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Impact of Different Radiation Schemes on the Prediction of Extreme Cold Weather Events over Bangladesh

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Abstract A cold wave is a weather phenomenon that is distinguished by marked cooling of the air, or with the invasion of very cold air, over a large area. In the present study, the Weather Research and Forecasting (WRF) model was tested through 30 different combinations of radiation parameterization schemes to simulate the regional climate over the Bangladesh. The objective was to investigate the response to the radiation parameters schemes for dynamic down-scaling of climatic variables. The temperature from the 30 different WRF setups were compared with the BMD observed data and were found sensitive to the radiation physics. The 30 combination of radiation physics along with the fixed WRF Single-moment 3-class microphysics, Kain-Fritiches cumulus physics, Noah Land Surface Physics and YSU planetary boundary-layer physics produced comparable results for 02 to 05 January 2019, 15 to 18 January 2019, 02 to 05 February 2019 and 28 to 31 December 2019. Having analyzed the simulation results using the different radiation physics schemes on the basis of RMSE at 2-meter air temperature at 34 stations over Bangladesh, we conclude that the New Goddard for long wave and Dudhia for short wave schemes combination (2.140764) is the most appropriate to simulate in the winter Extreme temperature. Then the selected combinations of WRF parameterizations were used to downscale the Extreme cold weather events, which showed good agreement with the reference data. The suggested WRF parameters from this study could be utilized for regional climate modeling of Bangladesh.

Keywords: *plantain, physical, local cultivars, biochemical composition, boiling*

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1. Introduction

Bangladesh has a unique geographical location with the Bay of Bengal in the south and the Himalayan range in the north and is the most vulnerable in the world in respect of disasters of hydrometeorological origin. The country acts as the playground of different types of disasters like thunderstorms/tornado, drought, tropical cyclones and associated storm surges, floods, flash floods, cold waves and heat waves, heavy rainfall, erratic rainfall, etc. Of these, cold wave is the common meteorological event, which occurs in the winter season (December-February) over Bangladesh and has worst disastrous impact in the western part of the country as a whole. A cold wave is a prolonged period of abnormally cold weather. While definitions vary across and even within countries, cold waves are generally measured relative to the usual weather in the area and relative to normal temperatures for the season. Bangladesh Meteorological Department (BMD) uses the term ‘cold wave’ when minimum day temperature attains 10°C or less. The operational classifications of cold wave in BMD are as follows: Mild = (8.1-10)°C, Moderate = (6.1-8)°C, Severe = (4.1-6)°C and very Severe ≤ 4°C.

In this century, more frequent cold extremes are observed at mid latitudes [1]. For example, bitterly cold waves occurred in Europe and the USA during the winters of 2010/2011, 2013/2014, and 2014/2015 [2,3]. East Asia has also been repeatedly affected by cold waves in recent decades, with examples including the freezing disaster in southern China in early January 2008, January–February 2012, and the winter of 2015/2016 [4,5,6]. All the above cold events resulted in a huge amount of damage and great economic loss. Therefore, researchers have started to focus on midlatitude cold waves and their possible contributory factors. Given that most midlatitude cold waves originate from the Arctic, we are motivated to explore the linkage between the Arctic changes and the midlatitude cold waves. Temperatures have increased about twice as fast in the Arctic as in midlatitudes, which is known as Arctic amplification. Disparate mechanisms are responsible for the Arctic amplification, including sea ice, snow, cloud, solar cyclic, and the Planck and lapse rate effects [7,8,9]. Some studies have proposed that upward heat flux from an ice-free ocean warms the Arctic [10] and hence the prior-autumn Arctic sea ice exerts cross-seasonal influences on subsequent-winter circulations, which induce stationary Rossby wave train propagation [11], the impact of which on the occurrence of East Asian snowstorms [12,13] leads to cooling of midlatitudes [14,15,16,17]. However, the influence of sea ice is still under discussion [6,9,18,19]. Because there has been an enormous reduction in Barents–Kara Sea ice since 2007, it should have been cold every winter, which has not been the case [19]. Francis [9] has suggested that sea ice is not the Arctic amplification; some other factors, such as water vapor, clouds, and stratosphere, which could change the atmospheric radiation and circulation, must be considered.

The recent perceived prevalence of cold waves, exacerbated by heightened media attention to each event, is at odds with a rather obvious first-order hypothesis: a warming climate should lead to warm extremes getting warmer, and cold extremes getting less cold. This first-order trend has indeed been validated, both with regard to specific cold waves becoming less severe and frequent than they would have been without anthropogenic warming [20,21,22], and as a regional, long-term trend toward milder and less frequent cold waves across the United States over many decades [23,24,25] and similarly over Europe [26]. Cold waves have not been increasing in frequency and severity, rather they have been getting milder, as expected. For example, the cold winter of 2013/14 in the Upper Midwest region of the US was shown to have been 20–100 times less likely to occur in today's climate relative to the 1880s due to long-term warming [27]. Cold waves and cold stress occur almost every year in Bangladesh, the severity of which is more over western and northwestern parts of the country. These events affect severely agricultural crops, reduce crop production significantly, livelihoods and deteriorate human and animal health as well as hampers food security greatly. The wind circulations associated with cold waves at different levels of the troposphere have not yet been studied broadly in Bangladesh.

The objective of this study is to examine the Advanced Research WRF (WRF-ARW) model capability for the prediction by simulating the extreme cold weather event that occurred over Bangladesh during winter season with the WRF model through sensitivity test of radiation physics. The model-derived intensity and development of the cold wave will be analyzed by comparing temperature at 2m height, surface pressure, low level wind flow, and other associated parameters.

2. Experimental Setups

2.1. Model Description and Configuration

This study was conducted using the advanced weather research and forecasting regional climate model, version WRF 4.3.0. WRF is a non-hydrostatic, primitive-equation, mesoscale meteorological model with advanced climate dynamics, physics and numerical schemes. Detailed descriptions of the WRF can be found in the model manual [28] and also on the WRF user web site (http://www.mmm.ucar.edu/wrf/users). The selection of schemes and fine tuning of parameters for various modules of WRF, domain configurations and grid resolutions play a major role in the performance of WRF. The parameterization schemes in WRF are grouped into these modules: (1) microphysics (MP), (2) longwave radiation (LW), (3) shortwave radiation (SW), (4) land surface model, (5) cumulus (Cu), and (6) planetary boundary layer (PBL). Each of these modules has two or more parameterization schemes, with some schemes more applicable for climate modeling while others for weather forecasting, or both, thus making WRF a popular RCM. In fine tuning WRF, we could only test 30 combinations make with 5 long wave and 6 short-wave radiation parameterization schemes, instead of testing all possible combinations. The performance of WRF for modeling the regional weather of Bangladesh is assessed by its ability to reproduce the spatial and temporal patterns of the observed weather of Bangladesh.

