Urban Meteorology and Climate Conference; ANCST-CityU Sponsored Conference at City University Hongkong

Impacts of land-use land cover and urban canopies on Meteorology and Air Quality from WRF modelling

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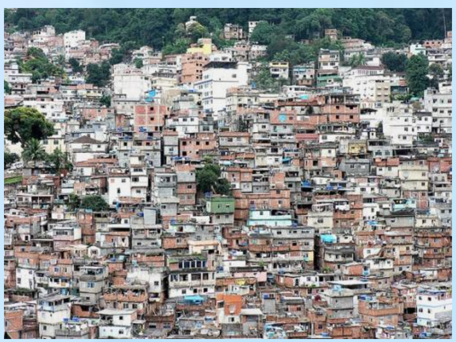
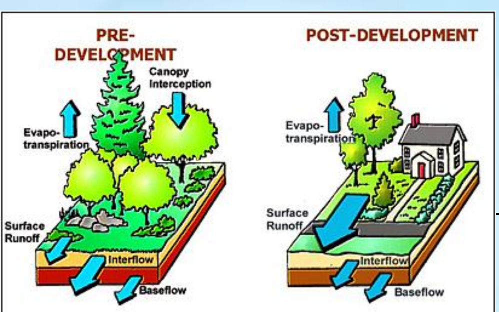
Overview

- Introduction
- Case studies about impact of LULC on weather and Air Quality
- Field Campaigns over Delhi
- WRF-Modelling including landuse landcover and urban canopies
- Conclusions

Introduction





- **50% of the global population lives in the urban areas**
  - **projected to reach around 69% by 2050.**
- **Primary drivers of LULC changes**
  - **Continuous population growth→economic expansion**
- **Environmental changes across the globe mainly in the developing countries.**
- **Rapid worldwide change of the green and agricultural land to urban settlements.**
- **Urbanization significantly impacts regional near-surface air temperatures, wind fields, the evolution of the planetary boundary layer (PBL), and precipitation, subsequently influencing air quality, human comfort, and health.**

Introduction *(contd..)*

Role of land use/land cover

- **Fluxes of energy, momentum, water, heat are parametrized in NWP models as functions of**
  - **Surface albedo**
  - **Surface moisture availability**
  - **Surface emissivity**
  - **Surface roughness**
  - **Surface thermal inertia**

  Which are specified for a given LULC.

- **Thus, Land use/cover determines inputs to be used by land surface models which compute land-atmosphere fluxes.**

LU changes across the megacities of world

Dubai (1990-2007)

Shanghai (1990-2010)

Panama (1930-2009)

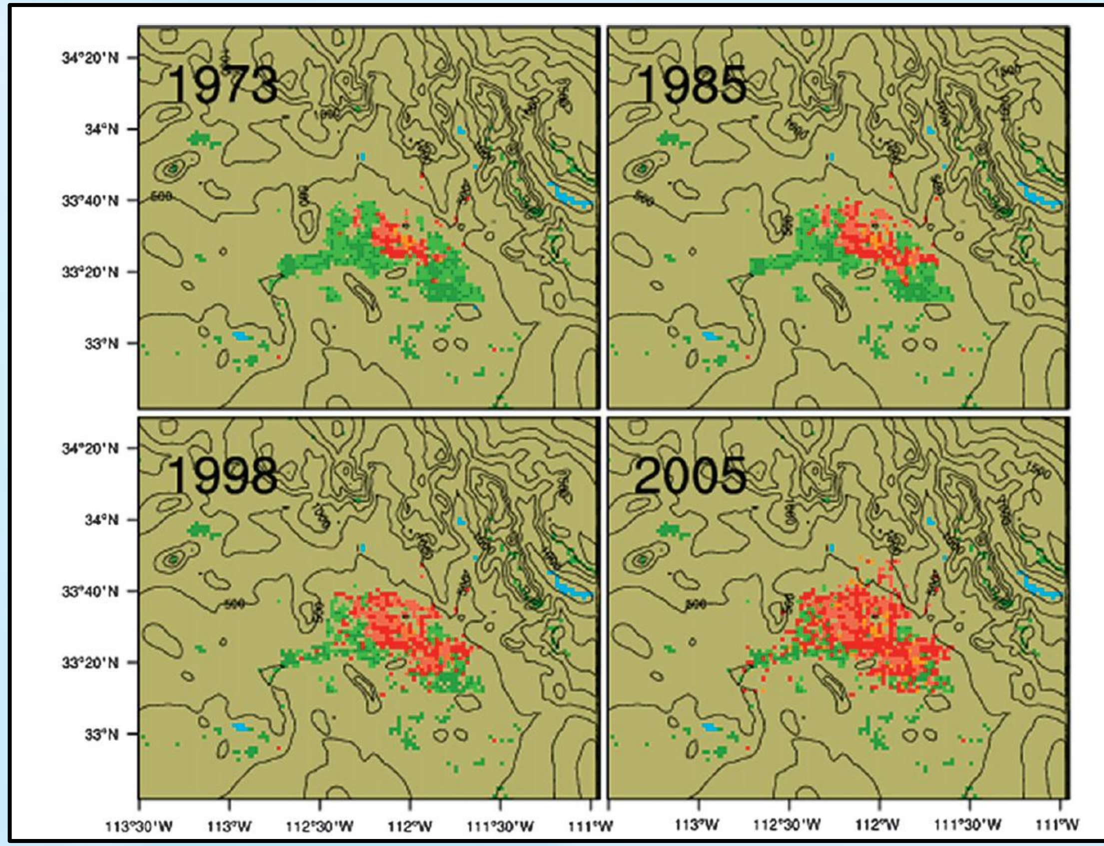
Tokyo (1960 -2010)

