Sensitivity of the WRF Model to Parameterization Schemes to Predict Pre-monsoon Temperature over Bangladesh

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Abstract

A set of 12 experiments, using various combinations of physical parameterization schemes in the Weather Research and Forecasting (WRF) model, were carried out to choose a combination suitable for simulating the Bangladeshi Pre-monsoon temperature. Regional climate models (RCMs) have been used to simulate temperature at 2 meters (T2) height at relatively high spatial and temporal resolutions useful for design and management. In this study, the sensitivity of the weather research and forecasting (WRF) model, the regional weather of the Bangladesh was investigated using 12 combinations of different physical parameterization schemes which include 2 Planetary Boundary Layer (PBL), 2Land-Surface Model (LSM) and 3Radiation (RA) package schemes. The simulations are conducted for 72 hours from 0000 UTC of 24 April 2019 to 0000 UTC of 27 April 2019 over Bangladesh. In the simulation National Centre for Environment Prediction (NCEP) Final Reanalysis (FNL) data has been used as initial and lateral boundary conditions, WRF was configured to model the weather of Bangladesh at a resolution of 10 km with 32 vertical levels. The simulations using WRF were compared with BMD data for 2 m air temperature (T2). The results indicate that the simulated Bangladeshi pre-monsoon temperature is sensitive to the physical parameterization schemes in the WRF model and that choosing the correct combination of physical parameterization schemes is essential for simulating the Bangladeshi Pre-monsoon (Mar-May) realistically. Our analysis shows that a model setup with the Kain−Fritsch cumulus scheme, the WRF Single-Moment 3-class microphysics scheme, a radiation package with the Dudhia shortwave and Rapid Radiative Transfer Model longwave schemes, the Yonsei State University (YSU) planetary boundary layer scheme and the Rapid Update cycle (RUC) land surface model is suitable for simulating the temperature realistically. The model setup with a combination of these physical parameterization schemes was found to have smaller root mean square errors (RMSE) in the simulated 2m Air temperature, along with a realistic simulation of intraseasonal variability of temperature. The results of this study will be useful to researchers and forecasters using the WRF model to improve the Bangladeshi Pre-monsoon (March-May) simulations/forecasts over the Bangladesh region.

1. Introduction

Bangladesh with a population of over 150 million is facing a number of challenges including environmental hazards, sociopolitical conflicts, development crisis, and effects of climate change. Climate change and its associated hazards, including variations in temperature and rainfall, increased intensity of flood, drought, cyclone and storm surge, and salinity intrusion are already affecting the communities, ecosystems and infrastructure of the country. The impacts and vulnerabilities of such climate induced hazards are greater in Bangladesh, and may be due to its geophysical location, hydro-logical influence of the monsoons and regional water flow patterns, low-level resilience of the affected people in terms of technical and financial capacity, and lack of proper arrangement and implementation of policy and institutions to address the challenges (Rahman et al., 2007). The monsoon of Bangladesh is a complex large-scale circulation system defined by changes in surface and lower-level wind direction. Its initiation is associated with meridional horizontal temperature gradient between the Bay of Bengal and continent. The Bangladeshi monsoon involves interactions of many multi-scale atmospheric circulation components such as monsoon flow, Bay southerly Waves (BSW), and Mesoscale Convective Systems (MCS). This makes the simulation of regional climate over this area and its surroundings quite challenging. In Bangladesh, the temperature is predicted to increase by 0.7°C in monsoon and 1.3°C increases in winter (World Bank, 2000). The recent report indicates that the temperature is generally increasing in the monsoon (June, July and August) while the average winter (December, January and February) maximum and minimum temperatures show respectively a decreasing and an increasing trend (Rahman and Alam, 2003). Increased temperature especially during pre-monsoon (March-April-May) is a major concern as expressed in different community consultation in the recent past in the coastal zone. Previous studies have shown varying performances with different parameterized physical atmospheric processes in regional climate simulations. For example, Flaounas et al. (2011) examined the sensitivity of WRF to convection and PBL schemes. They found that temperature, vertical distribution of humidity, and rainfall amount simulated by WRF is very sensitive to PBL schemes, while the dynamics and variability of precipitation simulated are sensitive to convective parameterization schemes. Furthermore, the Mellor-Yamada-Janjic (MYJ) PBL was found to produce more realistic humidity, temperature, and West African Monsoon (WAM) onset when combined with Kain-Fritsch (KF). The different combinations, used in Flaounas et al. (2011) however, revealed the role of different regional climate features in the dynamics of West African Monsoon (WAM). Shahid et al. (2012) analyzed the spatial and seasonal patterns in the trends of Diurnal Temperature Range (DTR) in Bangladesh. The result showed that both mean minimum and mean maximum temperatures of Bangladesh have increased significantly at a rate of 0.15°C/decade and 0.11°C/decade, respectively. However, the significance of seasonal trends showed that DTR in Bangladesh has decreased in winter and pre-monsoon, and increased in monsoon. Temperature of Bangladesh has increased significantly in the last fifty years; more increase has been noted in night time minimum temperature compared to daytime maximum temperature. Lijun (2009) has studied the monthly mean temperatures at 562 stations in China using a statistical downscaling technique. The technique used is multiple linear regressions of principal components. Kjellströmet al. (2005) has shown that the seasonal mean temperature errors are generally within ±1°C except during winter in north-western Russia where a larger positive bias is identified. The diurnal and annual temperature range is found to be underestimated in the model. The pattern of temperature increase showed a pronounced land-sea contrast due to the thermal inertia of the oceans that warmed more slowly than land areas. Kumar et al. (2012) suggested that the north-south gradient in 2m temperature is most prominent during winter. The gradient is also seen during autumn but it is smaller and is within 5K. The estimated RMSE in temperature is largest at the surface 3.3–3.9K and is about 1–2K at all other pressure levels. Both mean bias (MB) and RMSE in temperature are estimated to be higher at the surface and lower at upper levels. The WRF model has been employed over the India and Bangladesh regions to study extreme weather events (Alam; (2014); Rajeevan et al.; (2010); Dutta and Prasad; (2010). The study indicates that the WRF model has the ability to simulate the events and produces much better forecasts with assimilated fields. Xiaoduo et al. (2012) studied the dynamic downscaling of near-surface air temperature at the basin scale using WRF in the Heihe River Basin, China. Their daily validation results show that the WRF simulation has good agreement with the observed data. Alam (2013) has conducted 12 experiments by using different microphysics in combination of different cumulus parameterization schemes to study which microphysics and cumulus parameterization schemes are better for the simulation of heavy rainfall event during 7–9 October 2007. Ahasan et al. (2015) has simulated and studied the Tornado event of 22 March 2013 over Brahmanbaria, Bangladesh using WRF model with 3D Var DA techniques.

