Employing WRF-ARW models to simulate heat wave events and creation comfort indices for stations in Dhaka, Khulna, Jashore, and Rajshahi

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Abstract

High-resolution Weather Research and Forecasting (WRF-ARW v4.12) model is used for the simulation of heat wave events that occurred during 10-13 April 2016, 24-27 April 2019, and 09-12 May 2019. So, an attempt has been made to simulate the extreme temperature conditions over Bangladesh using the WRF model and then an effort has been made to construct the Comfort Index (CI) by the RayMan model. National Centers for Environmental Prediction (NCEP) final reanalysis (FNL) data (1°×1° resolution) are used as initial and lateral boundary conditions (LBCs) which are updated at three hourly intervals. A single domain is used which is set up with 9 km horizontal resolution with a vertical level up to 100 hPa. The WRF model runs for 144, 120, and 96 hrs which are treated as 72, 48, and 24 hrs before the event using Kesler microphysics (MP) schemes, YSU PBL schemes, and Kain-Fritsch (KF) cumulus schemes. Physiological Equivalent Temperature (PET) is the human thermal comfort condition that is investigated at extreme weather conditions. To simulate Physiological Equivalent Temperature (PET), the primary meteorological parameters T2 (2-m air temperature), RH2 (2-m relative humidity), WS10 (wind speed at 10 m), and FNL data are used. Describe only four stations of Bangladesh as Dhaka, Khulna, Jashore and Rajshahi divisions where the best results were found. WRF model performance is very well in predicting T2, RH2, and WS10 values and RayMan Pro model is good enough to compute CI (comfort index).

Keywords: Heat wave, PET, WRF model, RayMan Pro model.

1. Introduction

A heat wave (HW) is a prolonged period of intense heat that may also be accompanied by excessive humidity. HW is often calculated concerning local weather patterns and average seasonal temperatures. Individuals who live in colder climates define heat waves as temperatures that are typical for individuals in hotter places. The World Meteorological Organization defines a heat wave as occurring when the daily maximum temperature is nine degrees higher than the average maximum temperature for more than five days in a row (Koppe *et al*., 2004; Powers *et al*., 2017). The Bangladesh Meteorological Department (BMD) reports that daytime highs of above +40 °C (104 °F) were recorded in several northern towns, which is unusual for the summer in Bangladesh. There was also a great deal of humidity. It is now necessary to comprehend what thermal comfort indices (CI) like physiological equivalent temperature (PET) are. Because of the way the human body reacts to several environmental factors, including air temperature, humidity, wind, and radiation, body temperature might differ from that of the surrounding air. Thermal comfort indicators such as standard effective temperature (SET*), predicted mean vote (PMV), and PET (Höppe *et al*., 1999). The temperature that a human body experience is called Physical Equivalent Temperature (PET), sometimes referred to as Comfort Index (Höppe *et al.,* 1993). People of different ages feel PET in different ways due to differences in their skin state and rate of energy production. There has been a noticeable rise in heat waves during the last few decades. Consequently, many others were harmed by the HW events, including the deceased. A mini systematic review was conducted by Kaltsatou, A., Kenny, G. P., Flouris, A. D., *et al.,* (2018) to examine the effect of heat waves on mortality among the elderly population. Ultimately, the findings of all these studies highlight the importance of reviewing and revising each nation's heat wave mitigation plans as well as the necessity for national health departments to create new preventative measures in order to protect the public and lessen the consequences of excessive heat. Acclimatization was a major factor in many of the locations where heat wave fatalities happened; hence, strategies to lower this risk have to be developed. Thus, it is necessary to develop and deploy global mechanisms to mitigate the effects of heat waves. Using physiological equivalent temperature as an indicator, Andreas Matzarakis and Bas Amelung (2008) investigate how climate change affects human thermal comfort. They claimed that more thorough research connecting many GCMs, such as regional climatic effects, extreme events (heat waves), and anticipated future land use changes, should broaden the analysis. Additionally, they stressed how the thermal bioclimate conditions are affected by the uncertainties in the input data, which are also present in the data obtained from the climate scenarios. Thus, the consequences of climate change on human health have been exaggerated since they are based on previous research that relied on variations in air

temperature rather than variations in PET. Decisions in the areas of tourism, health, and regional development are most likely being influenced by the data and conclusions in their current form.

In this study, we analyze the performance of simulated 24, 48, and 72-hour advanced run-on data obtained from 10–13 April 2016, 24–27 April 2019, and 09-12 May 2019 in four divisions of Bangladesh: Dhaka, Khulna, Jashore, and Rajshahi. Temperature at 2m (T2), relative humidity at 2m (RH2), and wind speed at 10m (WS10) values are computed using these data, followed by the calculation of physiological equivalent temperature (PET) and a comparison of T2 and PET. So, we clearly understand the difference between temperature with PET and which station suffer most. And take necessary steps when and where the feeling temperature or skin temperature as PET is high. For better understand we have to do more work for this.

2. Data Used and Methodology:

The weather research and forecasting models used in this investigation. Nonetheless, the WRF ARW model outperforms all other forecasting models in our area. This work made use of the YSU planetary boundary layer, the Kesler microphysics schemes, the Kain-Fritsch cumulus schemes, the Monin-Obukhov Surface Layer, the Noah land surface model, the Rapid Radiative Transfer Model (RRTM) for longwave radiation, and the Dudhia schemes for shortwave radiation. The RayMan Model will analyze the human thermal comfort level, or Physiological Equivalent Temperature (PET), which is looked at to forecast heat waves that occurred between April 10 and 13, 2016, April 24 to 27, 2019, and May 09 to 12, 2019.

RayMan Pro Model

In both simple and complicated situations, the RayMan Pro model is widely used to calculate mean radiation temperature and thermal indices, including Predicted Mean Vote (PMV), Physiologically Equivalent Temperature (PET), and Standard Effective Temperature (SET*). These computations are made for scientific case study research and practical usage, mostly related to urban bioclimate. The model is based on two German documents: VDI-3789, Part II: Environmental Meteorology, Interactions between Atmosphere and Surfaces; Calculation of the Short- and Long-wave Radiation, and VDI-Guidelines 3787: Environmental Meteorology, Methods for the Human-Biometeorological Evaluation of Climate and Air Quality for Urban and Regional Planning at Regional Level. Climate in Section I.

RayMan software are,

Uses:

- Applied meteorology and climatology.
- Landscape and ecological planning.
- Forest and agricultural metorology.
- Urban meteorology and climatology.
- health, recreation and tourism

In order to quantify thermal conditions (thermal comfort, cold stress, and heat stress) for various climates and places, RayMan calculates the mean radiant temperature and several thermal indices.

Possibilities of calculation and visualization

• Sunshine duration
• Sunpaths or sun orbit
• Shadow
 • Global radiation
• Mean radiant temperature (Tmrt)
• Predicted Mean Vote (PMV)
• Physiologically Equivalent Temperature (PET)
• Standard Effective Temperature (SET*)
• Perceived Temperature (PT)
• Universal Thermal Climate Index (UTCI)
 RayMan can be run for simple and complex environments.

Basic Configuration

The RayMan model works with Microsoft Windows and is capable of analyzing complex urban buildings in addition to other environments. The RayMan Pro model (version 3.1) clearly offers an environment that is easy to use, as seen by the input window shown in Figure 1. A data file with meteorological parameter values, a variety of fish-eye photo options, building and vegetation details, and free sketching with editing capabilities are just a few of the many input options that are accessible. There is a big advantage in being able to do the

assignment quickly. Since this is a glass-box model, it is expected that all of the input variables and the resulting precise radiation and energy fluxes are well understood.

FIGURE 1: RayMan Pro model (version 3.1) input window

Using only basic meteorological data (air temperature, air humidity, and wind speed), this model's key advantage is its ability to determine radiation fluxes and common thermal indices for the thermal human-bioclimate (Matzarakis, Rutz, and Mayer, 2007; Matzarakis, Rutz, and Mayer, 2010).

Statistical software

One of the most used methods for assessing the accuracy of forecasts is root means square error, also known as root mean square deviation (Chai, T. and Draxler, R. R. 2014). It illustrates the Euclidean distance between measured true values and forecasts. RMSE is often used in supervised learning applications since it demands and makes use of real measurements at each predicted data point.

RMSE is denoted by the formula,

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}[y(i)-\hat{y}(i)]^2}{N}} \tag{1}$$

Where N is the total number of simulated outputs, y(i) is the model simulated values, $\hat{y}$(i) is the observed values.

For example, Chaki *et al.* (2022) experimented with the assessment of WRF model performance in the simulation of heat wave events over Bangladesh. The April heat wave event's temperature RMSE score is lower than the May heat wave events, but both results show close simulation.

Again, Willmott's agreement index will be used to verify the model performances (Willmott *et al.* 2011). Willmott's Index of Agreement, *d*

$$d = 1 - \frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}(|P_i - \bar{O}| + [O_i - \bar{O}])^2} \tag{2}$$

d is a dimensional, bounded parameter for the performance of the numerical model.

d =0: Complete disagreement; d = 1: Perfect model. Oi represents the observation value, Pi is the forecast value, and $\bar{O}$ represents the average observation Value.

The WRF model runs for 144, 120, and 96 hours with the following initial conditions. These are considered to be 72, 48, and 24 hours ahead of time show Table 1:

Events	Initial conditions of the run	Run up to	Run treated as
1) 24-27 April 2019	0000 UTC of 21 April 2019	0000 UTC of 27 April 2019	144, 120, and 96 hrs.
2) 10-13 April 2016	0000 UTC of 11 April 2016	0000 UTC of 13 April 2016	144, 120, and 96 hrs.
3) 09-12 May 2019	0000 UTC of 6 May 2019	0000 UTC of 12 May 2019	144, 120, and 96 hrs.

