Sensitivity of Different Physics Schemes in the WRF Model During Winter Temperature over Bangladesh

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Abstract:
In this paper, results of the experiments those have been conducted by using Microphysics (MP) physics in combination with radiation (Rad) physics is presented. The simulations are conducted for 72 hours from 0000 UTC of 02 January 2019 to 0000 UTC of 05 January 2019 over Bangladesh. In the simulation NCEP Final Reanalysis (FNL) data has been used. In this paper, 4 long-wave radiation (RRTM, CAM, RRTMG and Goddard) physics, 4 short-wave radiation (Dudhia, CAM, RRTMG and Goddard) physics and a variety of microphysics schemes (Kessler, Purdue Lin, WSM3, WSM6 and WDM6) are used to produce simulations for the Bangladesh area. The influence of different radiation schemes on the predicted 2m air temperature was simulated using the mesoscale WRF model (v4.3.0), and the simulation results from different combinations of schemes were analyzed based on comparison with the measured BMD data. After fixing the appropriate combination, it has studied three cases and simulated results of WRF and ECMWF data were analyzed based on comparison with the measured BMD data. Result shows that the effect of the different radiation schemes on predicted power was obvious. Having analyzed the simulation results of the different radiation physics and microphysics schemes, it is concluded that the RRTM-Dudhia schemes combination with WDM6 (WRF Double-Moment 6-class scheme) are the most appropriate diurnally in the winter and our experiment also demonstrated that the regional Climate model (WRF) is better for the northern part of Bangladesh to predict temperature than the Global Climate model (ECMWF) during the winter.

1. Introduction

Bangladesh is one of the largest deltaic countries in the world. It is a flat low-lying plain land made up of alluvial soil having small hilly areas in the northeast and southeast regions. The great Himalayan Range is to the north and the vast Bay of Bengal is on the south. It is located between 20.57^{0}N to 26.63^{0}N and 88.02^{0}E to 92.68^{0}E. It is bounded on the west, north and east by India. In the southeast there is a common border with Myanmar. There are 230 rivers in Bangladesh out of which 57 originate from outside the country and most of the river's flow to the Bay of Bengal from north to south through Bangladesh. The main rivers are the Ganges (Padma), the Brahmaputra, and the Meghna. The coastline of Bangladesh is about 720 km long along the continental shelf which has a shallow bathymetry. The entire area of Bangladesh is about 1, 44,735 sq. km. The population of Bangladesh is about 160 million but about 80% of them live in the rural areas.
Bangladesh is located in the subropical monsoon climate regime. Based on the analysis of pressure, rainfall and temperature, the climate of this country can be described under the following four seasons: 1. Winter or Northeast Monsoon (December – February), 2. Summer or Pre-Monsoon (March – May), 3. Southwest Monsoon (June – September) and 4. Autumn or Post-Monsoon (October – November).

Winter or Northeast Monsoon (December – February)

This season is characterized by very light northerly winds, mild temperature. Dry weather and clear to occasionally cloudy sky with fog over the country is the common characteristics of this season. The mean temperature is in the range of 18^0-22^0 C. During this period when the ridge of sub-continental high pressure extends up to northwestern part of Bangladesh, temperature begins to fall over Bangladesh. Sometimes minimum temperature goes below than 10^0 C and cold wave situation occurs over western and northern part of the country. Only 2% of the annual total rainfall occurs in this season.

In Bangladesh, the temperature is predicted to increase by 0.7^0 C in monsoon and 1.3^0 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). Mooney et al (2013) also found the summer surface temperature of Europe simulated by WRF was mostly controlled by the selection of land surface models (LSMs) and radiation schemes but less sensitive to MP and PBL. In their study, they found the NOAH LSM simulated surface temperature that better agree with the observed data than the RUC LSM, even though under NOAH the surface temperature tends to be under-simulated, especially when combining NOAH with the CAM radiation scheme.

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. Kjellström et al (2005) has shown that the seasonal mean temperature errors are generally within $\pm 1^0$ 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 (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.

Dudhia (1989) have studied convection observed during the winter monsoon experiment using a mesoscale two-dimensional model numerically. A two-dimensional version of the Pensylvania state university mesoscale model has been applied to winter monsoon data in order to simulate the diurnally occurring convection observed over the south China sea. The goal of his study was to develop and employ a mesoscale model capable respecting these tropical convective clusters in sufficient detail to answer several questions regarding their development and maintenance. 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). Ratnam 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. Research was 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 V4.3.0) 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 winter temperature of 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 MP and RADIATION parameterization schemes. Also, it will focus what model is better to predict winter temperature between global and regional model.

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 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 50hPa. 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 1^0x1^0 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 microphysics and 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 Physical parameterization schemes tested in this study.

EXPERIMENT NUMBER.	EXPERIMENT NAME	MICROPHYSICS SCHEMES NAME.	RADIATION PHYSICS NAME	
			LONG-WAVE	SHORT-WAVE
EXPT1	Mp1_r11	Kessler scheme (Kessler, 1969)	RRTM	Dudhia
EXPT2	Mp1_r33	Kessler scheme	CAM	CAM
EXPT3	Mp1_r44	Kessler scheme	RRTMG	RRTMG
EXPT4	Mp1_r55	Kessler scheme	Goddard	Goddard
EXPT5	Mp2_r11	Purdue Lin scheme (Lin et al, 1983)	RRTM	Dudhia
EXPT6	Mp2_r33	Purdue Lin scheme	CAM	CAM
EXPT7	Mp2_r44	Purdue Lin scheme	RRTMG	RRTMG
EXPT8	Mp2_r55	Purdue Lin scheme	Goddard	Goddard
EXPT9	Mp3_r11	WRF Single Moment 3-class scheme	RRTM	Dudhia
EXPT10	Mp3_r33	WRF Single Moment 3-class scheme	CAM	CAM
EXPT11	Mp3_r44	WRF Single Moment 3-class scheme	RRTMG	RRTMG
EXPT12	Mp3_r55	WRF Single Moment 3-class scheme	Goddard	Goddard
EXPT13	Mp6_r11	WRF Single Moment 6-class scheme	RRTM	Dudhia
EXPT14	Mp6_r33	WRF Single Moment 6-class scheme	CAM	CAM
EXPT15	Mp6_r44	WRF Single Moment 6-class scheme	RRTMG	RRTMG
EXPT16	Mp6_r55	WRF Single Moment 6-class scheme	Goddard	Goddard

EXPT17	Mp16_r11	WRF Double Moment 6-class scheme	RRTM	Dudhia
EXPT18	Mp16_r33	WRF Double Moment 6-class scheme	CAM	CAM
EXPT19	Mp16_r44	WRF Double Moment 6-class scheme	RRTMG	RRTMG
EXPT20	Mp16_r55	WRF Double Moment 6-class scheme	Goddard	Goddard

2.2 Domain configuration for the Bangladesh

Global climate models (GCMs), European center for Medium-Range Weather Forecast (EMCWF) 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 16-19 December 2018, 02-05 January 2019, 15-18 January 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.: 18^{o} N, Central Lon.: 89^{o} 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 50hPa)
Time integration	3rd order Runge-Kutta
Spatial differencing scheme	6th order centered differencing
Initial conditions	Three-dimensional real-data (FNL: 1^{o}x1^{o})
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	Kessler, Purdue Lin, WSM3, WSM6 and WDM6
Radiation package scheme	RRTM LW with Dudhia SW schemes, CAM, RRTMG and Goddard for both sw and lw.
Surface layer	Monin–Obukhov similarity theory scheme
Land surface parameterization	Noah
Cumulus parameterization scheme	Kain–Fritsch scheme (KF)
PBL parameterization	YSU
Time of simulation	00 UTC of 02 January 2019 to 00 UTC of 05 January 2019
Output interval	6 hours

These schemes were selected either because they performed well in previous studies or they have not been tested before. There are 20 experiments: combinations of 5 Microphysics and 4 combination radiations schemes. 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. 20 combinations of schemes selected to fine tune WRF over Bangladesh are shown in Table 1.

