EVALUATION OF HIGH RESOLUTION URBAN LULC FOR SEASONAL FORECASTS OF URBAN CLIMATE USING WRF MODEL

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ABSTRACT:

In all mesoscale models with urban parameterizations, urban area represented as a single entity to represent the influence of urban morphology. In the last few years, many Urban Canopy Models (UCM) have been developed by many researchers to model the urban energy fluxes, but their spatial resolution is too coarse. These models proves to be a hindrance in obtaining improved results for urban climatic studies due to their coarser resolution. So downscaling of climatic variables in an urban area is primary significance for urban climatic studies. Weather Research Forecasting Model (WRF) is the one of the models that has been used widely for downscaling the climatic variables at urban scale and it has been also integrated with UCM along with a number of urban sub physics options. In this study, modified high resolution Land Use Land Cover (LULC) representing three urban classes for the city of Chandigarh has been ingested into the model to examine and validate the model output with respect to ground observations. The model has been configured with two domains with a resolution of 3KM and 1KM and simulations were carried out for three days of the of four seasons of India, winter, summer, monsoon and post-monsoon for the analysis of seasonal variation. Improved values of Root Mean Square Error (RMSE) for surface temperature, relative humidity and wind speed was observed with modified high resolution LULC with BEM option as compared to single urban built up class. In terms of temperature, summer season showed very less RMSE than other seasons, i.e, 0.76°C and . In terms of relative humidity, monsoon season showed very less RMSE than other seasons, i.e., 2.63% and in terms of wind speed, post monsoon season is giving less RMSE i.e., 1.01 m/s.

1. INTRODUCTION

1.1 Back ground

More than 54% of the world's population has been residing in urban areas(United Nations, 2007). The urban population of the world has grown up rapidly since 1950, from 746 million to 3.9 billion in 2014. Asia, despite its lower level of urbanization, is home to 53 per cent of the world's urban population. India, China and Nigeria together are expected to account for 37 per cent of the estimated growth of the world's urban population between 2014 and 2050. India is estimated to add 404 million urban dwellers, China 292 million and Nigeria 212 million. (UNDESA, 2014). Due to rapid development of industries, special economic zones, infrastructure, government schemes related to smart cities, connectivity are the main reasons to increase the urban population in India.[*]

Urbanization usually increases the temperature at surface as well as changes in the spatial patterns and intensities of precipitation, but their extents depend on season, climate regime, day time, geographical location, circulation feedback and surrounding land cover. (Papamanolis, Dimellib, & Ragia, 2015) (Li, Zheng, Zhang, & Chen, 2018). Such a large scale human intervention with the natural environment has given rise to the phenomenon of Urban Heat Island (UHI) in which the temperature of the urban core is higher than the surrounding areas subject to calm weather conditions. According to the World Resources Institute (WRI), an international research organization, a major proportion of the world population will be subjected to frequent inland floods, rising sea levels, intense storms and more frequent periods of extreme hot and cold owing to climate change

Cities affect climate at various scales as mentioned by Garratt 1990 following the scales given by Oke T R which ranges from micro scale (10^{-2} to 10^{3} m e.g. building and street), local scale (10^{2} to 5 X 10^{4} m), meso scale (10^{4} to 2 X 10^{5} m city and surrounds) and macro-scale (10^{5} to 10^{8} m regional and global). Due to large amount of heterogeneity of urban landscape and varied scales of urban effects, the study of urban climate becomes a bit complex. The ground based observational studies and large scale CFD models picks the local phenomenon but fails to take into account the regional phenomenon. On the other hand, Global Climatic Models (GCMs) are able to simulate global phenomenon quite accurately but unable to resolve local effects. Hence, it is necessary to downscale the local and regional weather.

GCMs models to urban scale in order to account for the meso scale as well as local scale phenomenon. Weather Research and Forecasting (WRF) Model is one such Numerical Weather Prediction (NWP) model which has the capability to downscale upto the 0.5-1km grid spacing at local urban scale. It is a multi-agency effort for meso-scale weather prediction and data assimilation. At such a fine horizontal resolution it becomes important to realistically represent the role of urban land use in local and regional weather.