Impact of LULC Changes: Case Studies

(i) Extreme heat events in Phoenix Metropolitan Area*

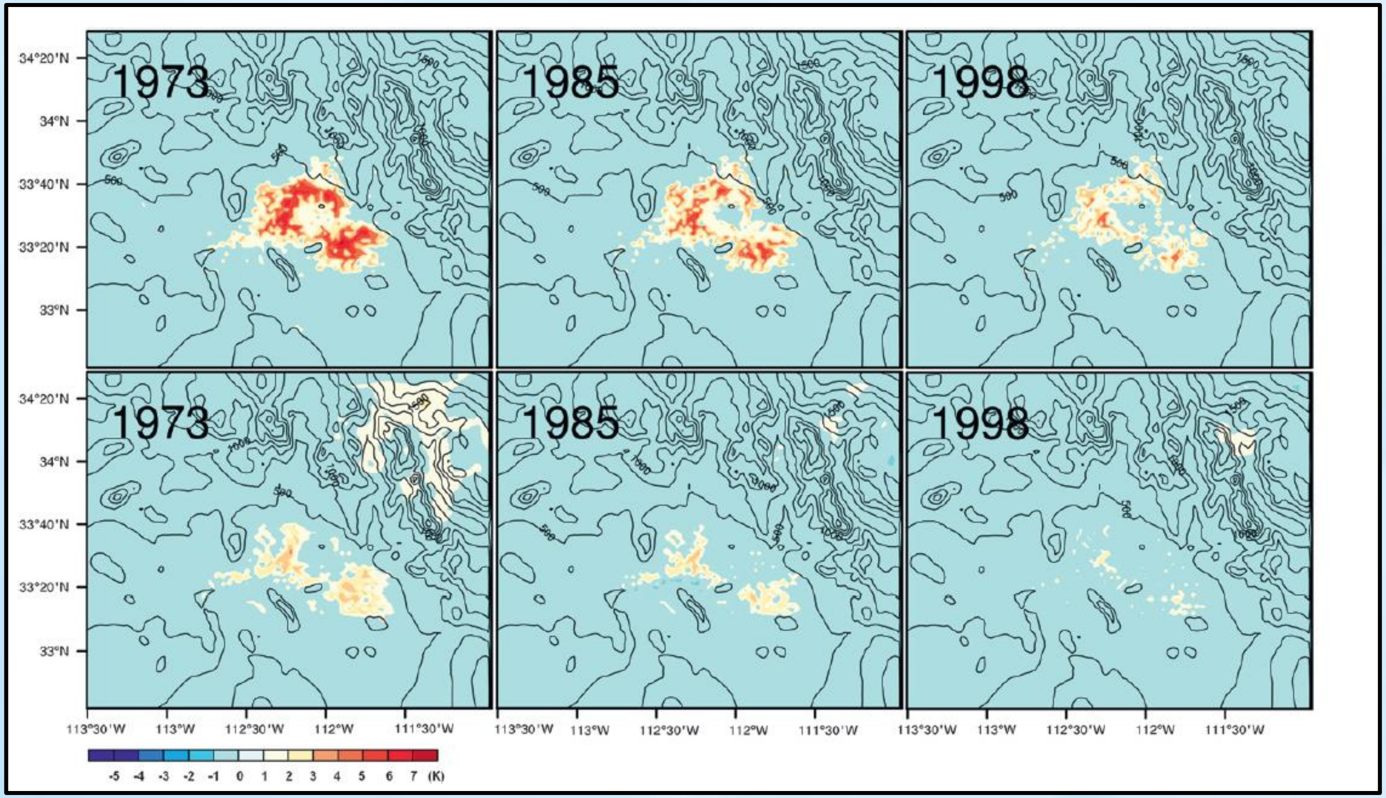
Here, the WRF/Noah UCM modeling system is applied to analyze the effects of urban land use changes on the magnitude of day- and nighttime temperatures during the Extreme heat events.

Landsat derived land use data for 1973, 1985, 1998, and 2005 are used to provide the basis for model parameter values.



Topography (contours from 0 to 3000 m; interval 250 m) and LULC for 1973, 1985, 1998, and 2005. based on Landsat satellite-derived LULC data .To emphasize the urban land use changes the colors are grouped together for the rural land use classes (grassland,shrubland, deciduous broadleaf forest, evergreen needle leaf forest).

