat when the daily maximum temperature exceeds by at least 5°C (9°F) the average daily maximum temperature of the same calendar days in the period 1960-1990. The categories of heat wave for Bangladesh are defined by Bangladesh Meteorological Department (BMD) as follows:

When maximum temperature lies between 36-38^{0}C = Mild Heat Wave

When maximum temperature lies between 38-40^{0}C = Moderate Heat Wave

When maximum temperature lies between 40-42^{0}C = Severe Heat Wave

When maximum temperature >43^{0}C = Extreme Heat Wave

Heat wave is emerging as a great threat worldwide. The 2003 European heat wave was the deadliest event in Europe causing fatalities of over 70000 people across Europe with France being the worst-hit [4]. More than 87% of all disaster deaths were due to heat related complications between 2000-2016 [5]. Over 3800 people died from the excess heat across Bangladesh during the 8-day heat wave in 2008 [5].

Heat wave can cause severe impacts on human health. Health issues related to heat waves include, dehydration, heat cramps, heat exhaustion, heatstroke to name a few. Besides, extreme heat hampers the physiological processes of human body resulting in stress. The heat related stress is determined by bioclimatic indices. PET (Physiologically Equivalent Temperature) is one such index which is based on MEMI (Munich Energy balance Model for Individual) and incorporates the physiological effects with atmospheric condition [6]. The PET index can be calculated using the RayMan model, which is a specialized bio-climate computing model [7]. RayMan model is extremely user-friendly, allowing for sophisticated computations of mean radiant temperature as well as other thermal indices.

This study embarked on the simulation of heat wave event swept during May, 2017 using numerical weather prediction model Advanced Research WRF and determination of prevailing heat stress (PET) over eight divisional stations. The uniqueness of this study is the association of PET with the analysis of heat wave.

2. Experimental Set up, Data used and Methodology

This study is segregated into three major steps, (i) simulation of heat wave event and validation with observed data, (ii) determination of observed heat stress indicated by PET values, (iii) evaluation of WRF model performance. The simulation of heat wave has been conducted using Advanced Research WRF model, version 4.2.2. WRF model is maintained and developed by National Center for Atmospheric Research and is an assemble of WRF software framework, ARW dynamic solver, WRF pre-processing system and WRF data assimilation. As the initial condition of simulation, 6 hourly GFS (Global Forecasting System) has been used. The model is run with 10 km horizontal grid size and for single domain (central points of the domain 23.9°N, 90.5°E). The physics options used in this study are presented in table 1.

Table 1: Physics options used in this study

Microphysics	WRF Single-moment 6-class scheme
Cumulus Parameterization Scheme	Kain-Fritsch (KF)
PBL Parameterization	Yonsei University Scheme (YSU)
Surface Layer	Revised MM5
Land Surface Parameterization	Noah Scheme
Radiation Scheme	RRTM
Shortwave Radiation	Dudhia Scheme

For the calculation of heat stress, we use PET (Physiologically Equivalent Temperature). PET is defined as the equivalent air temperature of a standardized room (v = 0.1 ms^{-1}, VP = 12 hPa) where human body feels same thermal stress as in outdoor environment [8]. The definition of PET is based on MEMI model incorporating heat balance equation of human body as given below:

$$M + W + R + C + E_D + E_{Re} + E_{SW} + S = 0$$

Where, M is the metabolic rate, W is the physical work output, R is the net radiation of the body, C is the convective heat flow, E_D is the latent heat flow to evaporate water diffusing through the skin, E_{Re} is the sum of heat flows for heating and humidifying the inspired air and S is the storage heat flow. PET is calculated by RayMan version 1.2 using temperature, relative humidity, wind speed as input.

