CUSTOMIZATION OF WEATHER RESEARCH FORECAST (WRF) MODEL BY CONDUCTING THE NUMERICAL SIMULATION ANDSENSITIVITY EXPERIMENT OF PBL SCHEMES OVER GURUGRAM

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Abstract
The present study has been conducted for analysis the performance of five dissimilar Planetary Boundary Layer (PBL) parameterizations schemes [Mellor-Yamada-Janjic (MYJ), Mellor-Yamada-Nakanishi-Niino (MYNN), Asymmetric Convective Model (ACM2), Yonsei University (YSU) and Quasi Normal Scale Elimination (QNSE)] in the WRF model (version 4.1) over a tropical site Gurugram (28.4595° N, 77.0266° E). January (winter), April (summer), August (monsoon) and November (post monsoon) have been used as season's representative month in the present study according to India Meteorological Department (IMD). The five days (12-17, 2017) in each study month have beencarefully chosen as non-synoptic activity days (clear weather days) for reproduction and identification of vertical variables as well as meteorological variables from WRF with high resolution (3 km in inner most domain) and 31 vertical levels. For the model validation, the meteorological variables observation during the study period collated from near airport station and upper radiosonde observations obtained from University of Wyoming (http://weather.uywo.edu/upperair/sounding.html).After carefully examination, it has been originated that many parameters well performed by YSU and YSU followed by MYJ and ACM2 schemes produced better comparisons with observations.A statistical investigationcreatedby using four different errors methods such as correlation coefficient, mean bias, root mean square and mean bias exposedfinestpresentation of YSU tracked by MYJ and ACM2 schemesfor integrating various vertical thermal structure parameters over Gurugram. Within the restrictions, this study advised that YSU trailed by one non-local ACM2 and one local MYJ schemes PBL turbulent dispersal parameterizations of weather research model are suitable over Gurugram.
[Keywords: WRF model, Boundary Layer, PBL parameterizations, Mesoscale]

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1. Introduction

Ruined of the last few years, fast industrial development and suburbanization near Delhi-
NCR regions has controlled to a significantdilapidation of regional air quality. The correct
exemplification of meteorological variables required the regional air quality modelling with
realistic estimation of the air pollutant dispersion and concentrations. The atmospheric
models are playing the very useful role for simulating and predicting the meteorological large
and small scale circulations (Hanna and Yang, 2001).The schemes of PBL procedures are
very energetic for the progression of lower atmospheric flow-field parameters,surface
atmospheric parameters and different other parameters that distress the dispersion of air
pollutants (Hariprasad et al., 2014, Rahul et al., 2015, 2016, Madala et al., 2019).The impost
of air pollutant by integrating form atmospheric models' treaties with anamount of difficulties
as the influence of vertical besides horizontal and resolutions, and most important that
initialization and schemes of planetary boundary layer (Baker et al., 2013).According to
Chou (2011) and Gego et al., (2005)the vertical and straight and determinations are most
challenging disputes in meso-scale atmospheric models.

The meteorological in-situ observations parameters are lacking in most of the regions in the
world, but it is necessary to require the gridded meteorological data into air quality dispersion
models. Henceforth, produced the gridded parameters of meteorologicalfor quality of air
dispersion models has need to meteorological models. Accordingly, the reservations of the
meteorological model have anundesirableencouragement on results (Sistla et al., 1996;
Kumar et al., 2017) of air dispersion model. Around is notirreplaceable set of PBL schemes
of parameterization choices that could simulate accurately of surface level meteorological
parameters at all grid points in model. WRF model performance depends on model vertical
and horizontal resolution and parameterizations of PBL(Madala et al., 2019; Shrivastava et
al., 2015, Rahul et al., 2017b).Overall, growth in the plane grid tenacity of numerical
modelhas raised the skill to determination the features of topography.

It hasproblematictowarddescribe the plane grid arrangementtrendy mandatetowardaccomplish
a favouredclose of truthfulness. It has estimated the enactment of the WRF model on behalf
of a small period windenergy forecastschemeover Turkey(Tan et al. 2013). It was remarked
that a thicker resolution (3 km) simulated dangerous breeze cases in compression
tosufficient1 km of resolution.Role of the schemes of PBL have emphasized in the various
studies for simulation of the atmospheric flows by applying WRF model (e.g. Floors et al.,
2013; Yang et al., 2013, Madala et al., 2015, Rahul et al, 2016, 2017a). Several current
studies on the tropical regions of India emphasize the character of PBL arrangementship

atmospheric simulations via atmospheric simulation models for the correct demonstration of thermodynamic vertical structure and meteorology (Singh et al. 2015, Madalaet al., 2017, 2019; Preeti and Manju, 2017).In Nagpur city, WRF model sensitivity experiments of various PBL schemes have been conducted by Rahul et al. (2016) and conclude that numerical model (WRF) can internment the native scale movementarena and the special position of meteorological variables over Nagpur. In the Indian region, proximate are comparativelyrestrictedrevisions on the recital of WRF model (Srinivas et al. 2007, Madalaet al., 2014, 2017, Rahul et. al., 2016, 2017b).In employment WRF inspected the urban area of Singapore with a single-layer urban canopy model and identified that anthropogenic heat played a significant role in relative humidity (RH), temperature, surface runoff, boundary layer elevation by Lee et al. (2013).

After the collected works review, the situation is believed that revisionsscheduled the sensitivity experiment of different PBL schemes of WRF model or other atmospheric modeling for surface horizontal vertical meteorological parameters are restricted in the central part of India. Currently, the PBL scheme of the WRBL model in Gurugram has been used to investigate the sensitivity and surface meteorological variables. The goal of this study be present to estimate the enactment of WRF model for integrate boundary level meteorological parameters with five different PBL schemes that test sensitivity.

2. Study region

Gurugram (28.4595° N, 77.0266° E) is largest city in located in the northern Indian state of Haryana and near the capital of India Delhi. Gurugram is the fast growing metropolis and most populous city in Haryana and the centre for industrialization, development, commercial activity and urbanization. The total area of Gurugram is 738.8 square kilometres. Under the Köppen climate classification, Gurgaon experiences a monsoon-influenced overall climate. Summers, from early April to mid-October, are generally hot and humid, with an average daily high June temperature of 40 ° C. The keys of the heat easily feel breaking 43 degrees Celsius. Winters are cold and foggy with few days of sunshine.Western disturbances bring some rain in winter which further increases the cold. Spring and autumn are mild andpleasant seasons with low humidity. The monsoon season usually starts in the first week of July and continues till August. Thunderstorms are not uncommon during the monsoon. Average annual rainfall is about 714 millimetres(IMD 2016).

3. Data and methodology

3.1 Data and study period

The obtainableobservation parameters of meteorological such as wind direction (WD) and wind speed (WS) at 10 m height, the temperature and relative humidity (RH) at 2 m height have beenacquired from the IMD for Gurugram. Obtainable upper air observations of radiosonde residing of WD(degree), WS(ms^{-1}), RH (%) and theta (K), gained from the University of Wyoming (http://weather.uywo.edu/upperair/sounding.html), are charity for authentication of the vertical thermal structure over Gurugram. Atrri and Tyagi (2010) propose as per IMD arrangement, the same arrangement has been used some other researchers (Boadh et al. 2016, Madala et al. 2014 etc.) according to them there are four

altered seasons are categorized as post-monsoon (October, November), winter (December, January and February), summer or pre-monsoon (March, April and May) and monsoon (June, July, August and September). Based on the previous study and suggested by Atrri and Tyagi (2010), in this study, January and April (representing winter and summer season respectively), August and November (representing the monsoon and post monsoon season respectively). For every month, the simulations are complemented for six clear weather days (11-17). For each month, simulations are conducted for six fair weather days (11-17) during which is not rainy day.The designated dates (11-17) for simulations of the WRF model were assimilated for a started 12 UTC on 11 January 2017 to 24 UTC 17 January 2017, 12 UTC on 11 April 2017 to 24 UTC 17 April 2017, 12 UTC on 11 August 2017 to 24 UTC 17 August 2017, 12 UTC on 11 November 2017 to 24 UTC 17 November 2017 the total hours of simulated is 132 h. Total 20 simulations for 120 have been completed in the present study.