*Clarke, S. G., Zehnder, J. A., Loridan, T. & Grimmond, C. S. B. (2010). Contribution of Land Use Changes to Near-Surface Air Temperatures during Recent Summer Extreme Heat Events in the Phoenix Metropolitan Area. *Journal Of Applied Meteorology And Climatology* 49: 1649–1664.

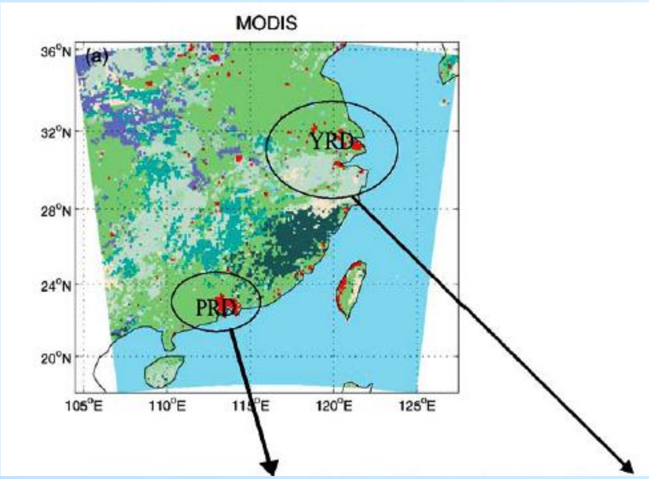


Average difference in air temperature 2 m 2005 LULC and historic LULC data 1973, 1985, and 1998) for (top) 0500 LST and (bottom) 1700 LST. Also included are topography contours (from 0 to 3000 m; interval 250 m).

Results show that urban land use characteristics that have evolved over the past about 35 years in the Phoenix metropolitan region have had a significant impact on extreme near-surface air temperatures occurring during EHEs in the area. Simulated maximum daytime and minimum nighttime temperatures were notably higher because of the conversion of agricultural to urban land use.

Clarke et al, (2010). *Journal Of Applied Meteorology And Climatology* 49: 1649–1664.

(ii) Meteorology and Air Quality in Pearl and Yangtze River Delta*



A month-long simulation were conducted by Xuemei et al., (2009) using WRF-Chem to investigate the effects of urban expansion on surface meteorology and ozone concentrations in two rapidly expanded urban areas located in slightly different climate regimes: Pearl River Delta (PRD) and Yangtze River Delta (YRD) regions of China.

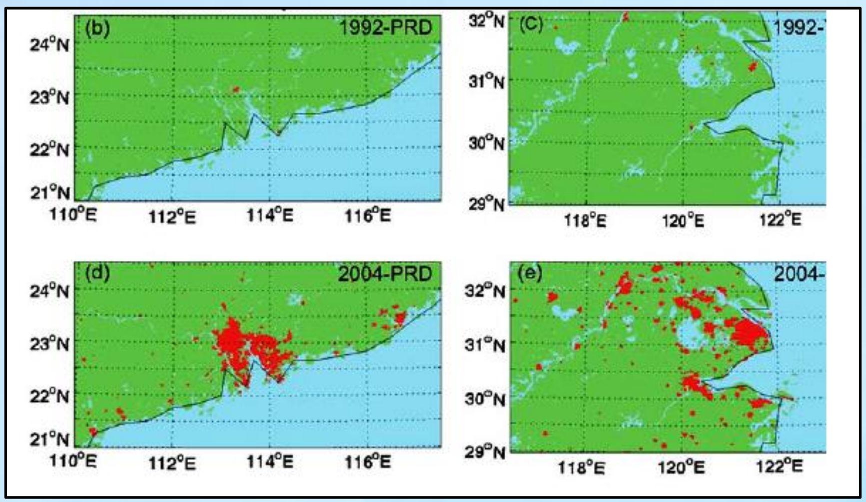


Fig: The land-use data sets used for the WRF-Chem simulations:

Upper panel is for 1992–1993 USGS data of PRD (left) and YRD (right)

Lower panel is for 2004 MODIS data of PRD, PRD (left) and YRD (right)

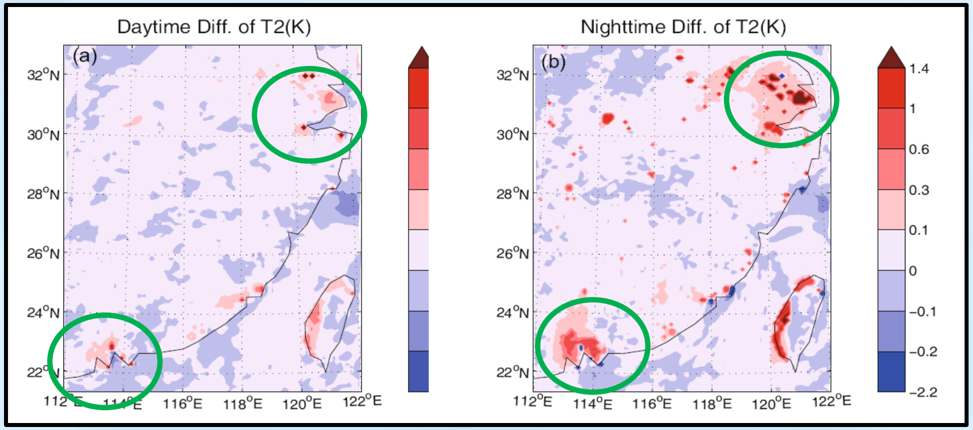
The only change between upper and lower panel for both the regions is the urban areas marked in red.