3. Result

3.1 Simulation of Heat Wave

Figure 1 shows the model derived temperature profile for the heat wave event 19-26 May, 2017 based on the initial condition of 0000 UTC 19 May, 2017. On 19th May, the temperature across the country was above 32°C
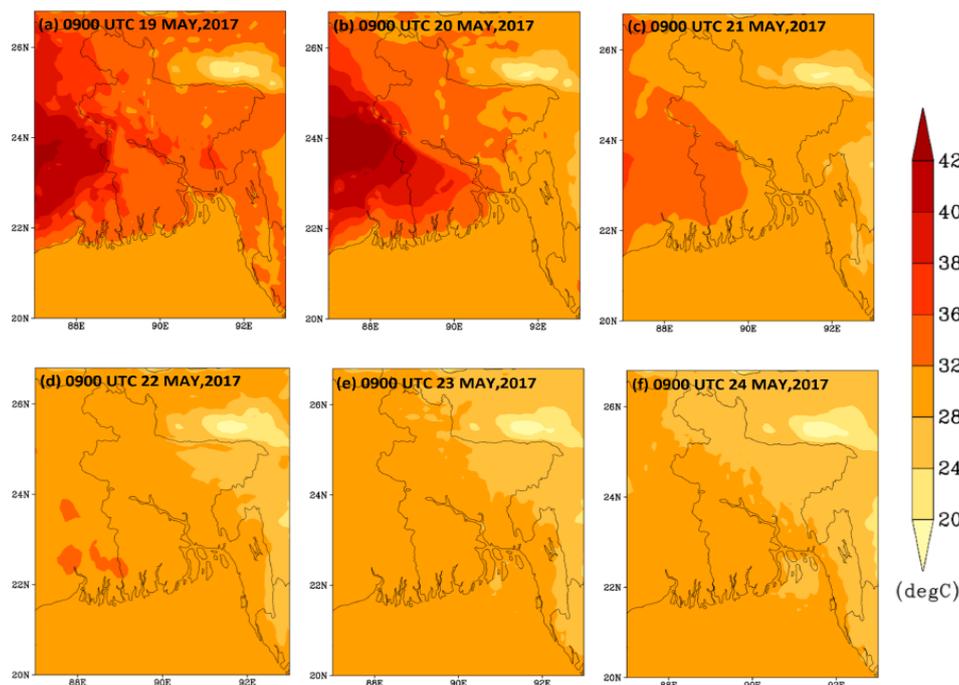

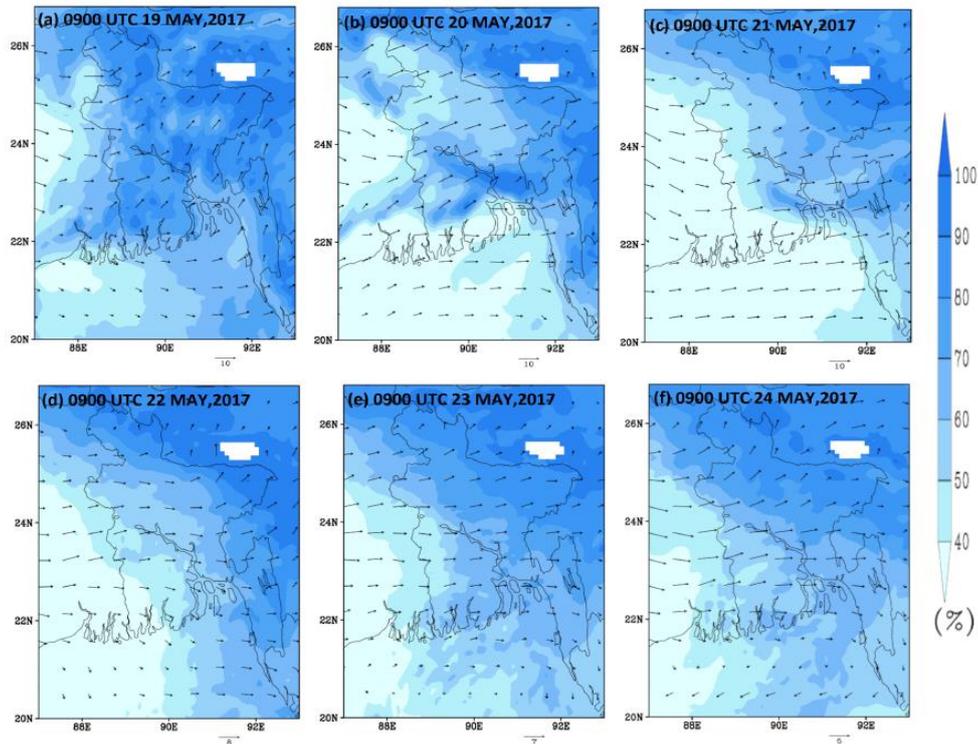**Figure 1:** WRF model simulated temperature during 0900 UTC of 19-24 May, 2017