Cipagauta et al. (2014) studied the sensitivity of the surface temperature to change in total solar irradiance calculated with the WRF model and has found that the mean monthly values of temperature over the full grid did not present significant variations due to the change of either initial conditions or Total Solar Irradiance (TSI). Takeshi Doi et. al. (2017) examined the Sensitivity of Indian summer monsoon simulation to physical parameterization schemes in the WRF model by using 17 various combinations of physical parameterization schemes in the Weather Research and Forecasting (WRF) model, were carried out to choose a combination suitable for simulating the Indian summer monsoon. They decided that after all the model experiments tested, they find the experimental setup, with the KF cumulus, Dudhia shortwave, RRTM longwave, YSU PBL, WSM3 micro physics, MSS surface layer schemes, and the Unified Noah LSM to be suitable for simulating the Indian summer monsoon precipitation realistically. Mamun and Alam (2017) have been used the Weather Research and Forecast (WRF-ARW V3.5.1) model to simulate the pre-monsoon temperature during 2010-2014 at different stations of Bangladesh. Finally, they have taken decision from their research that the WRF-ARW model is suitable for 24 to 72-hours lead time temperature prediction. 24hour lead time predicted temperatures are in good agreement with the observed temperatures.

The goal of this study is to complement previous studies by further quantifying the dependency of summer temperature over Bangladesh simulations on the choice of physics parameterizations focusing on suitable combination schemes. The motivation behind the approach is to identify optimal combinations of various physics schemes for regional weather simulation over the Bangladesh region. This is intended to provide guidance for the model community in making selection of optimal sets of physics parameterization for weather of Bangladesh simulations and applications and will be used as a basis for follow-on studies over regional weather projection. The study focuses and presents the inter-comparison of some selected regional physics from choices of PBL, LSM and RADIATION parameterization schemes. Section 2 gives a detailed description of the WRF model, the data used, and the experimental design. Section 3 presents and discusses the results, and conclusions are drawn in Section 4.

2. Experimental Setup, Data Used and Methodology

2.1 Experimental Setup

This study was conducted using the advanced weather research and forecasting regional climate model, version WRF 4.1.2. 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 of Skamarock et al. (2008) and also on the WRF user web site (http://www.mmm.ucar.edu/wrf/users). Like other (Regional Climate Model) RCMs, WRF tends to over or under simulate the amount of temperature, but it can capture essential features of storm events, such as the time of occurrence, evolution, duration and location of storms (Hong and Lee (2009); Chen et al. (2010)). Possible factors contributed to this common shortcoming of climate models are such as uncertainties of initial conditions, limited knowledge on the rainfall generation process, cloud microphysics, numerical round-off errors, etc. (Fowle and Roebber (2003); Fritsch and Carbone (2004)). However, 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. In the pre-processing stage of WRF, we evaluated two land use databases, sea surface temperature, setting of vertical layers and relaxation zones for lateral boundaries of the study domain. WRF was finally set up with 32 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, NCEP final reanalysis (FNL) data for Medium Range Weather Forecasts at 1^o x 1^o resolution and 6-h time steps. Compared with other reanalysis data, past studies show that the NCEP final reanalysis (FNL) data best represented certain aspects of the climate system, such as the air temperature (Mooney et al. (2011)); Troy and Wood (2009); Screen and Simmonds (2011). 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 a limited combination of all available 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 Physical parameterization schemes tested in this study

Experiment No.	PBL physics	LSM physics	Radiation Physics	
			LW physics	SW physics
EXPT1	YSU	Noah	RRTM	Dudhia
EXPT2	YSU	Noah	CAM	CAM
EXPT3	YSU	Noah	RRTMG	RRTMG
EXPT4	YSU	RUC	RRTM	Dudhia
EXPT5	YSU	RUC	CAM	CAM
EXPT6	YSU	RUC	RRTMG	RRTMG
EXPT7	ACM2	Noah	RRTM	Dudhia
EXPT8	ACM2	Noah	CAM	CAM
EXPT9	ACM2	Noah	RRTMG	RRTMG
EXPT10	ACM2	RUC	RRTM	Dudhia
EXPT11	ACM2	RUC	CAM	CAM
EXPT12	ACM2	RUC	RRTMG	RRTMG

These schemes were selected either because they performed well in previous studies or they have not been tested before. There are 12 experiments: combinations of 2 PBL, 3 Rad schemes and 2 LSM. Since the dynamics and variability of Temperature are sensitive to convection parameterization schemes, the vertical distribution of temperature, humidity, and rainfall amount can be significantly affected by the PBL schemes. In this study, the popular Yonsei University (YSU) scheme (Hong et al. (2006)) and the Asymmetric Convective Model (ACM2) scheme (Pleim, (2007)) with non-local upward mixing and local downward mixing were tested.

The radiation schemes tested were the Rapid Radiative Transfer Model (RRTM) LW scheme (Mlawer et al. (1997)) with Dudhia (1989) SW schemes, Community Atmosphere Model (CAM) (Collins et al. (2004)) and a new version of RRTM (RRTMG) (Iacono et al. (2008)) for both the LW and SW radiation schemes. Lastly, the two land surface models tested were the Noah (Ek and Mahrt (1991)) and the rapid update cycle (RUC) (Smirnova et al. (1997, 2000)). RUC is set up to simulate soil temperature and moisture for six layers, snow and frozen soil physics for multiple layers while the Noah LSM simulates soil temperature and moisture for four layers. 12 combinations of schemes selected to fine tune WRF over Bangladesh are shown in Table 1.

2.1.1 Domain Configuration

Global climate models (GCMs) are numerical climate models designed to simulate physical processes in the atmosphere, ocean, cryosphere and land surface at a global scale (IPCC-TGICA 2007). GCMs are the main tools for projecting future global climate in response to rising concentrations of greenhouse gases in the atmosphere. The RCM (Regional Climate Model) called weather research and forecasting (WRF) which has a wide range of physical parameterizations, has been applied to whole parts of Bangladesh. 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 the best of authors knowledge, only a few RCM studies have been tested over the Bangladesh, and BMD has done a limited test on the performance of WRF over the whole South Asia which was set up as a single domain at 10 km or less resolution. The objective of this study is to fine tune the configuration and parameterization schemes of WRF, so that it can simulate reliable regional weather of Bangladesh for 0000 UTC of 24 April 2019 to 0000 UTC of 27 April 2019 using the NCEP final reanalysis data at 10 km resolution. The brief description of domain is as below:

Table 2: WRF model and domain configurations

Dynamics	Non-hydrostatic
Number of domains	1
Central points of the domain	Central Lat.: 18º N, Central Lon.: 89º E
Horizontal grid distance	10 km
Integration time step	30 s
Number of grid points	310 x 290 [w-e x s-n]
Map projection	Mercator
Horizontal grid distribution	Arakawa C-grid
Nesting	One way
Vertical co-ordinate	Terrain-following 32 sigma levels (up to 50 hPa)
Time integration	3rd order Runge-Kutta
Spatial differencing scheme	6th order centered differencing
Initial conditions	Three-dimensional real-data (FNL: 1ºx1º)
Lateral boundary condition	Specified options for real-data
Top boundary condition	Gravity wave absorbing (diffusion or Rayleigh damping)
Bottom boundary condition	Physical or free-slip
Diffusion and damping	Simple diffusion
Microphysics	WSM3-class scheme
Radiation package scheme	RRTM-Dudhia, CAM, RRTMG
Surface layer	Monin–Obukhov similarity theory scheme
Land surface parameterization	Noah, RUC
Cumulus parameterization scheme	Kain–Fritsch scheme (KF)
PBL parameterization	YSU, ACM2
Time of simulation	0000 UTC of 24 April 2019 to 0000 UTC of 27 April 2019
Output interval	3 hours

2.2 Data Used and Methodology

Using FNL reanalysis data, model was run from 0000 UTC of 23 April to 0000 UTC of 27 April 2019. From the output of WRF Model, 3 hourly 2m temperature, 2m relative humidity, 10m wind, sea level pressure and rainfall have been extracted during the study period of 0000 UTC of 24 April to 0000 UTC of 27 April 2019 considering 24 hours as spin up the model. 10 meteorological stations of BMD are considering to cover the different places of Bangladesh.