*Xuemei, W., Fei, C., Zhiyong, W., Zhang, M., Tewari, M., Guenther, A. & Wiedinmyer, C. (2009). Impacts of Weather Conditions Modified by Urban Expansion on Surface Ozone: Comparison between the Pearl River Delta and Yangtze River Delta Regions. *Advances In Atmospheric Sciences*, 26(5): 962–972

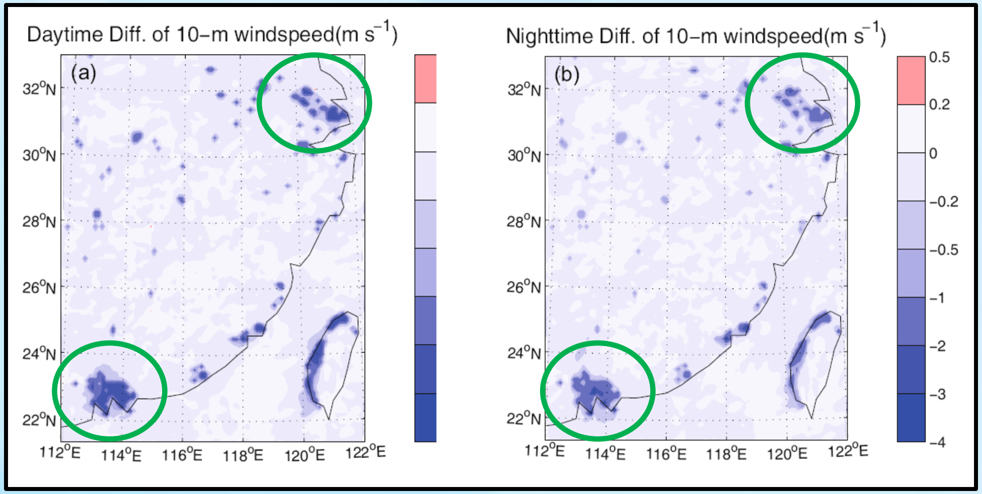
Simulation results indicate that urbanization (corresponding regions of PRD and YRD highlighted by green circles in the figures):

(1) increases both day- and night-time 2-m temperatures by about 0.6◦C and 1.4◦C, respectively;

(2) decreases both day- and night-time 10-m wind speeds, and the daytime reduction (by 3.0 m s−1) in wind speed is larger than that for the nighttime (by 0.5 to 2 ms−1)