Figure 2: WRF model simulated relative humidity and wind speed during 0900 UTC of 19-24 May, 2017
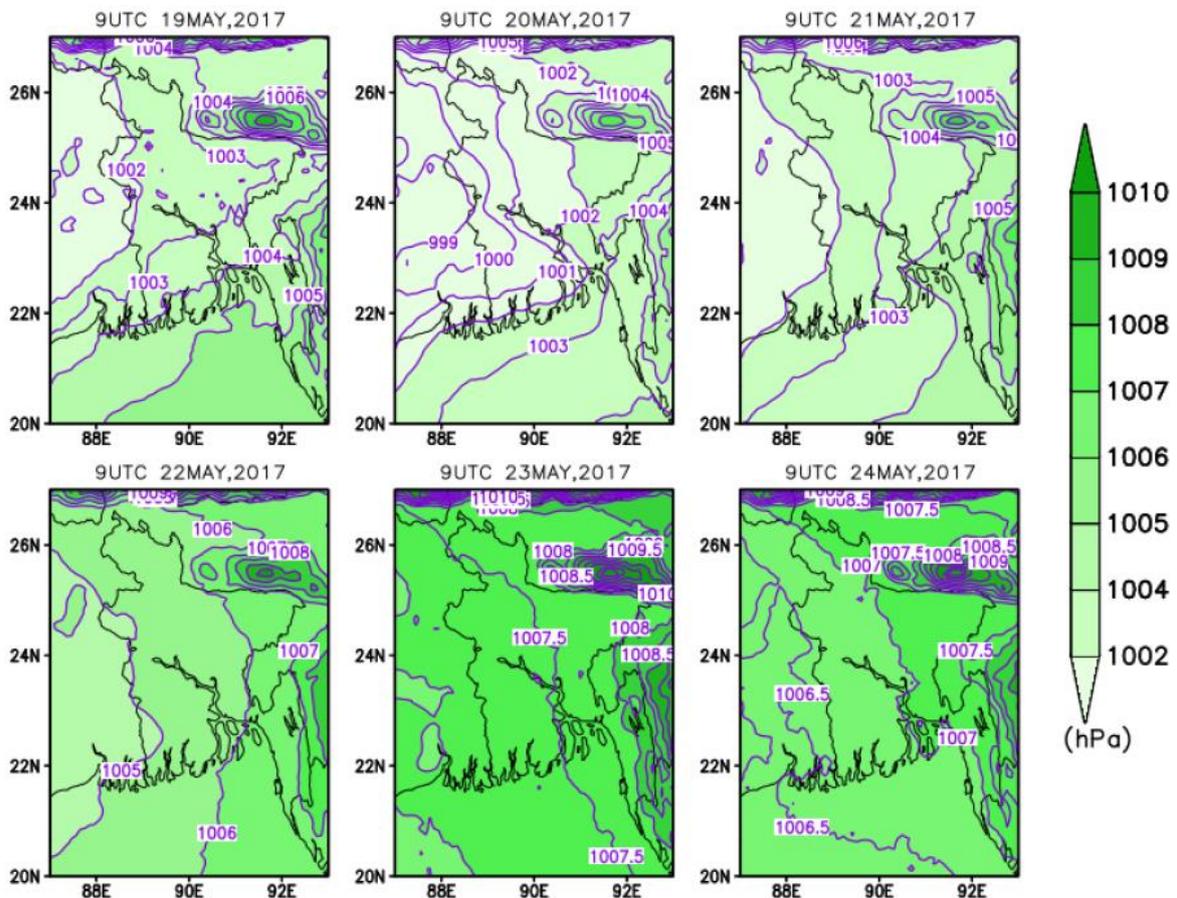
Figure 3: WRF model simulated surface level pressure at 0900 UTC of 19-24 May, 2017

at 0900 UTC, at regions lying along western border and the regions of Pabna, Kushtia, Rajbari and adjoining area. A temperate zone of high temperature (greater than 40°C) was found to lie over West Bengal which advanced to

the south-western region of Bangladesh on 20th May. Model predicted the occurrence of mild to moderate heat wave over the division of Khulna and neighboring regions. On 21st May, model simulated temperature lied above 28°C with regions of Rajshahi and Khulna divisions with a higher temperature. However, from 22nd May, model predicted a decrease in temperature on the north-eastern region lying below of 28°C.