3.2 Mesoscale model

In the present study, over Gurugram, WRF vs. 3.8, is used to simulate local-scale flow of meteorological variables and PBL characteristics on a 3-D non-hydrostatic atmospheric meso-scale model. Features of the ARW model include hydrostatic choices, absolute carols and curvature conditions, two-way nesting, fully compressed non-hydrostatic equations with map-scale factors,Arkawa C-grid for horizontal, Runge-Kutta 2nd and 3rd order for time integration, 2nd to 6th order optimization options for planetary boundary, atmospheric and surface radiation, microbiology, convection and land surface options.Detailed descriptions of equations, model physics and dynamics are accessible in Skamarock et al. (2008). The WRF model has many options for atmospheric physics such as cumulative convection, boundary layer turbulence, radiation, ground surface processes, etc.In various model physics, land surface parameters and PBL turbulence are important in the simulation of meso-scale phenomena (Berg and Zhong, 2005; Zhong et al., 2007) and thus simulate the air quality of winds and PBL height (Pleim, 2007 and Perez et al., 2006).

3.3 Model Configuration and Initialization

Horizontal and vertical resolutions are important factors in modelling of minorlevel atmospheric incidences.Chou, 2011 and other authors Mass et al., 2002; Gego et al., 2005 have been described the high-resolution consequences in additionaldetailed, betterdetermined, small-scale progressions, itsintensifications the model integration costs in their studies.The three nested gridded domain (27, 9 and 3 km) and 31 vertical sigma levels have been designed in WRF model during this study, over Gurugram (Fig. 1). The inner most domain (d03), second inner domain (d02) and the outer domain (d01) with the resolution 3, 9 and 27 km respectively 112 X 112 grids, 91 X 91 grids and 60 X 60 grids sizes respectively. The resolution 1 ° X 1 ° of final analysis (FNL) data for the boundary and initial conditions in model was adjusted. The configuration of WRF model described in table 1.
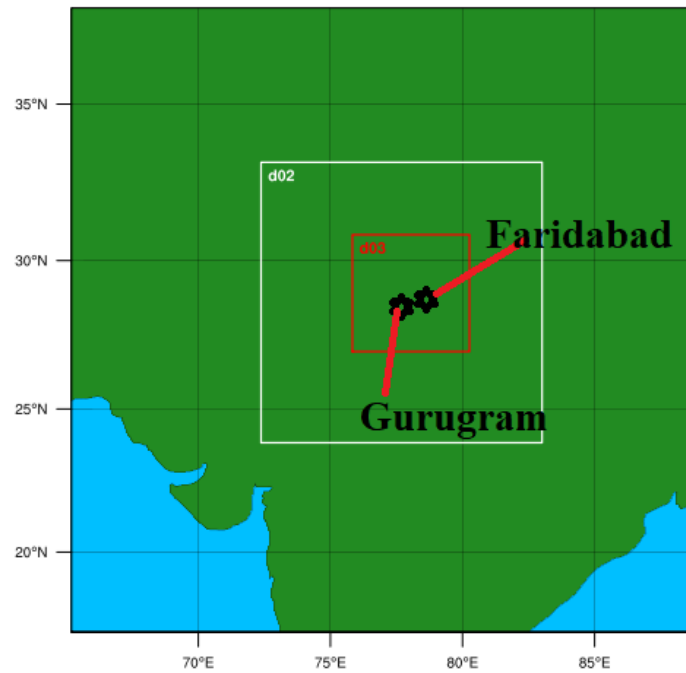
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Figure1. Three Nested grid domains used in WRF

Table1. The configuration and overview of WRF model over

Dynamics	Non hydrostatic
Data	NCEP FNL
Covered area	15.8º-38.6º N and 65.1º-89.4º E
Surface layer Parameterization	Noah land Surface Scheme (Chen and Dudia, 2001)
Short wave radiation	Dudhia scheme (Dudhia, 1989)
Cumulus Parameterization	Kain-Fritsch scheme (Kain, 2004)
Microphysics	Eta microphysics (Ferrier et al., 2002)
Long wave radiation	RRTM scheme (Mlawer et al., 1997)
Resolution	Domain3: 3km × 3km, Domain2: 9km × 9km,Domain1: 27km × 27km,
Spatial differencing scheme	6th order center differencing
Interval	6 hrs
Map Projection	Mercator
Vertical coordinates	Terrain-following hydrostatic pressure vertical co-ordinate with 31 vertical levels
Grid size	Domain3: (112× 112) × 31, Domain2: (91× 91) × 31, Domain1: (60× 60) × 31,
Time integration scheme	3rd order Runga-Kutta Scheme
Integration time step	90 sec
PBL Scheme	1) YSU (Hong et al., 2006), 2) QNSE (Sukoriansky et al., 2005), 3) ACM2 (Pleim, 2007) 4) MYJ (Janjic, 2002) and 5) MYNN2 (Nakanishi and Niino, 2004)
Horizontal grid system	Arakawa-C grid

3.4 *PBL sensitivity experiments*

In the lower part of the atmosphere,the wind, simulation of the turbulence, land surface influence the PBL parameterizations and other variables. Five different PBL parameterizations schemes, such as; three native turbulence kinetic energy (TKE) closer Mellor-Yomada-Janjic [MYJ][Janjic, 2002], (Quasi-normal scale elimination [QNSE] [Sukoriansky et al. 2005] and NiinoLevel 2,5 PBL [MYNN2][Nakanishi and Niino, 2004], Asymmetric Convective Model v. 2 [ACM2][Pleim, 2007]) and [Yonsei University [YSU][Hong et al., 2006] are two non-local schemes are used in the present study. For convective parameterization Kain–Fritsch scheme (Kain, 2004) used because in this scheme model physics opportunities applied. The detailed of PBL parameterization schemes provided by Hariprasad et al. (2014) and Kleczek et al. (2014).Several recent studies emphasize the role of the PBL parameterization in atmospheric flow-field simulations (e.g. Rahul et al., 2015, 2016; Madala et al, 2015, 2019; Hariprashadet el., 2014; Xie et el., 2012; Shin and Hong, 2011).

3.5 Statistical Evaluation and Validation of Model

The Surface meteorological variables generated by model such as Wind Direction (WD) at 10 m, Wind Speed (WS) at 10 m, relative humidity (RH) at 2 m, air temperature (AT) at 2m above ground leveland wind speed, wind direction, potential temperature theta (T), relative humidity (RH) vertically during the study (for illustrative days of all seasons used in this study such as winter, summer, monsoon and post monsoon)are validated with the available meteorological as well as radiosonde observations. The qualitatively and quantitatively study both results are compared for both surface meteorological parameters as well as thermodynamical structure of the atmosphere in this study.For Quantitative comparisons of results correlation coefficient (CC) (Wilks, 2011), mean absolute error (MAE), root mean square error (RMSE) and Mean bias (MB) are used in present study.

4.Results and Discussion

4.1 Meteorological parameters of surface level

In the present section, the diurnal variant of meteorological parameters of surface level such as WD (º), WS (ms-1), AT (ºC) and RH (%) alongside through in situ observations at hourly interval are interoperated performance of innumerable PBL parameterization schemes in numerical simulating by WRF model over Gurugram station.

4.1.1 Wind direction and wind speed

Wind speed and wind direction are estimated by combined frequency dispersion plots and are therefore called wind roses.The models generating WS and WD as wind roses are associated with observations for wholly study days throughout January, April, August and November 2017.The windroses organizedcomposedintended for all five study days for January, April, August and November 2017 and compared with the observation in figures 2, 3, 4 and 5 respectively.
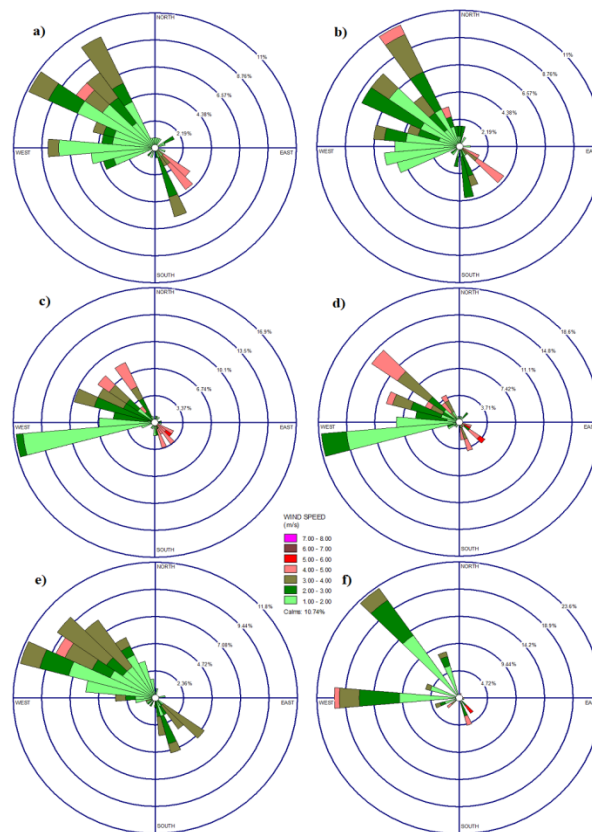
Fig.2: Wind roses simulated form different schemes of PBL of WRF model a) YSU, b) ACM2 2, c) MYJ, d) QNSE, e) MYNN2, with f) Observations, during January 2017 over Gurugram.