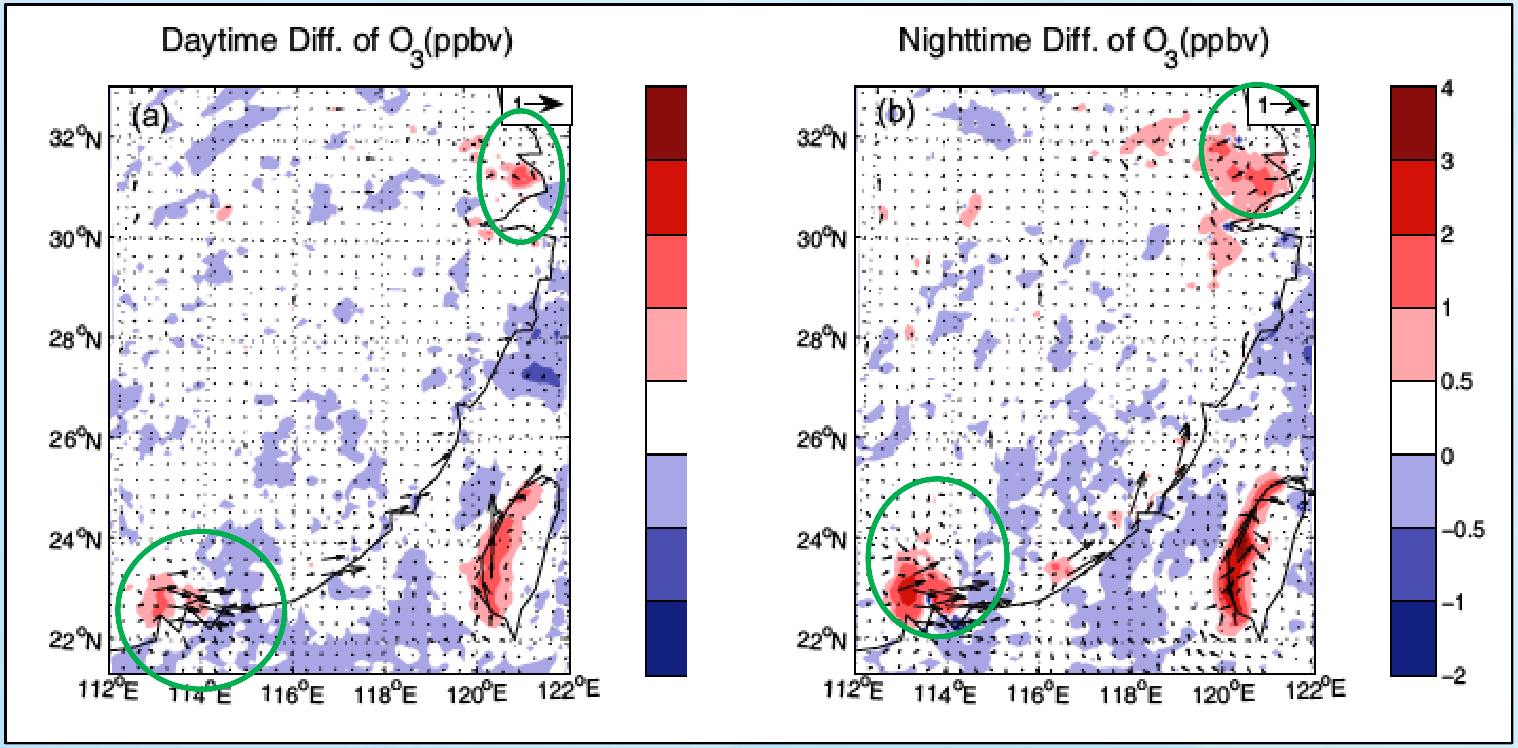
Differences of the 2-m temperatures (K) between the urban and pre-urban simulations. (a) Monthly average for the daytime and (b) monthly average for the nighttime.



As in above figure, but for the difference of the monthly-averaged 10-m wind speeds.

Xuemei, W., Fei, C., Zhiyong, W., Zhang, M., Tewari, M., Guenther, A. & Wiedinmyer, C. (2009). Impacts of Weather Conditions Modified by Urban Expansion on Surface Ozone: Comparison between the Pearl River Delta and Yangtze River Delta Regions. *Advances In Atmospheric Sciences*, 26(5): 962–972

Urbanization increases surface ozone concentrations by about 4.7%–8.5% for the nighttime and by about 2.9%–4.2% for the daytime in the PRD and YRD regions (highlighted by green color in the figures).



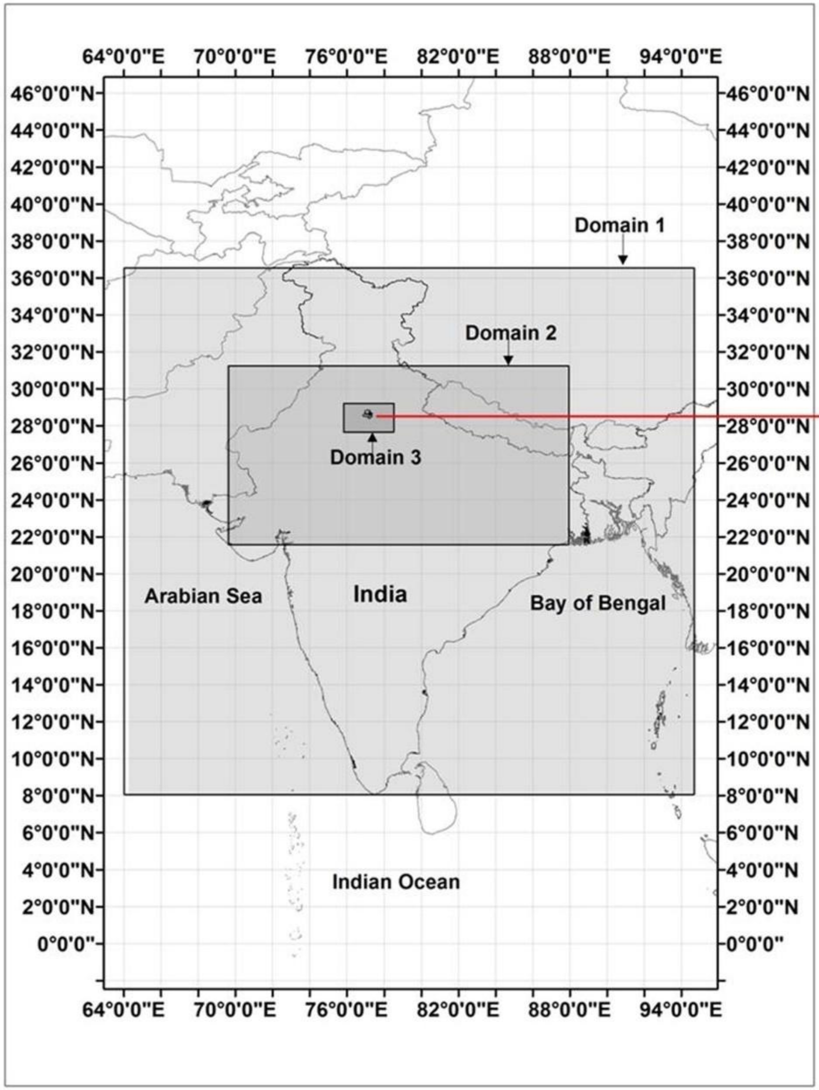
Difference of surface ozone: emphasis on Pearl River delta and Yangtze River Delta