2.3 Data and Methodology

The regional model (WRF4.3.0) was run from 0000 UTC of 01 January 2019 to 0000 UTC of 06 January 2019 with the Final Reanalysis (FNL) data (1^0x1^0) 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. There are 20 experiments: combinations of 5 Microphysics and 4 combination radiation schemes with keeping constant of Kain−Fritsch cumulus scheme, the Yonsei State University (YSU) planetary boundary layer scheme and the Noah land surface model.

From the output of WRF Model, 3 hourly 2m temperature have been extracted during the study period of 0000 UTC 02 January 2019 to 0000 UTC of 05 January 2019 considering 24 hours as spin up the model. 34 meteorological stations of BMD are considering 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 transformed into Microsoft Excel and finally compared with the BMD observed temperature at 34 meteorological stations. BMD observed winter temperature and model simulated temperatures are used for calculating RMSE. 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.
The RMSE have been calculated for 34 meteorological stations to calculate the RMSE for 2m air temperature and fix the lowest value. From here, it has been taken the appropriate physical combination.
After fixing the appropriate combination, it has studied three cases over Bangladesh and model (WRF 4.3.0) was run. The WRF model output text (txt) format data was made in 6 hours intervals. Also, we were collected ECMWF (0.125^0x 0.125^0) data and made it 6 hourly text (txt) format data by using .gs file for the same stations and same domain. Simulated results of WRF and ECMWF data were analyzed based on comparison with the measured BMD data. These data transformed into Microsoft Excel and also calculate RMSE of 2m Air temperature for the model of WRF and ECMWF. Finally, we choose to fit for our domain to predict at 2m Air temperature.

3. Results and Discussion

Sensitivity of 2m Air Temperature

Surface temperature at 2m

Biases of the mean 2m air temperature simulated by WRF under different parameterization schemes with respect to observed data of BMD are shown in Table 3. The results show that spatial patterns of temperature simulated by WRF generally agree well with observed data with reasonable discrepancies. Even though the maximum cold bias can be -5^0 C at some places, the mean bias ranges from -3^0 C to 0.5^0 C. WRF clearly under-simulated the temperature of the Bangladesh when the WDM6 was used, and even the ECMWF data is also too cold for the Bangladesh when compared with the BMD data (Fig. 2). On the basis of differences between WRF's simulations and the BMD Temperature (^{0}C) over the Bangladesh for different combinations of MP and Rad schemes which simulate the radiation forcing and heat exchanges between the microphysical and the atmosphere exert stronger impact on air temperature simulated by WRF as shown in Table 3. Temperature biases over the Bangladesh were partly corrected by changing either the MP or the Rad scheme. The RRTM longwave and Dudhia shortwave combined with WDM6 simulated more accurate air temperature compared to other combination schemes as shown in Table 3.

Table 3: Average RMSE of 2m Air Temperature at 34 stations over Bangladesh.

Station_Name	mp1_r11	mp1_r33	mp1_r44	mp1_r55	mp2_r11	mp2_r33	mp2_r44	mp2_r55	mp3_r11	mp3_r33
Barishal	1.7109	1.6319	2.4952	1.9918	1.6044	1.5627	2.4539	2.0158	1.6249	1.5646
Bhola	2.7214	2.6082	3.4965	2.9670	2.6844	2.4693	3.3579	2.9710	2.7189	2.4559
Bogura	1.2224	1.3450	1.3222	1.2568	1.2152	1.3755	1.2789	1.2428	1.2157	1.3752
Chandpur	2.0917	2.0926	1.3287	1.7630	2.1435	2.0887	1.3915	1.7495	2.1401	2.0974
Chuadanga	2.7018	2.5704	3.6352	2.9939	2.5848	2.7321	3.6000	3.0305	2.5802	2.7183
Comilla	1.5660	1.5090	1.0478	1.1927	1.4468	1.5224	1.0750	1.1924	1.4329	1.5290
Cox's Bazar	3.0106	3.2562	3.4856	3.2319	3.1607	3.2821	3.3820	3.2209	3.1657	3.2819
Chittagong	4.5885	3.8813	3.3995	3.7270	3.9568	3.9329	3.5227	3.7209	3.9565	3.9386
Dhaka	0.9889	0.9192	1.1206	0.9170	0.9265	0.9457	1.0941	0.9076	0.9347	0.9560
Dinajpur	1.6630	1.7677	2.3018	1.8980	1.6357	1.7526	2.2696	1.8818	1.6372	1.7548
Faridpur	1.0589	1.1877	1.7507	1.2617	1.0253	1.0447	1.5961	1.2633	1.0764	1.0432
Feni	1.5581	1.3848	1.5959	1.3097	1.2857	1.3592	1.4034	1.3218	1.2783	1.3705
Hatiya	4.6778	4.4792	5.1147	4.8202	4.6985	4.4624	5.0600	4.8278	4.7164	4.4528
Ishurdi	2.0445	2.0261	2.8638	2.4069	1.9999	2.1161	2.8959	2.4178	2.0241	2.1058
Jashore	1.6826	1.8700	2.5324	1.9787	1.6409	1.7755	2.4210	1.9833	1.6725	1.7586
Khepupara	2.4904	2.3839	3.0112	2.4805	2.2709	2.2121	2.8681	2.5130	2.2604	2.1944
Khulna	1.3170	1.7270	1.6806	1.4243	1.3763	1.6917	1.5493	1.4063	1.3535	1.6974
Kutubdia	2.4295	1.6782	1.6890	1.7399	1.7097	1.6097	1.7699	1.7387	1.7126	1.6080
Madaripur	1.9623	2.1087	2.6348	2.2844	2.0314	2.0476	2.5117	2.2634	1.9967	2.0411
M.court	3.0066	2.7782	1.7684	2.2450	2.6750	2.9221	1.9068	2.2420	2.6619	2.9354
Mongla	1.6610	1.9151	1.3988	1.4536	1.6168	2.0147	1.3656	1.4675	1.5834	2.0234
Mymensing	1.0878	1.1969	1.8428	1.3882	1.0807	1.1470	1.7716	1.3794	1.0870	1.1398
Patuakhali	1.3964	1.4848	1.4850	1.2487	1.1925	1.3862	1.4629	1.2567	1.2047	1.3881

Rajshahi	2.8358	2.8459	3.5334	3.0767	2.7411	2.8088	3.5266	3.0716	2.7685	2.8101
Rangamati	2.6644	1.5349	1.2757	1.3417	1.4916	1.4822	1.2912	1.3478	1.4847	1.4783
Rangpur	1.3369	1.5198	1.8986	1.5514	1.2923	1.4536	1.8324	1.4765	1.2668	1.4514
Sandwip	5.7540	5.8694	6.2561	5.9573	5.8447	5.8549	6.1940	5.9724	5.8478	5.8520
Satkhira	1.7560	1.8881	2.7990	2.1548	1.7506	1.8752	2.7920	2.2153	1.7391	1.8561
Sitakunda	3.3356	2.9261	3.3589	2.8720	2.7602	2.6378	3.0161	2.9015	2.7111	2.6191
Srimongal	2.0848	1.8923	2.7934	2.4098	2.0660	1.8586	2.7448	2.4134	2.0654	1.8516
Syedpur	1.6898	1.7590	2.2402	1.8615	1.6420	1.6588	2.1585	1.8452	1.6162	1.6528
Sylhet	1.5377	1.7885	1.2358	1.4164	1.5557	1.8864	1.2984	1.4541	1.5728	1.9057
Tangail	2.3095	2.3319	2.9144	2.5481	2.3171	2.2192	2.8814	2.5498	2.3144	2.2030
Teknaf	5.2065	3.8222	2.4360	2.4581	2.8758	2.8929	2.1824	2.4466	2.8071	2.8994
Avg_RMSE	2.3279	2.2347	2.4630	2.2244	2.1265	2.1789	2.4096	2.2267	2.1244	2.1768