In January 2017, it is clearly seen that the observed wind roses (Fig. 2f) mostly blowing from westerly and north-westerly. YSU (Fig. 2a) and MYJ (Fig. 2c) is showing the almost similar pattern but in less magnitude. ACM2 (Fig. 2b) and MYNN2 (Fig. 2e)is showing that wind is blowing in north-westerly but in less magnitude and QNSE (Fig. 2d) showing that is blowing form northwest direction but in high magnitude as compared to the observation and other model simulated schemes. QNSE manufactured high wind speed (5-6 ms^{-1}) from south-east and west-west south direction and MYJ (4-5 ms^{-1}) form south-south east direction as compared to rest of the PBL scheme (YSU, MYNN2 and ACM2) in north to west direction, south and northwest direction respectively in the month of the January 2017. The high wind speed (7-8 ms^{-1} and more than 8 ms^{-1}) captured by MYJ (Fig. 3c) and QNSE (Fig. 3d) in April 2017 (Fig. 3) from northwest and northwest north side. The similar patterned with observation (Fig. 3f)predicted by the YSU (Fig. 3a) followed by ACM2 (Fig. 3b) and MYNN2 (Fig. 3e) in slightly high magnitude (6-7 ms^{-1}) as compared to observation (6-5 ms^{-1}).

Fig.3:Wind roses simulated form different schemes of PBL of WRF model a) YSU, b) ACM2 2, c) MYJ, d) QNSE, e) MYNN2, with f) Observations, during April 2017 over Gurugram.

In August (Fig. 4), high wind speed (more than 8 ms^{-1}) predicted by the MYJ (Fig. 4c) and QNSE (Fig. 4d) form west west-southerly and west-southerly. It has been observed wind roses (Fig. 4f) mostly blowing form west and south-westerly in slightly high magnitude (5-6 ms^{-1}). The model predicated wind roses by MYNN2 (Fig. 4e) captured in almost throughout domain in less magnitude in the comparison to the other schemes of PBL. YSU (Fig. 4a) and ACM2 (Fig. 4b) predicted wind roses slightly followed the similar patterned as compared to the observation but in the different magnitude.

Fig.4. Wind roses simulated form different schemes of PBL of WRF model a) YSU, b) ACM2 2, c) MYJ, d) QNSE, e) MYNN2, with f) Observations, during August 2017 over Gurugram.

In November month the wind roses have been shown in Fig.5. Observed wind roses (Fig. 5f) less in the magnitude (2-3 ms^{-1}) blowing form east direction and (3-4 ms^{-1}) blowing form east east-southerly. Slightly high wind speed (5-6 ms^{-1}) has been simulated by MYJ (Fig. 5c) and QNSE (Fig. 5d) PBL schemes in almost same direction as compared to observation. YUS (Fig. 5a) followed by ACM2 (Fig. 5b) and MYNN2 (Fig. 5e) with the same pattern and almost same magnitude (2-3 ms^{-1}). According to the previous work reported by earlier work (e.g. Rahul et al., 2016, Madala et al., 2015, Hariprasad et al., 2014 and Zhang et al., 2013) that overestimation of the winds seem like be a common practice with weather research forecast model. In wide-ranging, non-local schemes YSU and ACM2, the local scheme MYNN2 were able to slightly similar wind condition with observation as compared to the rest of the schemes MYJ and QNSE during the all study months January, April, August and November.
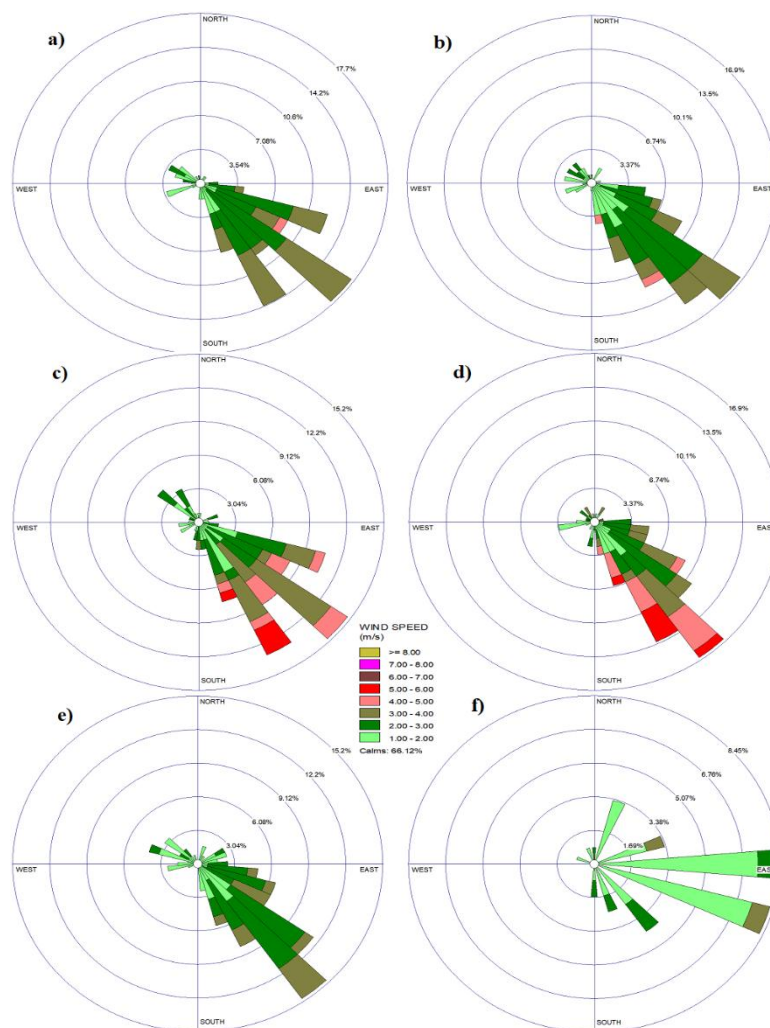

Fig.5. Wind roses simulated form different schemes of PBL of WRF model a) YSU, b) ACM2 2, c) MYJ, d) QNSE, e) MYNN2, with f) Observations, during November 2017 over Gurugram.