The RMSE have been calculated for 10 meteorological stations, because we want to show what the effect to the temperature due to standing different place for the different latitude and longitude. The RMSE for 72-h predicted temperature have been plotted using GrADS software for the year 2019.

Final Reanalysis (FNL) data (1°X 1°) was used as initial and lateral boundary conditions, which was brought from National Centre for Environment Prediction (NCEP). This data is updated at six hours interval. The model is adjusted with 0000, 0600, 1200 and 1800 UTC initial field of conforming date. The observational data of 10 stations has been obtained from Bangladesh Meteorological Department (BMD) all over Bangladesh. The model simulated temperatures have been extracted for 10 BMD temperature gauge stations. We have also extracted daily temperature data for the above mentioned 10 meteorological station points during the summer season of 2019. During the study period we made 3 hourly outputs from WRF model and these 3 hourly temperatures data then converted into daily temperatures data of April 2019. 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 transformed into Microsoft Excel and finally compared with the BMD observed temperature at 10 meteorological stations which were plotted by the software Surfer. BMD observed summer temperature and model simulated temperatures are used for calculating RMSE, and also for Sea level pressure, Relative Humidity at 2 meter and Wind speed at 10meter. The RMSE is mathematically expressed as follows (El-Shafie et al., (2011)).

RMSE= $\sqrt{[1/n \Sigma^{n}{}_{i=1} (x_i - y_i)^2]}$; Where n is the total number of simulated outputs, x is the model simulated values, y is the observed values.

3. Results and Discussions

3.1: Sensitivity of 2m Air Temperature

Table 3: RMSE of 2m Air temperature

Exptno.	Schemes	Dinajpur	Sylhet	Rajshahi	Mymensingh	Dhaka	Comilla	Khulna	Barishal	Chittago	Cox's	RMSE
EXPT1	pbl1_sf2_r11	3.56	1.76	2.21	1.54	1.71	1.48	2.17	1.90	2.68	3.42	2.24
EXPT2	pbl1_sf2_r33	3.31	2.35	1.72	1.88	2.18	2.24	2.84	2.60	3.44	3.19	2.57
EXPT3	pbl1_sf2_r44	4.11	2.15	2.58	2.01	2.18	1.91	2.27	2.30	2.42	3.40	2.53
EXPT4	pbl1_sf3_r11	2.80	1.88	1.25	1.14	1.76	1.42	2.18	1.67	2.78	3.52	2.04
EXPT5	pbl1_sf3_r33	2.55	2.71	1.55	1.59	2.98	2.26	2.92	2.44	3.80	3.78	2.66
EXPT6	pbl1_sf3_r44	2.95	2.21	1.34	1.48	1.58	1.66	2.09	1.83	2.83	3.51	2.15
EXPT7	pbl7_sf2_r11	3.52	1.83	2.13	1.54	1.69	1.65	2.14	2.41	2.74	3.41	2.31
EXPT8	pbl7_sf2_r33	3.40	2.28	1.97	2.00	2.26	2.19	2.96	2.95	3.32	3.17	2.65
EXPT9	pbl7_sf2_r44	4.11	2.23	2.89	2.07	2.32	2.02	2.58	2.71	2.50	3.34	2.68
EXPT10	pbl7_sf3_r11	3.00	1.89	1.27	1.27	1.91	1.53	2.06	2.01	2.77	3.42	2.11
EXPT11	pbl7_sf3_r33	3.17	2.71	1.24	1.92	3.25	2.37	3.04	2.76	3.81	3.30	2.76
EXPT12	pbl7_sf3_r44	3.51	2.29	1.25	1.65	2.02	1.90	2.22	2.32	2.83	3.39	2.34

3.1.1 Sensitivity to radiation schemes

The sensitivity of the Bangladeshi summer temperature to the radiation schemes was tested by comparing the result of EXPT1 to EXPT12 (Table 3).

In Table 3, a group of set by EXPT1, EXPT2, EXPT3 is made; where the YSU PBL and Noah LSM physics is stable and only radiation physics is varied. This group is treated as first group. In radiation physics, there are three different combination of short and long wave radiation those are tabulated in Table 1. It is very clear from the RMSE (Table 3), the combination of RRTM long wave and Dudhia short wave radiation parameterization scheme gives the lowest RMSE for 2m Air temperature by the simulated temperature over 6 out of 10 chosen data stations. 6 stations are Khulna, Barishal, Dhaka, Comilla, Sylhet and Mymensingh. Among rest of 4, CAM both for long and short-wave radiation give the lowest RMSE at Rajshahi, Dinaj pur and Cox's bazar stations. It is noted that the RMSE value with RRTM-Dudhia radiation is very closer to that with CAM radiation physics. Rest of the station Chittagong, RRTMG is given the lowest RMSE value and RRTM-Dudhia radiation parameterization scheme is given second value from the lowest. So, the performance of the combination of RRTM long wave and Dudhia short wave radiation parameterization scheme is better than others considering 10 stations. The second group of set is formed by EXPT4, EXPT5 and EXPT6, where YSU PBL and RUC LSM physics is used as fixed and radiation physics are varied. Results with second group (EXPT4, EXPT5, EXPT6) are similar to those generated by first group EXPT1, EXPT2, EXPT3. The RRTM-Dudhia radiation scheme (EXPT4) also has smaller RMSE compared to the CAM (EXPT5) and RRTMG (EXPT 6) radiation schemes in simulating the 2 m air temperatures over the Bangladesh landmass. EXPT4 (RRTM-Dudhia) has the lowest RMSE ranges from 1 to 2°C at Sylhet, Rajshahi, Mymensingh, Comilla and Barishal but at Chittagong, the value is 2.78. EXPT6 (RRTMG) gives the lowest RMSE at Dhaka, Khulna and Cox's bazar. EXPT5 (CAM) gives the lowest RMSE at Dinajpur.

Similarly, the third group of set is formed by EXPT7, EXPT8 and EXPT9, where ACM2 PBL and Noah LSM physics is fixed and radiation physics are varied. EXPT7 (RRTM-Dudhia) has simulated the lowest RMSE value at Sylhet, Dhaka, Khulna, Mymensingh, comilla and Barishal. EXPT8 (CAM) has simulated the lowest RMSE value at Rajshahi, Dinajpur and Cox's bazar. EXPT9 (RRTMG) has simulated the lowest RMSE value only at Chittagong. Finally, the 4^{th} group of set is formed by EXPT10, EXPT11 and EXPT12; where ACM2 PBL and Noah LSM physics is fixed and radiation physics is varied. Comparing among them, it is seen that, EXPT10 (RRTM-Dudhia) has simulated the lowest RMSE at Sylhet, Dinajpur, Dhaka, Khulna, Chittagong, Mymensingh, Comilla and Barishal. EXPT11 (CAM) has simulated the lowest RMSE value at Rajshahi and Cox's bazar. Here, it is highlighted that at Rajshahi, RMSE is simulated 1.24°C and 1.27°C by CAM and RRTM-Dudhia respectively.