Table 1. Summary of radiation parameterization combination schemes that are tested in this study

EXPT. No.	EXPT Name	Longwave	Shortwave	EXPT. No.	EXPT Name	longwave	shortwave
01	Lw1_sw1	RRTM	Dudhia	16	Lw4_sw4	RRTMG	RRTMG
02	Lw1_sw2	RRTM	GSFC	17	Lw4_sw5	RRTMG	Goddard
03	Lw1_sw3	RRTM	CAM	18	Lw4_sw7	RRTMG	Fu-Liou-Gu
04	Lw1_sw4	RRTM	RRTMG	19	Lw5_sw1	Goddard	Dudhia
05	Lw1_sw5	RRTM	Goddard	20	Lw5_sw2	Goddard	GSFC
06	Lw1_sw7	RRTM	Fu-Liou-Gu	21	Lw5_sw3	Goddard	CAM
07	Lw3_sw1	CAM	Dudhia	22	Lw5_sw4	Goddard	RRTMG
08	Lw3_sw2	CAM	GSFC	23	Lw5_sw5	Goddard	Goddard
09	Lw3_sw3	CAM	CAM	24	Lw5_sw7	Goddard	Fu-Liou-Gu
10	Lw3_sw4	CAM	RRTMG	25	Lw7_sw1	Fu-Liou-Gu	Dudhia
11	Lw3_sw5	CAM	Goddard	26	Lw7_sw2	Fu-Liou-Gu	GSFC
12	Lw3_sw7	CAM	Fu-Liou-Gu	27	Lw7_sw3	Fu-Liou-Gu	CAM
13	Lw4_sw1	RRTMG	Dudhia	28	Lw7_sw4	Fu-Liou-Gu	RRTMG
14	Lw4_sw2	RRTMG	GSFC	29	Lw7_sw5	Fu-Liou-Gu	Goddard
15	Lw4_sw3	RRTMG	CAM	30	Lw7_sw7	Fu-Liou-Gu	Fu-Liou-Gu

2.2. Domain Configuration and Data

Domain configurations and grid resolutions play a major role in the performance of WRF. Domain will be taking 10km horizontal resolution with the center at (180 N, 890 E) and grid numbers is (w-e x s-n) 310 x 290, integration time step is 30 seconds. WRF is finally set up with 38 vertical pressure levels and the top level is at 50 hPa. The initial and lateral boundary conditions of WRF are based on the most recent, National Centers for Environmental Prediction (NCEP) final reanalysis (FNL) data for Medium Range Weather Forecasts at 10 x 1 0 resolution and 6-h time steps. Fixing the above physical parameter, model is run.

2.3. Methodology

WRF is computationally expensive and its optimal performance requires a tedious investigation over different combinations of parameterization schemes which vary from region to region. To find out the best combination of radiation physics options of WRF model, at first 6 shortwave and 5 longwave radiation physics schemes is selected among all available radiation schemes. 6 (six) shortwave radiation physics schemes are Dudhia, Goddard Space Flight Center (GSFC), Community Atmosphere model (CAM), Rapid Radiative Transfer model Goddard (RRTMG), New Goddard and Fu-Liou-Gu. Again, 5 longwave radiation physics schemes are Rapid Radiative Transfer Model (RRTM), Community Atmosphere model (CAM), Rapid Radiative Transfer model Goddard (RRTMG), New Goddard and Fu-Liou-Gu. All of these 6 shortwaves and 5 longwave radiation physics schemes have made 30 independent combinations for 30 independent runs using WRF model. Model is run one combination of radiation (both shortwave and longwave) scheme along with fixed of other physics options. Fixed physics option is chosen for PBL, cumulus, land surface model, Surface layer and micro-physics schemes are Younsi State University (YSU), KainFritisch, Noah Unified, Monin–Obukhov similarity theory and WRF single moment 3 class respectively. From the output of WRF Model, 3 hourly 2m temperature have been extracted during the study periods. 34 meteorological stations of BMD are considered to cover the different places of Bangladesh. The WRF model output gives the control (ctl) file and which is converted into text (txt) format data by using the Grid Analysis and Display System (GrADS). These data are transformed into Microsoft Excel and finally compared with the BMD observed temperature at 34 meteorological stations. BMD observed temperature and model simulated temperatures are used for calculating RMSE. The RMSE is mathematically expressed as follows [29]: RMSE= √[1/n Σ n i=1 (xi – yi) 2]; where n is the total number of simulated outputs, x is the model simulated values, y is the observed values. After calculating the RMSE for 2m air temperature at 34 stations over the Bangladesh; for the case, the appropriate radiation combination is fixed out using average lowest RMSE value. For validation of the performance of WRF model, model output is compared with observed data obtained from BMD.

3. Sensitivity Test of Radiation Physics

Analysis of the meteorological fields corresponding to selected radiation combination with both of long wave and short-wave parameterization schemes and its associated impact temperature over Bangladesh has been performed using the Fifth-Generation NCAR Mesoscale WRF Model [28].

The following investigations were done for the selected cases to complete the final goal of this research work:

- Sensitivity test of the different radiation parameterization combination with both of long wave and short-wave schemes of WRF model with coupling of the other fixing physical schemes for the prediction of the temperature due to Cold wave (02-05 January 2019, 15-18 January 2019, 02-05 February 2019 and 28-31 December 2019) and to settle the suitable radiation combination scheme.
- After finalization of radiation parametrization combination schemes of WRF model, other selected parameters which related in temperature are simulated accordingly.
- Afterwards an attempt has been made to validate the simulated temperature with the observed temperature of Bangladesh Meteorological Department.

The radiation schemes provide atmospheric heating due to radiative flux divergence and surface downward long wave and shortwave radiation for the ground heat budget. This downward long wave radiation includes infrared (or thermal) radiation absorbed and emitted by gases and surfaces. Upward long wave radiative flux from the ground is determined by the surface emissivity (depends upon land-use type and the ground (skin) temperature). Shortwave radiation covers the visible and surrounding wavelengths that make up the solar spectrum. Hence, the only source is the Sun, but processes include absorption, reflection, and scattering in the atmosphere and at surfaces. For shortwave radiation, the upward flux is the reflection due to surface albedo. Within the atmosphere, the radiation responds to model-predicted cloud and water vapor distributions, as well as specified carbon dioxide, ozone, and (optionally) trace gas concentrations. All the radiation schemes in WRF currently are column (one-dimensional) schemes, so each column is treated independently. The fluxes correspond to these schemes in infinite horizontally uniform planes, is a good approximation if the vertical thickness of the model layers is much less than the horizontal grid length. This assumption would become less accurate at high horizontal resolution [Skamarock, W.C. et al., 2008].

The sensitivity test of radiation physics of WRF model has been tested, verified and found that the New Goddard long wave and Dudhia short wave scheme has captured the meteorological parameter reasonably well by which the extreme temperature in the Bangladesh can be predicted deterministically. From the Table of RMSE on the basis of 2m air temperature, it is found that radiation physics scheme New Goddard for long wave and Dudhia for short wave of WRF model respectively are finalized for this study.