The overestimation of winds by the weather research forecast model may be due to tempted turbulence strength and accredited to the non-accurate remedy of surface roughnessin the atmospheric shallow layer.It has also seen that one local PBL scheme MYNN2 and two non-local schemes YSU and ACM2 formed better PBL structures over Ranchi (Madala et al. 2015). Rahul et al., (2016) have also identified the local PBL scheme MYNN2 tracked non-local scheme YSU are appropriate schemes over Nagpur. Based on the qualitative evaluations, the YSU and ACM2 are followed by MYN2 predicted the better wind flow as compared to the rest of the schemes.
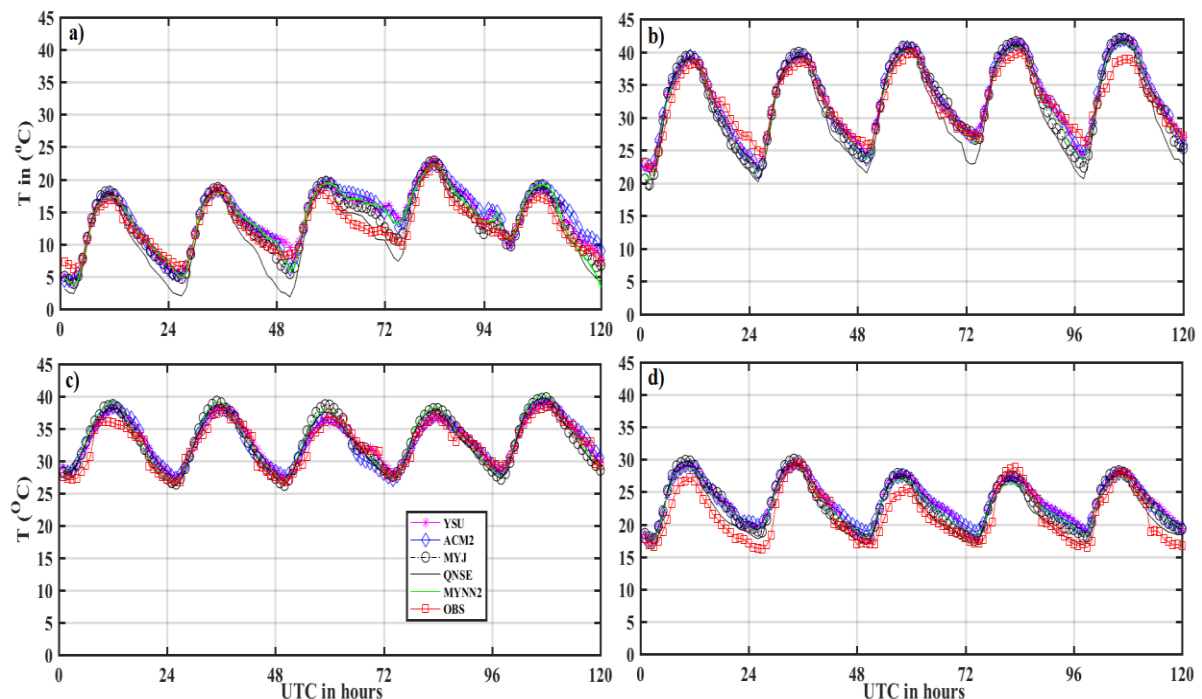
4.1.2 Air temperature

Fig.6. The diurnalvariation of temperature (ºC) of all five PBL scheme with available observation during a) January 2017, b) April 2017, c) August 2017 and d) November 2017 over Gurugram.

The diurnal variation of model simulated air temperature (AT) along with the existing observation for all season represented months (e.g. January for winter, April for pre-monsoon, August for monsoon and November for post monsoon) have been shown in the Fig. 6. The model simulated AT have cold bias (i.e., observation-model<0) and MYNN2 followed by QNSE largest bias during January (Fig. 6a). The PBL schemes MYJ is closer to the observation and followed by YSU and ACM2 schemes. The AT simulated by studied PBL schemes with available observation during April has been shown in Fig. 6b. It has been observed MYJ is the closer to the observation and followed by YSU and ACM2 schemes. During April (Fig. 6b) cold bias have been observed and QNSE followed by MYNN2 largest cold bias during April. During the monsoon period the warm bias (i.e., observation-model>0) have observed and almost all schemes are closer to the observation during August (Fig. 6c). MYJ followed by YSU and ACM2 and showing the slightly warm bias and MYNN2 followed by QNSE slightly cold bias during monsoon month. The cold bias has been

identified during the post monsoon month (Fig. 6d). The air temperature has simulated by YUS followed by the ACM2 shown the largest cold bias at night time.
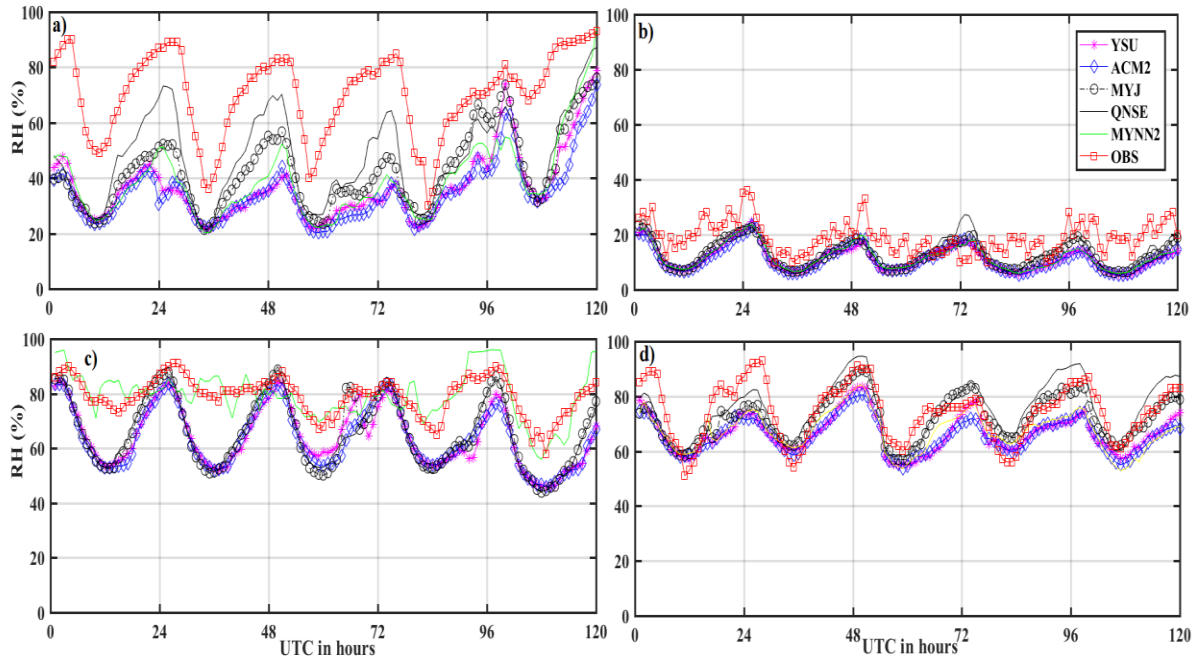

Fig.7. The diurnal variation of relative humidity (%) of all five PBL scheme with observation during a) January 2017, b) April 2017, c) August 2017 and d) November 2017 over Gurugram.

MYJ followed by QNSE are closer to the observation as compared to the other used schemes. Overall grounded on the adjacent analysis, throughout the daytime, almost all schemes of PBL are in decent arrangement with the available observation. Bonus cold bias observed with the simulations using MYNN2 and QNSE during night with the comparison of the simulated schemes. The similar results same as in present study have been identified over Nagpur by Rahul et al., (2016) and over Ranchi by Madala et. al., (2015). On close investigation, it has been noticed that non-local schemes YUS and ACM2 and local scheme MYJ simulate air temperature practically fine.

4.1.3 Relative Humidity (RH)

The day to day variation of relative humidity (RH) during the all months represent the different months for represented seasons (e.g. January represent for the winter, April represent for the pre-monsoon, August represent for the monsoon and November represent for the post monsoon) have been shown in the Fig. 7. Underestimation of relative humidity is observed by the most PBL schemes, but model simulated PBL schemes were capable to capture the paralleltendency of the diurnal variation of RH as comprehendedtrendy the observationthroughout the study period. The warm bias has been observed by all the PBL schemes in January (Fig. 7a). The local schemes QNSE and MYJ are closer to the

observation as compared to the other schemes. That oneexistsnoticeablyunderstood in the Fig. 7b, the RH during April is low as compared to the other study months it could be due to hot and dry during summer in Gurugram. All simulated PBL schemes are closer to each other and warm bias observed during April. In, August (Fig. 7c) the RH varies from 50% to 95% and cold bias observed with MYNN2 schemes and warm bias observed with rest of the schemes.ACM2 followed by the local scheme MYJ produced reasonable estimation of RH as paralleled to further schemes (QNSE, MYNN2 and YSU) during August. The warn bias and cold bias observed during day time and night time respectively of RH in post monsoon month (Fig. 7d) over Gurugram. The local scheme QNSE captured the reasonably well RH and followed by MYJ. The non-local schemes YSU and ACM2 shown slightly warm bias during the November and followed by MYNN2. In general, non-local scheme ACM2, YSU and one local scheme MYJ predicted the reasonably well ofdiurnal variation of RH as compared to the further schemes. The higher magnitude has been shown of RH simulated by the QNSE as associatedwith other schemes. Cold bias has identified with QNSE due to over estimation of relative humidity. Rahul et al., (2016)shown over Nagpur and Madala et al., (2015) over Ranchi reported similar type of results.

4.2 Atmospheric thermodynamical structure

In this section, the vertical structure profiles of RH (%), Theta (degree), Wind direction (degree) and wind speed (ms^{-1}) derived from altered PBL schemes alongsidethroughobtainable observations of radiosonde. Department of Atmospheric Science, University of Wyoming site used for obtaining the observation data of radiosonde. The observations of radiosonde are available at 00:00 UTC this is only limitation of the present study.