Figure 2 illustrates the model simulated relative humidity at 2m height and wind speed at 0900 UTC of each day starting from 19 to 24 May, 2017 based on the initial condition of 0000 UTC of 19 May, 2017. During 0900 UTC of 19 May, the relative humidity across the country was found to be (70-90) % due to the influence of strong south-westerly wind except at some parts of north-western parts. On 20 May, the amount of moisture reduced to (40-60) % over the north-western and central regions, however, over the eastern region, relative humidity was (70-80) %. On the third day, north-westerly wind was simulated over West Bengal and as a consequence, relative humidity fell to below 40 %. There is a turning of wind over the northern and north-eastern region. Belts of varying relative humidity (with low humidity over south-western region and strong over north-eastern area) found to lie
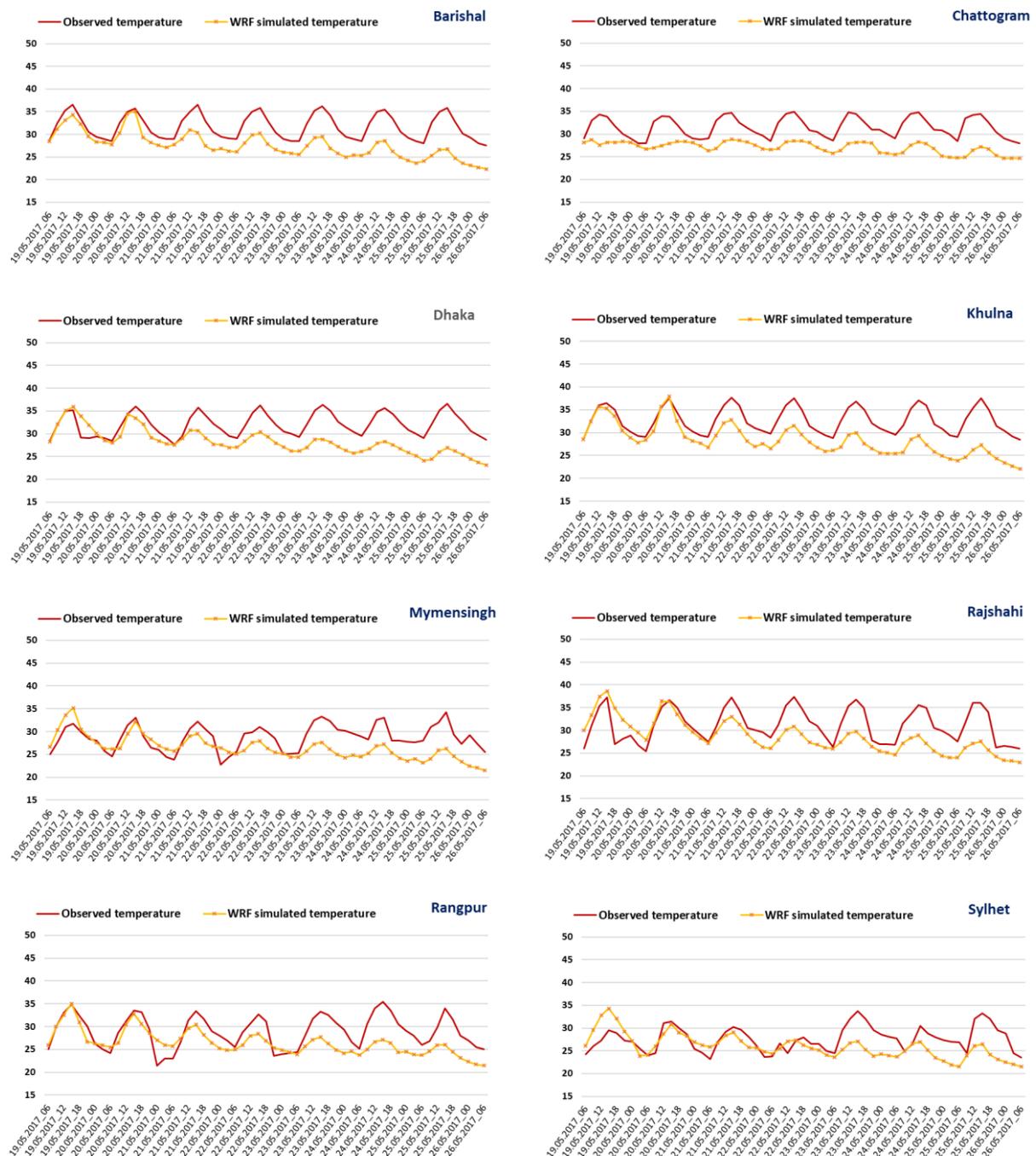