Table 2. Final selection of radiation physics of WRF model for the prediction of the temperature due to cold wave and heat wave (02-05 January 2019, 15-18 January 2019, 02-05 February 2019 and 28-31 December 2019)

Time	lw1_sw1	lw1_sw2	lw1_sw3	lw1_sw4	lw1_sw5	lw1_sw7
Jan2-5/19	2.160187	2.561455	2.489089	2.430999	2.455829	13.773188
Jan15-18/19	2.178639	2.784889	2.702548	2.63541	2.684085	14.084282
Feb2-5/19	2.126005	2.395583	2.324905	2.28295	2.34739	16.563725
Dec28-31/19	2.335643	3.053864	2.973296	2.885945	3.107309	12.556504
Avg. RMSE	2.200118	2.698947	2.622459	2.558826	2.648653	14.244424
Time	lw3_sw1	lw3_sw2	lw3_sw3	lw3_sw4	lw3_sw5	lw3_sw7
Jan2-5/19	2.324644	2.240535	2.216355	2.198702	2.212819	15.697282
Jan15-18/19	2.074741	2.291151	2.2400005	2.207208	2.231873	16.124433
Feb2-5/19	2.313886	2.214456	2.187184	2.174439	2.192131	18.231027
Dec28-31/19	2.409827	2.545686	2.487052	2.468975	2.557428	14.577083
Avg. RMSE	2.280774	2.322957	2.282647	2.262331	2.298562	16.157456
Time	lw4_sw1	lw4_sw2	lw4_sw3	lw4_sw4	lw4_sw5	lw4_sw7
Jan2-5/19	2.168555	2.560013	2.490944	2.429045	2.469511	13.829642
Jan15-18/19	2.191875	2.813563	2.729241	2.664908	2.701481	14.048011
Feb2-5/19	2.126101	2.421981	2.345419	2.302769	2.246984	16.484734
Dec28-31/19	2.313908	3.046594	2.967234	2.930875	2.752727	12.550685
Avg. RMSE	2.200109	2.710537	2.633209	2.581899	2.542675	14.228268
Time	lw5_sw1	lw5_sw2	lw5_sw3	lw5_sw4	lw5_sw5	lw5_sw7
Jan2-5/19	2.16424	2.331819	2.275821	2.209166	2.260389	14.984038
Jan15-18/19	2.060467	2.523576	2.448205	2.422309	2.438516	15.550231
Feb2-5/19	2.197436	2.24848	2.202597	2.174106	2.17591	17.670787
Dec28-31/19	2.15156	2.690573	2.644407	2.772737	2.540496	13.808499
Avg. RMSE	2.143425	2.448612	2.392757	2.394579	2.353827	15.503388
Time	lw7_sw1	lw7_sw2	lw7_sw3	lw7_sw4	lw7_sw5	lw7_sw7
Jan2-5/19	2.099292	2.363887	2.305264	2.256062	2.285311	2.333906
Jan15-18/19	2.127603	2.705394	2.625289	2.562532	2.606692	2.459485
Feb2-5/19	2.143403	2.351847	2.296754	2.260605	2.387064	2.331219
Dec28-31/19	2.411592	3.119917	3.045992	2.964139	3.179866	2.701205
Avg. RMSE	2.195472	2.635261	2.568324	2.510834	2.614733	2.456453

4. Result and Discussion

Extreme Temperature of 22 to 27 January 2016. An Extreme temperature (Cold Wave) events have been taken for NWP study, which was occurred on 22 to 27 January 2016 over some stations of Bangladesh at 0000 UTC. It was a severe Mild cold wave, with Northwesterly gusty wind. The wind speed at 10-meter height was 56 kmh-1. For this cold wave event, no rainfall is recorded by BMD over Bangladesh on that days, and the recorded mean sea level pressure was 1006 hPa at 0000 UTC.

4.1. Analysis of Mean Sea Level Pressure

Model simulated MSLP of 6 days from 22 January to 27 January 2016 at 0000 UTC based on the initial conditions of 0000 UTC of 22 January 2016 are shown in Figure 1(a-f). On 22 January at 0000 UTC it is found that, a trough of westerly high (1017 – 1018) hPa is simulated over Bihar, West Bengal and adjoining nearest part of Bangladesh, while (1016 − 1017) hPa is simulated over the whole area of the country Bangladesh except Kutubdia and Teknaf (1015-1016) hPa and also a convergence zone of very low (1016 − below1015) hPa is simulated over the Mayanmer and some area of Meghalaya. The trough of high moved to east on 23 January and on 24 a convergence zone of high MSLP (1020−1019) hPa is simulated over West Bengal and adjoining whole western part of Bangladesh. The Bay of Bengal is (1015 - 1018) hPa. At 0000 UTC, simulation result shows that MSLP is continued to decrease gradually from northwest to southeast.

For the validation of model simulated MSLP, a comparison is made with 0000 UTC on 22 to 27 January 2016 observed MSLP recorded by BMD. The comparison is shown in the Figure 2. It has revealed that the model is captured to simulate MSLP very well except Ishurdi station. This station the model simulate MSLP is over estimate for the all 6 days. It has concluded that the WRF-ARW model is capable to capture the MSLP reasonably well.

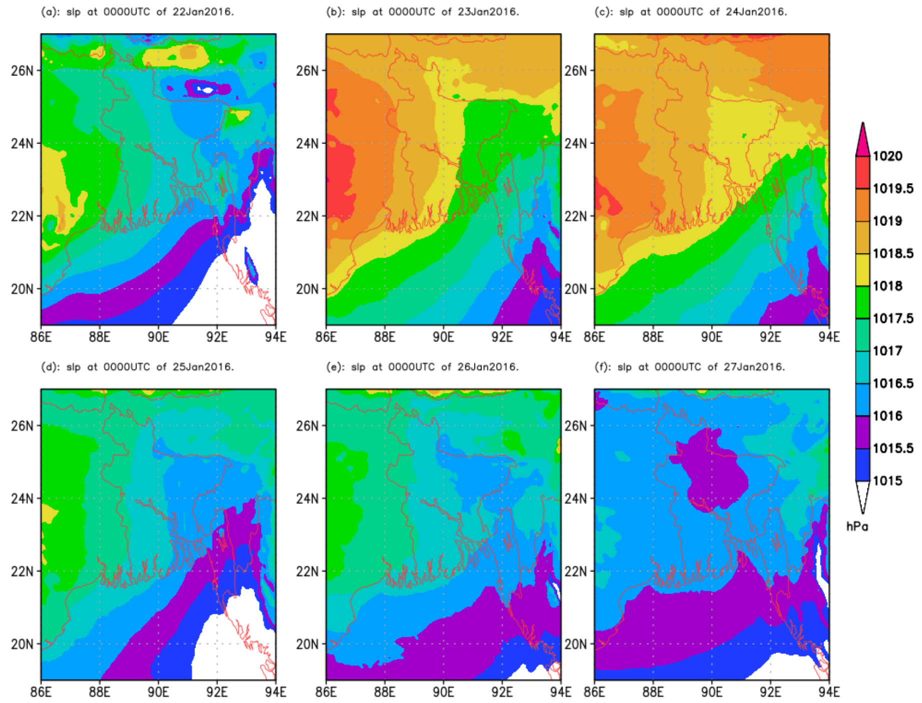

Figure 1. Model simulated Sea Level Pressure at 0000 UTC on 22 to 27 January 2016