For the sake of the permanency, the present results for one day (13 January 2017) for winter representing month (Fig.8), one day (13 April 2017) summer representing month (Fig. 9), one day (13 August 2017) monsoon representing month (Fig. 10) and one day (13 November 2017) post monsoon representing month (Fig. 11) have been shown over Gurugram. The relative humidity, wind speed, theta and wind direction integrated by dissimilar PBL schemes of model with accessible radiosonde observation at 00 UTC have been shown in Fig. 8, 9, 10 and 11 respectively.The relative humidity in the winter season varies from 20% to 80% in the lower part of the atmosphere up to 2000 m (Fig. 8a), for summer the smaller magnitude (15% to 25%) of relative humidity (Fig. 9a) has been captured by the model PBL schemes, but in the monsoon season the variation of the relative humidity form 55% to 95% seen by model simulated PBL schemes (Fig. 10a) in the lower part of the atmosphere (up to 2000 m), the variation form 25% to 40% of RH (Fig. 11a) has been captured by model simulated PBL schemes during post monsoon season.
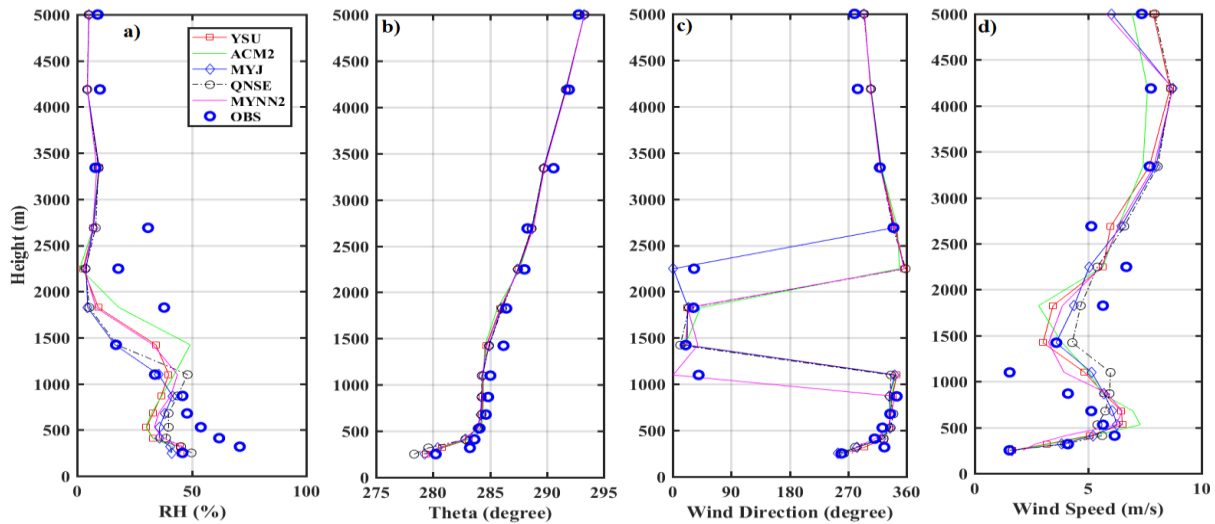
Fig. 8: Thermal structure profiles of vertical parameters by model simulated (a) relative humidity, (b) theta (degree), (c) wind direction (degree) and (d) wind speed (ms^{-1}) form all different PBL schemes with radiosonde observations on at 00UTC over Gurugram on 13 January 2017 (winter).

In general, the relative humidity captured by MYJ and YSU both are local non-local schemes respectively and follow by MYNN2 in good agreement with the observation in the winter season, but in the other season all PBL schemes well captured of similar trend of the RH as seen in observation. The potential temperature theta (degree K) of all seasons is represented in Fig. 8b, 9b, 10b and 11b respectively. In winter month, the model simulated PBL schemes YSU and MYNN2 is the closer to the observation in the lower part of the atmosphere at 250 m and MYJ and QNSE is slightly less as compared to other simulated schemes (Fig. 8b). In summer represented month the theta is in good agreement with the observation in lower atmosphere (Fig. 9b). All model simulated schemes are closer to each other and showing the same trend as seen in observation but in different magnitude.
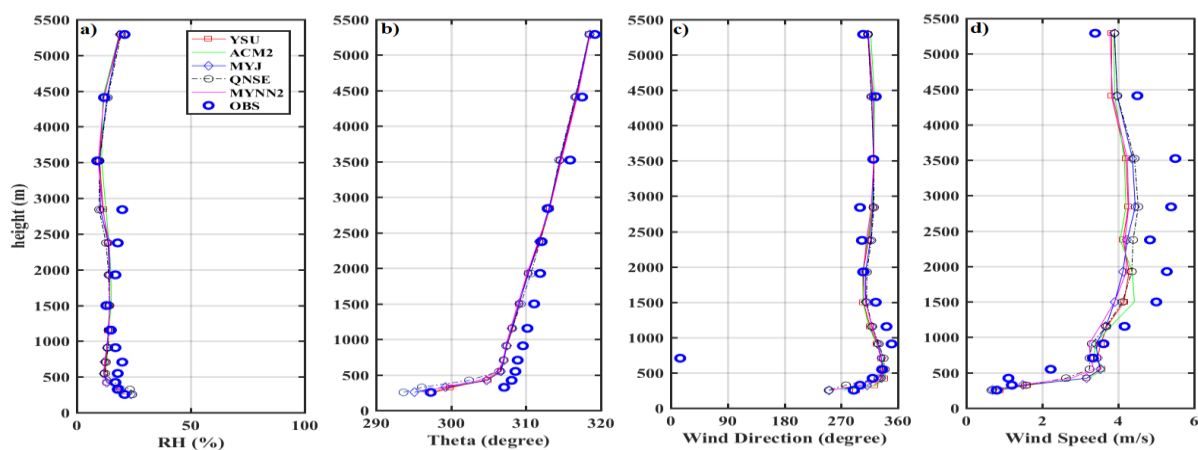

Fig. 9:Thermal structure profiles of vertical parameters by model simulated (a) relative humidity, (b) theta (degree), (c) wind direction (degree) and (d) wind speed (ms^{-1}) form all different PBL schemes with radiosonde observations on at 00UTC over Gurugram on 13 April 2017 (summer).

In lower part of the atmosphere nearly 240 m, all schemes are closer to the observation except MYNN2 during Monsoon month (Fig. 10b). But 1000 m height to 3000 m height model sublimated scheme MYNN2 captured similar trend as observation as associated to the remaining schemes of PBL (YSU, ACM2, QNSE and MYJ). Model simulated PBL schemes in post monsoon month (Fig. 11b) are shown the same pattern of the theta but in slightly different magnitude in the lower part of the atmosphere. In the rest part of the PBL height the theta integrated by the model are in decent arrangement with the observation and shown the similar trend as seen in the observation. The vertical variation of the wind direction (degree) over Gurugram have been shown in the Fig 8c, 9c, 10c and 11c during January, April, August and November month respectively. Winds are blowing from west northerly direction in the lower part of the atmosphere 250-800 m during January (Fig. 8c).The most of the wind found in north easterly direction at 1000-2250 m by the entire model simulated PBL schemes and observation. Model could able to captured the same trend as seen in observation at 800-2600 m but slightly different magnitude even though it's very difficult to capture the same pattern as observation by WRF model (Madala et. al., 2013, 2015, Rahul et al.,2016).
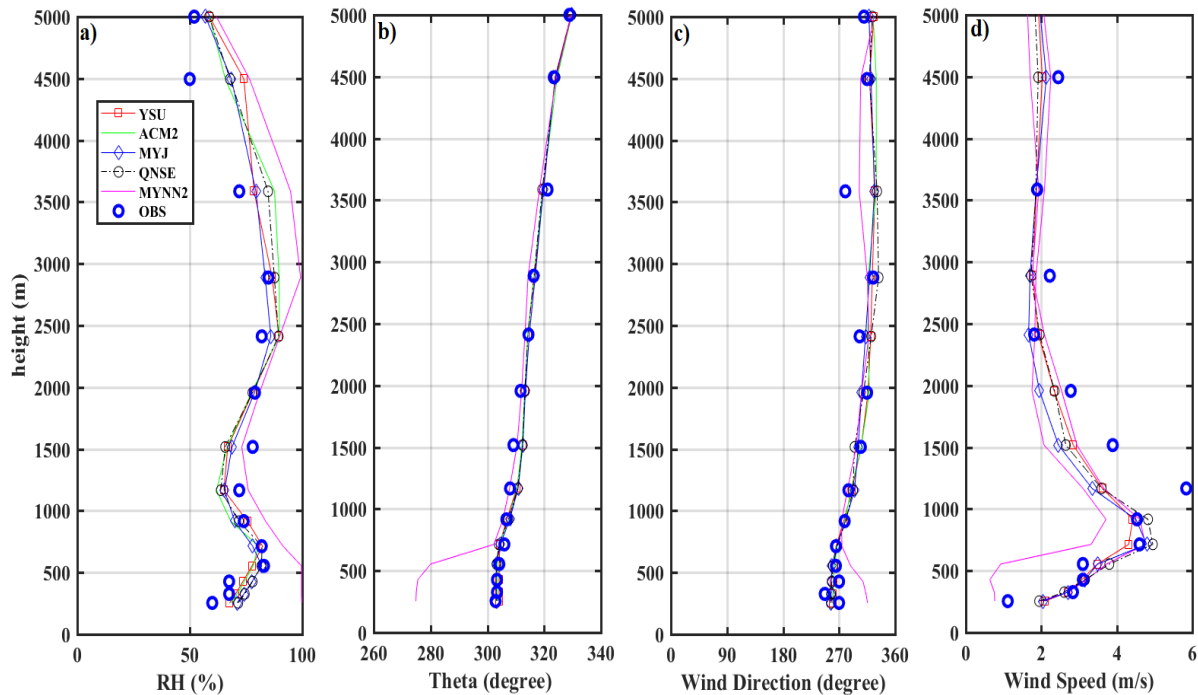