These results indicate that the RRTM longwave and Dudhia shortwave radiation parameterization scheme is superior to the CAM and the RRTMG for both longwave and shortwave scheme in simulating the 2m Air temperature under the present model setup. For RRTM-Dudhia combination, RSME is always the lowest with different value.

3.1.2 Sensitivity to land surface schemes

The land surface schemes model the surface processes and provide the surface sensible heat flux, surface latent heat flux, upward longwave radiation, and reflected upward shortwave radiation to the atmospheric model. Experiments are carried out with 2 land surface schemes, namely the Unified Noah LSM and the Rapid Update Cycle (RUC) land surface model, to test the sensitivity of the model temperature to these schemes. The comparison of the pairs of experiments, EXPT1 and EXPT4, EXPT2 and EXPT5, EXPT3 and EXPT6, EXPT7 and EXPT10, EXPT8 and EXPT11 and EXPT9 and EXPT12 (Table 1), clearly reveal the importance of specifying an appropriate land surface scheme (Table 3).

In Table 3, by analyzing the results of the pairs of experiments EXPT1 and EXPT4, EXPT2 and EXPT5, EXPT3 and EXPT6, EXPT7 and EXPT10, EXPT8 and EXPT11 and EXPT9 and EXPT12, which differ only in the LSM scheme used (Table 1), were compared to test the sensitivity of the model-simulated temperature to the LSM scheme. EXPT1, EXPT2, EXPT3, EXPT7, EXPT8 and EXPT9 use the Unified Noah LSM scheme, whereas EXPT4, EXPT5, EXPT6, EXPT10, EXPT11 and EXPT12 use the Rapid Update Cycle (RUC) scheme. The 2m air temperature simulated by EXPT1, EXPT2, EXPT3, EXPT7, EXPT8 and EXPT9 differs from that simulated by EXPT4, EXPT5, EXPT6, EXPT10, EXPT11 and EXPT12. Comparing EXPT 1(Noah) and EXPT 4 (RUC); where YSU PBL and RRTM-Dudhia radiation package physics is used and Land Surface Model (LSM) physics are varied. It can be seen that the temperature simulated by EXPT4 (RUC) has smaller RMSE compared to the temperature simulated by EXPT1 (Noah) over the Bangladesh landmass. Comparing EXPT2 (Noah) and EXPT5 (RUC); where YSU PBL and CAM radiation package physics is used and Land Surface Model (LSM) physics are varied. It can be seen that the temperature simulated by EXPT2 (Noah) has smaller RMSE compared to the temperature simulated by EXPT5 (RUC) over the Bangladesh landmass. Comparing EXPT3 (Noah) and EXPT6 (RUC); where YSU PBL and RRTMG radiation package physics is used and Land Surface Model (LSM) physics are varied. It can be concluded that the temperature simulated by EXPT6 (RUC) has smaller RMSE compared to that of the temperature simulated by EXPT3 (Noah) over the Bangladesh landmass. Comparing EXPT7n(Noah) and EXPT10(RUC); where ACM2 PBL and RRTM-Dudhia radiation package physics is used and Land Surface Model (LSM) physics are varied. It can be seen that the temperature simulated by EXPT10 (RUC) has smaller RMSE compared to the temperature simulated by EXPT7 (Noah) over the Bangladesh land mass. Comparing EXPT8 (Noah) and EXPT11 (RUC); where ACM2 PBL and CAM radiation package physics is used and Land Surface Model (LSM) physics are varied. It indicated that the temperature simulated by EXPT8 (Noah) has smaller RMSE compared to that of the temperature simulated by EXPT11 (RUC) over the Bangladesh land mass. Finally, comparing EXPT9 (Noah) and EXPT12 (RUC); where ACM2 PBL and RRTMG radiation package physics is used and Land Surface Model (LSM) physics are varied. It can be seen that the temperature simulated by EXPT12 (RUC) has given smaller RMSE value than EXPT9 (Noah) over the Bangladesh land mass.

It is evident that the temperature simulated with the Uniied Noah land surface scheme has larger RMSE compared to that simulated with the RUC LSM scheme. On comparing the RMSE simulated by the pairs of experiments EXPT1 and EXPT4, EXPT3 and EXPT6, EXPT7 and EXPT10 and EXPT9 and EXPT12, it is evident that the models with the Noah LSM scheme (EXPT1, EXPT3, EXPT7 and EXPT9) yielded a more unstable model (except the pair of EXPT2 and EXPT5 and EXPT8 and EXPT11) compared to those with the RUC LSM scheme (EXPT4, EXPT6, EXPT10 and EXPT12). After analyzing and synthesizing, it can be revealed that the Rapid Update Cycle (RUC) land surface model is superior than Noah unified Land surface model and is suitable to simulate Bangladeshi pre-monsoon temperature.

3.1.3 Sensitivity to PBL schemes

As seen in Table 3, analyzing the results of the pairs of experiments EXPT1 and EXPT7, EXPT2 and EXPT8, EXPT3 and EXPT9, EXPT4 and EXPT10, EXPT5 and EXPT11 and EXPT6 and EXPT12, which differ only in the PBL scheme used (Table 1), were compared to test the sensitivity of the model-simulated temperature to the PBL scheme. EXPT1, EXPT2, EXPT3, EXPT4, EXPT5 and EXPT6 used the YSU scheme, whereas EXPT7, EXPT8, EXPT9, EXPT10, EXPT11 and EXPT12 used the ACM2 scheme. The 2m air temperature simulated by EXPT1, EXPT2, EXPT3, EXPT4, EXPT5 and EXPT6 differs from that simulated by EXPT7, EXPT8, EXPT9, EXPT10, EXPT11 and EXPT12.