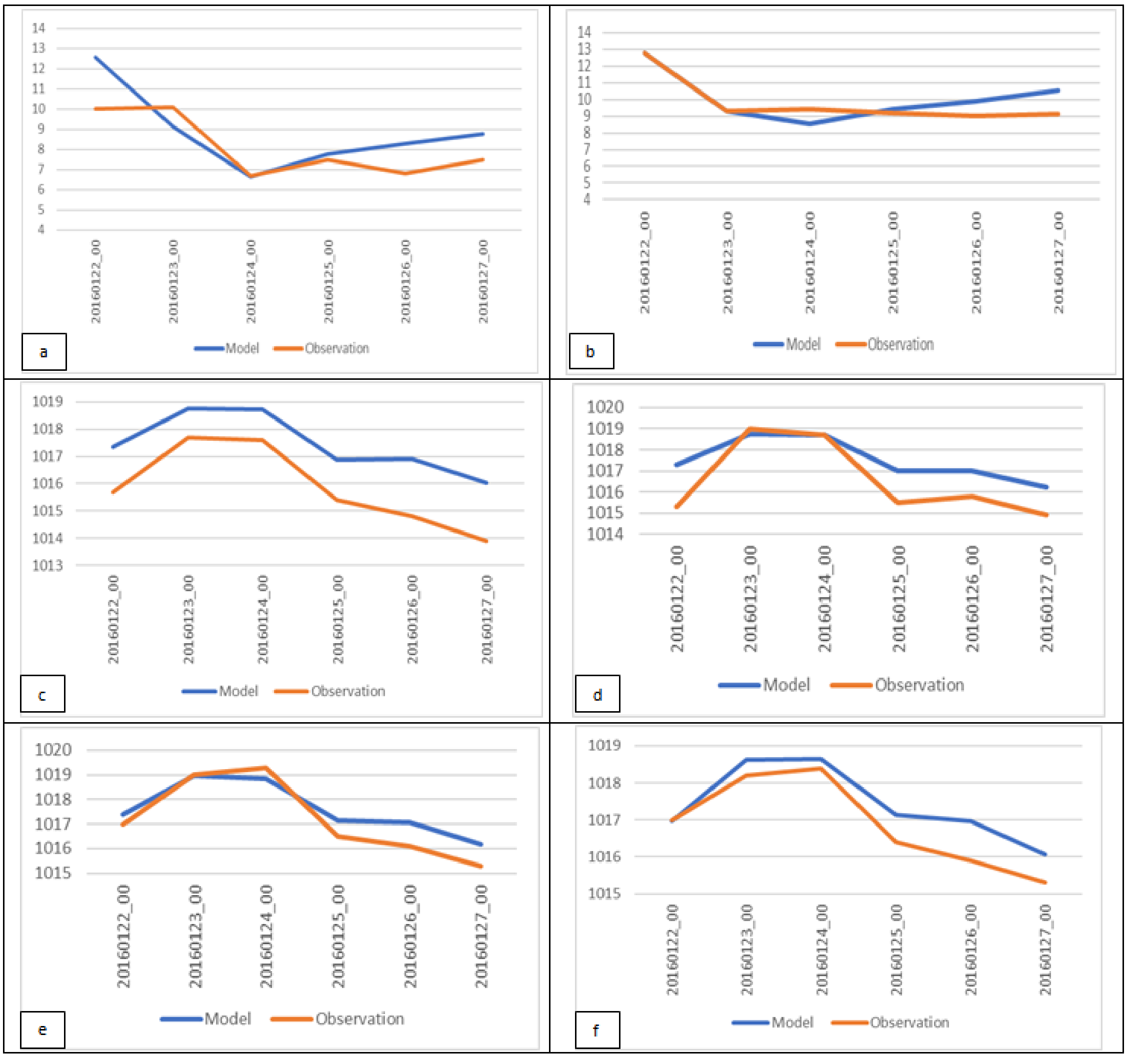

Figure 2. Comparison model simulated MSLP with observation (BMD) data at 0000 UTC on 22 to 27 January 2016 at (a) Chuadanga, (b) Dinajpur, (c) Ishurdi, (d) Jessore, (e) Rajshahi and (f) syedpur

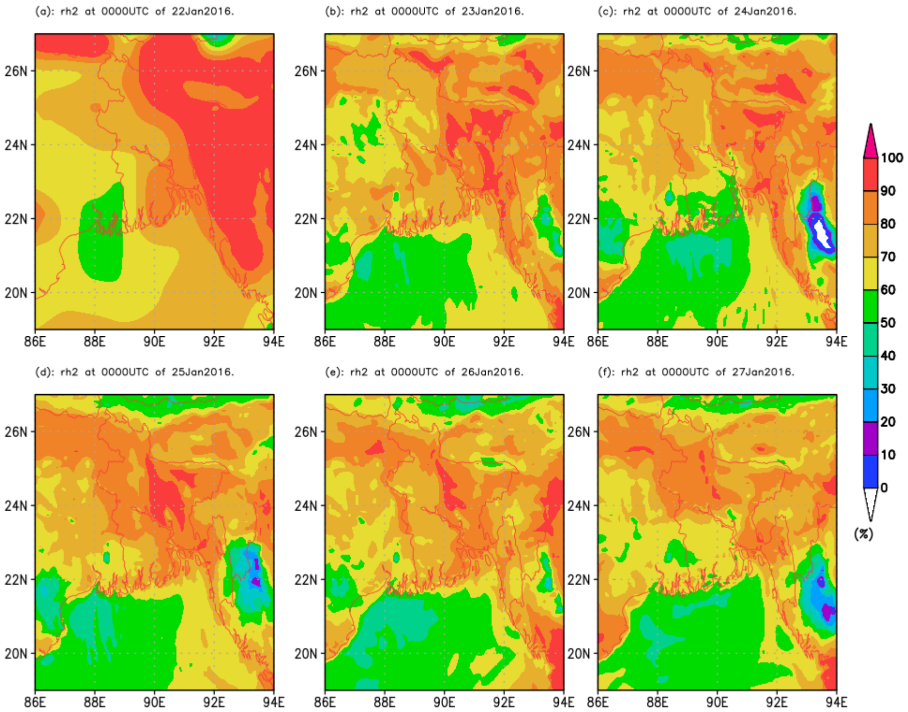

Figure 3. Model simulated relative humidity at 2m height at 0000 UTC on 22 to 27 January 2016