Fig. 10: Thermal structure profiles of vertical parameters by model simulated (a) relative humidity, (b) theta (degree), (c) wind direction (degree) and (d) wind speed (ms^{-1}) form all different PBL schemes with radiosonde observations on at 00UTC over Gurugram on 13 August 2017 (monsoon).
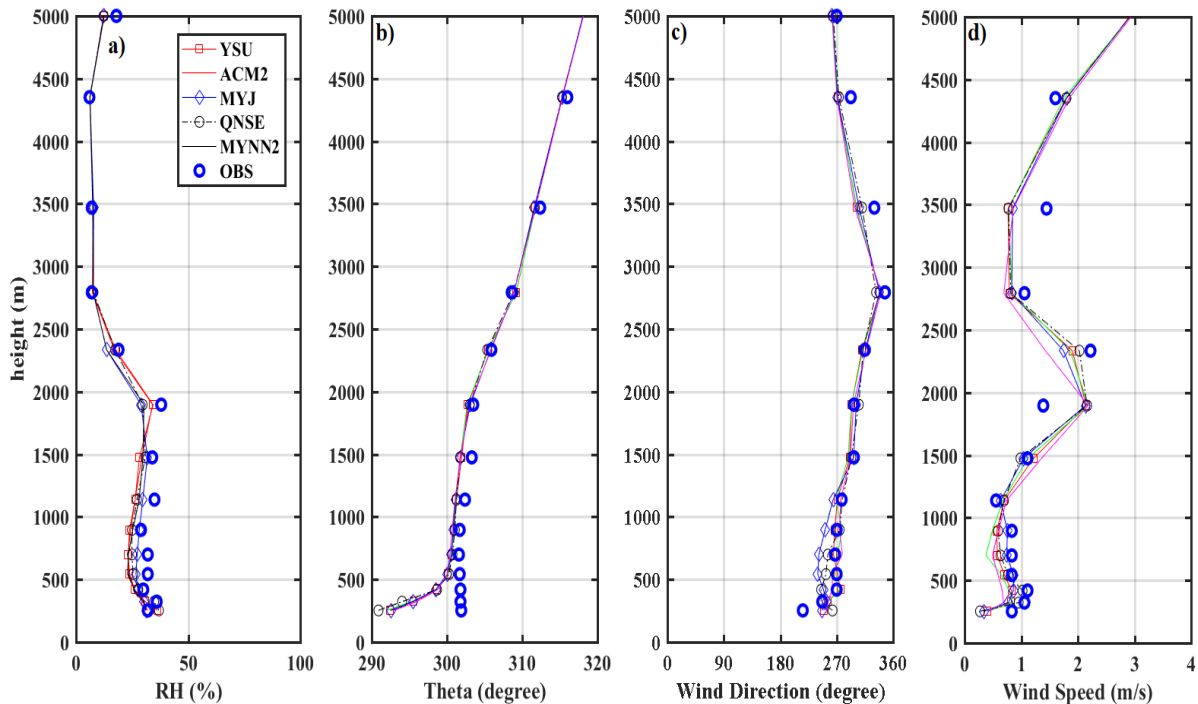
Fig. 11:Thermal structure profiles of vertical parameters by model simulated (a) relative humidity, (b) theta (degree), (c) wind direction (degree) and (d) wind speed (ms^{-1}) form all different PBL schemes with radiosonde observations on at 00UTC over Gurugram 13 November 2017 (post monsoon).

During April (Fig. 9c), model could not able to captured same trend as seen in observation at nearly 700 m height its slightly different because model simulated wind direction captured in north west northerly and consecrated wind direction in east east-northerly direction.Otherwise model simulated local (MYJ, QNSE and MYNN2) and non-local (YSU and ACM2) schemes are well captured the same trend as observation. Winds found westerly observed and model simulated PBL schemes at 250 m height in August (Fig. 10c) but MYNN2 simulated wind direction found in northwesterly. After this height all simulated schemes captured similar pattern as observation in almost same direction but in slightly different magnitude. In post monsoon month (Fig. 11c), ACM2 and YSU schemes both are non-local schemes are in better arrangement with the observation as associated to the other schemes (MYJ, MYNN2 and QNSE) in the lower part of the atmosphere at 260-1200 m height.After 1200 m height, model simulated PBL and observed winds found in west northerly. The wind speed (ms^{-1}) simulated by the model PBL schemes along with the observation have been shown in Fig. 8d, 9d, 10d and 11d at 00 UTC in January, April, August and November over Gurugram. In winter, wind speed varied 2-7 ms^{-1} in the lower atmosphere from 250-500 m (Fig. 8d). Model simulated wind speed followed the similar pattern as observed wind speed but slightly different magnitude. It has been also observed in January model PBL scheme YSU and MYNN2 could able to capture the similar pattern as seen in observation as compared to the rest of the schemes. The wind speed varies to 1-5 ms^{-1} and ACM2 followed by YSU and QNSE to capture the same trend as observation in summer (Fig. 9d). In monsoon month, MYNN2 has shown the low wind speed as compared to the rest

of the schemes but closer to the observation in the lower part of the atmosphere at 250 m height (Fig. 10d). Wind spend is simulated by the model is similar pattern to the observation but in different magnitude found at 1000-2000 m. In post monsoon month (Fig. 11d), all model simulated schemes of PBL are in decent arrangement through the observation but in different magnitude found in lower part of the atmosphere at 250 m height. MYJ and YUS are closer to the observation as compared to the rest of the schemes during post monsoon period.

After analysis of vertical profiles of RH, Theta, wind direction and wind speed expose a clear-cut variation during the study period. The PBL schemes used in this study are well simulate the all the features with very few differences. After qualitatively analysis based on the present study, it has been observed that in lower part of the atmosphere the vertical PBL thermodynamical structure rationally well simulated by non-local schemes YSU and tracked by AMC2 and MYJ schemes as compared with the rest of the PBL schemes over the Gurugram reason.

4.3 Error statistics of surface meteorological and vertical structure variables of atmosphere

The Statistical error is calculated between observed and simulated surface meteorological parameters i.e. Wind speed, air temperature, wind direction and relative humiditycovered all seasons shown in Table 2. The mean bias, correlation coefficient, mean absolute error and root mean squire error have been calculated for the above mention parameters during the study period. The model integrated are slightly dispersed around observations for AT, RH and broadly dispersed for wind speed representative better simulation of thermo-dynamical measures than the winds.