There are a few more meteorological factors that will be looked at in relation to heat wave events and the Comfort Index construction. Analyze the physiological equivalent temperature (PET) at (RayMan Pro) model, the air temperature at 2m, the relative humidity at 2m, the wind speed, and lastly compare T2 VS PET. Initially, the WRF model is run with the aforementioned physics settings. The output is then retrieved and plotted using Grid Analysis and Display System (GRADS). Plotting station data is also done using Microsoft Excel software.

Results and Discussion:

Temperature at 2m:

The sequential variations of model simulated temperature at Dhaka, Rajshahi, Khulna and Jashore for 24 -26 April 2019, 10 -13 April 2016 and 09-12 May 2019 using 24, 48 and 72 hrs advanced run along with observed temperature of the heat wave event are illustrated in Figure 2, 3 and 4 respectively. The pattern of the Figures is almost same for all stations. The simulated and observed maximum temperatures are obtained between 0600 and 0900 UTC but the minimum temperatures are obtained at 0000 UTC for all station of all the figures all the events.
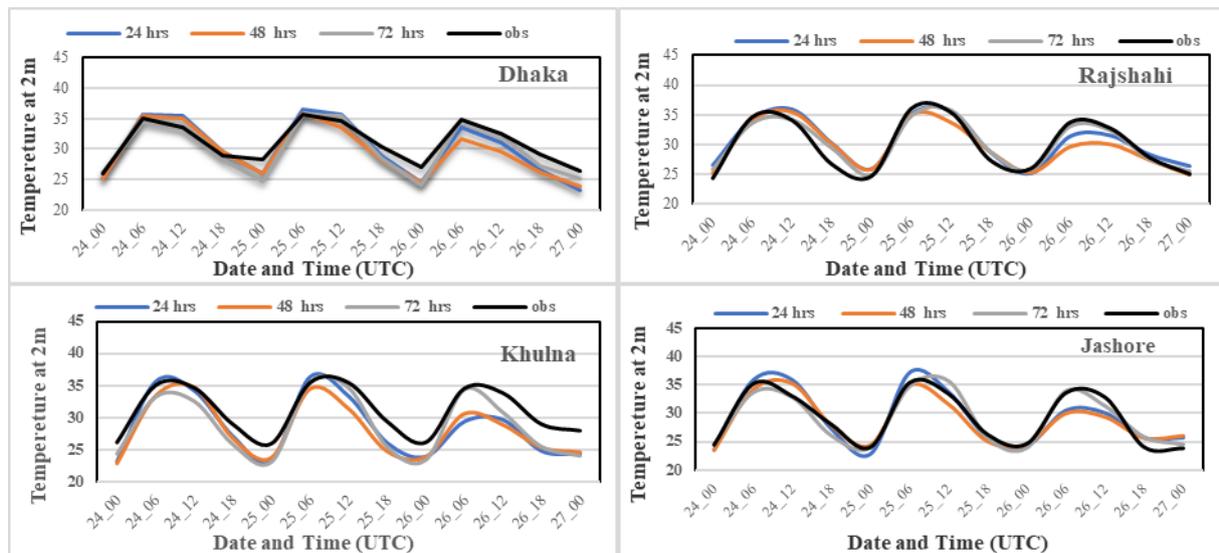

Figure 2: WRF model simulated and observed temperature at Dhaka, Rajshahi, Khulna and Jashore for 24 -26 April 2019 using 24, 48 and 72 hrs, advanced run.
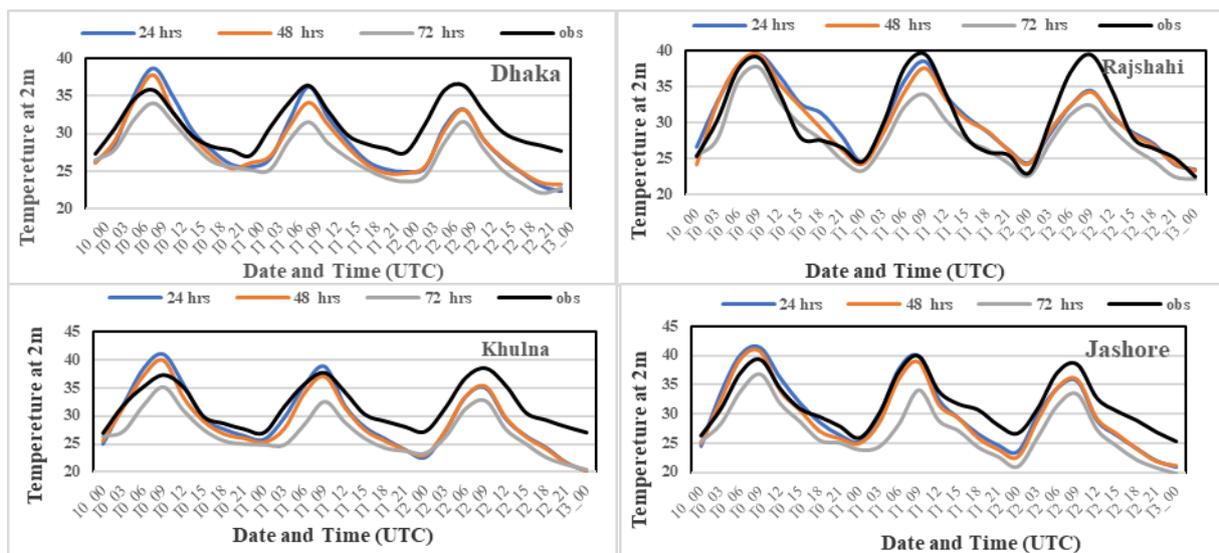

Figure 3: WRF model simulated and observed temperature at Dhaka, Rajshahi, Khulna and Jashore for 10 -13 April 2016 using 24, 48 and 72 hrs, advanced run.
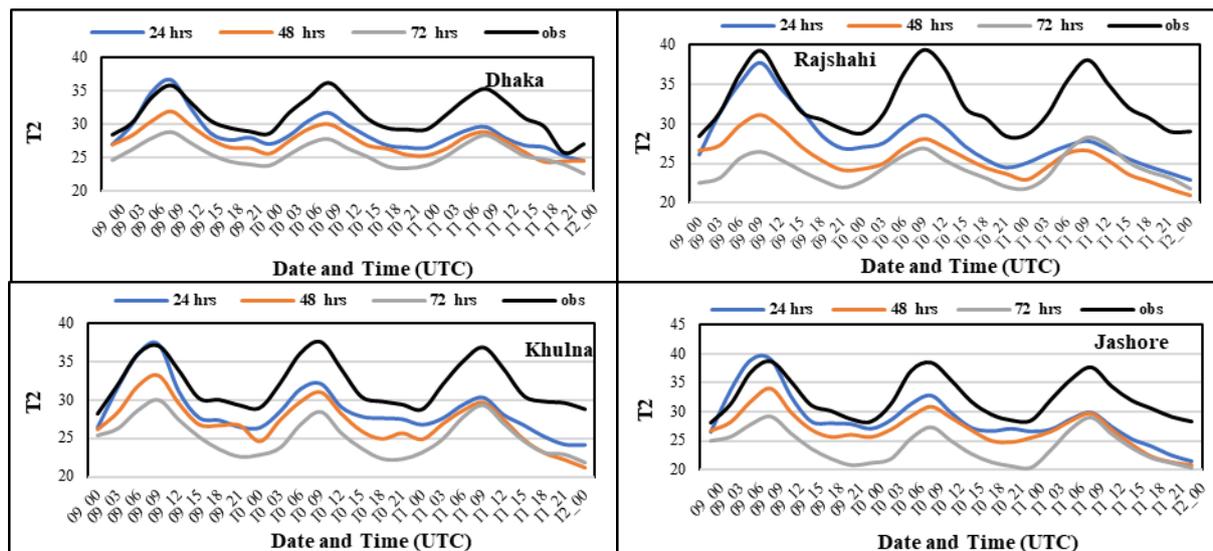
Figure 4: WRF model simulated and observed temperature at Dhaka, Rajshahi, Khulna and Jashore for 09-12 May 2019 using 24, 48 and 72 hrs, advanced run.

It is a good indication that WRF model simulates the diurnal variation of temperature. In figure 2 and 3 the value of the simulated maximum temperature is slightly more or less than that of observed but in figure 4 the simulated maximum temperature is much more deference than that of observed value whereas simulated minimum temperature is always less than that of observed. The maximum and minimum temperature for other stations is also shown the similar with respect to their values and occurred time compared to those of observed. The simulated value is lower than the observed value, as indicated by all the figures all the events, and the advanced run lasting 24 hours is closer to the observed value than the 48 and 72-hour runs.

Table 1: Comparison of RMSE and Willmott's Index of simulated temperature T2 and observed temperature at Dhaka, Rajshahi, Khulna and Jashore station using 24, 48, 72 hrs advanced run.