Besides, the model is coupled with various Urban Canopy Model (UCM) which simulates urban energy fluxes. In most of

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the operational forecasting, WRF is used by employing no urban physics option generally known as bulk parameterization , The WRF V2.0 released in 2003 which comprised a bulk urban parameterization in Noah LSM with modified parameter values to represent zero-order effects of urban surfaces: (1) roughness length of 0.8 m to represent turbulence generated by roughness elements and drag due to buildings; (2) surface albedo of 0.15 to represent shortwave radiation trapping in urban canyons; (3) volumetric heat capacity of 3.0 J m^{-3} K^{-1} for urban surfaces (walls, roofs, and roads), assumed as concrete or asphalt; (4) soil thermal conductivity of 3.24 W m^{-1} K^{-1} to represent the large heat storage in urban buildings and roads; and (5) reduced green vegetation fraction over urban areas to decrease evaporation'(Chen, Bornstein, & Ching, 2011). WRF has been combined with Urban Canopy Models (UCMs) to quantify variations in urban areas at sub grid level. Three sub physics options are inducted in the WRF-Urban model: Single Layer Urban Canopy Model (SLUCM), Building Energy Parameterization (BEP) and Indoor-Outdoor Exchange Model or Building Energy Model (BEM). SLUCM is a single layer model with simplified urban geometry which aggregates heat fluxes into energy and momentum exchange between the urban surface and the atmosphere. On the other hand, BEP and BEM are multi-layer models. BEP parameterizes the three dimensional nature of urban surfaces while BEM also takes into account the exchange of energy between interior of the building and outdoor atmosphere. Mohan & Bhati, 2011 studied various urban physics options to choose the best physics options for semi-arid region of India.

Land Use and Land Cover (LULC) is a very important parameter which reflects the human activities and it also impacts the climate. It normalizes the exchange of heat and momentum between the soil and the air, which in numerical models determine the calculation of meteorological magnitudes near the surface (Jim & Sistach, 2004)(Li et al., 2018). Because of this rapid growth of urbanization there is a requirement for accurate weather forecasts and climate change information within cities and contemporaneous increases in computer capabilities allow greater spatial resolution within models (Bin et al., 2009).

Global Land Use and Land Cover such as USGS, Corine, AWiFS represented urban built-up as a single class. However, urban areas exhibit large variability in terms of compactness, anthropogenic heat emission and roughness characteristics which has bearings on urban climate. A more effective land classification system is required to study the thermal behaviour of different land cover types on a local scale. Modified Urban LULC consisting of three urban classes was used by (Tewari, Chen, Kusaka, & Miao, 2007) to run the UCM cum WRF model for understanding the effect of urban heterogeneity on climatic patterns.

Climate change is a major concern of the world today making the understanding of urban climate even more imperative. Climate change models, such as the ones developed by the Intergovernmental Panel on Climate Change (IPCC), predict that temperatures in India are likely to rise by between 3 degrees Celsius and 4 degrees Celsius by the end of the 21st century. UCMs play an important role in urban micro-climatic modelling. UCM coupled with WRF model improves the quality of weather forecast and dispersion model. For a better understanding of the impact of complexity and rapid growth of urban areas on local climatic conditions, a highly precise prediction of climatic variables from the available models is required. Consequently, this study assesses the effect of ingesting the multi-class high resolution urban land use data on the simulation of meteorological variables for seasonal forecast.

2. STUDY AREA

Chandigarh is located near the foothills of the Shivalik range of the Himalayan North-West India. It covers an area of approximately 115 km^2 and shares its borders with two states of Haryana and Punjab (Figure 1). The exact coordinates of Chandigarh are 30.74° N and 76.79° E. It has an average elevation of 321 meters (1053 Ft.). It has a population of about 1,055,450 according to 2011 census. The city has an outstanding architecture, landscaping and planning, whose seeds were sown by Le Corbusier during the drafting of the city layout plan. Thus, the city today has been bestowed with a high quality of life and clean environment and the citizens enjoy a direct relationship of built-form with nature having abundant access to green spaces all over the city.