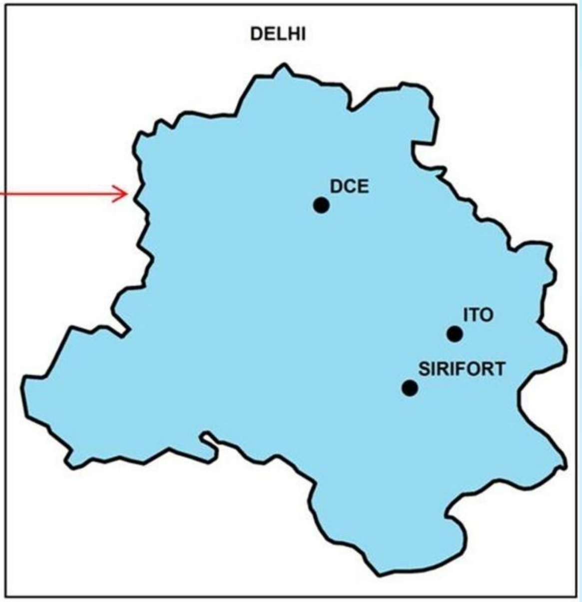
Xuemei, W., Fei, C., Zhiyong, W., Zhang, M., Tewari, M., Guenther, A. & Wiedinmyer, C. (2009). Impacts of Weather Conditions Modified by Urban Expansion on Surface Ozone: Comparison between the Pearl River Delta and Yangtze River Delta Regions. *Advances In Atmospheric Sciences*, 26(5): 962–972