	RMSE simulated and observed T2				Willmott's Index of simulated and observed T2			
	24 -26 April 2019							
Station	24 hours	48 hours	72 hours	Average	24 hours	48 hours	72 hours	Average
Dhaka	1.62	1.91	1.55	1.16	0.95	0.93	0.95	0.97
Rajshahi	1.75	2.04	1.33	1.56	0.94	0.92	0.97	0.95
Khulna	3.02	3.28	2.73	2.87	0.86	0.83	0.88	0.87
Jashore	2.05	2.17	1.88	1.68	0.95	0.93	0.95	0.96
	10 -13 April 2016							
Station	24 hours	48 hours	72 hours	Average	24 hours	48 hours	72 hours	Average
Dhaka	3.07	3.11	4.29	2.89	0.827	0.809	0.64	0.774
Rajshahi	2.36	2.24	3.10	2.48	0.941	0.947	0.895	0.943
Khulna	3.44	3.54	4.94	3.19	0.86	0.848	0.667	0.818
Jashore	2.81	2.88	5.02	3.25	0.922	0.917	0.738	0.884
	09-12 May 2019							
Station	24 hours	48 hours	72 hours	Average	24 hours	48 hours	72 hours	Average
Dhaka	3.1	4.1	5.8	4.3	0.71	0.52	0.34	0.53
Rajshahi	5.2	7.4	8.5	7	0.57	0.33	0.25	0.4
Khulna	3.8	5.2	6.9	5.3	0.68	0.52	0.35	0.52
Jashore	4.7	5.9	8.6	6.4	0.65	0.5	0.31	0.5

Root mean square error (RMSE) of simulated temperature is shown in Table 1. Furthermore, RMSE lying in the range (1.33-8.6) which indicate good simulation for event 1 rather than event 2 or 3. Event 1, the RMSE lying in the range (1.33-3.2) indicate good simulation. For Dhaka station, RMSE value using 24, 48 and 72 hrs advanced run are almost same. The RMSE value obtained from the average temperature using 24, 48 and 72 hrs advanced run are less than any individual run. Similar situation is also obtained for Jashore station. For Rajshahi and Khulna stations, 72 hrs advanced run is little bit better than those obtained from average as well as 48 and 24 hrs advance run. Event 2, the RMSE lying in the range (2.24-4.94) indicate good simulation. The RMSE value obtained from the average temperature using 24, 48 and 72 hrs advanced run are less than any individual run.

Similar situation is also obtained for Jessore station. For all station, 24 hrs advanced run is little bit better than those obtained from average as well as 48 and 72 hrs advance run. Event 3, the RMSE lying in the range (3.1-8.6) indicate as not good simulation. The RMSE value for each station utilizing the 24, 48, and 72-hour advanced runs shows that the 24-hour simulation is better than the 48 and 72-hour advanced runs. The table shows that the average RMSE value of Dhaka station is better than the other stations.

According to the value obtained from the Willmott's index of agreement tabulated in Table 1, all values are almost perfect match because these values for all station near to the 1. Out of the events, results from events 1 and 2 are better than those from event 1. Out of all the stations, the Dhaka station corresponds better for events 1 and 3. Additionally, Rajshahi station matches better than any other station during the second event

Wind speed at 10m:

The sequential variations of model simulated WS10m at Dhaka, Rajshahi, Khulna and Jashore for 24 -26 April 2019, 10 -13 April 2016 and 09-12 May 2019 using 24, 48 and 72 hrs. advanced run along with observed WS10m of the heat wave event are illustrated in Figure 3, 4 and 5 respectively.
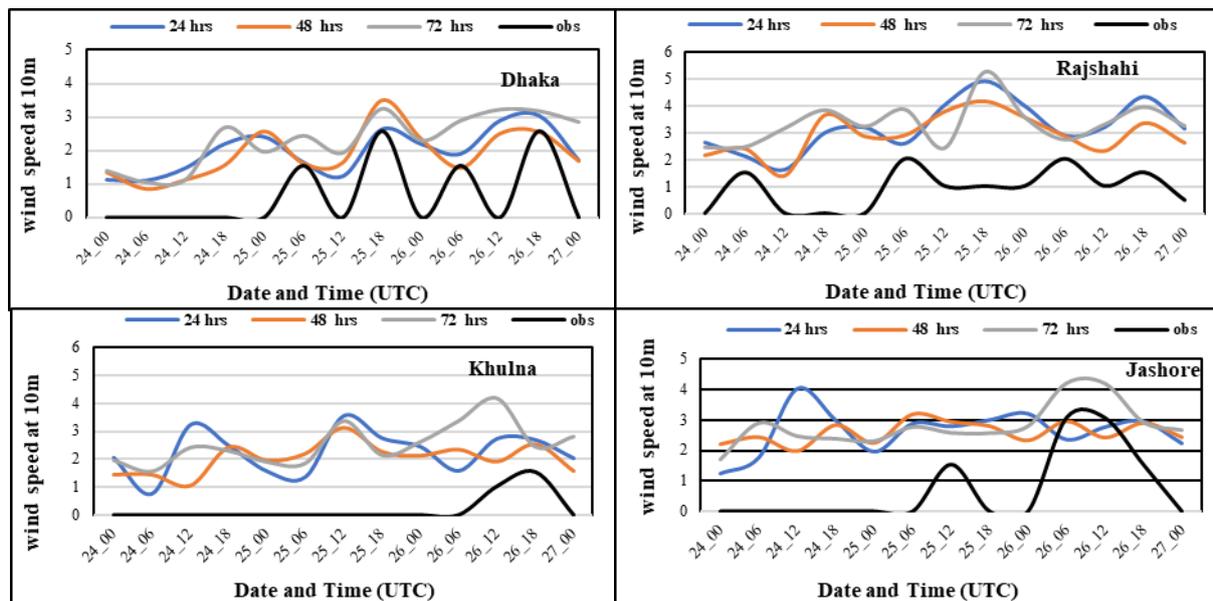

Figure 5: WRF model simulated and observed WS10m at Dhaka, Rajshahi, Khulna and Jashore for 24 -26 April 2019 using 24, 48 and 72 hrs. advanced run.
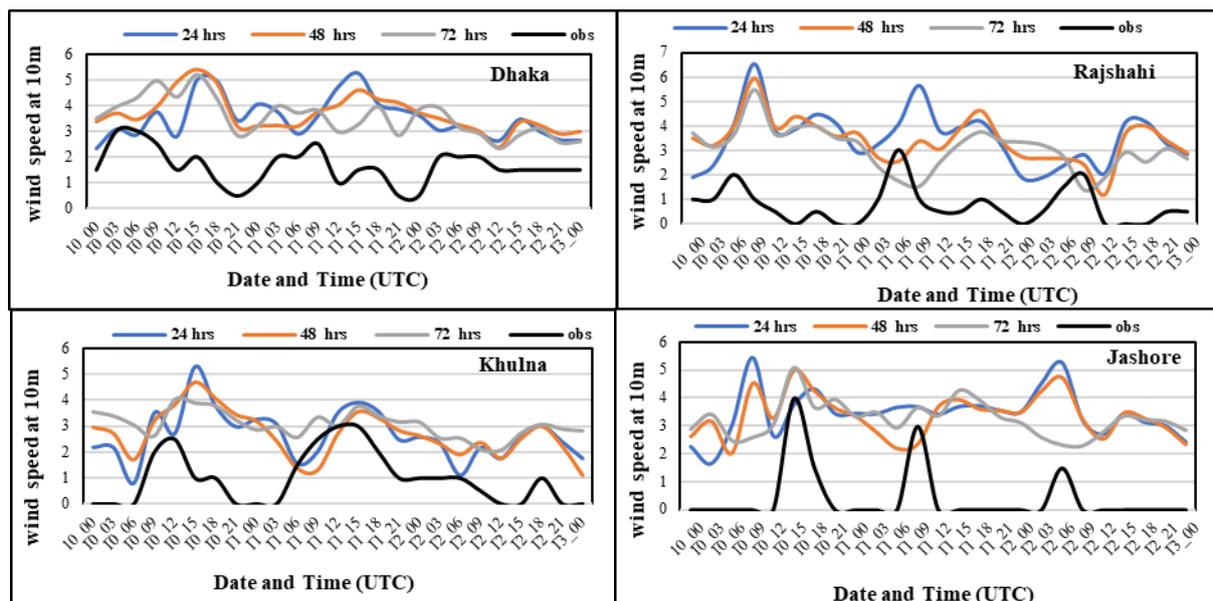

Figure 6: WRF model simulated and observed WS10m at Dhaka, Rajshahi, Khulna and Jashore for 10 -13 April 2016 using 24, 48 and 72 hrs. advanced run.

The observed value expressively lower than the simulated value. We can apparent that, model simulated WS10m value is totally different from observed value because of it localize effect. Except figure 7 for Jashore station the observed value is more than simulated value. The observed value is between 0-8 and the simulated value is 1-7 for Dhaka, Rajshahi, Khulna and Jashore station.
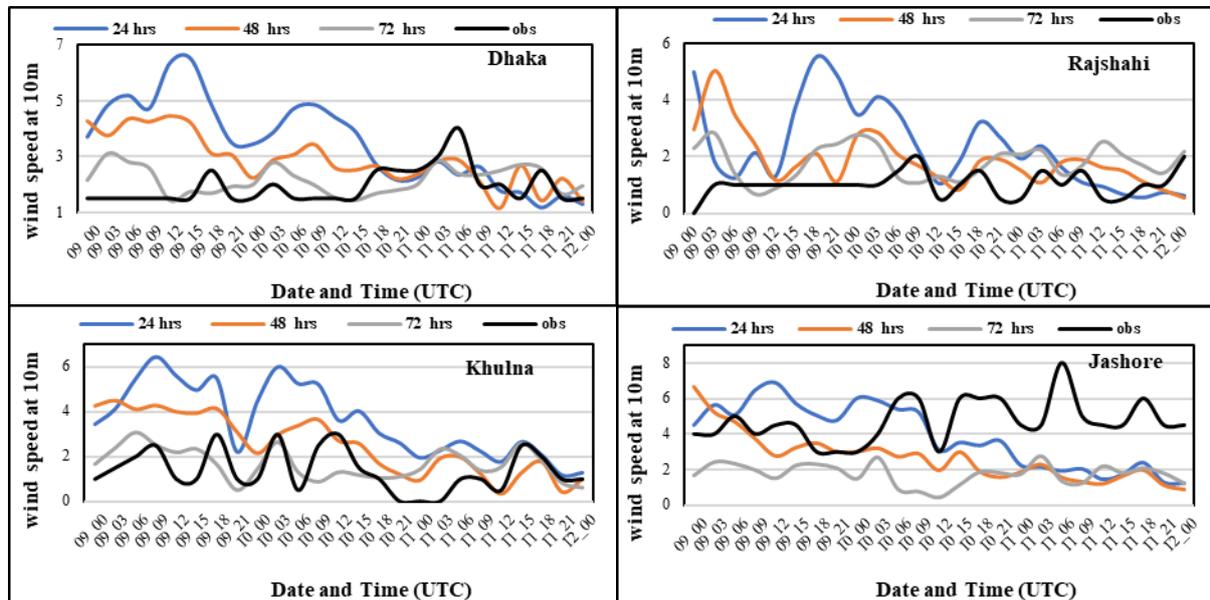

Figure 7: WRF model simulated and observed WS10m at Dhaka, Rajshahi, Khulna and Jashore for 09 -12 May 2019 using 24, 48 and 72 hrs. advanced run.