Figure 4: Comparison of observed and WRF simulated temperature during 19-25 May, 2017

over Bangladesh on 22 and 23 May. Strong westerly wind was found to blow during these two days, however, on 24 May, there was a turning of wind over the northern parts and another one found over Bay of Bengal.

Model derived results for surface level pressure for six days based on the initial condition of 0000 UTC of 19th May, 2017 are illustrated in the figure 3. A low pressure zone (1002 hPa) was found over West Bengal on 0900 UTC of 19 May and across the country, the range of pressure was (1003-1005) hPa. On the following day, low pressure zone became a trough (999hPa) extending up to north-east Bay with pressure varying in the range (1001-1004) hPa. Surface pressure was nearly same on 21 May across the country, however, an increase in pressure is noted. During 0900 UTC of the following day, four isobaric contour lines passed over main land of Bangladesh with magnitude starting from 1005hPa. The notable feature of last two days is relatively higher pressure (1007-1007.5) hPa with less variation across the land.

Comparing the model derived results with BMD recorded data for the respective days, we found that WRF model has underestimated the observed temperature for all the eight station during 19-26 May, 2017 heat wave
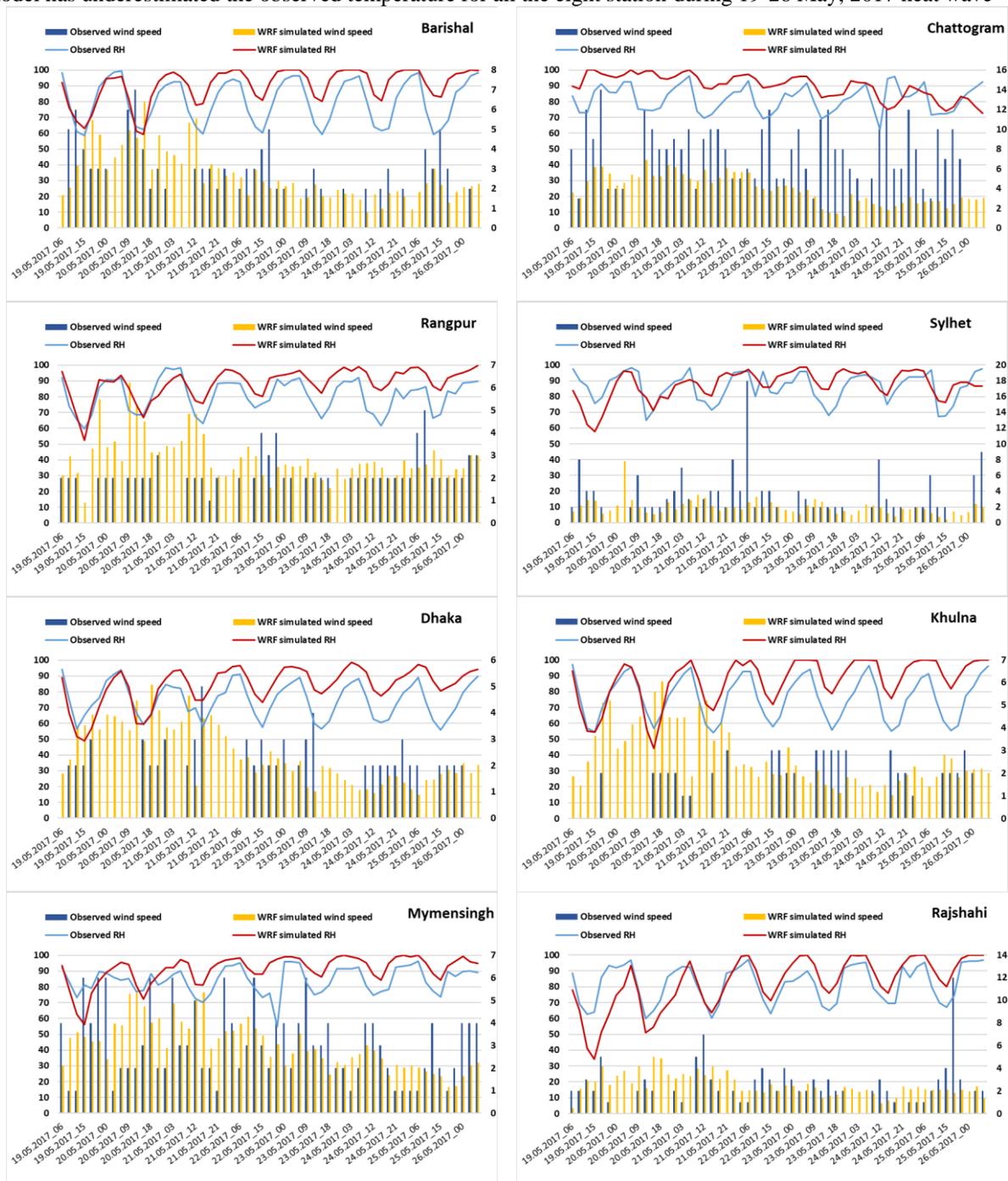