Table 2: Statistical Analysis of surface meteorological parameters (T, RH, WS and WD)

Parameter	Errors	YSU	QNSE	MYNN2	MYJ	ACM2
Temperature (^{O}C)	MB	0.87	1.47	0.92	1.46	1.1
	MAE	0.91	1.48	0.97	1.45	1.12
	RMSE	0.95	3.54	2.14	1.75	1.25
	CC	0.90	0.67	0.76	0.94	0.88
RH (%)	MB	3.81	-12.43	-10.04	4.44	2.16
	MAE	1.90	2.10	3.83	1.25	3.19
	RMSE	8.23	13.41	11.54	10.66	9.98
	CC	0.35	0.43	0.46	0.35	0.41
Wind Speed (ms^{-1})	MB	-2.37	-8.71	-6.09	-5.51	-5.87
	MAE	4.21	6.84	9.35	3.52	5.84
	RMSE	2.63	2.78	3.05	1.95	2.08
	CC	0.67	0.38	0.56	0.75	0.76

Wind Direction (degree)	MB	-10.23	-41.20	-38.37	-25.09	-12.34
	MAE	4.36	6.98	10.21	5.86	8.02
	RMSE	1.76	3.41	6.98	2.98	3.98
	CC	0.44	0.25	0.38	0.48	0.44

Non-local schemes YSU and ACM2 are relatively highly correlated for temperature and relative humidity and for wind speed and wind direction the QNSE and MYJ are highly correlated. The mean observed temperature during January is perceived as 14 $^{\circ}$C, 32 $^{\circ}$C in April, 30 $^{\circ}$C in August and 20°C in post monsoon month (November). The cold bias has been found with the all PBL schemes in AT with non-local PBL schemes YSU and ACM2 followed by MYJ are calculated higher in correlations and less in other errors.

Table 3: Statistical Analysis of Vertical thermodynamics Parameters

Parameter	Errors	YSU	QNSE	MYNN2	MYJ	ACM2
RH (%)	MB	-0.23	-0.65	-0.67	-0.30	-0.45
	MAE	1.60	1.78	1.52	1.69	1.71
	RMSE	1.28	2.44	3.18	3.36	3.37
	CC	0.84	0.64	0.76	0.89	0.88
Potential Temperature (K)	MB	0.45	0.63	0.47	0.57	0.63
	MAE	1.79	2.87	2.25	1.69	1.72
	RMSE	1.68	3.89	3.54	3.57	3.60
	CC	0.90	0.65	0.59	0.86	0.88
Wind Speed (ms^{-1})	MB	-1.17	-3.74	-5.51	-2.42	-4.35
	MAE	2.17	3.20	2.63	1.67	2.15
	RMSE	2.63	2.78	3.05	1.95	2.08
	CC	0.90	0.88	0.86	0.88	0.89
Wind Direction (degree)	MB	-1.23	-1.57	-1.64	-1.37	-1.19
	MAE	0.46	1.80	1.94	0.54	1.60
	RMSE	0.75	1.34	1.01	0.93	0.99
	CC	0.98	0.89	0.77	0.91	0.92

QNSE and MYNN2 are shown the humid bias and ACM2 followed by YSU and MYJ for showing dry bias for humidity. The YSU, ACM2 and MYJ shown the less RMSE error (~9.98) as compared to the rest of the schemes and during the study period the 57.23% mean The mean observed wind speed 1.87 ms^{-1} is noted during the all study months and all PBL schemes shown the mean cold bias. MYJ, ACM2 and YSU are showing the less RMSE error (~2.08) and ACM2 and MYJ are showing good correlation and followed by YSU as associated with the remaining schemes. The model simulated mostly PBL schemes might unable to captured the wind direction all schemes are shown the higher cold mean bias but YSU, MYJ and ACM2 shown the less RMSE as compared to the other schemes and MYJ is in good correlation with the compassion to the other PBL schemes. The statically analysis like root mean square error, mean bias, correlation coefficient and mean absolute error between observed and simulated vertical profile of wind speed, relative humidity, potential temperature and wind direction using five diverse PBL schemes have been shown in table 3, observed humidity is noted.

It is clearly seen in the table 3, all PBL schemes produced cold mean bias in relative humidity, wind speed and wind direction (i.e., model-observation<0). Overall, it has been investigated from the statically errors that ACM2 followed by YSU and MYJ are in decent arrangement with the observation in the comparison of the remaining schemes (QNSE and MYNN2) to simulate the surface parameters of meteorology as well as vertical thermodynamically structure.

4. Summary and conclusions

In the present study, the advanced weather research forecast model (WRF) could imprisonment the lower atmospheric flow filed and location-explicit meteorological variables at Gurugram region with five different PBL schemes with realistic variances for the application of air quality studies. The numerical integrated simulations show broadly changeable flows in air temperature, relative humidity, wind speed and wind direction in four different seasons (according to IMD) would be impact on air pollutant sources near around Gurugram reason. Between the different planetary boundary layer parameterizationAMC2 followed by the MYJ and YSU for integrated the closer the AT, RH and wind speed (in the form of wind roses in all the seasons. The ACM2, YSU and MYJ are with the better agreement in the representation of the vertical thermal parameters in all the study seasons. The statistical analysis of meteorological and vertical parameters discovered best performance of YSU and MYJ followed by the ACM2 over the Gurugram region.

Within the reflectionconstrictions, the present study advocates that YSU followed by MYJ and ACM2 PBL schemes of WRF model are proper over the study region.

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6. References

1. and Air Quality Research, 17, 1825–1837.

Attri, S.D., Tyagi, A., 2010. Climate Profile of India. Met Monograph No. Environment Meteorology-01/2010. Government of India, Ministry of Earth Sciences, India Meteorological Department.

Baker, K.R., Misenis, C., Obland, M.D., Ferrare, R.A., Scarino, A.J., Kelly, J.T., 2013. Evaluation of surface and upper air fine scale ARW meteorological modeling of the May and June 2010 CalNex period in California. Atmos. Environ. 80, 299e309.

Berg, L. K., and Zhong, S. Y. (2005), Sensitivity of MM5-simulated boundary layer characteristics to turbulence parameterizations, Journal of Applied Meteorology and Climatology, Vol. 44, pp. 1467-1483.

Chen F. and J. Dudhia, 2001. Coupling an advanced land-surface/ hydrology model with the Penn State/ NCAR MM5 modeling system. Part I: Model de- scription and implementation. *Mon. Weather Rev.* 129, 569-585.

ChouS.H.,2011.Anexampleofverticalresolutionimpact on WRF-Var analysis. *Electron. J. Oper. Meteorol.* 12, 1-20.

DudhiaJ.,1989.Numericalstudyofconvectionobserved during the winter monsoon experiment using a me- soscale two-dimensional model. *J. Atmos. Sci.* 46, 3077-3107.

Ferrier, B.S., Lin, Y., Black, T., Rogers, E., and DiMego, G. (2002), Implementation of a new grid-scale cloud and precipitation scheme in the NCEP Eta model. In: Proceedings of the 15th Conference on Numerical Weather Prediction; San Antonio, Tex, USA, American Meteorological Society, pp. 280–283.

Floors, R., Vincent, C.L., Gryning, S.E., Pena, A., Batchvarova, E., 2013. The wind profile in the coastal boundary layer: wind lidar measurements and numerical modelling. Bound-Lay Meteorol. 147 (3), 469e491.

Gego E., C. Hogrefe, G. Kallos, A. Voudouri, J. Irwin and S. Rao, 2005. Examination of model predictions atdifferenthorizontalgridresolutions.*Environ.Fluid Mech.* 5,63-85.

Hanna, S. and Yang, R. (2001), Evaluations of mesoscale models' simulations of near-surface winds, temperature gradients, and mixing depths. Journal of Applied Meteorology, Vol. 40, pp. 1095-1104.

Hariprasad K. B. R. R., C. V. Srinivas, A. BagavathSingh,S.VijayaBhaskaraRao,R.BaskaranandB.Venkatra-man,2014.Numericalsimulationandintercomparison ofboundarylayerstructurewithdifferentPBLschemes in WRF using experimental observations at atropical site. *Atmos. Res.* 145,27-44.

Hong, S.Y., Noh, Y., and Dudhia, J. (2006), A new vertical diffusion package with explicit treatment of entrainment processes, Monthly Weather Review, vol. 134, pp. 2318-

2341.

India Meteorological Department 2016. Climatological Normals 1981–2010. India Meteorological Department. January 2015. pp. 305–306 and India Meteorological Department. December 2016. p. M64.

Janjic, Z. A. (2002), Non-singular Implementation of the Mellor–Yamada Level 2.5 Scheme in the NCEP. Meso model, NCEP Office Note, 437, 61.