Station_Name	mp3_r44	mp3_r55	mp6_r11	mp6_r33	mp6_r44	mp6_r55	mp16_r11	mp16_r33	mp16_r44	mp16_r55
Barishal	2.4413	1.9674	1.5843	1.5608	2.4421	1.9561	1.6001	1.5685	2.4829	2.0079
Bhola	3.3446	2.9080	2.6733	2.4540	3.3412	2.8704	2.6622	2.4658	3.3924	2.8959
Bogura	1.2704	1.2476	1.2117	1.3766	1.2684	1.2260	1.2144	1.3836	1.2788	1.2355
Chandpur	1.3984	1.7185	2.1484	2.0954	1.3959	1.7769	2.1477	2.0919	1.3890	1.7596
Chuadanga	3.5976	3.0422	2.5467	2.7189	3.5948	2.9687	2.5578	2.7260	3.6200	2.9927
Comilla	1.0768	1.1156	1.4488	1.5303	1.0749	1.2217	1.4549	1.5295	1.0914	1.2196
Cox's Bazar	3.3798	3.3564	3.1499	3.2813	3.3795	3.2357	3.1491	3.2848	3.3958	3.2540
Chittagong	3.5192	3.7163	3.9629	3.9437	3.5214	3.7325	3.9606	3.9291	3.4979	3.6998
Dhaka	1.0925	0.9605	0.9203	0.9561	1.0915	0.8931	0.9194	0.9513	1.1035	0.9132
Dinajpur	2.2580	1.9338	1.6325	1.7616	2.2568	1.8788	1.6278	1.7489	2.2972	1.9347
Faridpur	1.5833	1.2548	1.0141	1.0400	1.5810	1.2248	1.0108	1.0408	1.6174	1.2657
Feni	1.3980	1.3377	1.2891	1.3668	1.3947	1.2919	1.2969	1.3640	1.4237	1.2946
Hatiya	5.0637	4.8934	4.6926	4.4507	5.0626	4.8133	4.6864	4.4506	5.0733	4.8184
Ishurdi	2.8933	2.4506	1.9854	2.1036	2.8907	2.3954	1.9891	2.1176	2.9421	2.4369
Jashore	2.4077	2.0203	1.6241	1.7581	2.4064	1.9344	1.6371	1.7696	2.4427	1.9685
Khepupara	2.8583	2.7112	2.2555	2.1876	2.8518	2.5455	2.2485	2.2046	2.8915	2.5787
Khulna	1.5385	1.3273	1.3815	1.7001	1.5347	1.3894	1.3858	1.6906	1.5715	1.3872
Kutubdia	1.7618	1.7986	1.7101	1.6106	1.7622	1.7423	1.7043	1.6066	1.7829	1.7443
Madaripur	2.4906	2.3249	2.0453	2.0412	2.4951	2.3274	2.0420	2.0485	2.5151	2.3213
M.court	1.9340	2.1177	2.6883	2.9355	1.9298	2.2531	2.6953	2.9325	1.9008	2.2099
Mongla	1.3644	1.4254	1.6381	2.0230	1.3635	1.4669	1.6395	2.0213	1.3634	1.4427
Mymensing	1.7565	1.4113	1.0771	1.1378	1.7551	1.3950	1.0735	1.1448	1.7942	1.4412
Patuakhali	1.4626	1.2141	1.1919	1.3886	1.4572	1.1996	1.1936	1.3844	1.4857	1.2175
Rajshahi	3.5312	3.0938	2.7376	2.8113	3.5319	3.0620	2.7267	2.8102	3.5421	3.1085
Rangamati	1.2816	1.2993	1.4950	1.4804	1.2852	1.3721	1.4892	1.4696	1.2954	1.3622
Rangpur	1.8342	1.5344	1.2939	1.4475	1.8320	1.5045	1.2973	1.4383	1.8363	1.5507
Sandwip	6.1991	6.0409	5.8334	5.8473	6.1965	5.9841	5.8365	5.8584	6.2041	6.0021
Satkhira	2.7719	2.0719	1.7257	1.8462	2.7687	2.1561	1.7459	1.8752	2.8137	2.2137
Sitakunda	2.9869	2.8840	2.7568	2.6149	2.9851	2.9011	2.7515	2.6188	3.0244	2.9403
Srimongal	2.7361	2.5150	2.0649	1.8517	2.7355	2.4023	2.0613	1.8565	2.7595	2.4272
Syedpur	2.1579	1.9263	1.6429	1.6554	2.1603	1.8570	1.6309	1.6132	2.1349	1.8490
Sylhet	1.3061	1.3365	1.5483	1.8883	1.3104	1.4011	1.5702	1.9069	1.3147	1.3803
Tangail	2.8744	2.5384	2.3121	2.2101	2.8721	2.5444	2.2914	2.2027	2.8941	2.5570
Teknaf	2.2102	2.3370	2.8562	2.8929	2.1977	2.4847	2.8286	2.8647	2.0975	2.3414
Avg_RMSE	2.4053	2.2303	2.1217	2.1755	2.4037	2.2179	2.1214	2.1756	2.4197	2.2286

3.1 Sensitivity to radiation schemes

The sensitivity of the Bangladeshi winter temperature to the radiation schemes was tested by comparing the result of EXPT1 to EXPT20 (Table 3).

In Table 3, a group of set by EXPT1, EXPT2, EXPT3 and EXPT4 is made; where the Kessler MP physics is stable and only radiation physics is varied. This group is treated as first group. In radiation physics, there are four 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 Goddard (EXPT4) both long wave and short-wave radiation parameterization scheme gives the lowest RMSE for 2m Air temperature by the simulated temperature over the Bangladesh. So, the performance of the combination of Goddard both long wave and short-wave radiation parameterization scheme is better than others considering 34 stations over Bangladesh.

The second group of set is formed by EXPT5, EXPT6, EXPT7 and EXPT8, where Purdue Lin MP physics is used as fixed and radiation physics are varied. Results with second group (EXPT5, EXPT6, EXPT6 and EXPT8) are different to those generated by first group EXPT1, EXPT2, EXPT3 and EXPT4. The RRTM LW-Dudhia SW combination radiation scheme (EXPT5) has smaller RMSE compared to the both for LW and SW; CAM (EXPT6), RRTMG (EXPT7) and Goddard (EXPT8) combination radiation schemes in simulating the 2 m air temperatures over the Bangladesh landmass.

Similarly, the third group of set is formed by EXPT9, EXPT10, EXPT11 and EXPT12, where WSM3 MP physics is fixed and radiation physics are varied. EXPT9 (RRTM LW-Dudhia SW) has simulated the lowest RMSE value over the Bangladesh.

The Fourth group of set is formed by EXPT13, EXPT14, EXPT15 and EXPT16, where WSM6 MP physics is used as fixed and radiation physics are varied. Results with fourth group (EXPT13, EXPT14, EXPT15 and EXPT16) are similar to those generated by second and third groups. The RRTM LW-Dudhia SW radiation scheme (EXPT13) has smaller RMSE compared to the both for LW and SW; CAM (EXPT14), RRTMG (EXPT15) and Goddard (EXPT16) radiation schemes in simulating the 2 m air temperatures over the Bangladesh landmass.

Finally, the 5th group of set is formed by EXPT17, EXPT18, EXPT19 and EXPT20; where WDM6 MP physics is fixed and radiation physics is varied. Comparing among them, it is seen that, EXPT17 (RRTM LW-Dudhia SW) has simulated the lowest RMSE compared to the both for LW and SW; CAM (EXPT18), RRTMG (EXPT19) and Goddard (EXPT20) radiation schemes in simulating the 2 m air temperatures over the Bangladesh landmass.
These results indicate that the combination of RRTM longwave and Dudhia shortwave radiation parameterization scheme is superior to the CAM, the RRTMG and the Goddard 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.