Comparing EXPT1(YSU) and EXPT7(ACM2); where Noah LSM and RRTM-Dudhia combining radiation, physics is used and planetary Boundary Layer (PBL) physics are varied. It can be seen that the temperature simulated by EXPT1 (YSU) has smaller RMSE of 4 stations compared to the temperature simulated by EXPT7 (ACM2) over the Bangladesh landmass. Whereas EXPT7 (ACM2) has smaller RMSE of 6 stations than EXPT1 (YSU). Comparing EXPT2 (YSU) and EXPT8 (ACM2); where Noah LSM and CAM both long and short-wave radiation physics is used and planetary Boundary Layer (PBL) physics are varied. It can be seen that the temperature simulated by EXPT2 has smaller RMSE of 6 stations compared to that of the temperature simulated by EXPT8 over the Bangladesh landmass. Whereas EXPT8 has smaller RMSE of 4 stations than EXPT2.Comparing EXPT3(YSU) and EXPT9(ACM2); where Noah LSM and RRTMG both long and short-wave radiation physics is used and planetary Boundary Layer (PBL) physics are varied. It can be concluded that the temperature simulated by EXPT3 has smaller RMSE of 9 stations compared to that of the temperature simulated by EXPT9 over the Bangladesh landmass. Whereas EXPT9 has smaller RMSE of only Cox's bazar station than EXPT3. Comparing EXPT4 (YSU) and EXPT10 (ACM2); where RUC LSM and RRTM-Dudhia combination radiation physics is used and planetary Boundary Layer (PBL) physics are varied. It can be seen that the temperature simulated by EXPT4 has smaller RMSE of 7 stations compared to the temperature simulated by EXPT10 over the Bangladesh land mass. Whereas EXPT10 has smaller RMSE of only 3 stations (Khulna, Chittagong and Cox's bazar) than EXPT4. Similarly comparing EXPT5(YSU) and EXPT11(ACM2); where RUC LSM and CAM both long and short-wave radiation physics is used and planetary Boundary Layer (PBL) physics are varied. It can be decided that the temperature simulated by EXPT5 has smaller RMSE of same numbers (Dinajpur, Mymensingh, Dhaka, Comilla, Khulna, Barishal and Chittagong) stations compared to that of the temperature simulated by EXPT11 over the Bangladesh landmass. Whereas EXPT11 has smaller RMSE only 3 stations (Rajshahi, Sylhet and Cox's bazar) than EXPT4. Finally, comparing EXPT6 (YSU) and EXPT12 (ACM2); where RUC LSM and RRTMG with long and short-wave radiation physics is used and planetary Boundary Layer (PBL) physics are varied. Under the consideration of the lowest RMSE, it can be observed that the temperature simulated by EXPT6 has smaller of 7 out of 10 stations (Table 3) compared to those of the temperature simulated by EXPT12; Whereas EXPT12 has smaller of 3 stations than EXPT6 over the Bangladesh.

It is evident that the temperature simulated with the ACM2 PBL scheme has larger RMSE compared to that simulated with the YSU PBL scheme. On comparing the RMSE simulated by the pairs of experiments EXPT1 and EXPT7, EXPT2 and EXPT8, EXPT3 and EXPT9, EXPT4 and EXPT10, EXPT5 and EXPT11 and EXPT6 and EXPT12, it is evident that the models with the ACM2 PBL scheme (EXPT8, EXPT9, EXPT10, EXPT11 and EXPT12) yielded a more unstable model (except the pair of EXPT1 and EXPT7) compared to those with the YSU PBL scheme (EXPT2, EXPT3, EXPT4, EXPT5 and EXPT6). We propose and reveal extremely that the Yonsei University (YSU) PBL scheme is suitable to predict Bangladeshi pre-monsoon temperature.

After analyzing and synthesizing, we propose and reveal extremely that the RRTM for longwave, Dudhia for shortwave radiation parameterization schemes, Rapid Update Cycle (RUC) land surface model and Yonsei University (YSU) PBL scheme is suitable to predict Bangladeshi pre-monsoon temperature at 2m height.

For the brevity, it was described in briefly only the sensitivity at 2m air temperature. Similarly, the sea level pressure and wind speed have indicated the same result which showed in Table 4 and Table 5. Only the relative humidity at 2m height did not match previous parameter's result but it is the nearest to compare the lowest RMSE value which showed in Table 6.

Table 4: RMSE of Sea level pressure

Expt.no.	Schemes	Dinajpur	Sylhet	Rajshahi	Mymman	Dhaka	Comilla	Khulna	Barishal	Chittagon	Cox's	RMSE
EXPT1	pbl1_sf2_r11	0.84	0.75	0.74	0.66	0.80	0.65	0.88	0.70	0.55	0.97	0.75
EXPT2	pbl1_sf2_r33	1.34	0.83	1.21	1.15	0.64	0.87	1.29	0.79	0.96	0.71	0.98
EXPT3	pbl1_sf2_r44	1.69	0.93	1.53	1.35	0.73	0.94	1.39	0.86	0.85	0.73	1.10
EXPT4	pbl1_sf3_r11	0.63	0.62	0.59	0.59	0.91	0.64	0.92	0.80	0.57	1.02	0.73
EXPT5	pbl1_sf3_r33	1.08	0.90	0.91	1.17	0.66	0.91	1.15	0.78	0.93	0.68	0.92
EXPT6	pbl1_sf3_r44	1.21	0.95	0.97	1.27	0.72	0.91	1.14	0.82	0.83	0.73	0.96
EXPT7	pbl7_sf2_r11	0.78	0.82	0.67	0.63	0.98	0.73	0.93	0.75	0.54	1.09	0.79
EXPT8	pbl7_sf2_r33	1.22	0.79	1.13	1.06	0.63	0.82	1.32	0.82	0.95	0.76	0.95
EXPT9	pbl7_sf2_r44	1.49	0.84	1.39	1.16	0.63	0.81	1.33	0.78	0.76	0.78	1.00
EXPT10	pbl7_sf3_r11	0.72	0.72	0.75	0.56	1.06	0.69	1.01	0.88	0.57	1.09	0.81
EXPT11	pbl7_sf3_r33	0.98	0.80	0.81	0.95	0.62	0.84	1.11	0.74	0.94	0.74	0.85
EXPT12	pbl7_sf3_r44	1.05	0.79	0.82	0.96	0.66	0.76	1.06	1.00	0.78	0.78	0.87

Table 5: RMSE of Wind speed at 10m

Expt.no.	Schemes	Dinajpur	Sylhet	Rajshahi	Mymman	Dhaka	Comilla	Khulna	Barishal	Chittagon	Cox's	RMSE
EXPT1	pbl1_sf2_r11	1.78	2.25	1.92	1.94	2.12	1.95	2.29	2.65	3.76	4.29	2.50
EXPT2	pbl1_sf2_r33	2.03	2.38	1.86	2.12	2.04	2.09	2.31	2.46	3.85	3.86	2.50
EXPT3	pbl1_sf2_r44	1.96	2.30	2.11	2.01	2.29	2.44	2.72	2.83	3.71	4.03	2.64
EXPT4	pbl1_sf3_r11	1.19	2.25	1.57	1.43	1.78	1.98	1.94	2.22	3.65	4.16	2.22
EXPT5	pbl1_sf3_r33	1.44	2.30	1.71	1.66	1.90	2.22	1.99	2.27	3.79	3.67	2.30
EXPT6	pbl1_sf3_r44	1.31	2.28	1.63	1.59	1.72	2.25	2.26	2.51	3.68	3.94	2.32
EXPT7	pbl7_sf2_r11	1.92	2.34	1.93	1.90	1.99	1.95	2.35	2.50	3.74	4.33	2.50
EXPT8	pbl7_sf2_r33	1.90	2.43	1.90	2.09	2.16	2.07	2.32	2.64	3.89	4.06	2.55
EXPT9	pbl7_sf2_r44	1.91	2.40	2.35	2.04	2.28	2.24	2.58	2.88	3.70	4.06	2.65
EXPT10	pbl7_sf3_r11	1.34	2.37	1.57	1.36	1.88	1.96	1.85	2.12	3.54	4.58	2.26
EXPT11	pbl7_sf3_r33	1.44	2.53	1.64	1.63	2.03	2.13	2.03	2.27	3.78	3.79	2.33
EXPT12	pbl7_sf3_r44	1.37	2.41	1.65	1.51	1.88	2.16	2.12	2.46	3.51	4.03	2.31