Relative Humidity at 2m:

The sequential variations of model simulated RH2 at Dhaka, Rajshahi, Khulna and Jashore for 24 -26 April 2019, 10 -13 April 2016 and 09-12 May 2019 using 24, 48 and 72 hrs advanced run along with observed temperature of the heat wave event are illustrated in Figure 8, 9 and 10 respectively. The simulated and observed pattern are almost same and the minimum value get 0009 UTC and the maximum value get 0000 UTC most of the time all the events (Jaman *et al*., 2022, Chaki *et al*., 2022). Here we can see model simulated RH2 advanced 24, 48 and 72 hrs value is quite different from observed value. Figure 8 for Dhaka station, RH2 is bellow to 90% some point is up to the mark but for Rajshahi, Khulna and Jashore station it is up to 95-100%. So, we clearly see that Rajshahi, Khulna and Jashore station RH2 is more than Dhaka station. Figure 9 the
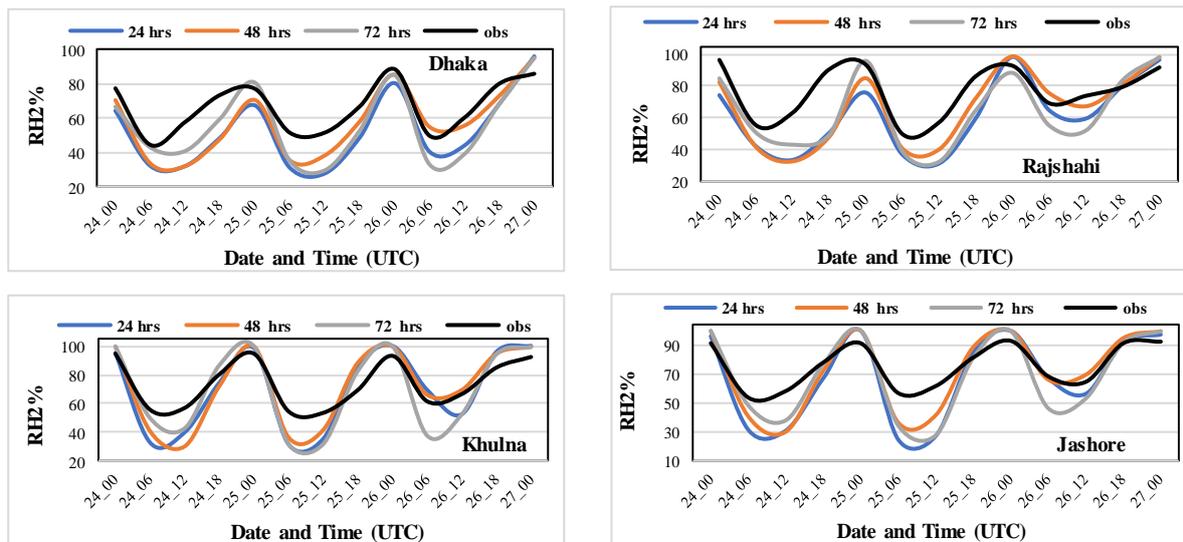

Figure 8: WRF model simulated and observed RH2 at Dhaka, Rajshahi, Khulna and Jashore for 24 -26 April 2019 using 24, 48 and 72 hrs advanced run

Dhaka, Khulna and Jashore station RH2 is more than Rajshahi station. Figure 10 the Dhaka, Rajshahi and Jashore station RH2 is more than Khulna station.
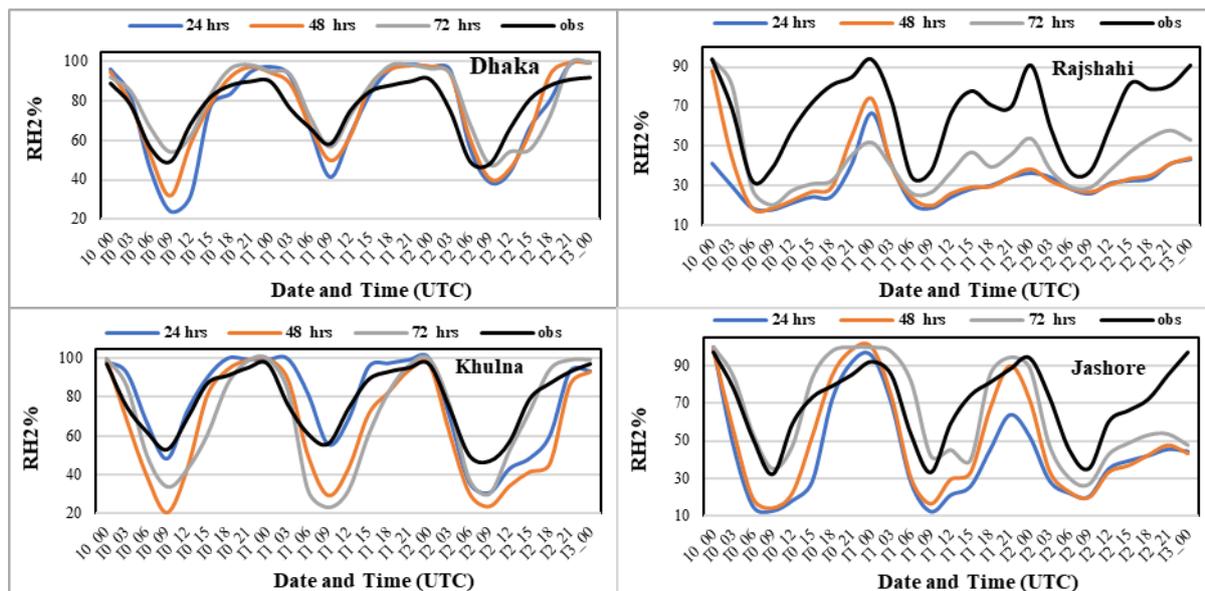
Figure 9: WRF model simulated and observed RH2 at Dhaka, Rajshahi, Khulna and Jashore for 10 -13 April 2016 using 24, 48 and 72 hrs advanced run.

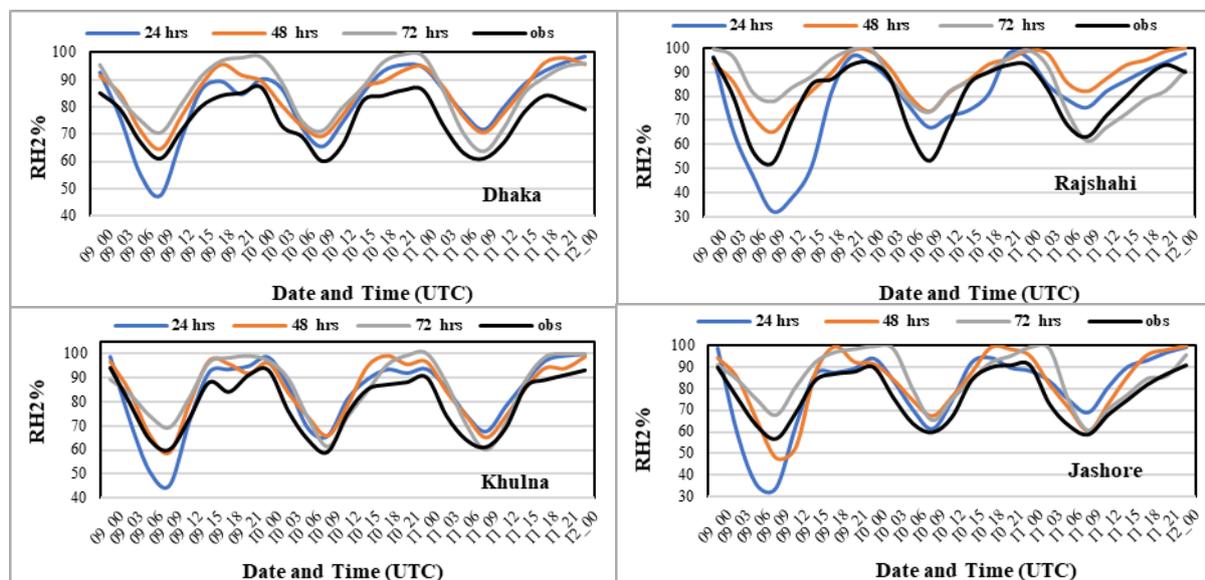**Figure 9:** WRF model simulated and observed RH2 at Dhaka, Rajshahi, Khulna and Jashore for 10 -13 April 2016 using 24, 48 and 72 hrs advanced run.