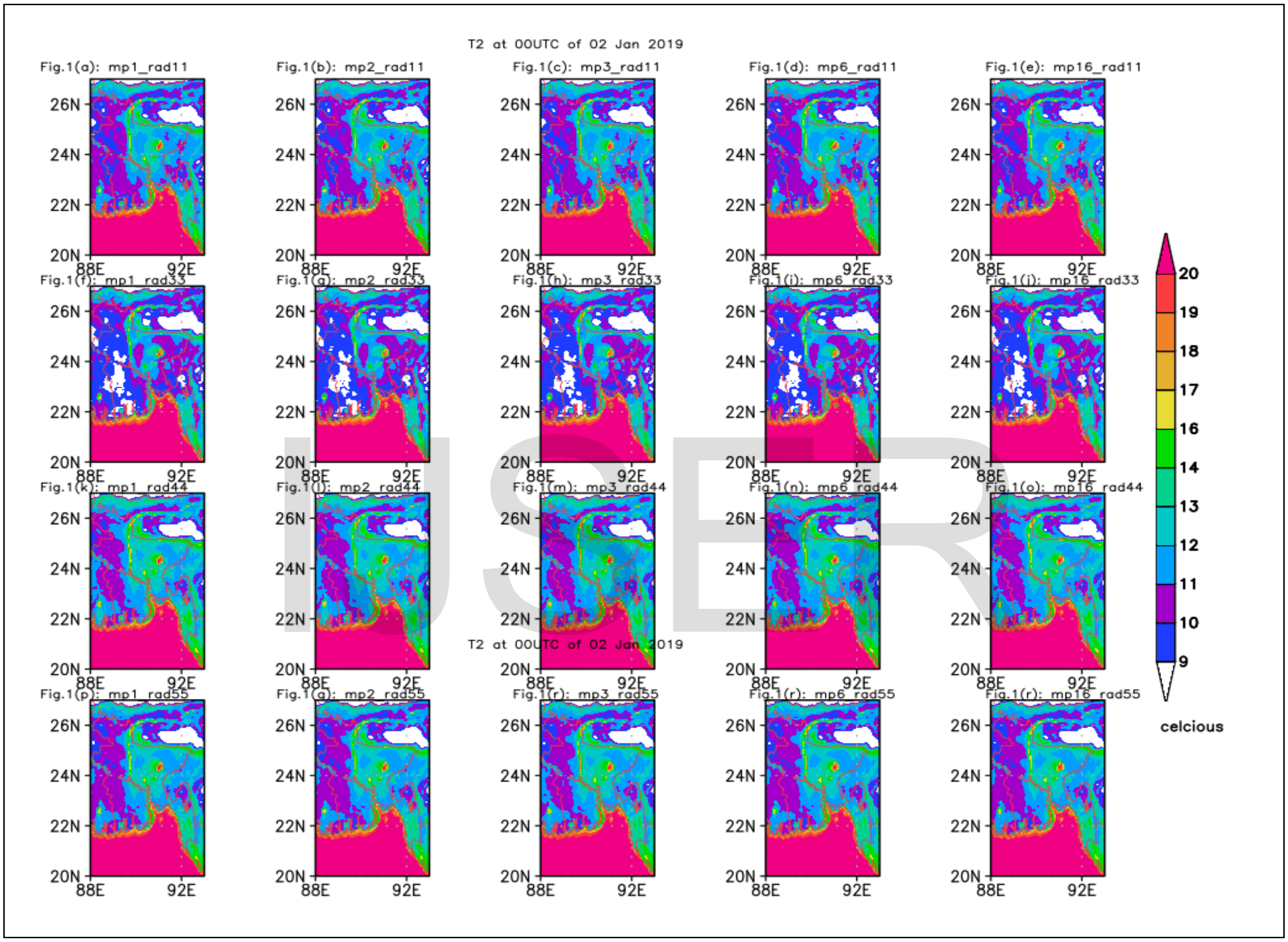


Fig. 1: T_2 Temperature at 0000 UTC of 02 January 2019 for the Different combination of MP physics and Radiation Physics

3.2 Sensitivity to Microphysics schemes

Microphysics includes explicitly resolved water vapor, cloud, and precipitation processes. The model is general enough to accommodate any number of mass mixing-ratio variables, and other quantities such as number of particles per unit dry air mass. 'The various microphysics options have differing numbers of moisture variables, depending on the ice-phase and mixed-phase processes included. Mixed-phase processes are those that result from the interaction of ice and water particles, such as riming that produces graupel or hail. As a general rule, for grid sizes less than 10 km, where updrafts may be resolved, mixed-phase schemes should be used, particularly in convective or icing situations. For coarser grids it may not be worth the added expense of these schemes because riming is not likely to occur with the relatively weak vertical motion that is resolved. Many schemes are also double-moment for some species and include number per unit dry air mass for those as extra advected variables. Experiments are carried out with 5 Micro physics schemes, namely Kessler, Purdue Lin, WRF Single Moment 3-class scheme, WRF Single Moment 6-class scheme and WRF Double Moment 6-class scheme, to test the sensitivity of the model temperature to these schemes. The comparison of the pairs of experiments, EXPT1, EXPT5, EXPT9, EXPT13 and EXPT17; EXPT2, EXPT6, EXPT10, EXPT14 and EXPT18; EXPT3, EXPT7, EXPT11, EXPT15 and EXPT19; EXPT4, EXPT8, EXPT12, EXPT16 and EXPT20 (Table 1), clearly reveal the importance of specifying a Microphysics scheme (Table 3).

In Table 3, by analyzing the results of the pairs of experiments EXPT1, EXPT5, EXPT9, EXPT13 and EXPT17; EXPT2, EXPT6, EXPT10, EXPT14 and EXPT18; EXPT3, EXPT7, EXPT11, EXPT15 and EXPT19; EXPT4, EXPT8, EXPT12, EXPT16 and EXPT20 (Table 1), which differ only in the MP physics scheme used (Table 1), were compared to test the sensitivity of the model-simulated temperature to the MP physics scheme. EXPT1, EXPT2, EXPT3 and EXPT4 use the Kessler MP physics scheme, whereas EXPT5, EXPT6, EXPT7 and EXPT8 use the Purdue Lin MP scheme. EXPT9, EXPT10, EXPT11 and EXPT12 use the WSM3 MP physics scheme, whereas EXPT13, EXPT14, EXPT15 and EXPT16 use the WSM6 MP scheme. EXPT17, EXPT18, EXPT19 and EXPT20 use the WDM6 MP physics scheme.

The 2m air temperature simulated by EXPT1, EXPT5, EXPT9, EXPT13 and EXPT17; EXPT2, EXPT6, EXPT10, EXPT14 and EXPT18; EXPT3, EXPT7, EXPT11, EXPT15 and EXPT19; EXPT4, EXPT8, EXPT12, EXPT16 and EXPT20 (Table 1) differs from every combination to combination.

Comparing EXPT1 (Kessler), EXPT5 (Purdue Lin), EXPT9 (WSM3), EXPT13 (WSM6) and EXPT17 (WDM6); where RRTM-Dudhia radiation package physics is used and Microphysics (MP physics) are varied. It can be seen that the temperature simulated by EXPT17 (WDM6) has smaller RMSE compared to the temperature simulated by EXPT1 (Kessler), EXPT5 (Purdue Lin), EXPT9 (WSM3) and EXPT13 (WSM6) over the Bangladesh landmass.

Comparing EXPT2 (Kessler), EXPT6 (Purdue Lin), EXPT10 (WSM3), EXPT14 (WSM6) and EXPT18 (WDM6); where CAM radiation package physics is used and Microphysics (MP physics) are varied. It can be seen that the temperature simulated by EXPT14 (WSM6) has smaller RMSE compared to the temperature simulated by EXPT2 (Kessler), EXPT6 (Purdue Lin), EXPT10 (WSM3) and EXPT18 (WDM6) over the Bangladesh landmass.

Comparing EXPT3 (Kessler), EXPT7 (Purdue Lin), EXPT11 (WSM3), EXPT15 (WSM6) and EXPT19 (WDM6); where RRTMG radiation package physics is used and Microphysics (MP physics) are varied. It can be seen that the temperature simulated by EXPT15 (WSM6) has smaller RMSE compared to the temperature simulated by EXPT3 (Kessler), EXPT7 (Purdue Lin), EXPT11 (WSM3) and EXPT19 (WDM6) over the Bangladesh landmass.

Finally, Comparing EXPT4 (Kessler), EXPT8 (Purdue Lin), EXPT12 (WSM3), EXPT16 (WSM6) and EXPT20 (WDM6); where Goddard radiation package physics is used and Microphysics (MP physics) are varied. It can be seen that the temperature simulated by EXPT16 (WSM6) has smaller RMSE compared to the temperature simulated by EXPT4 (Kessler), EXPT8 (Purdue Lin), EXPT12 (WSM3) and EXPT20 (WDM6) over the Bangladesh landmass.

It is evident that the temperature simulated with the Kessler micro physics scheme has larger RMSE compared to that simulated with the others microphysics scheme. it is evident that the models with the Kessler microphysics scheme (EXPT1, EXPT2, EXPT3 and EXPT4) yielded a more unstable microphysics scheme compared to those with the rest of the other Microphysics schemes (EXPT5 to EXPT20).