Chandigarh has excellent educational and health facilities. The growth of service industry has been remarkable in IT field. This makes the city Chandigarh a fast developing Union Territory (UT). Furthermore, this growth pattern has increased the pressure from the neighbouring states for various infrastructures such as educational institutions, hospitals and other recreational opportunities. This is letting the city beautiful with increased slums, increased traffic congestions and increased population. The city comes under Koeppen's CWG category, which means that summers are very hot and humid; winters are cool while heavy rainfall is experienced during the monsoons. In all, weather is usually dry all through the year.As per National Building Code of India (NBC), Chandigarh falls into composite climate. Chandigarh enjoys four different seasons, (i) summer season (mid-March to Mid-June) (ii) monsoon season (late-June to mid-September); (iii) post monsoon autumn season (mid-September to mid-November); and (iv) winter (mid-November to mid-March). This cycle starts with summers when the climate is humid with maximum temperature reaching to 37°C and minimum being 25°C. In worst cases, the temperature may even go up to 44°C and such conditions continue till June. After June, there is a fall in temperature with monsoon season making its way. An average rainfall of 700 mm to 1200 mm is experienced here. After the monsoon season, winters that

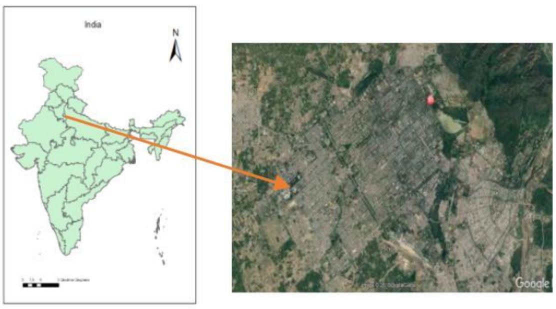

Figure 1. Study Area

Usually start in last December continue till mid-March. In January, maximum temperature is 23°C while minimum can be up to 3.6°C.

3. MATERIALS AND METHODS

This section describes the domain configuration, Static geographical, meteorological data and simulation period used for the study. The section further details the methodological steps to carry out this study.

3.1 Domain Configuration

The two domains, having the spatial resolution of 3KM and 1 KM were configured in the WRF Model. The grid points in each of the domain were set to be 227*228 and 217*212 respectively with the innermost domain d02 containing study area of Chandigarh (Figure2). The Initial and boundary conditions for the meteorological fields were provided from the National Centre for Environmental Predictions (NCEP) Global Forecast System (0.25°) three hourly data. (https://rda.ucar.edu/datasets/ds083.2/)

3.2 Static Geographic data/ Terrestrial data

The downscaling of met variables at high resolution grid spacing cannot be in isolation with other land surface parameters**.** In this study, high resolution Digital Elevation Model (DEM) SRTM 90m was used. Besides, the default Green Fraction data integrated in the model corresponds to time period of 1986-1991 with spatial resolution of 0.144°and monthly temporal resolution generated from the AVHRR satellite data. This data was out dated and it cannot signify recent changes in land use and impacts on vegetation like drought effects on vegetation on weekly or bi-weekly scale from extreme events. The same condition was observed with other land surface parameters. Hence, for better representation of land surface energy exchange processes, updated high resolution land surface parameters should be ingested in the. This parameters provides a better opportunity to investigate the direct impact of reliable land surface using a regional climate model. Land surface parameters such as Fapar (Fraction of Absorbed Photo synthetically Active Radiation)(http://land.copernicus.eu/global/products/fapar Sensor), Fcover(Fraction of Vegetation Cover)(http://land.copernicus.eu/global/products/f cover Sensor), WRF compatible AWiFs Land Use Land Cover (LULC), Leaf Area Index(LAI), Albedo and Green fraction were updated and ingested into WRF model after converting them into c WRF compatible format (Table 1). Additionally, Resourcesat-2 LISS IV data (5.8 m resolution) was used for generating the high resolution urban LULC with three urban built-up classes i.e. High Intensity Residential, Low Intensity Residential and Commercial/Industrial/Transportation**.** The LISS-IV sensor is a multispectral high resolution camera which is having spatial resolution of 5.8m at nadir.

Table 1 Data Used

Datasets	Resolution
Shuttle Radar Topographic Mission (SRTM) DEM	30 m
Resourcesat-2 Linear Imaging Self-Scanning Sensor (LISS) IV Urban LULC	5.8 m
Albedo	1 km
Green Fraction	1 km
Leaf Area Index (LAI), Fraction of Absorbed Photo synthetically Active Radiation (FAPAR),Fractionof Vegetation Cover (FCover)	500 m
NCEP GFS data (every 3hrs.) Source: http://rda.ucar.edu/datasets/ds084.1/	0.25°
IMD station, Chandigarh(Validation)	Hourly observation data
INSAT 3D Precipitation (validation)	4 km
AWIFS WRF compatible LULC(source: Bhuvan NICES)	1 km