Physiological Equivalent Temperature (PET):

The sequential variations of model simulated PET at Dhaka, Rajshahi, Khulna and Jashore for 24 -26 April 2019, 10 -13 April 2016 and 09-12 May 2019 using 24, 48 and 72 hrs advanced run along with observed temperature of the heat wave event are illustrated in Figure 11, 12 and 13. The observed PET is bigger than simulated PET for all station. The patterns are almost same all the event for all station. The highest and lowest PET values that we obtain are 0900 and 0000 UTC, respectively, with little bit variations sometimes. For figure 11 at Dhaka station the observed highest value 50.2, 51.1, 49.3 ℃ is obtained 1200 UTC 24, 25, 26 April 2019 respectively but the simulated highest value 45.6, 46.1, 41.1℃ for 24 hrs 45.8, 44.2, 39℃ for 48 hrs 44.6, 44.9, 42.6 ℃ for 72 hrs advanced run is obtained 0900 UTC 24, 25, 26 April 2019 respectively. For Rajshahi station the observed 50.8, 48.5, 47.6 ℃ and simulated 45.1, 39.3, 44.3 ℃ for 24 hrs 43.6, 37.8, 43.7 ℃ for 48 hrs 46.3, 41.7, 44.5 ℃ for 72 hrs advanced run highest value both are obtained 0900 UTC 24, 25, 26 April 2019 respectively except the observed value 50.8 ℃ obtained 1200 UTC 24 April 2019. For Khulna station the observed highest value 51.1, 51.8 ℃ is obtained 1200 UTC 24 and 25 April 2019 and 49.3 ℃ is obtained 0900 UTC 26 April 2019 but the simulated highest value 48.8, 46, 41 ℃ for 24 hrs 46.5, 43.3, 38.2 ℃ for 48 hrs 44.5, 46.3, 41.7 ℃ for 72 hrs advanced run is obtained 0900 UTC 24, 25, 26 April 2019 respectively. For Jessore station the observed 52.9, 44.2, 43.8 ℃ and simulated 46.8, 45.4, 39.7 ℃ for 24 hrs 44.9, 43.5, 38 ℃ for 48 hrs

43.5, 45.4, 40.9 °C for 72 hrs advanced run highest value both are obtained 0900 UTC 24, 25, 26 April 2019 respectively.
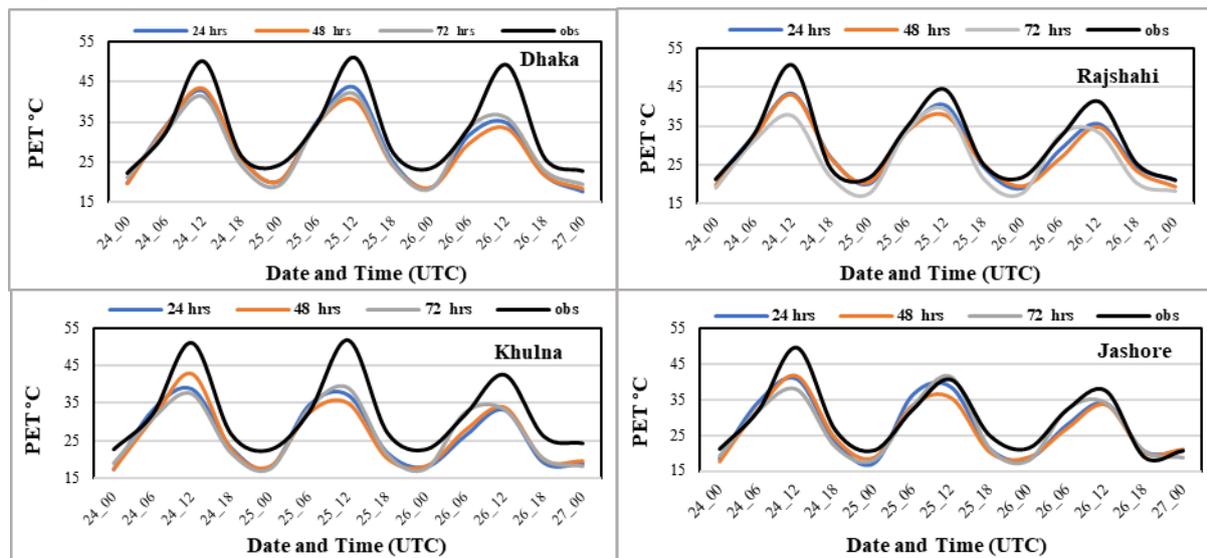

Figure 11: WRF model simulated and observed PET at Dhaka, Rajshahi, Khulna and Jashore for 24 -26 April 2019 using 24, 48 and 72 hrs. advanced run.
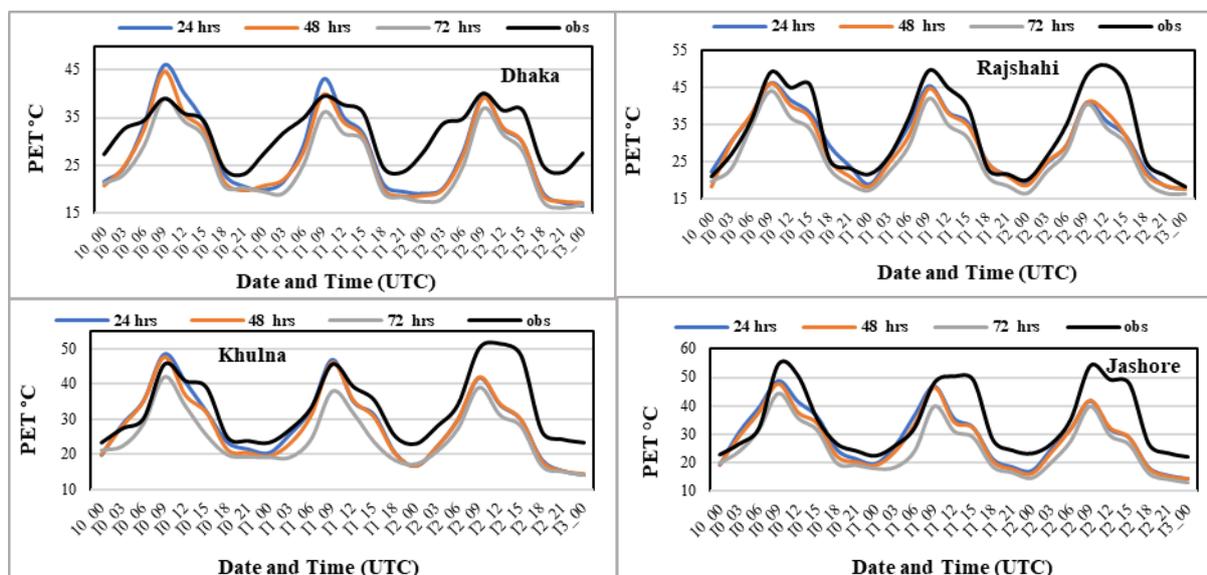

Figure 12: WRF model simulated and observed PET at Dhaka, Rajshahi, Khulna and Jashore for 10 -13 April 2016 using 24, 48 and 72 hrs. advanced run.

For figure 12 the Dhaka station the observed PET 39.1, 39.6, 40.2 °C and the simulated 45.9, 43, 39.2°C for 24 hrs 44.7, 39.9, 39.1°C for 48 hrs 39, 36.1, 36.9 °C for 72 hrs advanced run highest value both are 0900 UTC 10, 11, 12 April 2016 respectively. For Rajshahi station the observed 49.2, 49.6, 48.3 °C and simulated 46.2, 45.4, 40.9 °C for 24 hrs 46.3, 44.8, 41 °C for 48 hrs 44.2, 42.1, 40.5 °C for 72 hrs advanced run highest value both are obtained 0900 UTC 10,11, 12 April 2016 respectively. For Khulna station the observed highest value 45.6, 45.6 °C is obtained 0900 UTC and 51.4 °C is obtained 1200 UTC 10, 11 and 12 April 2016 respectively but the simulated highest value 48.6, 47, 41.8 °C for 24 hrs 47.5, 46, 41.9 °C for 48 hrs 42.1, 38, 39.1 °C for 72 hrs advanced run is obtained 0900 UTC 10,11, 12 April 2016 respectively. For Jashore station the observed 54.6, 54.1 °C is obtained 0900 UTC 10 and 12 April 2016 and 50.4 °C is obtained 1200 UTC 11 April 2016 and simulated 48.6, 46.7, 41.6 °C for 24 hrs 47.8, 46.5, 42 °C for 48 hrs 44.3, 39.8, 39.8 °C for 72 hrs advanced run highest value both are obtained 0900 UTC 10,11, 12 April 2016 respectively.

For figure 13 the Dhaka station the observed PET 45.6, 46.1, 44.2 °C and the simulated 43.4, 36.3, 35.7°C for 24 hrs 37.2, 35.4, 35.8°C for 48 hrs 34.9, 34.6, 34.6 °C for 72 hrs advanced run highest value both are 0900 UTC 9, 10, 11May 2019 respectively. For Rajshahi station the observed 46.7, 45.8, 45°C and simulated 46.3, 37.7, 37 °C for 24 hrs 40.2, 37, 38.6 °C for 48 hrs 36.2, 38.2, 38 °C for 72 hrs advanced run highest value both