Among all the experiments, EXPT17 (WDM6) has given the lowest RMSE value 2.121355, EXPT13 (WSM6) has given the second lowest RMSE value 2.121731, EXPT9 (WSM3) has given the third lowest RMSE value 2.124374 and EXPT5 (Purdue Lin) has given the fourth lowest RMSE value 2.126453.

After analyzing and synthesizing, it can be revealed that the WRF Double Moment 6-class microphysics (WDM6) scheme is superior than Kessler, Purdue Lin, WRF Single Moment 3-class scheme and WRF Single Moment 6-class scheme, and is suitable to simulate Bangladeshi winter temperature.

Table 4: Comparison of 2m Air Temperature among WRF, ECMWF and BMD data at 34 stations over Bangladesh for 3 Events.

Events No.1: 17 to 19 December 2018

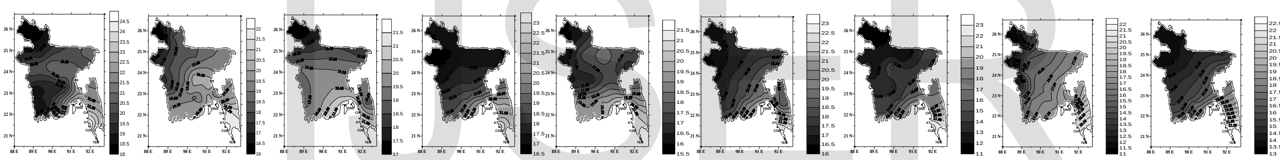
	17_12_18_00			18_12_18_00			19_12_18_00		
Station name	WRF-ARW	BMD	ECMWF	WRF-ARW	BMD	ECMWF	WRF-ARW	BMD	ECMWF
Barishal	20.3885	18.6	20.1394	18.9853	19.2	18.7181	14.924	16.8	16.2847
Bhola	21.2111	19.3	20.5563	19.8464	19.3	19.4719	16.9972	17	17.0902
Bogura	19.0819	18	18.6017	16.9166	17.7	16.9721	12.2514	15.4	13.9459
Chandpur	19.4378	19.7	20.0034	18.3573	18.4	18.8182	15.1929	17.2	16.1449
Chuadanga	19.8902	17.3	19.1578	17.222	16.3	16.9961	13.0421	12.3	14.6985
Comilla	21.5999	20.4	19.811	18.6216	18	19.3711	15.5458	17.7	16.7674
Cox'sBazar	24.9969	22.2	21.6418	23.5173	21.5	22.4732	23.7635	20.4	21.801
Chittagong	22.7171	22.4	20.5738	21.2275	21.8	20.3694	17.6372	19	19.5665
Dhaka	20.6375	20.4	19.7862	17.6524	17.5	18.2066	14.5182	16.4	15.4781
Dinajpur	18.2993	16	17.4929	16.943	15.8	16.6552	11.6511	11.5	13.6514
Faridpur	19.5732	19	19.8978	17.9221	16.8	17.9625	13.7148	16.4	15.3276
Feni	21.879	19	20.0772	19.5364	18.7	19.5275	16.7589	17	17.3475
Hatiya	23.2827	20.3	21.4275	21.1421	20.5	20.9005	19.1111	17.7	18.6623
Ishurdi	20.2982	18	19.6801	17.1958	17	16.981	12.4805	15.5	14.377
Jessore	18.6575	18	19.3366	17.8298	17.2	17.3035	13.4518	14.6	15.0502
Khepupara	21.0821	19.8	20.7213	19.9574	19.2	20.0441	17.7939	17.4	17.7683
Khulna	19.1212	19	19.7031	18.5079	18.6	17.8094	14.1194	16.5	15.4661
Kutubdia	23.9809	21.8	20.9184	22.0391	21	21.2771	21.4819	19.8	20.6133
Madaripur	19.0019	20	19.915	18.4401	18	18.2585	14.0608	16.5	15.7087
M.court	21.7635	20.2	20.4397	19.5746	19.4	19.5494	16.9323	18	17.3256
Mongla	18.7993	19.8	19.6016	18.8578	19	17.9998	14.1085	16.7	15.8632
Mymensing	20.2363	18.5	18.9205	17.3065	18.5	17.6366	12.2343	15.8	14.8535
Patuakhali	20.3735	19.8	20.2788	19.4018	19.5	19.2634	15.915	17.3	17.0269
Rajshahi	19.9395	17.6	19.2441	16.7933	16.5	16.5009	13.2418	12.7	14.0183
Rangamati	22.0828	20.4	18.8423	20.9971	19.8	18.6015	17.7765	19.2	18.8781
Rangpur	18.2362	18	17.6978	17.2954	16.4	17.0825	11.8779	13.5	13.9135
Sandwip	23.7151	20.7	21.4366	22.0512	20.4	21.0407	19.5959	18.1	19.0047
Satkhira	18.5575	19.2	19.3334	18.5801	19	17.488	14.4227	15.8	15.3385
Sitakunda	22.2596	20	20.6597	20.9447	20.6	20.0824	17.6649	16.8	18.5934
Srimongal	20.1422	19	19.2897	17.4847	16.6	18.977	14.8553	17.1	16.676
Syadpur	18.1882	17	17.1377	17.5961	16.4	16.856	11.1866	12.5	13.5342
Sylhet	20.7636	19.2	18.2292	17.2842	17.5	17.657	14.6411	17	15.0325
Tangail	20.9269	18.8	19.3891	17.5781	17.4	17.496	15.3449	15.9	14.6464
Teknaf	20.833	21.7	22.007	21.1843	21.4	23.0689	22.0767	22	22.7269

Events No.2: 02 to 04 January 2018

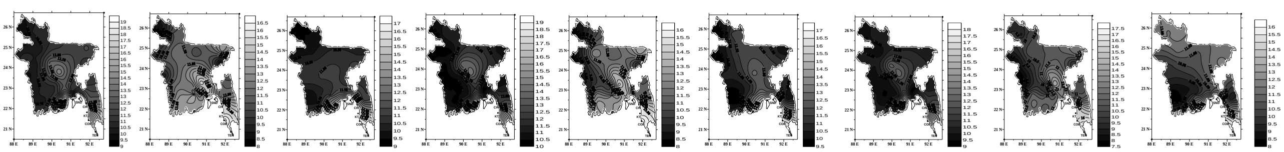
	02_01_2019_00			03_01_2019_00			04_01_2019_00		
Station Name	WRF-ARW	BMD	ECMWF	WRF-ARW	BMD	ECMWF	WRF-ARW	BMD	ECMWF
Barishal	11.5003	11.6	10.9323	11.204	11	11.6122	10.0465	9.6	9.10671
Bhola	15.0044	12	12.4064	13.6987	12	13.3692	14.0151	10.9	10.5027
Bogura	10.1969	12	9.94096	10.3778	12.6	11.3672	9.63779	11	11.6589
Chandpur	12.8114	15.4	11.2313	12.5498	14.8	12.3587	11.5373	14.7	10.3471
Chuadanga	9.93904	9.3	10.9734	10.2678	8.7	10.7136	9.79946	7.5	9.82824
Comilla	11.5857	13.6	10.7284	10.9626	12.8	11.594	10.2045	12.4	11.5249
Cox'sBazar	20.1606	17	16.4844	20.0007	16.5	16.1371	19.2169	16	15.5523
Chittagong	12.9559	15.9	14.2851	12.4587	15.8	13.6715	11.4994	16.7	12.9869
Dhaka	14.4539	13.8	11.282	14.5082	13.7	12.6983	12.9128	13.1	10.4303
Dinajpur	9.43925	8.3	9.21171	10.3165	8.5	9.86194	9.44773	10	12.1255
Faridpur	12.1607	12.4	11.0572	10.7486	10.6	11.1007	10.0838	10.4	9.80241
Feni	11.3507	13	11.3986	10.4913	12	11.6213	9.66643	11.5	10.9788
Hatiya	20.0515	13.2	15.6737	19.8601	13.8	16.0155	19.1578	12.6	14.5784
Ishurdi	9.96043	10.8	10.8271	10.3508	9.6	10.4311	9.89733	9	9.95863
Jessore	10.1733	11.6	10.3191	10.3474	9.4	10.1409	9.73859	8.2	8.96595
Khepupara	12.8074	13.2	13.7109	14.3216	12.7	13.7002	12.276	11	12.7603
Khulna	10.7126	12.8	9.97095	10.585	12.2	9.74413	9.44809	11.6	8.5806
Kutubdia	16.8116	15	15.0837	16.5504	15	14.6248	15.0538	15.7	13.9698
Madaripur	11.0947	12	10.6339	10.9132	10	10.9436	10.3419	9.5	9.20116
M.court	10.9593	15	11.8722	10.1525	13.8	12.4652	9.09882	13	10.4862
Mongla	10.3068	13.5	9.92733	10.1457	13.3	9.77598	9.67109	12.3	8.51046
Mymensing	11.7077	10.6	10.8167	12.634	11	11.884	10.7086	11.1	10.8479
Patuakhali	11.7738	14.2	12.0251	11.1866	13	12.4684	10.6227	12	10.4555
Rajshahi	11.0751	11	10.2813	10.6688	8.7	9.82183	10.5733	8.1	9.99483
Rangamati	12.5783	12.5	11.0633	12.3544	12.5	10.0889	11.45	11.5	8.97973
Rangpur	10.6908	11	9.51372	11.4	10	11.6588	10.308	10	12.3489
Sandwip	20.9622	14.1	15.767	20.7824	13.1	15.7374	19.9638	12.6	14.8623
Satkhira	10.422	11.3	9.45607	11.125	10.3	9.66723	10.2051	10	8.04775
Sitakunda	13.9341	11.7	13.5155	13.27	11	13.1659	12.2945	11.3	12.254
Srimongal	11.2493	8.5	11.2184	11.55	9.4	11.4778	10.6538	9.4	12.3403
Syadpur	10.471	9.6	9.50893	11.1628	9.4	10.2505	10.2322	8.8	11.8925
Sylhet	12.0893	13.4	10.3048	10.9186	13.5	10.2571	10.2405	12.5	11.5481
Tangail	13.1302	11.9	10.8646	13.8345	11.5	11.7827	12.7437	10.4	10.6941
Teknaf	14.582	15	17.2193	14.1673	15	17.1186	13.2094	18	16.1528