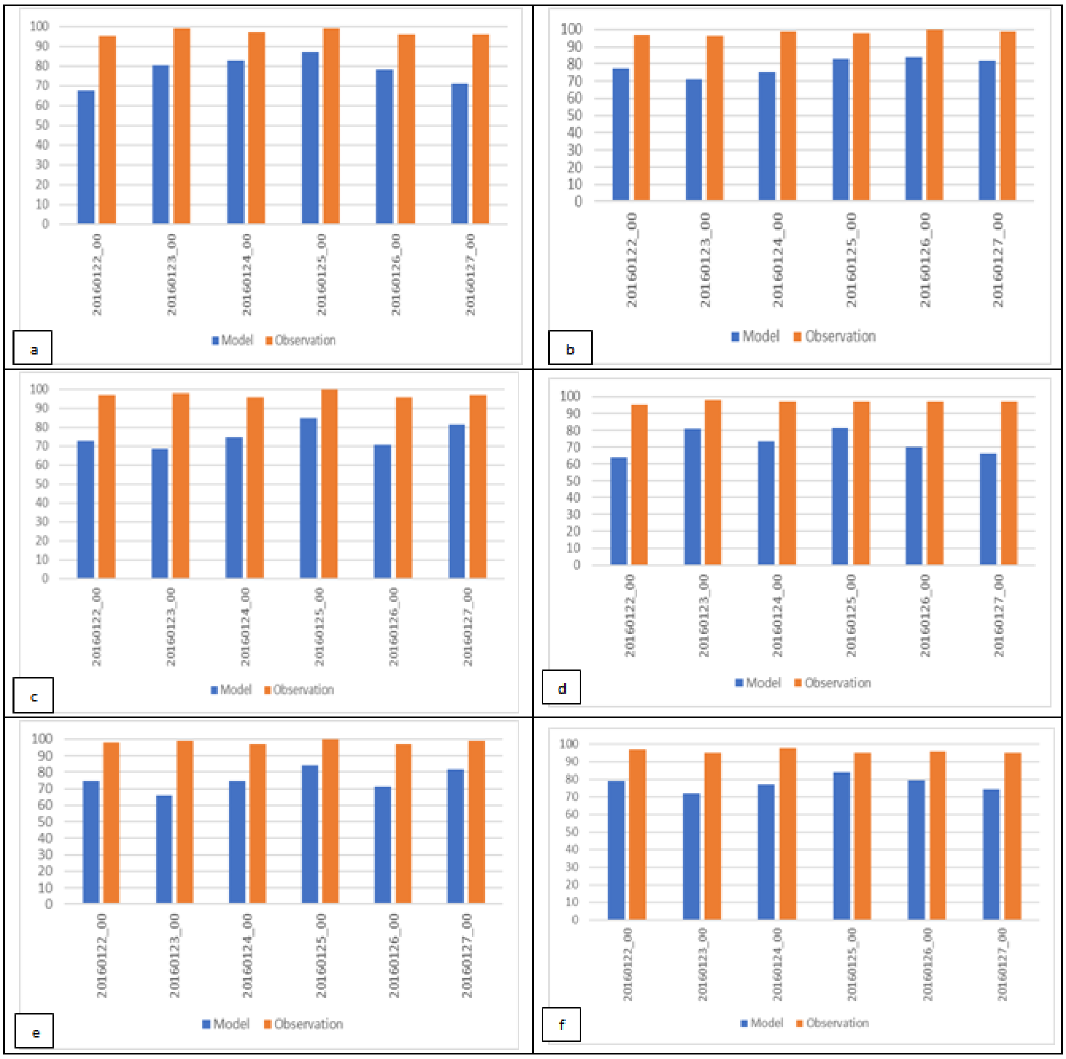

Figure 4. Comparison model simulated relative humidity at 2m height with observation (BMD) data at 0000 UTC on 22 to 27 January 2016 at (a) Chuadanga, (b) Dinajpur, (c) Ishurdi, (d) Jessore, (e) Rajshahi and (f) syedpur

4.2. Analysis of Relative Humidity at 2-meter Height

Relative Humidity (RH) is an important ingredient of CW formation. The RH of 22 January to 27 January 2016 at 0000 UTC of model simulation for 6 days based on the initial conditions 0000 UTC of 22 January are presented in Figure 3 (a-f) respectively. The high amount of RH is an important environmental variable associated with cloud and rain formation. From the analysis of relative humidity, on 22 January, (60 − 70)% RH is found over West Bengal Bihar and adjoining area Chuadanga, Jessore and Satkhira of Bangladesh and (90 − 100)% RH is found over eastern and central part of Bangladesh and Meghalaya, while the RH of western part of Bangladesh and adjoining some part of Bihar is about (70 − 90)%. The RH at the adjoining area of south-eastern part of Bangladesh, i.e. Paletwaya, Mongchu (Myanmer) is very low (0-10) hPa on 24 January and it continues next 3 days, whereas it is about (90 − 100)% in the central area of Bangladesh, on 25 and 26 January. From these Figures, model RH at 0000 UTC from 23 to 27 January is (50 − 70)% in Bay of Bengal.

To verification of model performance; from the Figure 4 it has observed that the model simulated data is always under estimate compare to the BMD observed data.

4.3. Analysis of Rain

The WRF model simulated accumulated rainfall distribution valid for 00-h, 24-h, 48-h, 72-h, 96-h & 120-h based on the initial conditions 0000 UTC of 22 January are presented in Figure 5 (a-f) respectively. No significant rainfall amount is simulated over Bangladesh on 22 to 27 January 2016 during this period. so, it is an important argument for normal temperature continuation.

4.4. Analysis of Temperature at 2-meter Height

Temperature is a vital element of CW. Model-simulated temperature at 2m height from 22 January to 27 January 2016 at 0000 UTC based on 0000 UTC of 22 January are shown in Figure 6(a-f) and comparison these result with observed simulated temperature by BMD are shown in Figure 7(a-f). From the temperature analysis it is observed that on 22 January 2016, the model simulated lowest temperature (09 − 11) °C is Mizoram (India) and connecting region of Chittagong Division, (10 − 11) °C is over the Nawabgonj (Rajshahi) and adjoing area of Murshidabad (Bihar, India), (11 − 12) °C is Bihar, west Bengal and adjoining part of Bangladesh i.e. over the Ishurdi, (12 − 13) °C is also a small part over some adjoining area of Chuadanga and the highest temperature (14 − above) °C is the middle part of Bangladesh and Bay of Bengal at 0000 UTC. On 23 January at the same time i.e. 0000 UTC, the temperature is about (07 − 10) °C in western part of Bangladesh, i.e. Dinajpur, Rajshahi, Ishurdi, Chuadanga, Jessore and also the coastal area of Bay and Chittagong Division. On that day the lowest temperature is Mizoram, Meghalaya and West Bengal (India). In Bangladesh, the lowest temperature (07 − 08) °C is Dinajpur, Rajshahi, Chuadanga and Khagrachori. And 24 January, the temperature is about (05 − 06) °C is simulated by model over Borguna and (04 − below) °C is simulated over Bihar, Meghalaya, Mizoram (India) and Mayanmer. The temperature of the most of the part of Bangladesh is (06 − 10) °C. For the validation of model simulated temperature at 2m height, a comparison is made with 0000 UTC on 22 to 27 January 2016 observed temperature recorded by BMD. The comparison is shown in the Figure 7. It has found that the model is captured to simulate temperature very well.

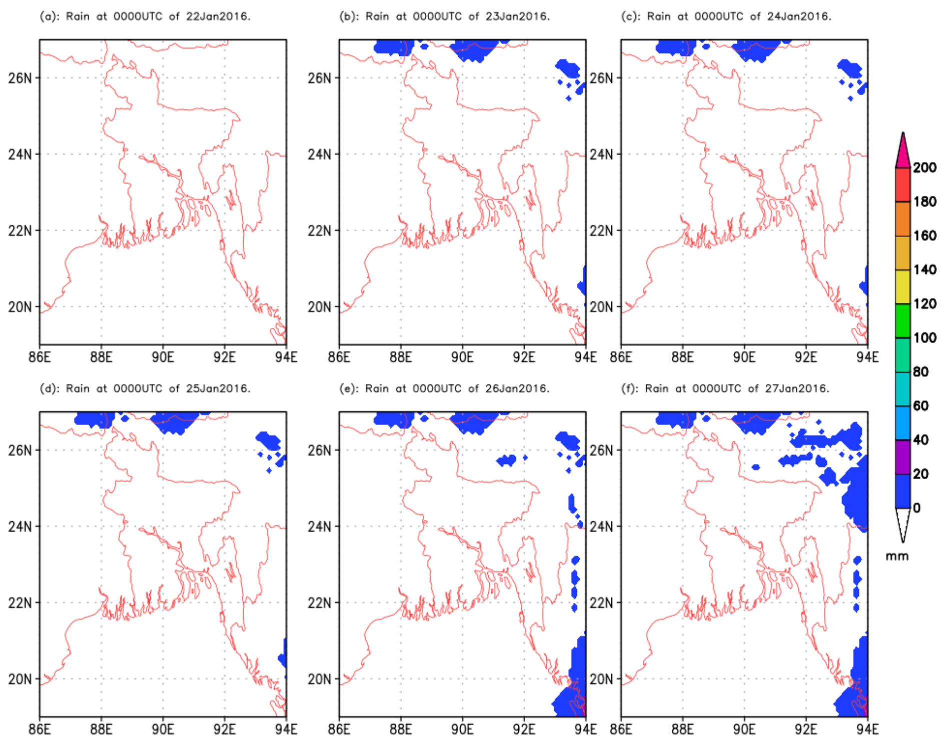

Figure 5. The model simulated 24-h rainfall for 00-h, 24-h, 48-h, 72-h, 96-h & 120-h model run respectively