3.3 Meteorological data:

To provide atmospheric conditions properly at the synoptic-scale, long-term data records are needed from ground based stations, or grid points, well distributed throughout the region of interest. The ground based data at such a wide network is generally not available. Hence, National Center for Environmental Prediction (NCEP) Global Forecast System (GFS) data which provides air temperature, sea level pressure, humidity, sea surface temperature, soil temperature, skin temperature, vertical wind velocity, wind direction, evaporation, sea level pressure, geo potential height, ice cover, vorticity, surface winds, soil moisture and vertical moisture in 0.25° grids operationally at every 6 hours URL: (http://dss.ucar.edu/datasets/ds083.2) was used in this study to provide the initial and boundary conditions(Table 1)

3.4 Simulations Periods

Simulations were carried out for three days for all four major seasons of Chandigarh region: 1-4 January 2017, 11-14 May 2017, 19-22 August 2017 and 6-9 November, 2017 with modified LULC, updated urban parameters and land surface parameters and High resolution DEM using GFS (0.25°) meteorological data. The dates in different seasons were chosen carefully to take into account various weather systems operating in the region. The January is the coldest month and the period chosen is known to be peak winter season in the area. The area

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experiences cold wave conditions due to snow fall in high and middle altitudes of Himalayan region. The month of May falls in summer season and witnesses the high temperature due to heat waves in the northern plains of India. Monsoon rains is received by Indian peninsula in the month of July- September and August month is known as the heaviest rain month. During August 19-20 August, Chandigarh has experienced a heavy rainfall, which led to water logging in various parts of the cities. The November 6-9, 2017 period follows the crop burning and festival period and is known to have high pollution concentration in the northern region. However, Chandigarh being a planned city and bestowed with lot of greenery in and around, did not witness high rates of air pollution.

4. METHODOLOGY

4.1 WRF Model Domain setup and Initialization

The first step was to run the geogrid.exe which defines model domains and interpolates static geographical data to model grids. The two domains configured in the WRF Model had the spatial resolution of 3 km and 1 km as described in section 3.1. Table 2 describes the model setup and various physics options employed for this study based on previous research experience in this region. The urban physics option 3 i.e. BEP+BEM were employed to take into account the impact of urban on energy exchange and radiation budget. Unified Noah Land surface model was adopted since, it is coupled with BEP+BEM urban physics scheme.

The high resolution LULC was ingested into the model after making suitable changes in GEOGRID.TBL and namelist. wps. Only the inner domain d02 required the new dataset and hence the LULC layer was upscaled according to the study area. The rest of the area used default Advanced Wide Field Sensor (AWiFS) dataset.

Table 2: Physics options and model setup

Physics	All domains
Micro Physics	WSM6
Long wave radiation scheme	RRTM
Short wave radiation scheme	Dudhia
Surface layer(sf_sfclay_physics)	Monin-Obukhov(Janjic Eta) scheme
Land Surface physics Scheme(sf_surface_physics)	Unified Noah land surface model
PBL scheme(bl_pbl_physics)	Mellor-Yamada-Janjic scheme

4.2 Preparation of Modified LULC

The modified urban LULC map of Chandigarh was prepared by following the methodology detailed in Dastidar et al., 2017 by utilizing Resourcesat-2 LISS IV data. Supervised classification was performed on the image to classify five broad land use classes in the first step, such as: built-up, agriculture, water bodies, industries and vegetation. After this classification, vectorization was done and then 100 m x 100 m fishnet was overlaid on the classified vector image. Further, percentage of built-up area in each grid cell was calculated to classify built area in low intensity residential and high intensity residential. The third urban LULC class i.e. Industrial/commercial/transportation was added based on ancillary data. The generated output was further recoded as per USGS classification scheme and then converted into WRF compatible format. The high resolution LULC was ingested into the model after making suitable changes in GEOGRID.TBL and namelist. Wps. Only the inner domain d02 required the new dataset and hence the LULC layer was upscaled according to the study area. The rest of the area used default Advanced Wide Field Sensor (AWiFS) WRF compatible LULC dataset from Bhuvan NICES.

4.3 Ingestion of High Resolution DEM and Land surface parameters into WRF Model

The downloaded SRTM_30m DEM file was converted into a binary format in LINUX and renamed as "00000.number of columns-00000.number of rows". An index file was also created and in GEOGRID.TBL, a new entry was created in existing HGT_M. namelist.wps was also updated according to the new DEM. Similar approach was applied for ingestion of all other LSPs i.e. Albedo, green fraction Fapar, Fcover and LAI in the model.