Figure 5: Comparison between observed and WRF simulated relative humidity and wind speed during 19-25 May, 2017

event (Figure 4). However, the pattern of observed temperature has been captured by the numerical model, except for Chattogram.

On the other hand, the model simulated relative humidity was higher than that of BMD recorded value during the event (Figure 5). The observed relative humidity curve shows a sinusoidal pattern for all stations with a slight variation in Rangpur and Sylhet. The model derived results for relative humidity also follow this pattern. However, for Chattogram, model simulated curve is different than that of observed. In terms of wind speed, observed wind speed is found to be greater in Chattogram and Sylhet. WRF model overestimated the speed of wind over Dhaka, Khulna and Rangpur.
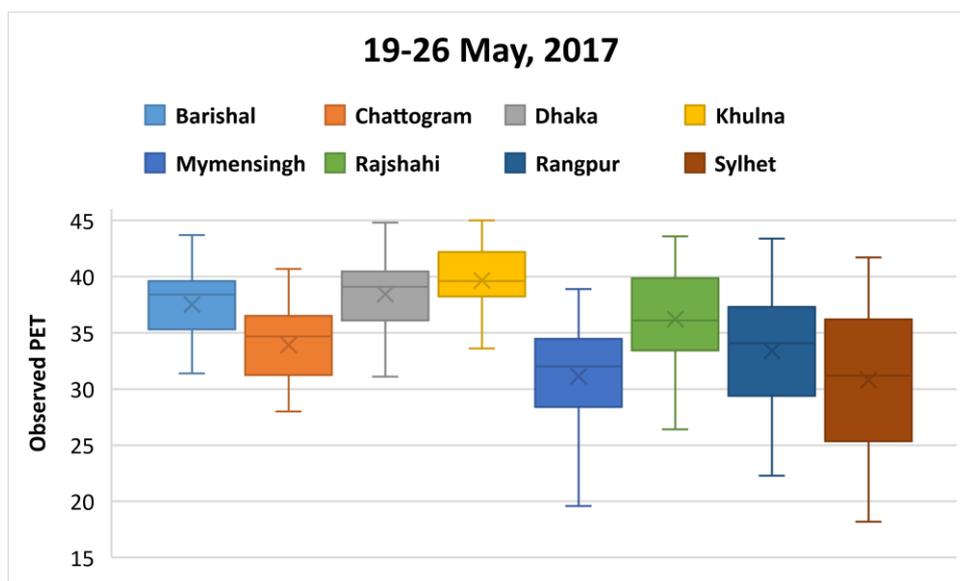
3.2 Analysis of Heat Stress