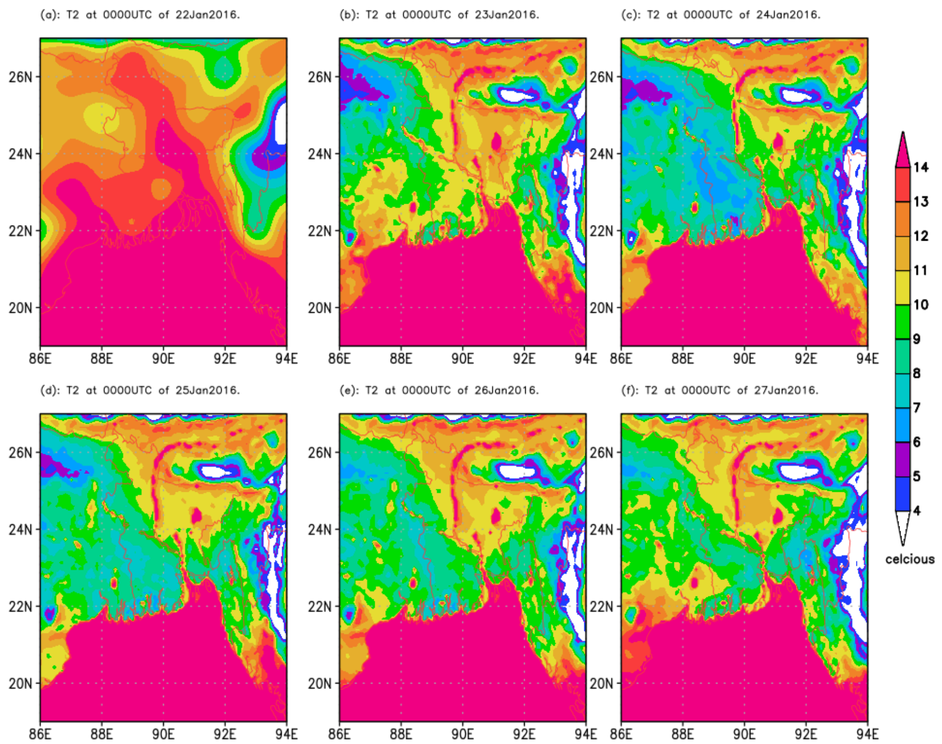

Figure 6. model simulated 2m air temperature at 0000 UTC on 22 to 27 January 2016

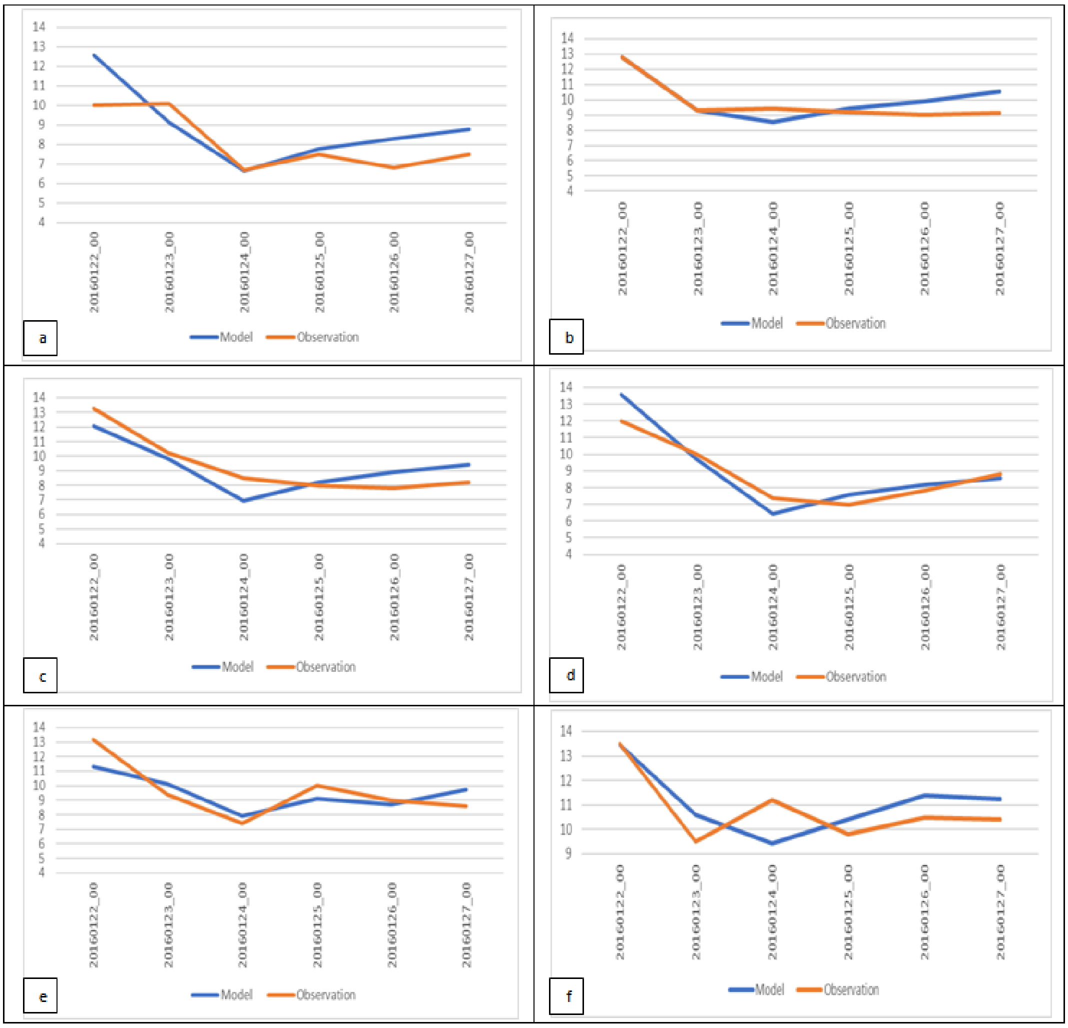

Figure 7. Comparison model simulated 2m air temperature with observation (BMD) data at 0000 UTC on 22 to 27 January 2016 at (a) Chuadanga, (b) Dinajpur, (c) Ishurdi, (d) Jessore, (e) Rajshahi and (f) syedpur