Table 6: RMSE of Relative Humidity at 2m

Expt.no.	Schemes	Dinajpur	Sylhet	Rajshahi	Mymman	Dhaka	Comilla	Khulna	Barishal	Chittagon	Cox's	RMSE
EXPT1	pbl1_sf2_r11	27.6	10.6	29.8	31.3	23.2	23.5	19.9	22.7	15.1	11.9	21.6
EXPT2	pbl1_sf2_r33	29.3	10.3	25.2	28.3	20.9	21.4	20.2	23.0	19.0	13.1	21.1
EXPT3	pbl1_sf2_r44	34.2	9.4	28.2	32.0	22.7	23.6	21.4	23.4	15.5	13.0	22.3
EXPT4	pbl1_sf3_r11	23.7	4.9	13.8	21.0	12.5	20.2	11.9	18.4	16.0	11.4	15.4
EXPT5	pbl1_sf3_r33	18.5	4.4	10.9	16.5	12.3	18.5	13.3	17.4	18.6	14.1	14.4
EXPT6	pbl1_sf3_r44	21.2	6.0	12.4	18.5	2.21	19.7	13.5	18.3	16.6	12.7	14.1
EXPT7	pbl7_sf2_r11	37.6	10.6	32.4	35.2	26.1	27.3	23.2	27.1	17.1	10.5	24.7
EXPT8	pbl7_sf2_r33	33.9	10.9	29.8	34.1	26.5	26.1	26.0	28.1	20.8	12.3	24.8
EXPT9	pbl7_sf2_r44	38.5	11.4	32.7	35.8	25.7	26.5	24.8	26.1	16.9	11.6	25.0
EXPT10	pbl7_sf3_r11	28.1	7.0	17.9	24.3	16.2	23.6	18.6	24.8	17.7	9.7	18.8
EXPT11	pbl7_sf3_r33	25.0	5.3	15.5	20.5	15.3	22.9	17.9	24.4	19.8	10.8	17.7
EXPT12	pbl7_sf3_r44	27.6	6.8	15.2	23.2	17.1	23.9	18.9	24.3	18.0	10.3	18.5

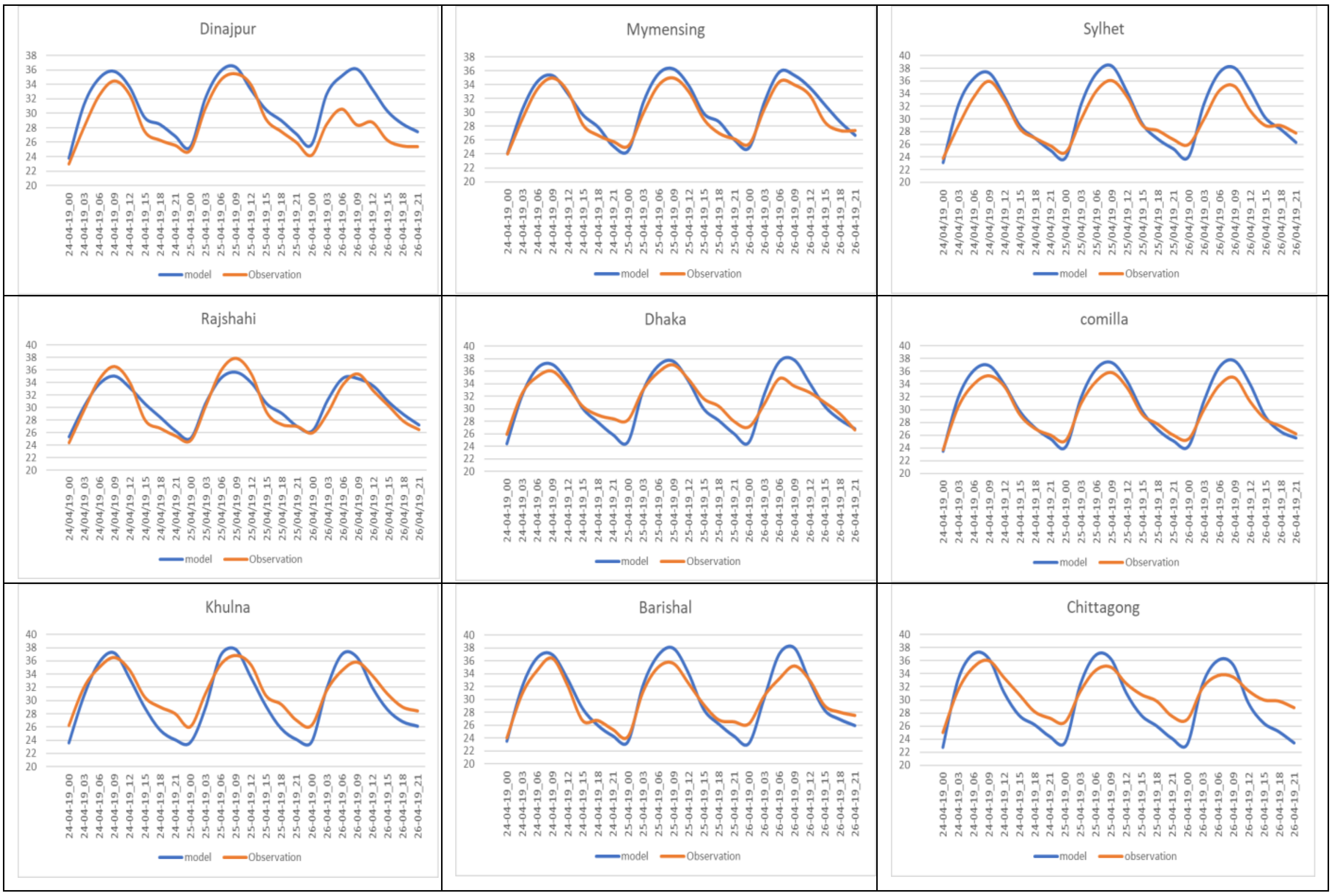

Figure 3: Comparison of model simulated 2m air Temperature (◦ C) with the observation (BMD) data.

4. Diurnal Changes of 2m Air Temperature

Figure 3 shows the diurnal change of observed and simulated temperature for 24 to 26 April 2019 using EXPT4. Simulation maximum temperature of Barishal, Comilla and Sylhet stations are matched with that of observed at 0900 UTC for three days.