are obtained 0900 UTC 9, 10, 11May 2019 respectively. For Khulna station the observed highest value 45.7, 46.3, 47.9 °C and the simulated 43.9, 36.8, 37.4°C for 24 hrs 39, 36.5, 39.1°C for 48 hrs 36.5, 38.9, 38°C for 72 hrs advanced run is obtained 0900 UTC 9, 10, 11May 2019 respectively. For Jashore station the observed 50.6, 49.2, 48.1 °C and simulated 46.7, 38.5, 37.5 °C for 24 hrs 38.1, 35.8, 37.5 °C for 48 hrs 37.8, 36.3, 35.9 °C for 72 hrs advanced run highest value both are obtained 0900 UTC 9, 10, 11May 2019 respectively.
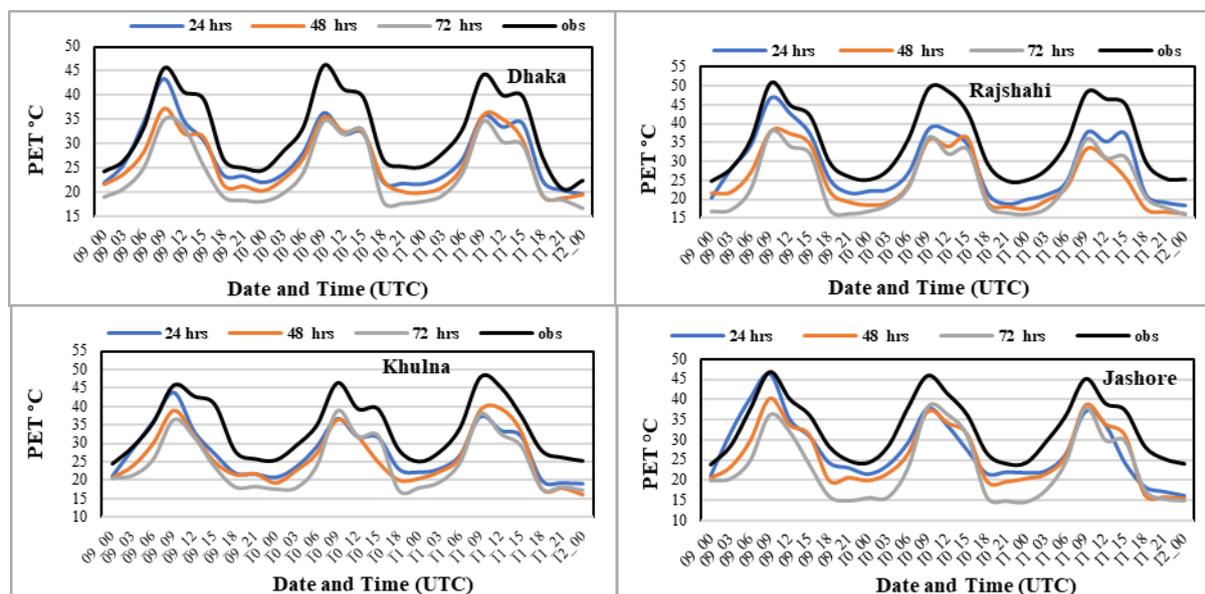

Figure 13: WRF model simulated and observed PET at Dhaka, Rajshahi, Khulna and Jashore for 09-12 May 2019 using 24, 48 and 72 hrs. advanced run.

RMSE of observed and simulated PET are shown in Table 10. Event 1 the RMSE value give better result for Jashore station, event 2 Rajshahi station give better result and event 3 the Dhaka station give better result than any other station.

According to the value obtained from the Willmott's index of agreement tabulated in Table 10, all values are almost perfect match because these values for all station near to the 1. Among the events, 24hrs advanced run matches better than any other advance run.

Table 10: Comparison of RMSE and Willmott's Index of simulated and observed PET at Dhaka, Rajshahi, Khulna and Jessore station using 24, 48, 72 hrs advanced run.

	RMSE simulated and observed T2				Willmott's Index of simulated and observed T2			
	24 -26 April 2019							
Station	24 hours	48 hours	72 hours	Average	24 hours	48 hours	72 hours	Average
Dhaka	5.77	6.62	6.10	5.80	0.917	0.887	0.906	0.905
Rajshahi	4.39	5.11	6.32	8.27	0.948	0.929	0.902	0.932
Khulna	6.97	7.08	6.92	8.24	0.877	0.871	0.877	0.879
Jashore	4.49	4.65	4.72	4.32	0.945	0.937	0.938	0.945
	10 -13 April 2016							
Station	24 hours	48 hours	72 hours	Average	24 hours	48 hours	72 hours	Average
Dhaka	6.15	6.22	7.51	6.52	0.796	0.789	0.696	0.768
Rajshahi	5.53	5.51	7.45	6.01	0.925	0.929	0.873	0.914
Khulna	6.98	7.05	9.34	7.58	0.857	0.854	0.741	0.829
Jashore	8.83	8.99	11.26	9.52	0.828	0.824	0.738	0.803
	09-12 May 2019							
Station	24 hours	48 hours	72 hours	Average	24 hours	48 hours	72 hours	Average
Dhaka	5.4	6.5	8.5	6.8	0.86	0.81	0.73	0.8
Rajshahi	7	10	11	9.3	0.86	0.7	0.7	0.75
Khulna	6.7	8	9.5	8.1	0.81	0.76	0.7	0.76
Jashore	6.6	7.1	9.9	7.9	0.82	0.81	0.71	0.78

T2 vs PET:

The sequential variations of model simulated T2 vs PET at Dhaka, Rajshahi, Khulna and Jashore for 09 -12 May 2019 using 24, 48 and 72 hrs. advanced run along with observed temperature of the heat wave event are illustrated in Figure 14, 15 and 16 respectively. The pet value is greater than T2 at day time and the pet value is lower than T2 at night time because it's all Heat Wave event.
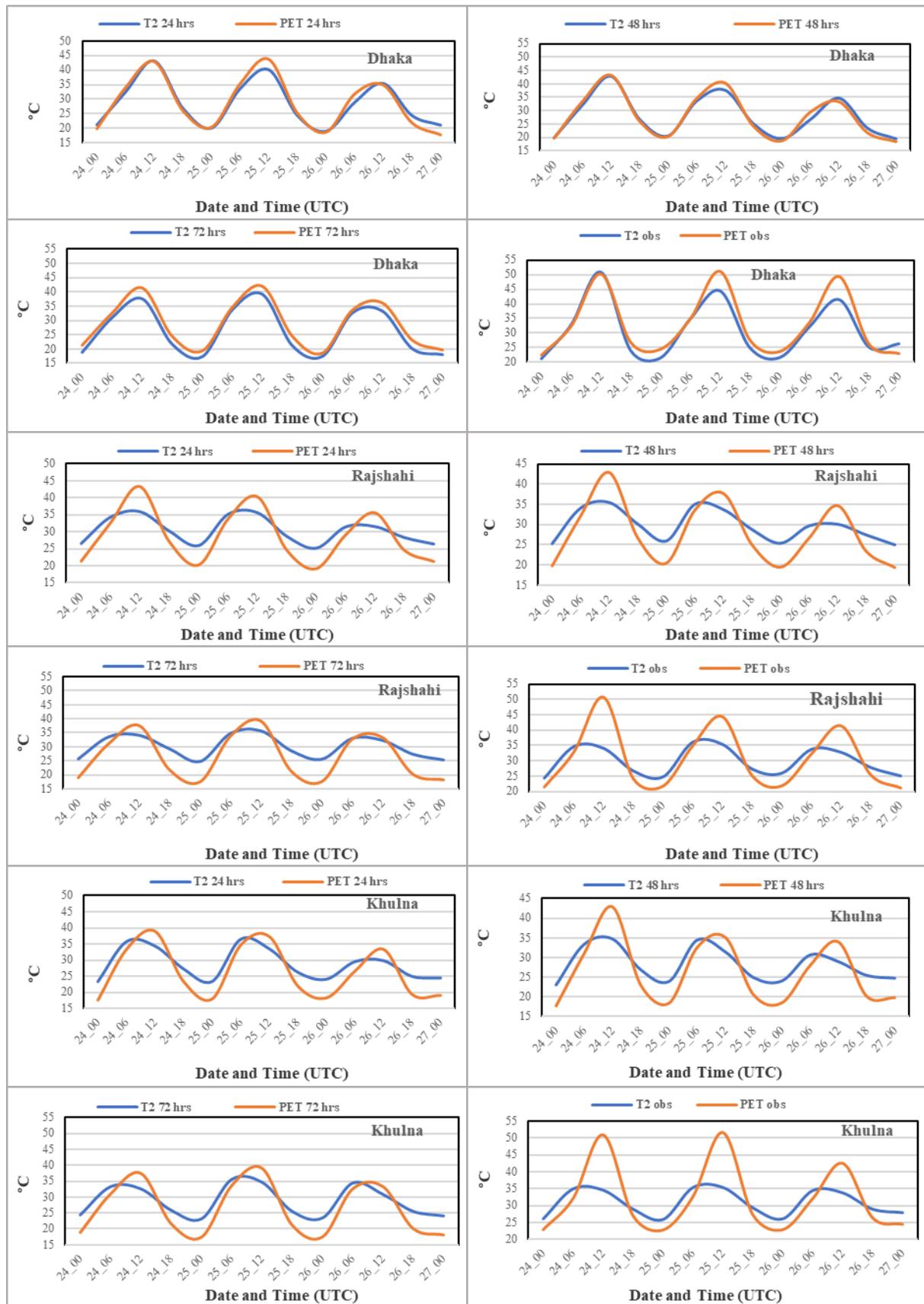
Figure 14(a): WRF model simulated and observed T2 vs PET at Dhaka, Rajshahi and Khulna for 24 -26 April 2019 using 24, 48 and 72 hrs. advanced run.
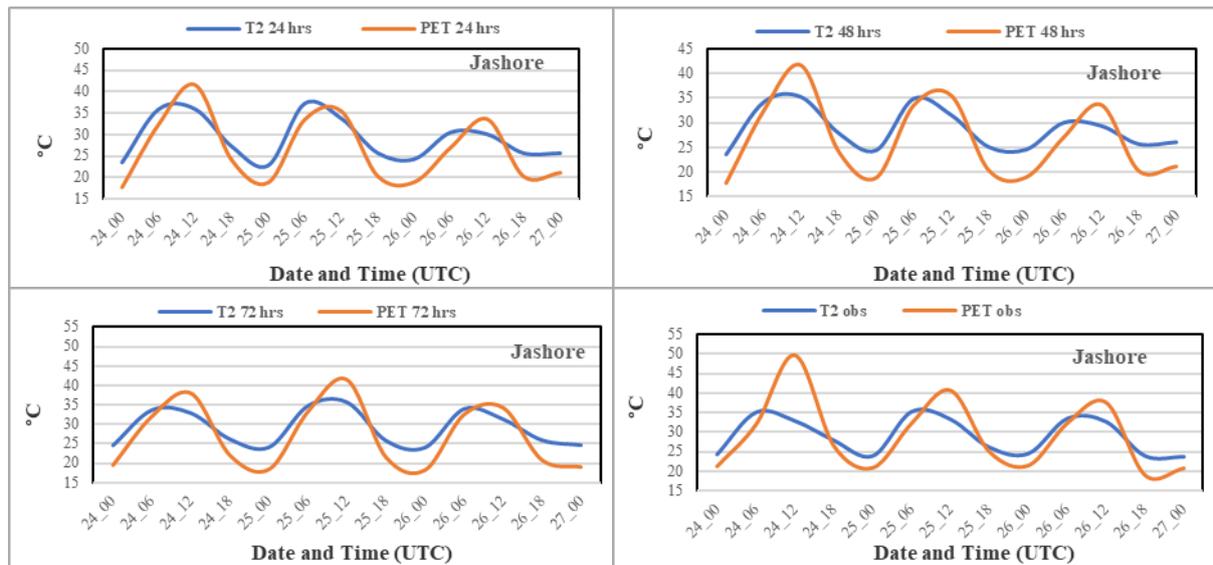
Figure 14(b): WRF model simulated and observed T2 vs PET at Jashore for 24 -26 April 2019 using 24, 48 and 72 hrs. advanced run.
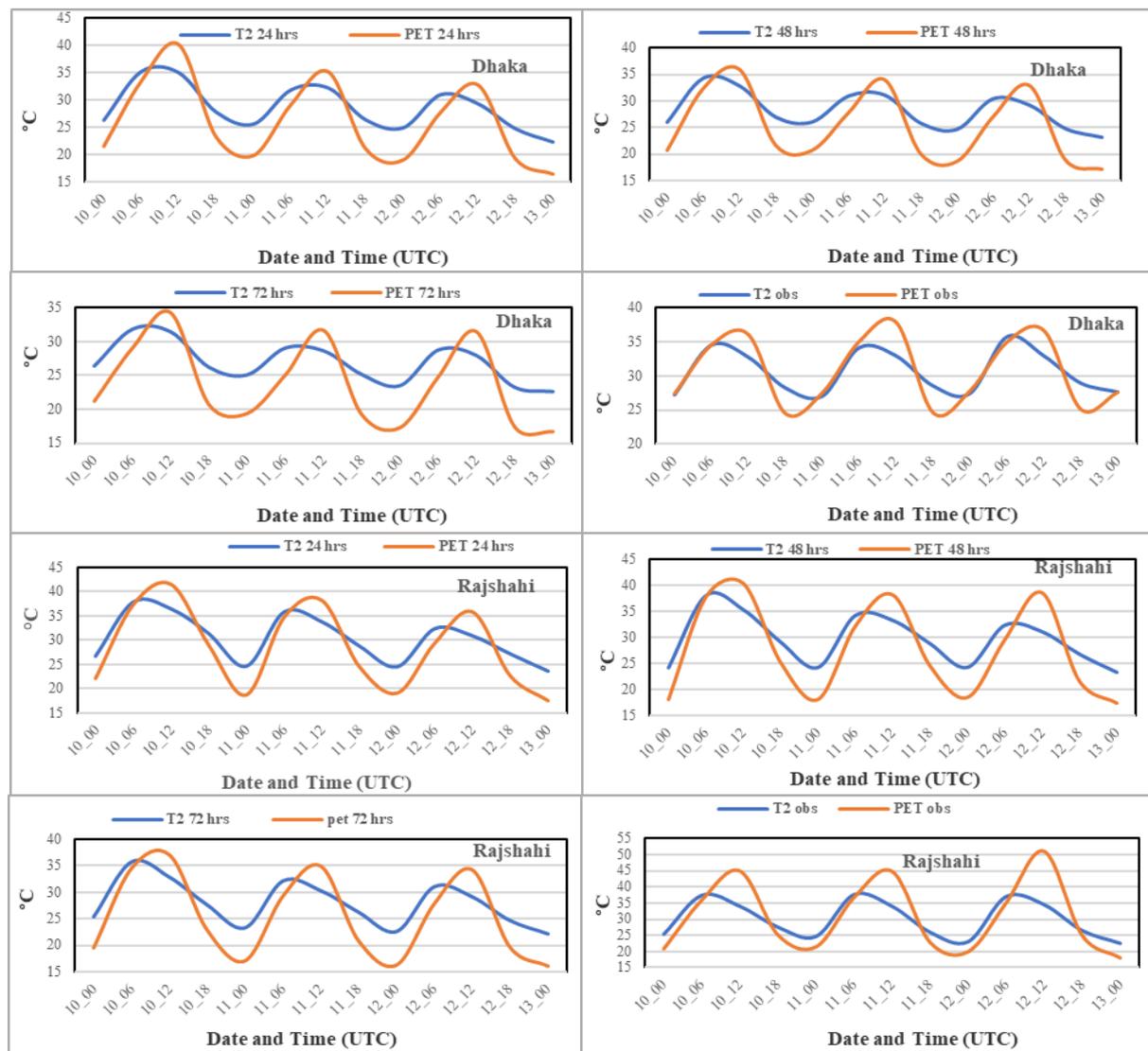