4.4 Ingestion of modified urban parameters to WRF Model

The URBPARAM.TBL table defines the values of urban parameters for all three urban classes. Since, the values in this table is based on the studies carried out in developed countries, it needs modification to represent the urban and material characteristics corresponding the study area and its climate zone. Hence, the urban parameter values were changed in URBPARAM.TBL by taking reference from National Building Code of India, literature and numerous websites. The modified urban parameters are shown in Table 3.

Table 3 Modified Urban Parameter Table

URBAN PARAMETERS	LOW INTENSITY RESIDENTIAL	HIGH INTENSITY RESIDENTIAL	COMMERCIAL/ INDUSTRIAL/ TRANSPORTATION
Roof Level Building Height (m)	9.0	20.0	10.0
Anthropogenic Heat [w m{-2}]	10.0	40.0	80.0
Thermal conductivity of building wall [J m{-1}s{-1}K{-1}]	0.811	0.811	1.100
Thermal conductivity of road [J m{-1}s{-1}K{-1}]	0.75	0.75	0.75
Thermal conductivity of roof [J m{-1}s{-1}K{-1}]	0.811	0.811	1.580
Surface albedo of roof	0.30	0.30	0.30
Surface albedo of building wall	0.20	0.20	0.20
Surface albedo of road	0.15	0.15	0.15

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5. RESULTS AND DISCUSSION

5.1 Modified LULC Map

Land Use and Land Cover is one of the important land surface parameter which strongly affects the surface skin temperature (Figure 2). The product of IRS P6-AWiFS Land Use/Land Cover is an extension of the default USGS Land Use and Land Cover data, having finer resolution than USGS. However, urban area is represented as a single class in Awifs WRF compatible LULC, which fails to take into account urban heterogeneity in the model. The modified urban LULC for this study consists of the three urban built-up classes which are High Intensity Residential, Low Intensity Residential and Commercial/Industrial/Transportation. The accuracy assessment of generated urban LULC with respect to ground shows 96% accuracy. The subsequent modification regarding albedo, soil moisture and roughness length pertaining to these three classes were incorporated into LANDUSE.TBL and URBPARAM.TBL. This urban LULC map was up scaled up to 100m resolution due to computational limitations and then further ingested in WRF Model.

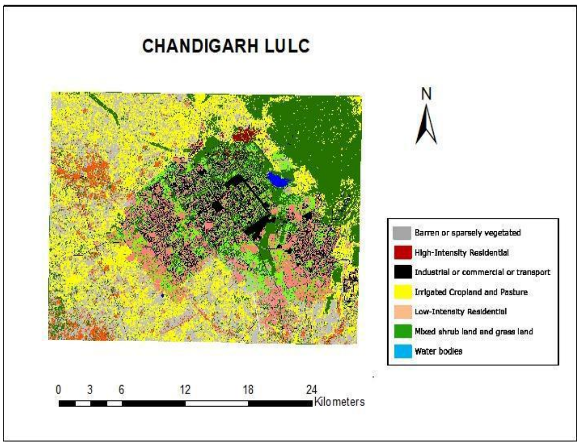

Fig 2: Urban LULC map, Chandigarh

5.2 Temperature

Figure 3 shows the spatial distribution of temperature at 2 m simulated for different seasons i.e. Jan 1st 11:30 IST (winter), May 11th 11:30 IST (summer), Aug 19th 11:30 IST (Monsoon) and Nov 6th 11:30 IST (Post- Monsoon) with BEP+BEM Urban Physics, modified high resolution urban LULC, high resolution DEM and updated land surface parameters. Maximum area comes under the temperature ranges from 9-21^{o}C, 30-35^{o}C, 25-35^{o}C and 21-27^{o}C for winter, summer, monsoon and post monsoon respectively. It can be seen from 11:30 hrs IST images of temperature that Chandigarh has negligible day time Urban Heat Island (UHI) effect due to abundant vegetation within its boundaries in all the seasons. The north eastern part of the domain has less temperature due to presence of forest area and undulating topography and part of Himalayan range. The urban area has highest temperature in all the simulations except august season simulation due to agricultural areas are showing more temperature than other areas.