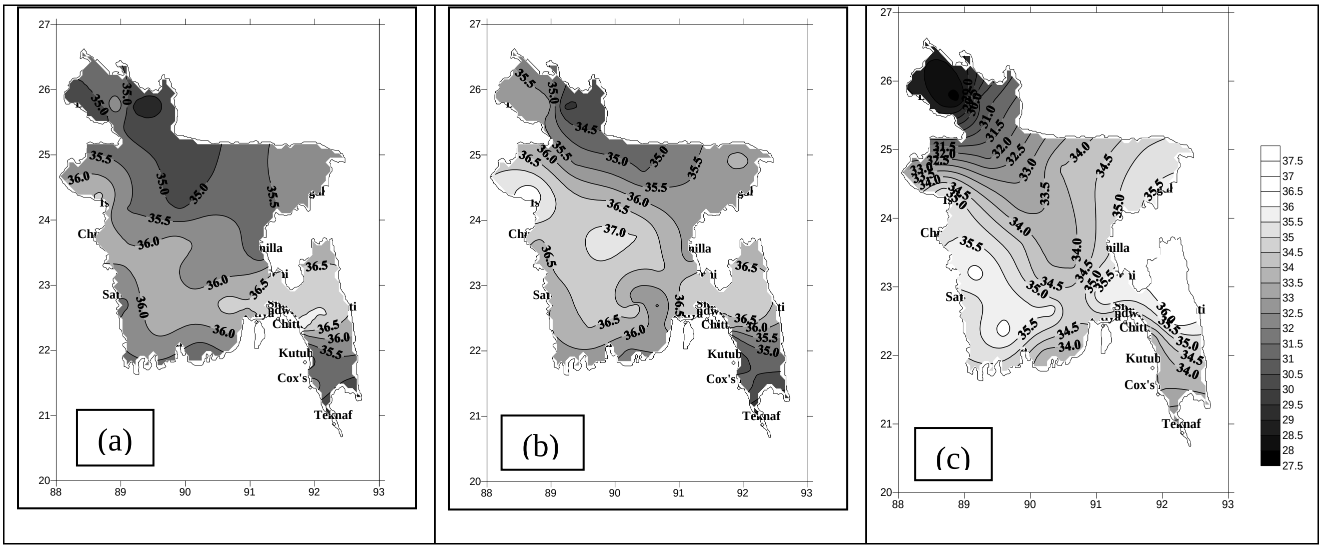

Figure 4 (a-c): Observation 2m Air Temperature at 0900 UTC on (a)24, (b)25 and (c)26 April 2019

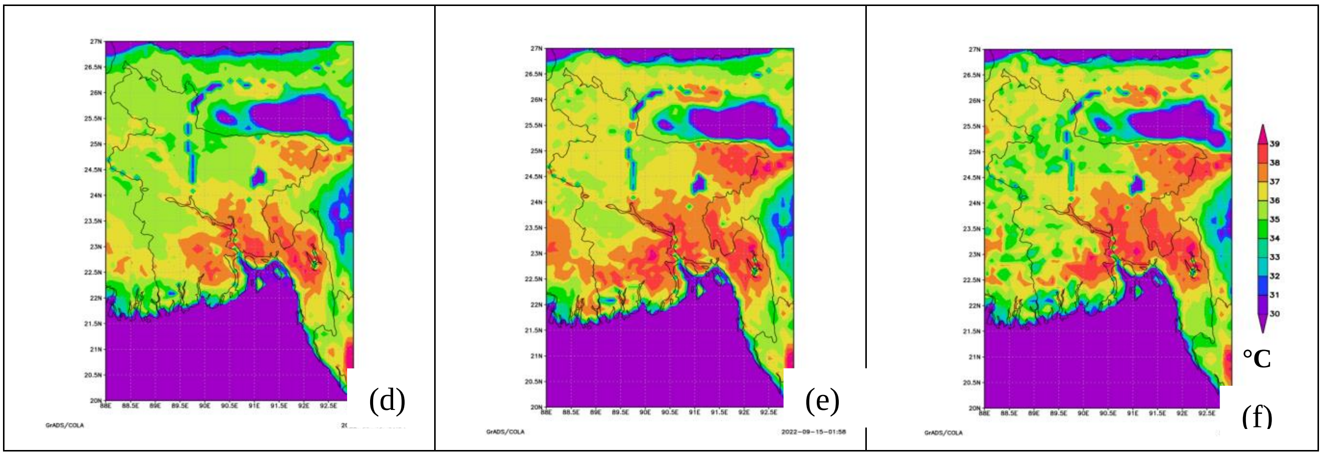

Figure 4 (d-f): Simulation scenario 2m Air Temperature at 0900 UTC on (d)24, (e)25 and (f)26 April 2019

For the station of Mymensingh, the simulation maximum temperature was matched with that of observed in 24 and 25 April 2019 at 0900 UTC but in 26 April and it was matched at 0600 UTC. For the stations of Dhaka and Dinajpur, the simulated maximum temperature was matched with that of observed in 24 and 25 April at 0900 UTC but in 26 April, the simulation maximum temperature obtained at 0900 UTC and the observed was 0600 UTC. For the stations of Khulna and Rajshahi, the simulation maximum temperature was matched with that of observed in first two days, (24 and 25 April) at 0900 UTC but in third day (26 April), the simulation maximum temperature obtained at 0600 UTC and observed was at 0900 UTC. For the stations of Chittagong, the simulation maximum temperature was matched with that of observed at 0600 UTC in 26 April. In 24 and 25 April, the simulation maximum temperature obtained at 0600 UTC, whereas the observed temperature was at 0900 UTC on those days. Observation maximum temperature of Cox's Bazar station obtained at 0600 UTC for all of three days, but simulation maximum temperature obtained at 1200 UTC in 24 and 25 April; in 26 April, it was at 1800 UTC. Model could not reproduce the real scenario of this station. So, simulated maximum temperature obtained mostly 0900 UTC for three days and sometimes it obtained between 0600 to 0900 UTC for all station except Cox's Bazar station where it obtained at 1200 and 1800 UTC. Most of the stations and days simulated maximum temperature matched with that of observed. On the other hand, Diurnal change of simulation minimum temperature is matched with that of observed at 0000 UTC for all stations for three days.

It may be concluded that simulation minimum temperature is matched with that of observed without any except for all station and for three days but simulated maximum temperature mostly matched with that of observed for three days for all station except Cox's Bazar station.

5. Spatial change of 2m Air Temperature

Figure 4(a-c) and 4(d-f) show the observed and simulated temperature at 0900 UTC on 24 to 26 April 2019 respectively. Figure 4(d-f) shows the simulated temperature at 0900 UTC for 24 to 26 April 2019. From the Figure 4(a), observed maximum temperature was 37°C and obtained at Noakhali, Feni, Chittagong, Dighinala (Khagrachori) and Rangamati and minimum was 34°C at Rangpur on 24 April 2019.

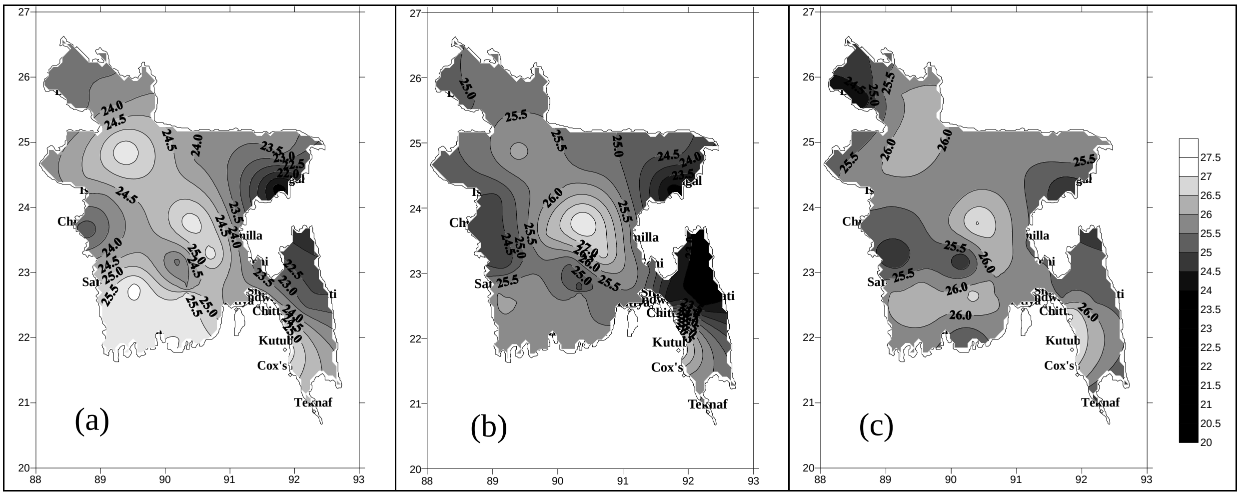

Figure 5(a-c): Observation of 2m Air Temperature at 0000 UTC on (a)24, (b)25 and (c)26 April 2019