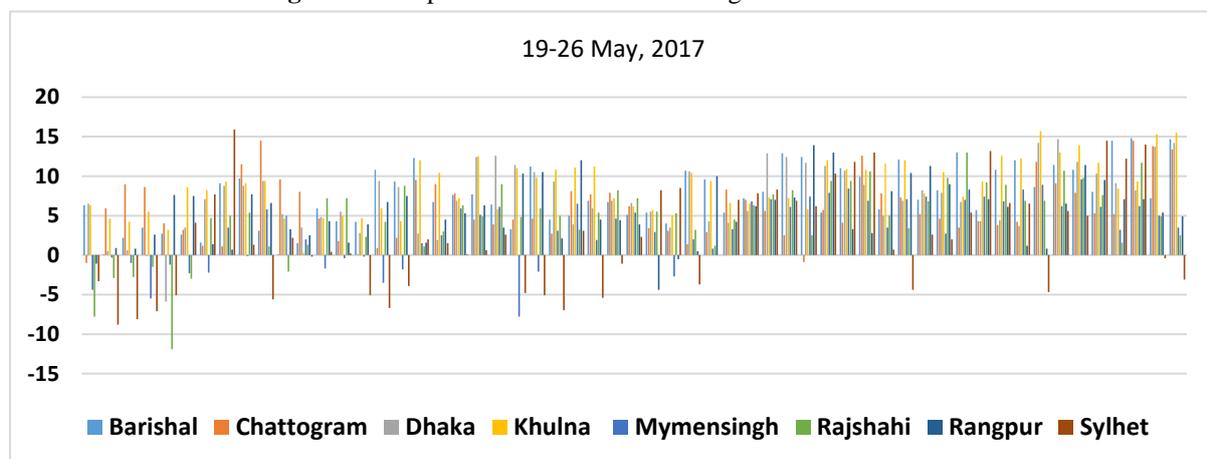**Figure 6:** Box plot for observed PET for eight divisional stations

Figure 7: Error plot of WRF simulated PET

Figure 6 illustrates the distribution of observed PET calculated using RayMan for each divisional station during 19-26 May, 2017. For Barishal, Dhaka and Khulna, the minimum value of PET were above 30°C and median value were around 38°C indicating moderate to strong heat stress during this heat wave. In Dhaka and Khulna, the maximum of PET reaches life-threatening high of 45°C. Also, the smaller box and whiskers for Khulna station indicate that 50 % of total PET values lie between 39-42°C (strong heat stress). In contrast to this, we observe that the box of Sylhet is wider and for most of the time the PET value was less than 36°C, ie, the third quartile value. Moderate to strong thermal stress for almost three-fourth of total time span has been found for Rajshahi and Chattogram. The median PET value for Rangpur station is 32°C, however, the maximum PET was on the same level of that of Rajshahi. The heat stress was comparatively lower in the Mymensingh and Sylhet.

To compare the model simulated PET with observed value, we plot the difference between PET values using observed data and WRF model simulated data for all the eight stations, where the positive value indicates that

observed PET is greater than simulated PET. This graph is shown in the figure 7, from which we found that WRF simulated PET is lower than observed PET for most of the time.

4. Conclusion

WRF model can simulate the trend of temperature and relative humidity over the stations, however, it fails to capture the observed pattern over Chattogram. Simulated temperature, relative humidity and wind speed are sensibly well compared with the data observed by BMD. Also, the low-pressure zone over West Bengal and adjoining area of Bangladesh during heat wave event has been successfully simulated by WRF.

Analyzing the observed heat stress over eight divisional stations reveals that Khulna is the region with highest thermal stress, followed by Barishal and Dhaka. In addition, moderate to strong heat stress is observed during heat wave across the country, except for Sylhet and Mymensingh. It has also been found that observed PET is higher than PET using simulated data. Analysis of PET in study of heat wave is novel in the context of Bangladesh. The findings will contribute to the understanding of prevailing heat stress condition over Bangladesh.

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