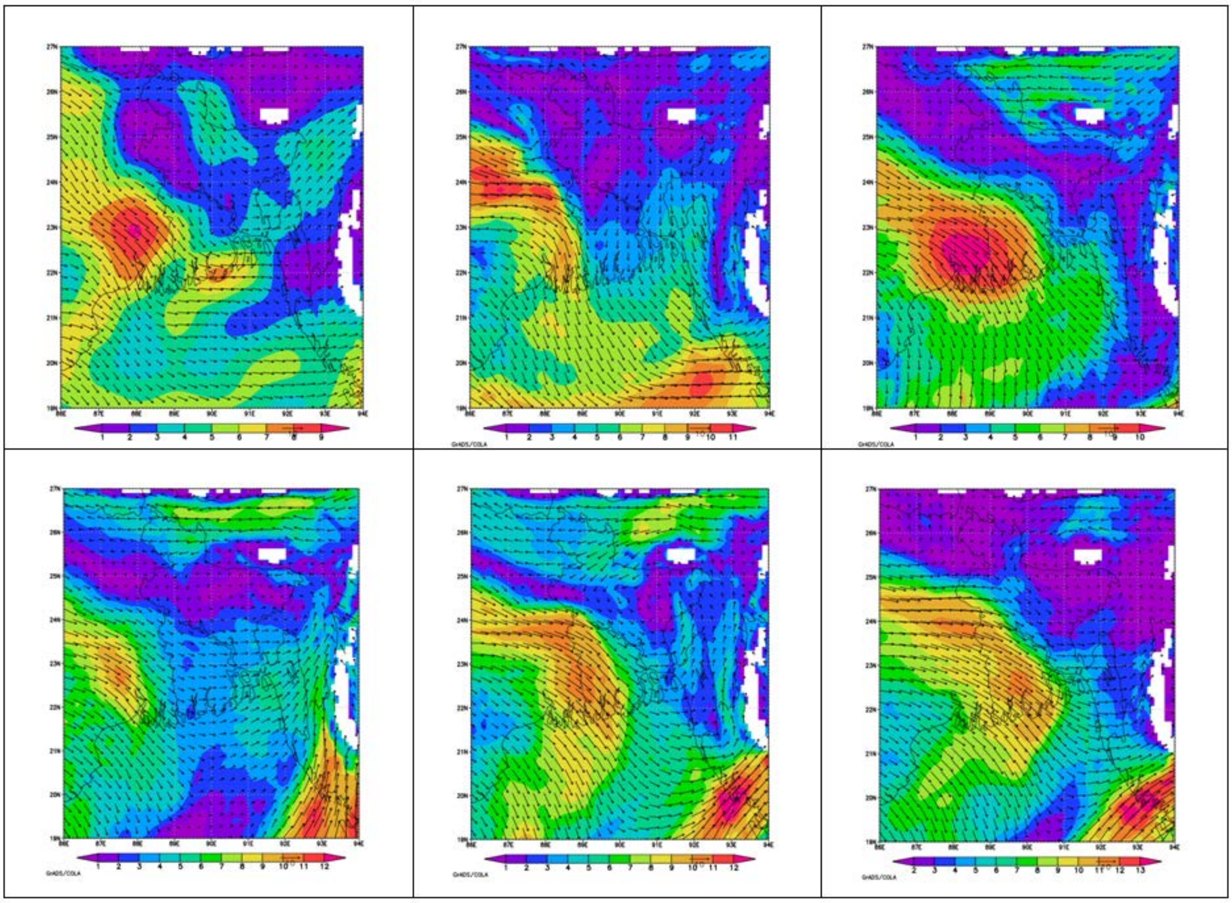

Figure 8. Model simulated wind pattern at 850 level at 0000 UTC on 22 to 27 January 2016

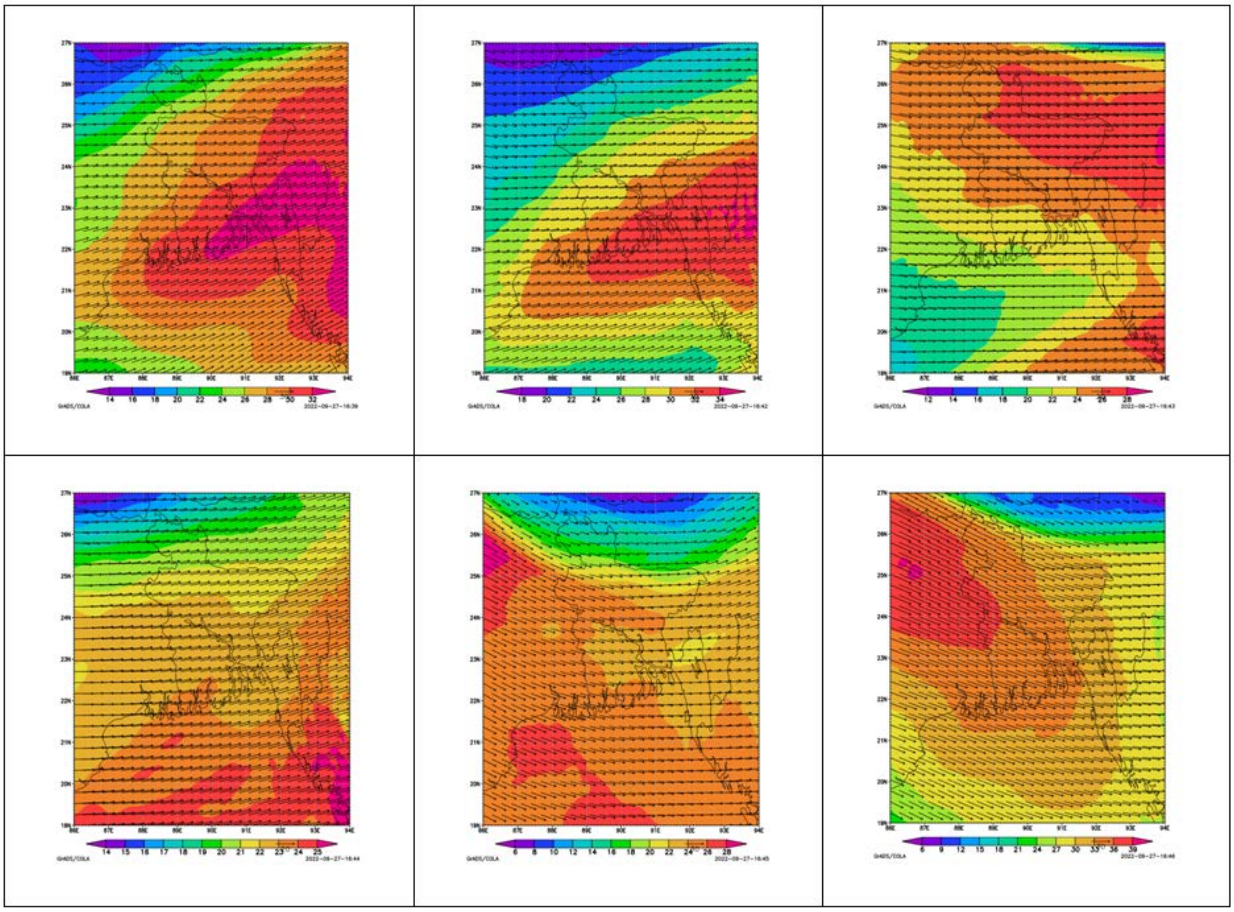

Figure 9. Model simulated wind pattern at 500 level at 0000 UTC on 22 to 27 January 2016.