Figure 15(a): WRF model simulated and observed T2 vs PET at Dhaka and Rajshahi for 10 -13 April 2016 using 24, 48 and 72 hrs. advanced run
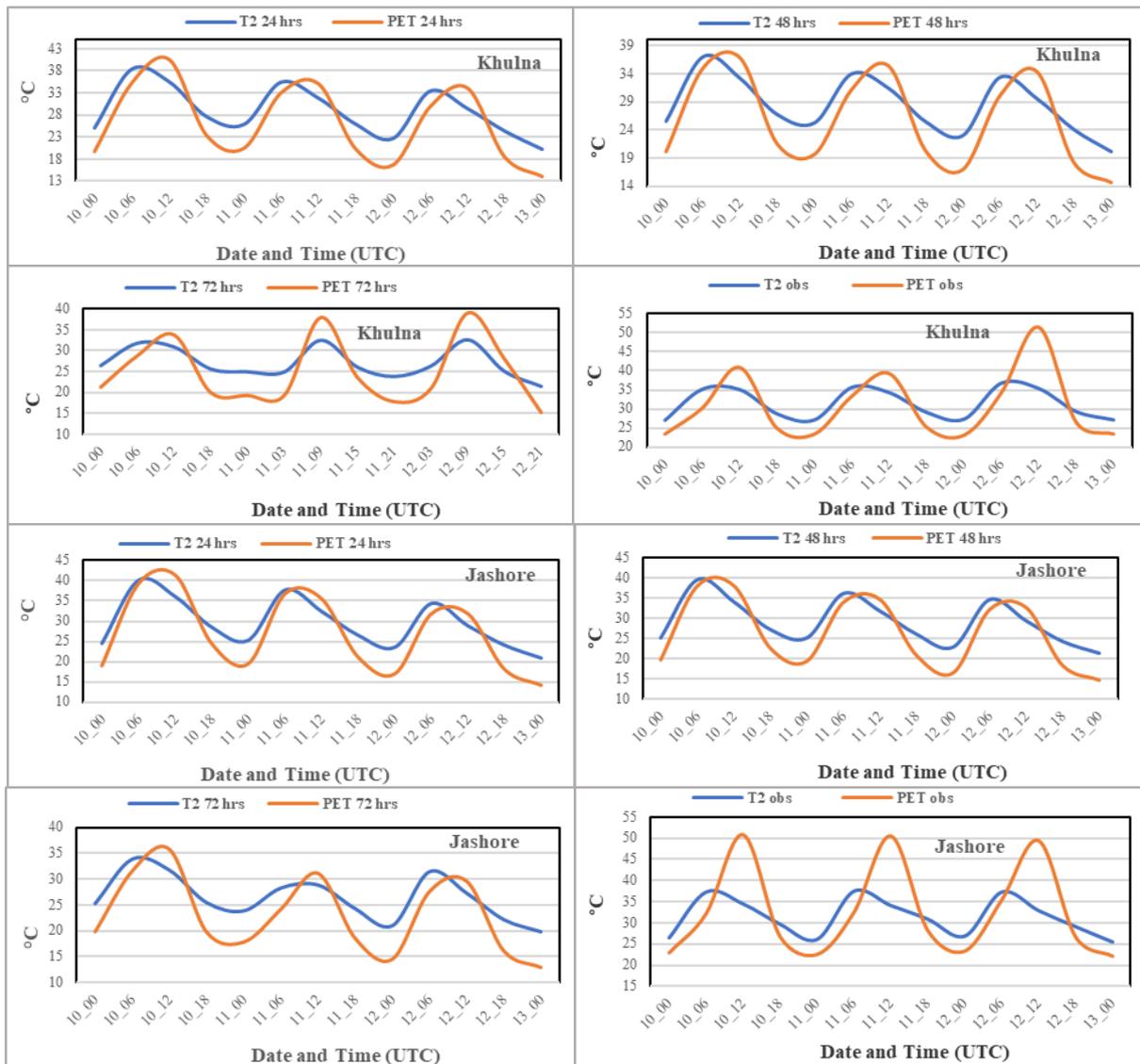
Figure 15(b): WRF model simulated and observed T2 vs PET at Khulna and Jashore for 10 -13 April 2016 using 24, 48 and 72 hrs. advanced run.
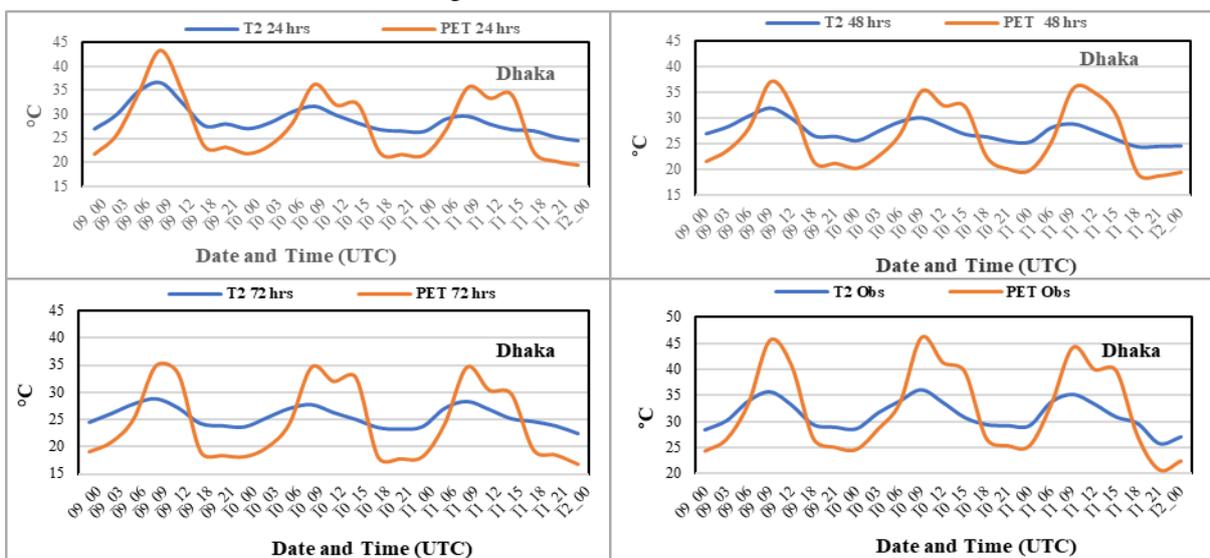