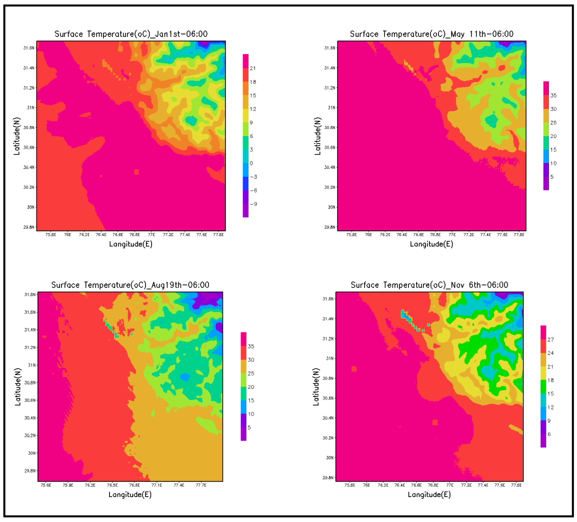

Figure 3. Spatial distribution of Temperature over d02 on different seasons Jan 1st 11:30 IST, May 11th 11:30 IST, Aug 19th 11:30 IST and Nov 6th 11:30 IST with BEP+BEM Urban Physics

5.3 Relative Humidity

Figure 4 shows the spatial distribution of relative humidity simulated for different seasons on Jan 1st 11:30 IST, May 11th 11:30 IST, Aug 19th 11:30 IST and Nov 6th 11:30 IST.. Maximum area comes under humidity ranges from 20-50%, 20-40%, 45-85% and 20-40% for winter, summer, monsoon and post monsoon respectively. Monsoon season is generally known as the very high humidity period which is well simulated by the WRF model. In remaining seasons because of dry seasons and clear sky conditions city is experiencing very less humidity.

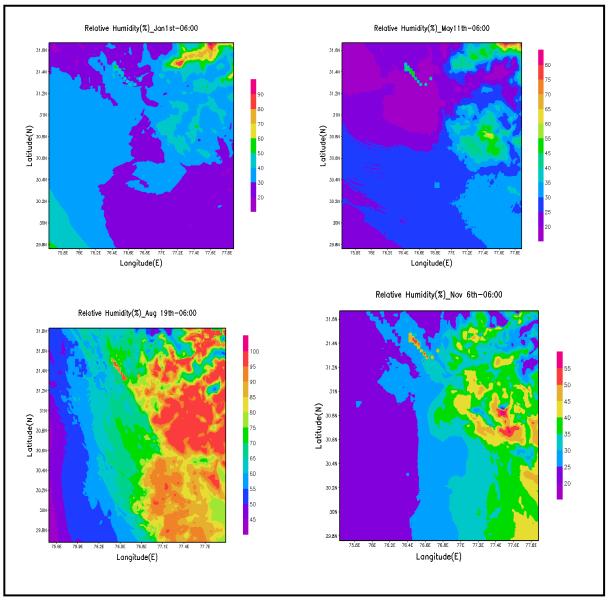

Figure 4. Spatial distribution of Relative Humidity over d02 on different seasons Jan 1st 11:30 IST, May 11th 11:30 IST, Aug 19th 11:30 IST and Nov 6th 11:30 IST with BEP+BEM Urban Physics

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5.4 Wind Speed

Figure 5 shows the spatial distribution of wind speed simulated on different seasons Jan 1st 11:30 IST, May 11th 11:30 IST, Aug 19th 11:30 IST and Nov 6th 11:30 IST. Maximum area comes under wind speed ranges from 1-8, 1-7, 6-11 and 1-3 m/s for winter, summer, monsoon and post monsoon respectively. Monsoon season is expecting more wind speed in urban built-up as compared with than other seasons, which is quite favourable due to high humidity conditions during this period. In summer season although wind speed are not very high, but due to dust storms coming from western part of the India, high level of wind activity is visible over city area.