Kain, J.S. (2004), The Kain–Fritsch Convective Parameterization an Update, Journal of Applied Meteorology, Vol. 43 (1), pp. 170–181

Kleczek, M. A., Steeneveld, G. J., and Holtslag, A. A. M. (2014), Evaluation of the weather research and forecasting mesoscale model for GABLS3: impact of boundary-layer schemes, boundary conditions and spin-up. Boundary-Layer Meteorol, DOI 10.1007/s10546-014-9925-3.

Kumar, A., Patil1, R.S., Dikshit, A.K. and Kumar, R. (2017) Application ofWRF model for air quality modelling and AERMOD – a survey. Aerosoland Air Quality Research, 17, 1825–1837.

Li, X.-X., Koh, T.-Y., Entekhabi, D., Roth, M., Panda, J. and Norford, L.K. (2013) A multi-resolution ensemble 125 study of a tropical urban environment and its interactions with the background regional atmosphere. Journal of Geophysical Research: Atmospheres, 118, 9804–9818.

Madala S., Satyanarayana, A.N.V., Srinivas, C.V., and Kumar,M. (2015), Mesoscale atmospheric flow-field simulations for air quality modelling over complex terrain region of Ranchi in eastern India using WRF, Atmospheric Environment, Vol. 107, pp. 315-328.

Madala, S., Santo V. S., Jun, W. and Soo C. L. (2019), Customization of the Advanced Research Weather Research and Forecasting model over the Singapore region: impact of planetary boundary layer schemes, land use, land cover and model horizontal grid resolution. Meteorological Applications, 26, 221-231.

Madala, S., Satyanarayana, A.N. and Srinivas, C.V. (2017) Performance of WRF for simulation of mesoscale meteorological characteristics for air quality assessment over tropical Coastal City, Chennai. Pure and Applied Geophysics, 175, 501–518. https://doi.org/10.1007/s00024-017-1662-3.

Madala, S., Satyanarayanam A.N.V. and Rao, T. N. (2014), Performance evaluation of PBL and cumulus parameterization schemes of WRF-ARW model in simulating severe thunderstorm events over Gadanki MST radar facility-case study, Atmospheric Research, Vol. 13, pp. 1–17.

Mass, C. F., Ovens, D., Westrick, K., and Colle, B. A. (2002), Does increasing horizontal resolution produce more skilful forecasts, Bulletin of the American Meteorological

Society, Vol. 83(3), pp. 407-430.

Mlawer, E.J., Taubman, S.J., Brown, P.D., Iacono, M.J., and Clough, S.A. (1997), Radiative transfer for inhomogeneous atmosphere RRTM, a validated correlated-k model for the longwave, J Geophys Res, Vol. 102 (D14), pp. 16663–16682.

Nakanishi, M. and Niino, H., (2004),An improved Mellor-Yamada level-3 model with condensation physics: Its design and verification. Boundary-Layer Meteorology, Vol. 112, pp. 1–31.

Perez, C., Jimenez, P., Jorba, O., Sicard, M. and Baldasano, J. M. (2006), Influence of the PBL scheme on high-resolution photochemical simulations in an urban coastal area over the Western Mediterranean, Atmospheric Environment, Vol. 40, pp. 5274-5297.

Pleim, J.E. (2007), A combined local and nonlocal closure model for the atmospheric boundary layer, Part I model description and testing, J ApplMeteorolClimatol, Vol. 46 (9), 1383–1395.

Preeti, G. and Manju, M. (2017) Sensitivity of WRF model estimates to various PBL parameterizations in different climatic zones over India. Atmospheric Research, 194, 43–65.

Rahul, B., A. N. V. Satyanarayana, T. V. B. P. S. Rama Krishna and S. Madala, 2015. Sensitivity of PBL parameterization schemes of weather research fore- casting model and integration with AERMOD in the dispersion of NOX over a coastal region of southern Visakhapatnam (India). *Asia-Pac. J. Chem. Eng.* 10, 356-368.

Rahul, B., A.N.V. Satyanarayana and T.V.B.P.S. Rama Krishna, 2017a, Comparison and evaluation of Air Pollution Dispersion Models AERMOD and ISCST-3 during pre-monsoon month over Ranchi, *Jr. of Industrial Pollution Control,* Vol. 33(1), pp 674-685

Rahul, B., ANV Satyannarayana, TVBPS Ramakrishna, A Subba Rao, P Rajendra, 2017b, Numerical simulation of boundary layer flow parameters by using WRF-ARW Model over a tropical region, *Jr. of Industrial Pollution Control,* Vol. 33(1), pp 1148-1154.

Rahul, B., Satyanarayana, A.N.V., Rama Krishna, T.V.B.P.S. and Madala, S. 2016. Sensitivity of PBL schemes of the WRF-WRF-ARW model in simulating the boundary layer flow parameters for their application to air pollution dispersion modeling over a tropical station. Atmósfera, 29, 61–81.

Shin, H.H., and Hong, S.Y. (2011). Intercomparison of planetary boundary-layer parameterizations in the WRF model for a single day from CASES-99. Boundary Layer Meteorology. Vol. 139, pp. 261–281.

Shrivastava, R., Dash, S.K., Oza, R.B. and Hegde, M.N. (2015) Evaluation of

parameterization schemes in the weather research and forecasting (WRF) model: a case study for the Kaiga nuclear power plant site. Annals of Nuclear Energy, 75, 693–702.

Singh, J., Yeo, K., Liu, X., Hosseini, R. and Kalagnanam, J.R. (2015) Evaluation of WRF model seasonal forecasts for tropical region of Singapore. Advances in Science and Research, 12, 69–72.

Sistla, G., Zhou, N., Hao, W., Ku, J.Y., Rao, S.T., Bornstein, R., Freedman, F. and Thunis, P. (1996) Effects of uncertainties in meteorological inputs on urban air shed model predictions and ozone control strategies. Atmospheric Environment, 30, 2011–2025.

Skamarock, W. C., Klemp, J. B., Dudhia, J., Gill, D. O., Barker, D. M., Dudha, M. G.,Huang, X. ,Wang, W. ,and Powers, Y. (2008), A Description of the Advanced ResearchWRF Ver.30. In: NCAR Technical Note. NCAR/TN-475STR. Meso-scale and Micro-scaleMeteorology Davison, National Centre for Atmospheric Research,Boulder Colorado, USA, 113 p.

Srinivas, C.V., Venkatesan, R. and Singh, A. B. (2007), Sensitivity of mesoscale simulations of land-sea breeze to boundary layer turbulence parameterization, Atmospheric Environment, Vol. 41, pp. 2534–2548.

Sukoriansky, S., Galperin, B. and Perov, V. (2005), Application of a new spectral theory of stably stratified turbulence to atmospheric boundary layers over sea ice, Boundary-Layer Meteorology, Vol. 117, pp. 231–257.

Tan, E., Mentes, S., Unal, E., Onol, B., Unal, Y.S., Yilmaz, E., Sayinta, M., Goktep, N., and Incecik, S. 2013. Performance evaluation of the WRF model for the short term wind energy prediction system (SWEPS) for Turkey. EWEA Wind Power Forecasting Technology Workshop, Rotterdam, December 4–5, 2013.

Wilks,D.S.,2011.*Statisticalmethodsintheatmospheric science*, 3rd ed. Elsevier Academic Press, 704pp. RF model for air quality modelling and AERMOD – a survey. Aerosol

Xie, B., Fung, J. C. H., Chan, A. and Lau, A. (2012), Evaluation of nonlocal and local planetary boundary layer schemes in the WRF model, Journal of Geophysical Research, Vol. 117, D12103.

Yang, Q., Berg, L.K., Pekour, M., Fast, J.D., Newsom, R.K., Stoelinga, M. and Finley, C. (2013) Evaluation of WRF-predicted near-hub-height winds and ramp events over a Pacific northwest site with complex terrain. Journal of Applied Meteorology and Climatology, 52(8), 1753–1763.

Zhang, H., Pu, Z. and Zhang, X. (2013), Examination of errors in near-surface temperature and wind from WRF numerical simulations in regions of complex terrain, Weather Forecast, Vol. 28 (3), pp. 893-914.

Zhong, S. Y., In, H. J. and Clements, C. (2007), Impact of turbulence, land surface and

radiation parameterizations on simulated boundary layer properties in a coastal environment, Journal of Geophysical Research, Vol. 112, D13110, doi: 10.1029/2006JD008274.

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Regional modelling of air quality indicators needs a
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obtained