Events No.3: 15 to 17 January 2018.

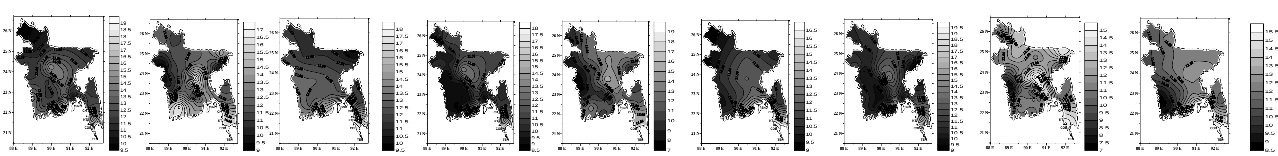
	15_01_2019_00			16_01_2019_00			17_01_2019_00		
Station Name	WRF-ARW	BMD	ECMWF	WRF-ARW	BMD	ECMWF	WRF-ARW	BMD	ECMWF
Barishal	12.4153	11.2	12.6094	9.47475	8.5	11.693	10.4988	10	11.5122
Bhola	14.843	12.4	13.6694	12.2009	9.7	12.8502	14.379	10.6	12.8238
Bogura	11.2112	12	11.3586	9.76545	12	10.4765	10.4743	13	11.5354
Chandpur	13.571	14.5	12.7902	11.5873	14.2	12.0195	12.434	15.4	12.4481
Chuadanga	11.8757	9.7	13.4118	9.22631	7	10.3852	10.6375	8.6	10.5664
Comilla	12.4972	12.6	12.2954	10.6686	13.9	11.9078	11.2366	11.6	12.3458
Cox'sbazar	19.8188	16.5	18.0194	19.3299	16	16.8424	20.3632	15.4	15.5996
Chittagong	12.5516	15.1	15.0771	10.8993	15.5	13.9475	13.367	13.8	13.9848
Dhaka	14.5173	17	12.6362	12.7008	15.6	12.0435	14.3508	15.3	12.6277
Dinajpur	9.9521	12.5	11.8262	8.97446	9	9.4608	10.463	10.3	11.0494
Faridpur	11.9685	12.3	13.1226	9.60857	11.6	11.4429	10.1575	13.3	11.4096
Feni	11.7963	12.7	12.4107	10.313	11	12.0164	11.0729	11.6	12.3028
Hatiya	19.4732	13.6	16.3701	17.4256	13.8	15.4981	18.1707	12.6	15.5687
Ishurdi	11.5423	11	12.6876	9.09826	8.3	10.5574	9.91136	10.5	11.4187
Jessore	12.8959	10.8	13.3969	9.35468	8	10.2479	10.5003	7.4	9.64817
Khepupara	15.5414	14.2	15.6955	12.2562	10	13.4627	12.509	10.4	12.7388
Khulna	12.1587	14.2	12.8137	9.20191	10.5	10.5149	10.2626	11	9.70133
Kutubdia	15.8126	16	16.4677	14.594	15	15.2948	17.0062	14	14.3598
Madaripur	12.31	12.3	12.6385	9.41537	9.8	11.3495	10.3011	10.5	11.1432
M.court	11.2713	13.8	12.8525	9.20719	13	12.4249	10.7852	14.3	12.562
Mongla	12.2667	16.7	12.9463	8.77994	13.7	10.0888	9.87727	11.6	9.16792
Mymensing	12.6981	12.2	11.6664	11.6118	14.2	11.6506	12.5751	11.2	12.3451
Patuakhali	12.0206	13.4	13.7701	9.61836	12.3	12.1674	10.4518	11.9	11.7104
Rajshahi	12.2135	9	12.4355	10.7273	8.4	9.59331	11.7819	11.5	10.946
Rangamati	12.3581	12.7	11.6686	10.8147	12	10.4928	12.9411	12	11.0973
Rangpur	10.4189	11	11.2671	11.2147	11.8	9.85411	11.4363	13.4	12.0353
Sandwip	20.5148	14	16.3285	19.0419	14	15.4511	20.2039	13	15.5108
Satkhira	14.218	13.9	13.5544	9.54098	9.8	9.74912	11.2058	9	8.56146
Sitakunda	13.564	13	14.1771	11.6223	12.4	13.3691	13.3447	10.2	13.5368
Srimongal	12.2538	9.8	11.7895	10.9944	9	11.1847	9.01976	10.2	12.7448
Syadpur	10.0816	12	11.3174	10.9687	10.4	9.53046	11.3598	11.5	11.1668
Sylhet	11.3588	14.2	10.0113	11.2326	13.5	10.3184	11.6332	14.5	12.038
Tangail	14.919	12	12.1499	13.4354	11	11.448	12.8635	11.7	12.2339
Teknaf	14.6311	17.2	18.0741	13.534	19.5	16.9004	13.547	13.5	16.0118



In 1st row, the 1st combination is at 0000 UTC of 17 December 2018, 2nd combination is at 0000 UTC of 18 December 2018 and 3rd combination is 0000 UTC of 19 December 2018.



In 2nd row, the 1st combination is at 0000 UTC of 02 January 2019, 2nd combination is at 0000 UTC of 03 January 2019 and 3rd combination is 0000 UTC of 04 January 2019.



In 3rd row, the 1st combination is at 0000 UTC of 15 January 2019, 2nd combination is at 0000 UTC of 16 January 2019 and 3rd combination is 0000 UTC of 17 January 2019.

Fig. 2: From the left, every three scenario makes a combination where the 1st one is WRF-ARW model simulated, 2nd one is BMD observed and 3rd one is ECMWF 2m Air temperature data (Table 4).

3.3 Spatial change of 2m Air Temperature

Comparison of 2m Air Temperature among WRF, ECMWF and BMD data at 34 stations over Bangladesh.
From Fig. 2, middle of the 1st row 1st combination shows the observed and simulated temperature with WRF-ARW and ECMWF model at 0000 UTC on 17, 2nd combination shows on 18 and 3rd combination shows on 19 December 2018; similarly, 2nd row is on 02, 03 and 04 January 2019 and 3rd row is on 15, 16 and 17 January 2019 respectively.