Figure 16(a): WRF model simulated and observed T2 vs PET at Dhaka for 19-22 May 2021 using 24, 48 and 72 hrs advanced run.
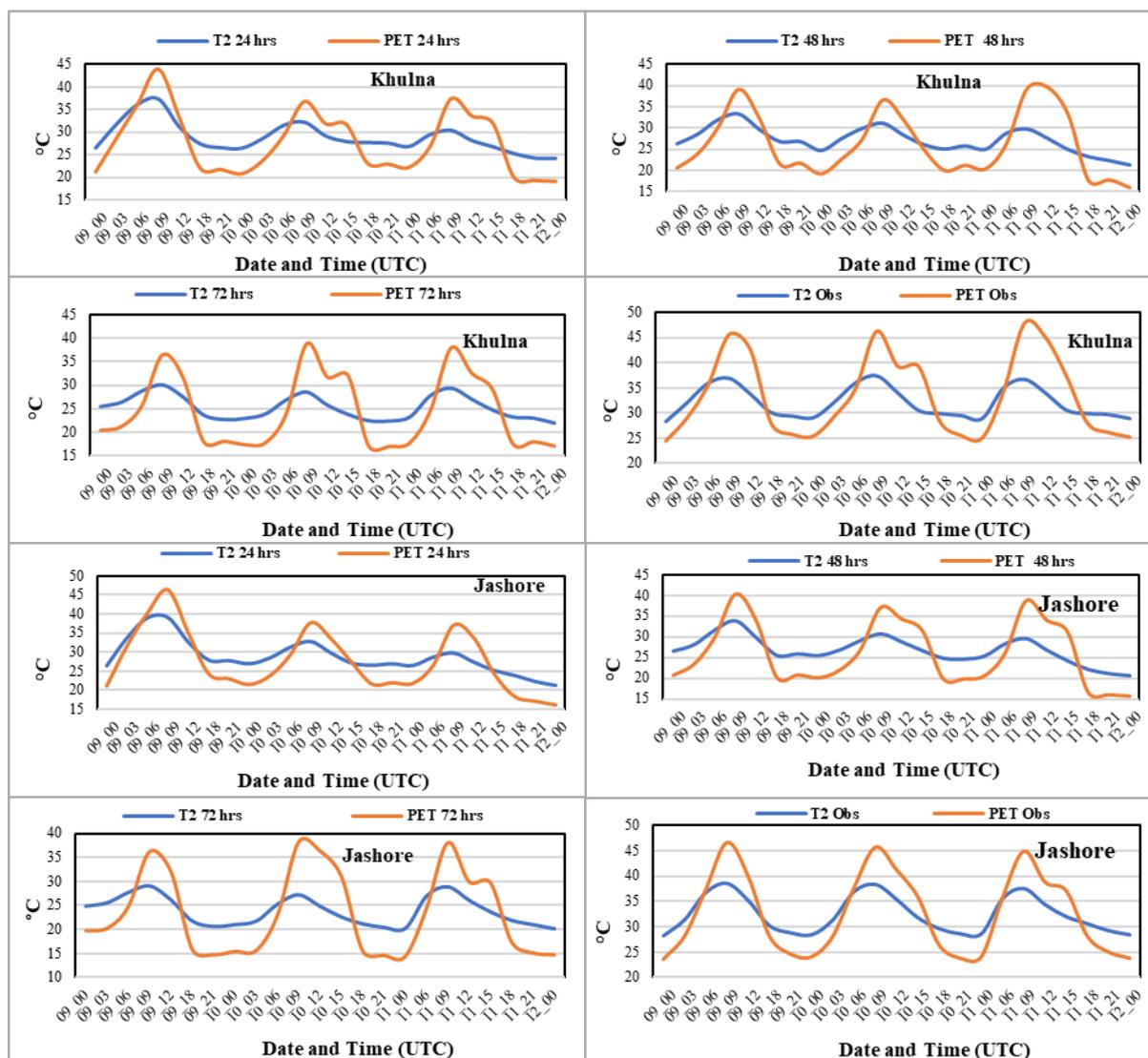
Figure 16(b): WRF model simulated and observed T2 vs PET at Rajshahi, Khulna and Jashore for 19-22 May 2021 using 24, 48 and 72 hrs advanced run.

Discusion:

The performance of the WRF model is sufficient to replicate the T2, RH2, WS10, PET, and observed values in the study. There are not many variations between the simulated and observed values for T2 and PET. WRF model performance is very well to predict T2 values with the observed value. But because of it localize impact, WS10m differs greatly from simulated and observed data. We can easily observe that T2 and PET are fairly equal for the Dhaka station, but PET is either more or less than T2 for the Rajshahi, Khulna, and Jessore stations. This is due to the fact that RH2 is higher in the stations in Rajshahi, Khulna, and Jashore than it is in Dhaka. Because we choose the study's summer event, we can observe that the pet value in this case is higher than T2. The PET value is larger than 41°C, which indicates extreme heat stress conditions that perfectly match our weather, the Rayman model operates well enough to calculate CI. Understanding PET is crucial for us, and developing places that encourage public usage throughout the year can be made easier by being aware of the many factors that affect thermal comfort in these areas. As was previously established, the comfort index plays a significant influence in both psychological and physical adaptation.

Reference:

1. Chai, T. and Draxler, R. R. (2014). Root mean square error (RMSE) or mean absolute error (MAE)? – Arguments against avoiding RMSE in the literature. Geosci. Model Dev., 7, 1247–1250, doi: 10.5194/gmd-7-1247-2014.

2. Chaki, S., Samad, M. A., Mallik, M. A. K. and Hassan, S. M. Q. (2022). Assessment of WRF model performance in simulation of heat wave events over Bangladesh. THE ATMOSPHERE, 9:46-53.

3. Höppe, P. R. (1993). Heat balance modeling. Experientia, 49(9), 741–746. doi: 10.1007/bf01923542.

4. Höppe, P. (1999). The physiological equivalent temperature - a universal index for the biometeorological assessment of the thermal environment. International Journal of Biometeorology, 43(2), 71–75. doi:10.1007/s004840050118.

5. Jaman, S., Islam, M. J., Imran, A., Kamruzzaman, M., Mallik, M. A. K., Paul, P., and Syed, I. M. (2022). Sensitivity of Different Physics Schemes in the Simulation of HW Events over Bangladesh Using WRF-ARW Model. Dhaka Univ. J. Sci. 70(1), 70-78, https://doi.org/10.3329/dujs.v70i1.60384.

6. Kaltsatou A, Kenny GP, Flouris AD (2018). The Impact of Heat Waves on Mortality among the Elderly: A Mini Systematic Review. J Geriatr Med Gerontol 4:053. doi.org/10.23937/2469-5858/1510053.

7. Koppe, K., Kovats, S., Jendritzky, G., & Menne, B. (2004). HWs: risks and responses, Health and Environmental Change, Series. No. 2, World Health Organization (WHO), Copenhagen.

8. Matzarakis, A., & Amelung, B. (2008). Physiological Equivalent Temperature as Indicator for Impacts of Climate Change on Thermal Comfort of Humans. Seasonal Forecasts, Climatic Change and Human Health, 161–172. doi: 10.1007/978-1-4020-6877-5_10.

9. Matzarakis, A., Rutz, F., & Mayer, H. (2007). Modeling radiation fluxes in simple and complex environments—application of the RayMan model. International Journal of Biometeorology, 51(4), 323–334. doi: 10.1007/s00484-006-0061-8.

10. Matzarakis, A., Rutz, F., & Mayer, H. (2010). Modeling radiation fluxes in simple and complex environments—application of the RayMan model. Int J Biometeorol 54:131–139, doi 10.1007/s00484-009-0261-0.

11. Powers, J. G., Klemp, J. B., Skamarock, W. C., Davis, C. A., Dudhia, J., Gill, D. O., Duda, M. G. (2017). The Weather Research and Forecasting Model: Overview, System Efforts, and Future Directions. Bulletin of the American Meteorological Society, 98(8), 1717–1737. doi:10.1175/bams-d-15-00308.1.

12. Willmott, C. J., Robeson, S. M., & Matsuura, K. (2011). A refined index of model performance. International Journal of Climatology, 32(13), 2088–2094. doi:10.1002/ joc.2419.