(1) WRF/Chem model validation for Ozone

Gupta and Mohan; Atmos. Environ., (2015), **122,** 220-229

Simulation Domains





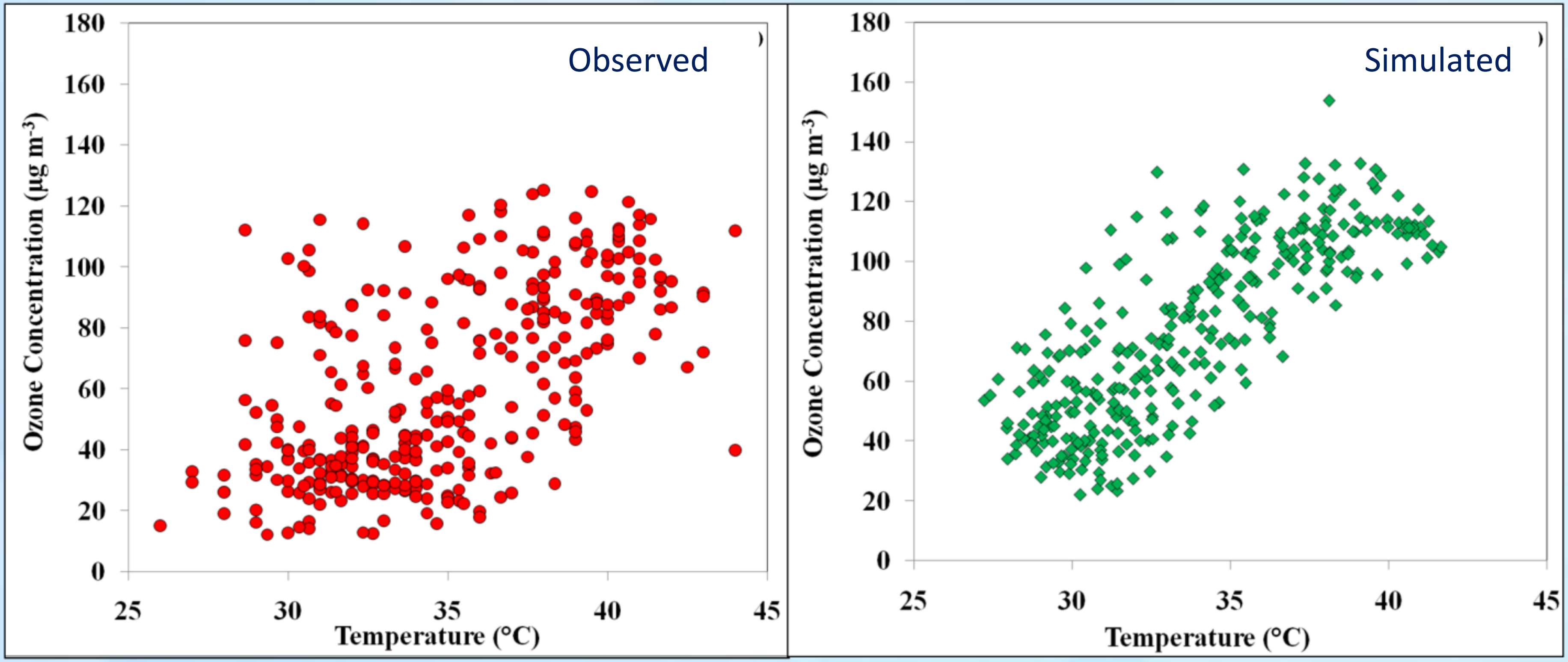
Description of selected sites

Station Name	Zone	Latitude	Longitude	Site Classification
Income Tax Office (ITO)	Central Delhi	28.63°	77.25°	Traffic Junction
SiriFort	South East Delhi	28.55°	77.21°	Residential site and sports complex
Delhi College of Engineering (DCE)	North Delhi	28.75°	77.11°	Institutional site

Sources of Model Input

Data	Source	Resolution
Terrestrial Data	USGS 24- category land use data	30´´
Meteorological Data	NCEP FNL Operational Global Analysis data	1°
Emission Data	EDGAR	0.1°

Air Quality: Effect of Temperature on Ozone Production



- For temp ≥ 38°C,
  40 µgm^{-3} ≤ Observed Ozone ≤ 120 µgm^{-3} and Simulated Ozone > 90 µgm^{-3} .

- For temp ≤ 28°C,
  Observed Ozone ≤ 30 µgm^{-3} and 30 µgm^{-3} ≤ Simulated Ozone ≤ 70 µgm^{-3}.

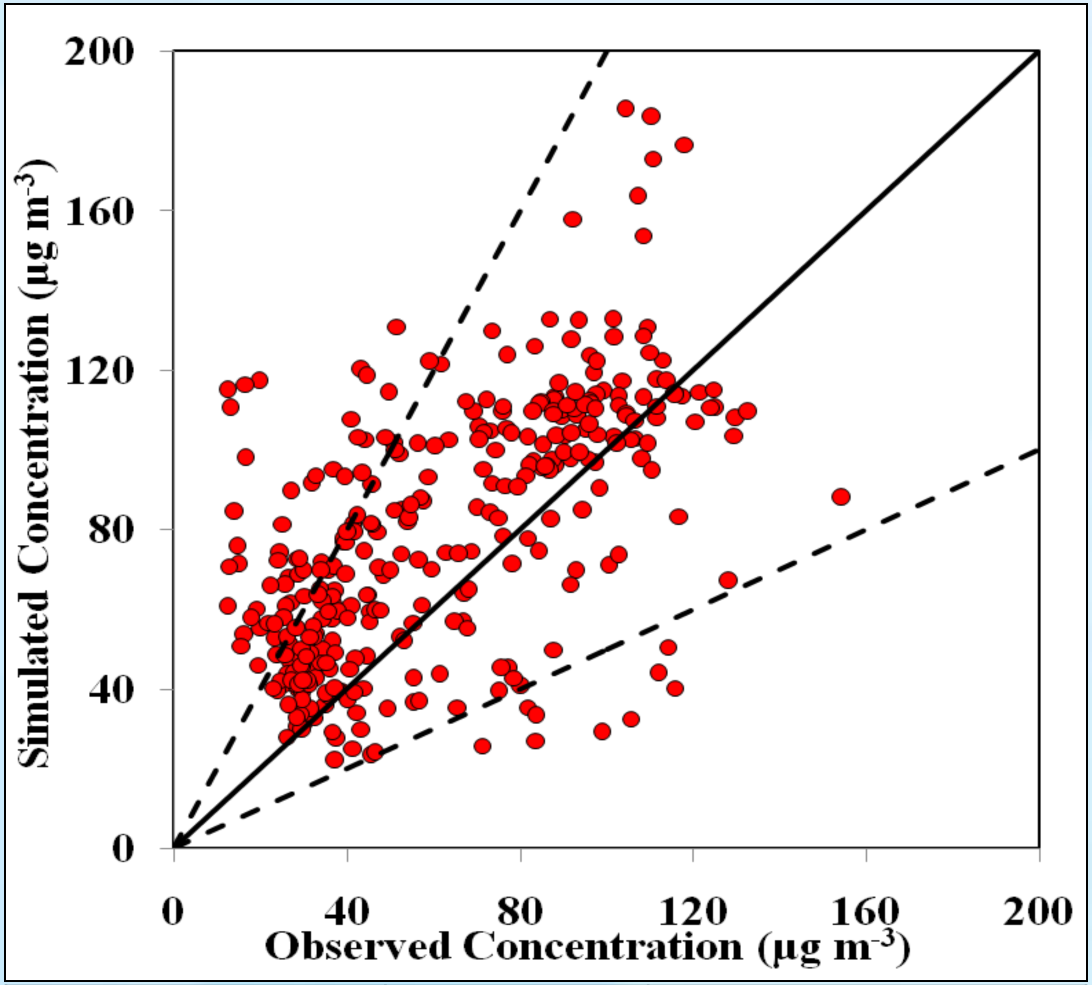
*Gupta and Mohan; Atmos. Environ., (2015), **122,** 220-229

O_3 concentration:

- Model performance for simulating O_3 concentrations is considered good.