Fig. 2, 1^{st} row shows the temperature at 0000 UTC for 17, 18 and 19 December 2018. From Fig. 2, 1^{st} row 1^{st} combination shows the temperature at 0000 UTC observed maximum temperature was 22^0 C and obtained at Teknaf and minimum was 11.5^0 at Dinajpur on 17 December 2018. Whereas, using WRF-ARW model simulated maximum temperature was 24^0 C and obtained at Cox's bazar and minimum was 11.5^0C at Syadpur; 2^{nd} lowest temperature is 12^0 C at Dinajpur and Rangpur. And ECMWF maximum temperature was 23^0C and obtained at Teknaf and minimum was 14^0C and obtained at Dinajpur, Syadpur and Rangpur.

From Fig. 2, 1^{st} row 2^{nd} combination shows the temperature at 0000 UTC observed maximum temperature was 22^0 C and obtained at Chittagong and 2^{nd} maximum temperature was 21.5^0 C at Cox's bazar and minimum was 16^0 at Dinajpur on 18 December 2018. Whereas, WRF-ARW model simulated maximum temperature was 24^0 C and obtained at Cox's bazar and minimum was 17^0C at Dinajpur and Rajshahi. And ECMWF maximum temperature was 23^0C and obtained at Teknaf and minimum was 16.5^0 C and obtained at Rajshahi, 2^{nd} minimum Temperature is 17^0 C at Dinajpur and Syadpur.

From Fig. 2, 1^{st} row 3^{rd} combination shows the temperature at 0000 UTC observed maximum temperature was 22.5^0 C and obtained at Chittagong and Cox's bazar and minimum was 16^0 at Dinajpur on 19 December 2018. Whereas, model simulated maximum temperature was 25^0 C and obtained at Cox's bazar and minimum was 18.5^0 C at Dinajpur, Syadpur and Rangpur. And ECMWF maximum temperature was 22^0 C and obtained at Teknaf and Cox's bazar and minimum was 17.5^0 C and obtained at Dinajpur and Syadpur.

Fig. 2, 2^{nd} row shows the temperature at 0000 UTC for 02, 03 and 04 January 2019.

From Fig. 2, 2^{nd} row 1^{st} combination shows the temperature at 0000 UTC observed maximum temperature was 16^0 C and obtained at Chittagong and minimum was 8^0 C at Dinajpur and the second minimum was 8.5^0 C at Srimangal on 02 January 2019. Whereas, WRF-ARW model simulated maximum temperature was 21^0 C and obtained at Sandip and second maximum was 20.5^0 C at Cox's bazar and minimum was 8.5^0 C at Srimangal; 2^{nd} lowest temperature was 9.5^0 C at Dinajpur. And ECMWF maximum temperature was 17^0 C and obtained at Teknaf and minimum was 9^0 C and obtained at Dinajpur.

From Fig. 2, 2^{nd} row 2^{nd} combination shows the temperature at 0000 UTC observed maximum temperature was 16.5^0 C and obtained at Cox's bazar, the second maximum was 16^0 C at Chittagong and minimum was 8.5^0 C at Dinajpur and second minimum was 9^0 C at Chuadanga and Rajshahi on 03 January 2019. Whereas, WRF-ARW model simulated maximum temperature was 21^0 C and obtained at Sandip and second maximum was 20^0 C at Cox's bazar and Hatiya and minimum was 10.5^0 C at Dinajpur, Chuadanga, Mongla and M.court. And ECMWF maximum temperature was 17.5^0 C and obtained at Teknaf and minimum was 10^0 C and obtained at Dinajpur, Rajshahi, Mongla and Satkhira; the second minimum Temperature is 10.5^0 C at Chuadanga.

From Fig. 2, 2^{nd} row 3^{rd} combination shows the temperature at 0000 UTC observed maximum temperature was 18^0 C and obtained at Teknaf and minimum was 7.5^0 C at Chuadanga; second lowest was 8^0 C at Jessore and Rajshahi on 04 January 2019. Whereas, WRF-ARW model simulated maximum temperature was 20^0 C and obtained at Sandip the second maximum was 19.5^0 C at Cox's bazar and minimum was 9.5^0 C at Ishurdi, Chuadanga and Jessore. And ECMWF maximum temperature was 16^0 C and obtained at Teknaf and the second maximum was 15.5^0 C at Cox's bazar and minimum was 8^0 C and obtained at Satkhira; the second minimum was 8.5^0 C at Khulna, Jessore and Mongla.

Fig. 2, 3^{rd} row shows the temperature at 0000 UTC for 15, 16 and 17 January 2019.

From Fig. 2, 3^{rd} row 1^{st} combination shows the temperature at 0000 UTC observed maximum temperature was 17^0 C and obtained at Teknaf; the second maximum was 16.5^0 C at Cox's bazar and Mongla and minimum was 9^0 C at Rajshahi on 15 January 2019. Whereas, WRF-ARW model simulated maximum temperature was 19.5^0 C and obtained at Cox's bazar and minimum was 9.5^0 C at Dinajpur; 2^{nd} lowest temperature was 10^0 C at Rangpur. And ECMWF maximum temperature was 18^0 C and obtained at Teknaf and Cox's bazar and minimum was 11^0 C and obtained at Rangpur; and second minimum was 11.5^0 C at Srimangal and Dinajpur.

From Fig. 2, 3^{rd} row 2^{nd} combination shows the temperature at 0000 UTC observed maximum temperature was 15.5^0 C and obtained at Dhaka and Chittagong and minimum was 7^0 C at Chuadanga and second minimum was 8^0 C at Jessore and Rajshahi on 16 January 2019. Whereas, WRF-ARW model simulated maximum temperature was 17^0 C and obtained at Hatiya and second maximum was 13^0 C at Dhaka and minimum was 8.5^0 C at Dinajpur; the second minimum was 9^0 C at Jessore and Chuadanga. And ECMWF maximum temperature was 15.5^0 C and obtained at Hatiya; the second maximum was 14^0 C at Chittagong and minimum was 9^0 C and obtained at Dinajpur and Rajshahi; the second minimum Temperature is 10^0 C at Chuadanga and Jessore.

From Fig. 2, 3^{rd} row 3^{rd} combination shows the temperature at 0000 UTC observed maximum temperature was 15^0 C and obtained at Dhaka, Chandpur and Cox's bazar and minimum was 7^0 C at Jessore; the second lowest was 8.5^0 C at Chuadanga and Satkhira on 17 January 2019. Whereas, WRF-ARW model simulated maximum temperature was 20^0 C and obtained at Sandip and Cox's bazar and minimum was 9^0 C at Srimangal; the second minimum was 10.5^0 C at Jessore and Chuadanga. And ECMWF maximum temperature was 16^0 C and obtained at Teknaf and the second maximum was 15.5^0 C at Teknaf; the second maximum was 15.5^0 C at Cox's bazar and minimum was 8.5^0 C and obtained at Satkhira; the second minimum was 9.5^0 C at Jessore.

Analyzing the above discussion, it is strongly revealed that the WRF-ARW model is able to capture the temperature at 2-meter height.

Table 5: Performance on the Basis of 2m Air temperature's RMSE which was compared with BMD observed data.