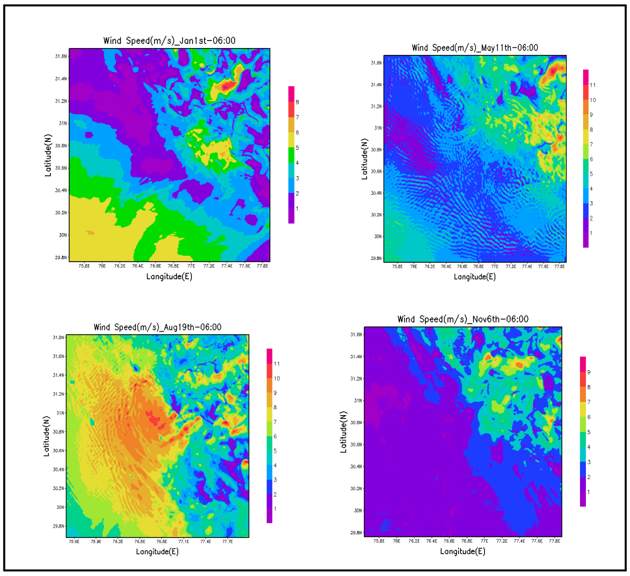

Figure 5. Spatial distribution of Wind speed over d02 on different seasons Jan 1st 11:30 IST, May 11th 11:30 IST, Aug 19th 11:30 IST and Nov 6th 11:30 IST with BEP+BEM Urban Physics

5.5 Validation

Validation was carried out using ground observation data of Chandigarh. IMD provided point observation data for every three hours for the simulation period. This data has ground observations of surface parameters of Temperature, RH and Wind speed. The validated results of temperature at 2 m, relative humidity and wind speed for all seasons with ground observed data are shown in Fig. 6 A, B and C respectively. If gone through the validated results of temperature and relative humidity showing diurnal variation similar to IMD data. But in Wind speed there is some difference is occurred due to lack of regional information.

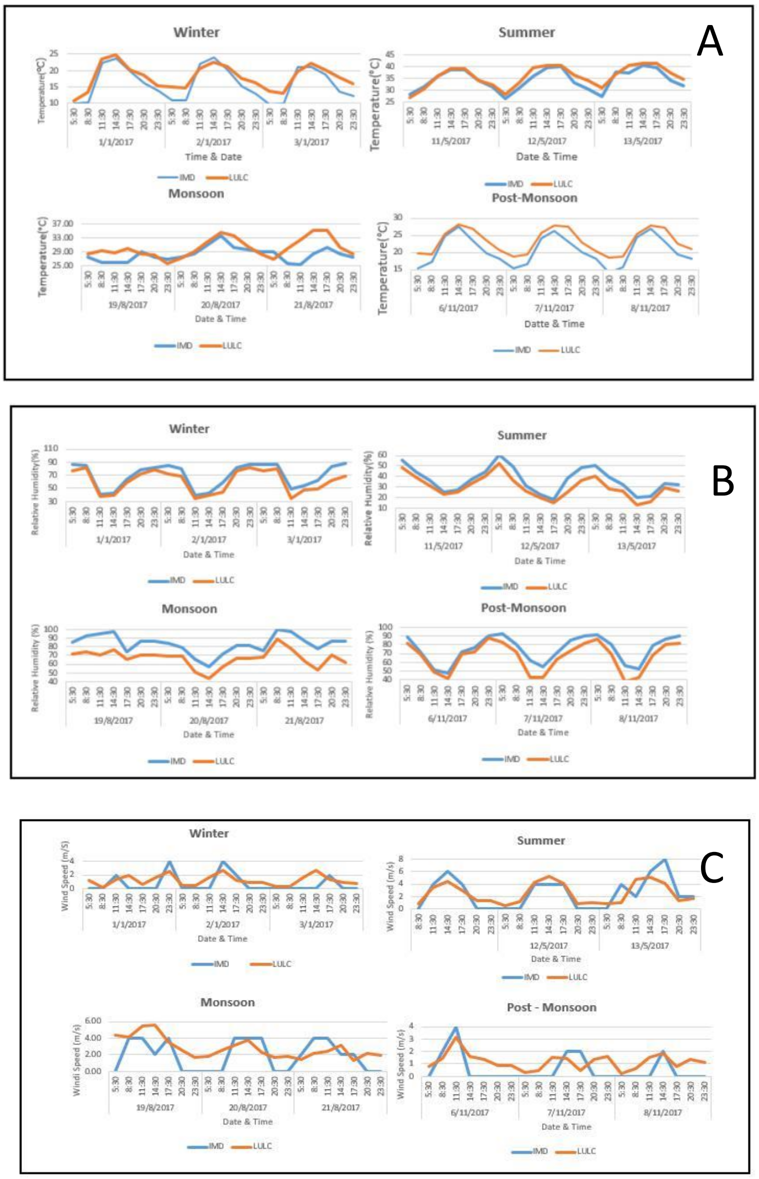

Figure 6. Comparison between observed and simulated A) Temperature B) Relative Humidity C) Wind Speed with LULC