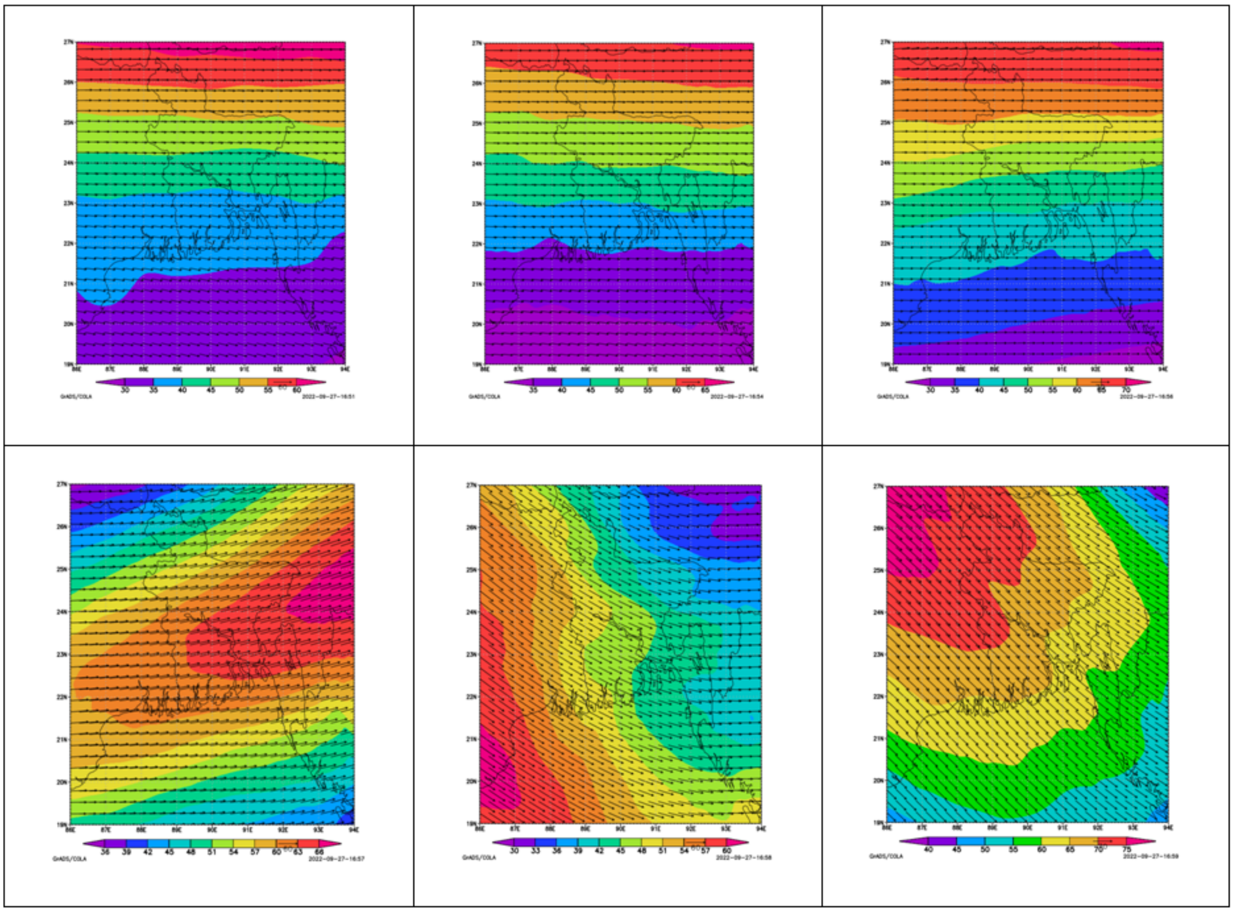

Figure 10. Model simulated wind pattern at 200 level at 0000 UTC on 22 to 27 January 2016.

4.5. Analysis of 850, 500 & 200 hPa Level Wind Flow

The distribution of 850 hPa, 500 hPa and 200 hPa wind flow (ms^{-1}) valid for 0000 UTC from 22 January to 27 January 2016 of model simulation for 6 days based on the initial conditions 0000 UTC of 22 January are shown in Figure 8(a-f), Figure 9(a-f) and Figure 10(a-f) respectively. At 850 hPa level, west/northwesterly wind of speed (6 − 8) ms^{-1} is simulated at Satkhira, Jashore, Mongla, Patuakhali and Borguna. Northwesterly wind of speed (8 − 10) ms^{-1} is simulated over Kolkata West Bengal. A convergence zone is seen over Khulna on 22 January where the wind speed is (3 − 5) ms^{-1}. On 23 January, A backing does occur in Murshidabad (India) and also Paletwaya (Mayanmer), Northwesterly/Northerly wind is found over most of the part of Bangladesh with wind speed (0 − 3) ms^{-1}. A convergence zone is seen over connecting area of Jashore, Sathkhira with wind speed (0 − 4) ms^{-1} and West Bengal (8 −10) ms^{-1}. At 500 hPa level, strong westerly wind of speed (20 - 26) ms^{-1} is simulated over West Bengal and adjoining part of Rangpur division, and over Feni, Barisal, coastal area of Barisal division, neighboring Chittagong and Mizoram (India), the southwesterly wind speed is (32 − Above) ms^{-1} on 22 January 2016; On 23 January, forcible westerly and southwesterly wind of speed (32−34 or Above) ms^{-1} is found over the same area. At 200 hPa pressure level, strong westerly wind of speed (50 − 60) ms^{-1} is simulated over Rangpur Division and Bihar, Asam, Meghalaya, West Bengal (India) while in Chittagong, Barisal Division and nearest part of Khulna the speed is (35−40) ms^{-1}, and during the next 2 days the westerly wind is increasing gradually with (55 − 65) ms^{-1} and (60 − 70) ms^{-1}. The Bay of Bengal is (30 − 40) ms^{-1}.

5. Conclusions

Cold Wave (CW) become significant over Bangladesh as they caused terrible damage on the live-in recent decades. Forecasting such events, especially in the winter region is quite challenging. Therefore, this study has made an attempt to simulate CW using WRF model to predict the future events more effectively. Different radiation physics schemes that is responsible for extreme temperature generation of WRF model have been used in this study. Model outputs are compared with BMD observed data. On the basis of the present study the conclusion can be drawn: The sensitivity test of different radiation parameterization schemes of WRF model show that the New Goddard for long wave and Dudhia for short wave option produces more or less realistic results in quantitative comparisons. Therefore, these schemes have been considered as the best for synoptic analysis and prediction of winter cold wave over the Bangladesh. Finally, it may be concluded that the Fifth-Generation PSU/NCAR mesoscale model WRF version 4.3.0 with the right combination of the single domain, the suitable parameterization schemes are able to simulate and predict the cold wave and its associated high impact 2m air temperature over the Bangladesh reasonably well, though there are some spatial and temporal biases in the simulated temperature.

The study recommended that WRF model may be operationally used for predicting the CW, its associated high impact temperature and its thermodynamic features over Bangladesh up to 72-hours advance. It is also recommended that similar study be extended for more number of cases for further refinement of the model application.

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