Stations Index	Station Name	20181216_00 - 20181219_00 WRF-ARW	20181216_00 - 20181219_00 ECMWF	20190102_00 - 20190105_00 WRF-ARW	20190102_00 - 20190105_00 ECMWF	20190116_00 - 20190119_00 WRF-ARW	20190116_00 - 20190119_00 ECMWF
41950	Barishal	1.6728	0.8702	1.2051	1.2555	1.3394	1.7554
41951	Bhola	1.5506	0.8773	2.6524	1.4266	2.4413	2.2592
41883	Bogura	1.2631	1.1656	1.1931	1.6888	1.2814	1.6280
41941	Chandpur	1.1079	0.5243	2.1631	3.3438	1.5510	1.8906
41926	Chuadanga	1.2129	1.1564	1.9158	1.6576	2.2250	1.9613
41933	Comilla	1.2185	0.9705	1.6907	2.3790	1.2552	1.2457
41992	Cox's Bazar	2.3452	1.4421	2.9175	1.7387	3.5111	1.4134
41978	Chittagong	1.6134	1.3001	3.1855	2.3496	2.6469	1.5895
41923	Dhaka	0.9064	0.9088	1.0124	2.8117	1.5584	2.6966
41863	Dinajpur	1.9311	2.0753	1.2137	1.2390	1.1977	1.4062
41929	Faridpur	1.5117	0.9229	0.5132	0.9301	1.3033	0.9439
41943	Feni	1.4384	1.0063	1.2559	1.4712	0.8438	1.0088
41963	Hatiya	2.2548	1.2782	4.7689	2.2055	4.4276	2.2791
41907	Ishurdi	1.4614	1.1368	1.4140	1.0643	1.0323	1.1623
41936	Jessore	1.3735	1.0855	1.1864	1.1375	1.6888	1.4181
41984	Khepupara	1.6756	1.0314	2.0035	1.9376	2.5067	1.9849
41947	Khulna	1.2726	0.8885	1.4087	2.0319	1.0759	1.3506
41989	Kutubdia	1.5355	0.8813	1.4531	1.4807	2.0081	1.0573
41939	Madaripur	1.8988	1.5476	1.2285	1.3176	0.8034	0.6485
41953	M.court	1.8595	0.9359	2.8995	2.5268	1.9764	1.1027
41958	Mongla	1.4040	0.7997	1.8396	2.2392	2.2205	2.0751
41886	Mymensing	1.6350	1.3573	0.8392	1.4023	1.1667	1.1768
41960	Patuakhali	1.3718	0.7721	1.1794	1.2834	1.1282	0.5459
41895	Rajshahi	1.1750	1.2603	2.4663	1.3508	2.3955	1.4767
41966	Rangamati	2.6248	2.3390	1.3123	1.5293	0.9676	1.0589
41859	Rangpur	1.4965	1.6079	0.8594	1.2628	0.9884	1.2624
41964	Sandwip	2.3931	1.3250	5.9871	2.4752	5.5409	2.4767
41946	Satkhira	1.7809	1.2585	1.4274	0.9848	1.8806	1.1123
41965	Sitakunda	1.9727	1.6377	2.4940	2.2836	3.1000	2.8796
41915	Srimongal	1.3779	1.1322	1.8285	2.3836	2.0672	2.4336
41858	Syadpur	1.5962	1.4175	1.0350	1.7012	0.8960	1.2942
41891	Sylhet	1.2598	1.9847	1.5531	2.3417	1.4198	2.3083
41909	Tangail	1.2688	1.0649	2.1030	1.0139	1.9837	0.8424
41998	Teknaf	1.1877	2.0193	2.8162	1.9304	2.2796	2.4258
	AVG_RMSE	1.5779	1.2347	1.9124	1.7699	1.9032	1.5933

Table 6: RMSE of 2m Air Temperature of Land Ocean Interface.

Station Name	20181216_00 - 20181219_00 WRF-ARW	20181216_00 - 20181219_00 ECMWF	20190102_00 - 20190105_00 WRF-ARW	20190102_00 - 20190105_00 ECMWF	20190116_00 - 20190119_00 WRF-ARW	20190116_00 - 20190119_00 ECMWF
Bhola	1.55	0.88	2.65	1.43	2.44	2.26
Cox's Bazar	2.35	1.44	2.92	1.74	3.51	1.41
Chittagong	1.61	1.30	3.19	2.35	2.65	1.59
Feni	1.44	1.01	1.26	1.47	0.84	1.01
Hatiya	2.25	1.28	4.77	2.21	4.43	2.28
Khepupara	1.68	1.03	2.00	1.94	2.51	1.98
Kutubdia	1.54	0.88	1.45	1.48	2.01	1.06
M.court	1.86	0.94	2.90	2.53	1.98	1.10
Mongla	1.40	0.80	1.84	2.24	2.22	2.08
Patuakhali	1.37	0.77	1.18	1.28	1.13	0.55
Sandwip	2.39	1.33	5.99	2.48	5.54	2.48
Satkhira	1.78	1.26	1.43	0.98	1.88	1.11
Sitakunda	1.97	1.64	2.49	2.28	3.10	2.88
Teknaf	1.19	2.02	2.82	1.93	2.28	2.43
AVG_RMSE	1.74	1.18	2.63	1.88	2.61	1.73

Table 7: RMSE of 2m Air Temperature of Northern Part of Bangladesh.

Name	20181216_00 - 20181219_00 WRF-ARW	20181216_00 - 20181219_00 ECMWF	20190102_00 - 20190105_00 WRF-ARW	20190102_00 - 20190105_00 ECMWF	20190116_00 - 20190119_00 WRF-ARW	20190116_00 - 20190119_00 ECMWF
Bogura	1.26	1.17	1.19	1.69	1.28	1.63
Dhaka	0.91	0.91	1.01	2.81	1.56	2.70
Dinajpur	1.93	2.08	1.21	1.24	1.20	1.41
Ishurdi	1.46	1.14	1.41	1.06	1.03	1.16
Mymensing	1.64	1.36	0.84	1.40	1.17	1.18
Rajshahi	1.18	1.26	2.47	1.35	2.40	1.48
Rangpur	1.50	1.61	0.86	1.26	0.99	1.26
Srimongal	1.38	1.13	1.83	2.38	2.07	2.43
Syadpur	1.60	1.42	1.04	1.70	0.90	1.29
Sylhet	1.26	1.98	1.55	2.34	1.42	2.31
Tangail	1.27	1.06	2.10	1.01	1.98	0.84
AVG_RMSE	1.40	1.37	1.41	1.66	1.45	1.61

3.4 2m Air Temperature of Northern Part of Bangladesh

From the Table 5, it was found the performance of GCM and RCM on the Basis of 2m Air temperature's RMSE which was compared with BMD observed data. On the dated from 0000 UTC 16 December 2018 to 0000 UTC 19 December 2018 (CASE-1), 0000 UTC 02 January 2019 to 0000 UTC 05 January 2019 (CASE-2) and 0000 UTC 16 January 2019 to 0000 UTC 19 January 2019 (CASE-3). After observing and analyzing all the three-cases studied, it has revealed that in the respect of all 34 stations over the Bangladesh, the ECMWF global model is better to predict temperature than the WRF v4.3.0 regional model. On the other hand, from the Table 6 where enlisted the RMSE of 2m Air Temperature of Land Ocean Interface stations; it has also declared that the same of the previous. But the Table 7, it has clearly seen that the CASE-1 on the December; ECMWF model has given the lower RMSE than WRF v4.3.0. whereas CASE-2 and CASE-3 on the January, the WRF regional model is simulating temperature better than ECMWF Global model. It is strongly suggested that for the winter, the temperature in the month of January, The Regional Climate Model has better performance to predict temperature over the Northern part of Bangladesh than the Global Climate Model.

4. Conclusions

We carried out a set of 20 experiments using various combinations of physical parameterization schemes in the WRF model to simulate the Bangladeshi winter 2m air temperature. The experiments were designed to select a suitable combination of physical parameterization schemes for simulating the spatial and temporal distribution of the 2m air temperature realistically. The experiments were formulated to test 4 shortwave radiation schemes, 4 longwave radiation schemes, 5 micro physics (Table 1) of 34 stations with the different longitude and latitude over the Bangladesh.
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 winter 2m air temperature over the Bangladesh landmass.
The results of experiments with different microphysics schemes indicate that the WDM6 scheme performs better in simulating the Bangladeshi winter 2m air temperature compared to the Kessler, Purdue Lin, WSM3 and WSM6 schemes. The Kessler 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, RRTMG and New Goddard radiation packages. 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 EXPT17, with the Dudhia shortwave, RRTM longwave, WDM6 microphysics to be suitable for simulating the Bangladeshi winter 2m air temperature realistically. Our work also revealed that the regional model (WRF) is better to predict winter temperature over the northern part of Bangladesh than the Global Climate Model (ECMWF) by using new combinational physical parameterization scheme. Our approach of using a regional model can improve the simulation of intra seasonal variability winter temperature of Bangladesh. We are now planning such a regional model with the combination of EXPT17 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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