Table 4 Validation of the simulated results of T2

Temperature at 2m(°C)					
Month	Physics options	RMSE	MAE	MEAN	STDV
January 2017 (Winter)	Ground Observation			16.02	5.55
	Modelled output	1.84	1.61	18.13	5.22
May 2017 (Summer)	Ground Observation			33.97	3.86
	Modelled output	0.76	0.05	33.92	4.37
August 2017 (Monsoon)	Ground Observation			28.27	2.01
	Modelled output	1.69	1.53	30.14	2.68
November 2017 (Post – Monsoon)	Ground Observation			20.83	4.43
	Modelled output	2.88	2.53	23.36	3.51

Table 4 shows validation of the simulated results of temperature at 2m for all four seasons with respect to IMD ground observations. In winter, monsoon and post monsoon seasons the model has little overestimated the mean temperature with high resolution LULC which is higher than observed mean temperature. In summer season, the model has almost shown close correspondence with observed mean temperature. So summer season is showing very less RMSE than the other seasons. The RMSE values of surface temperature are 1.84 °C, 0.76°C, 1.69°C and 2.88°C for winter, summer, monsoon and post monsoon respectively.

Table 5 Validation of the simulated results of Relative Humidity

Relative Humidity (%)					
Month	Physics options	RMSE	MAE	MEAN	STDV
January 2017 (Winter)	Ground Observation			68.57	9.21
	Modelled output	5.74	5.32	63.25	18.71
May 2017 (Summer)	Ground Observation			38.29	10.45
	Modelled output	4.21	3.99	34.31	9.20
August 2017 (Monsoon)	Ground Observation			88	7.83
	Modelled output	2.63	2.78	81.5	7.83
November 2017 (Post – Monsoon)	Ground Observation			77.14	8.87
	Modelled output	4.22	3.78	67.37	16.91

Table 5 showing validation of the simulated results of relative humidity for all four seasons. In all four seasons the model has underestimated the mean relative humidity with high resolution LULC which is lower than observed mean relative humidity.

Comparatively all seasons, monsoon season is showing close correspondence with observed humidity data. The RMSE values of relative humidity are 5.74%, 4.21%, 2.63% and 4.22% for winter, summer, monsoon and post monsoon respectively. Out of all seasons, monsoon season showed least RMSE value.

Table6 Validation of the simulated results of Wind Speed

Wind Speed (m/s)					
Month	Physics options	RMSE	MAE	MEAN	STDV
January 2017 (Winter)	Ground Observation			0.86	1.57
	Modelled output	1.26	0.47	1.33	0.80
May 2017 (Summer)	Ground Observation			2.57	2.51
	Modelled output	1.22	0.15	2.42	1.31
August 2017 (Monsoon)	Ground Observation			1.90	1.84
	Modelled output	1.82	0.89	2.80	1.26
November 2017 (Post – Monsoon)	IMD			0.86	1.57
	LULC	1.01	0.59	1.45	0.79

Tables 6 showing validation of the simulated results of wind speed for all four seasons. In winter, monsoon and post monsoon seasons the model has overestimated the mean wind speed with high resolution urban LULC which is higher than observed mean wind speed. In summer season, the model has underestimated the mean wind speed. The RMSE values of wind speed are 1.26 m/s, 1.22 m/s, 1.82 m/s and 1.01 m/s for winter, summer, monsoon and post monsoon respectively.

6. CONCLUSION

In this study, improved urban parameterization and modified multi-class urban LULC along with improved urban parameters values for all three classes have been incorporated in WRF Model for improved climatic variables over urban areas. In default LULC data, urban area is represented as a single class while in modified high resolution urban LULC data, urban area is represented in three classes. To assess the impact on seasonal forecast with improved parameters the WRF Model was run for three days in the month of January, May, August and November 2017. Validation was carried out using ground observation data, In terms of temperature, summer season shown similar temperature with ground observation data than other seasons. In terms of relative humidity, monsoon season is showing similar results with ground observation data than other seasons. And in terms of wind speed, winter, monsoon and post monsoon season's model data has over estimated than the ground observed data. In summer season, the model has underestimated the mean wind speed. Model also not predicted the crop burning influence due to lack of Chemical parameter information. Out of all the seasons there is a improvement in the simulation over the Chandigarh region. So WRF Model should be utilised for high resolution forecast of weather by using modified urban LULC and updated land surface parameters.

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