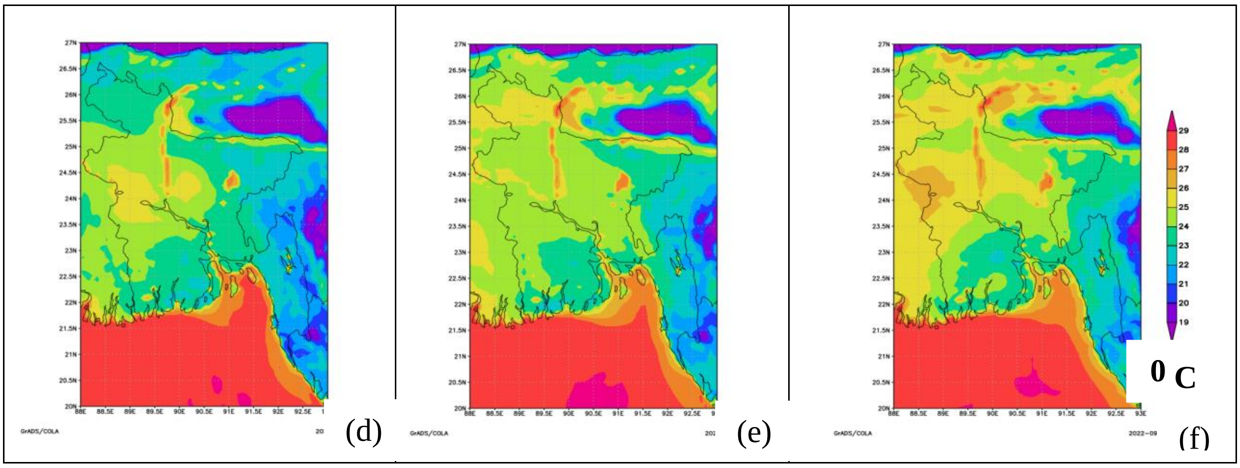

Figure 5(d-f): Simulation scenario of 2m Air Temperature at 0000 UTC on (d)24, (e)25 and (f)26 April 2019

Whereas from Figure 4(d), simulated maximum temperature was 39°C and obtained at Sitakunda and minimum was 30°C at Nikli (Kishorgonj) and Kurigram. From the figure 4(b) observed maximum temperature was 37.5°C and obtained at Rajshahi, Manikgonj and Rajbari and minimum was 33.5°C at Lalmonirhat on 25 April 2019. Whereas from Figure 4(e), simulated maximum temperature was 39°C and obtained at Madaripur and Dighinala. the minimum was 30°C and obtained at Nikli (Kishorgonj). From the figure 4(c) observed maximum temperature was 36°C and obtained at Rangamati, Dighinala, Jessore and Bagerhat and minimum was 27.5°C obtained at Tetulia, Panchagor, Thakurgaon, Dimla, Dinajpur and Nilphamary on 26 April 2019. Whereas from Figure 4(f) right, simulated maximum temperature was 39°C and obtained at Dighinala, Laksam, Shariyotpur, Madaripur and Barishal. the minimum was 30°C and obtained at Nikli (Kishorgonj).

Figure 5(a) and 5(b) show the observed and simulated temperature at 0000 UTC on 24 to 26 April 2019 respectively. Figure 5(b) shows the simulated temperature at 0000 UTC for 24 to 26 April 2019. From the Figure 4(a), observed maximum temperature was 26.5°C and obtained at Khulna and minimum was 21°C at Srimangol on 24 April 2019. Whereas from Figure 4(b1), simulated maximum temperature was 29°C and obtained at Jadur Char (Kurigram) and minimum was 21°C at Sajek, Ukhia, Nikhaingchori and Rakhiang. From the figure 5(a) second from left, observed maximum temperature was 28°C and obtained at Kutubdia and minimum was 23°C at Srimangol and Rangamati on 25 April 2019. Whereas from Figure 5(b2), simulated maximum temperature was 29°C and obtained at Jadur Char (Kurigram) the minimum was 21°C and obtained at Remarkly (Bandarban) and Alikadom (Bandarban) and second lowest temperature was 21.5°C and obtained at Dighinala and Teknuf. From the figure 5(a) right, observed maximum temperature was 27.5°C and obtained at Dhaka and Chittagong Ambagan and minimum was 24°C obtained at Teknuf on 26 April 2019. Whereas from Figure 5(b3), simulated maximum temperature was 29°C and obtained at Jadur Char (Kurigram); the minimum was 21°C and obtained at Remarkly (Bandarban).

6. Conclusion

We carried out a set of 12 experiments using various combinations of physical parameterization schemes in the WRF model to simulate the Bangladeshi summer 2 m air temperature. The experiments were designed to select a suitable combination of physical parameterization schemes for simulating the spatial and temporal distribution of the precipitation and 2 m air temperature realistically. The experiments were formulated to test 3 shortwave radiation schemes, 3 longwave radiation schemes, 2 planetary boundary layer schemes and 2 land-surface models (Tables 1) of 10 stations with the different longitude and latitude (table 3).

The analysis of the results indicates that the WRF model-simulated 2m air temperature is sensitive to the physical parameterization schemes used in the model and that choosing the correct combination is essential for simulating the summer 2m air temperature over the Bangladesh landmass.

The results of experiments with different PBL schemes indicate that the YSU PBL scheme performs better in simulating the Bangladeshi summer 2 m air temperature compared to the ACM2 PBL scheme. The ACM2 PBL scheme simulated a more unstable atmosphere resulting in an enhancement in the large RMSE over the Bangladesh landmass. The model experiments indicate that the radiation package with the Dudhia shortwave radiation and RRTM longwave radiation schemes simulate temperature over the Bangladesh landmass with smaller RMSE compared to the CAM and RRTMG radiation packages. The simulated temperature was also found to be sensitive to the Land surface model scheme as well as the land surface model. The RUC land surface layer scheme were found to be suitable for simulating the Bangladeshi summer 2 m air temperature. However, the simulated variability was dependent on the physical parameterization schemes used in the model. Of all the model experiments tested, we find the experimental setup of EXPT4, with the Dudhia shortwave, RRTM longwave, YSU PBL and the Rapid Update Cycle (RUC) LSM to be suitable for simulating the Bangladeshi summer 2 m air temperature realistically. Our approach of using a regional model can improve the simulation of intraseasonal variability of Bangladeshi summer temperature. We are now planning such a regional model with the combination of EXPT4 physical parameterization schemes to generate down scaled forecasts over Bangladesh in the future, with Cordex Global Climate Model (CGCM) forecasts as the boundary conditions.

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