- However, over prediction is observed in case of O_3.

- O_3 concentration levels are further evaluated in terms of its relationship with temperature.



Parameter (Ideal Value)	Statistic Value	Reported Value [Ref.]
IOA (1)	0.82	0.66 to 0.9 [4]
RMSE (0)	32.97	≈ 35 [5]
FB (0)	-0.24	± 0.15 [6]

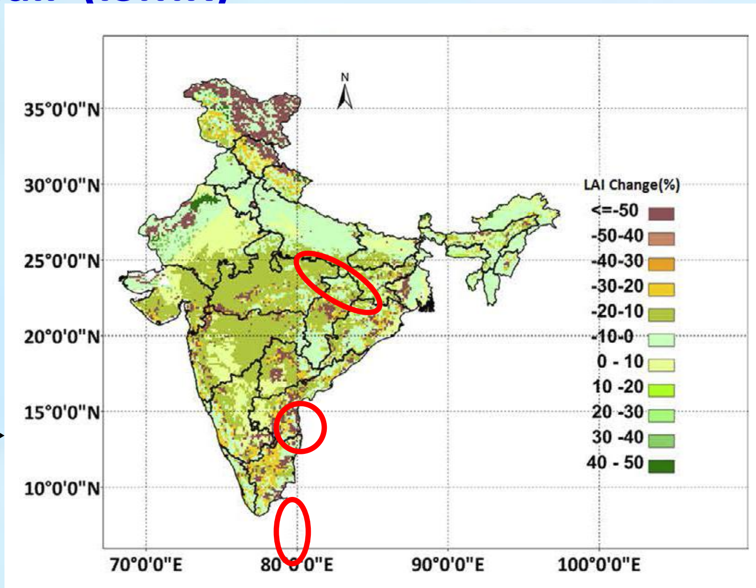
(iv) Impact on Indian Summer Monsoon Rainfall (ISMR)*

- Large-scale conversion from woody savannah to crop land in India from 1987 and 2005.

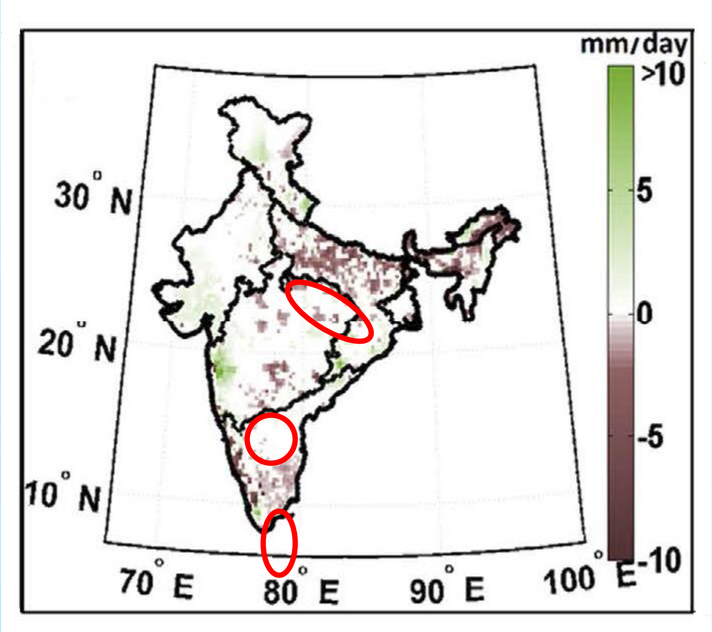
- Deforestation results in weakening of the ISMR because of the decrease in evapotranspiration and subsequent decrease in the recycled component of precipitation.

- Decrease in precipitation observed in Ganga Basin, Central India, and North East India corresponds to decrease in LAI over these areas.

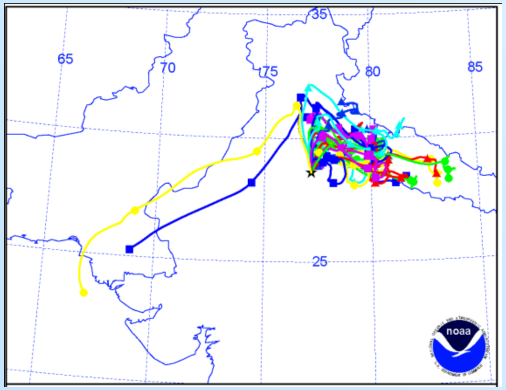
Changes in Leaf Area Index (%) →



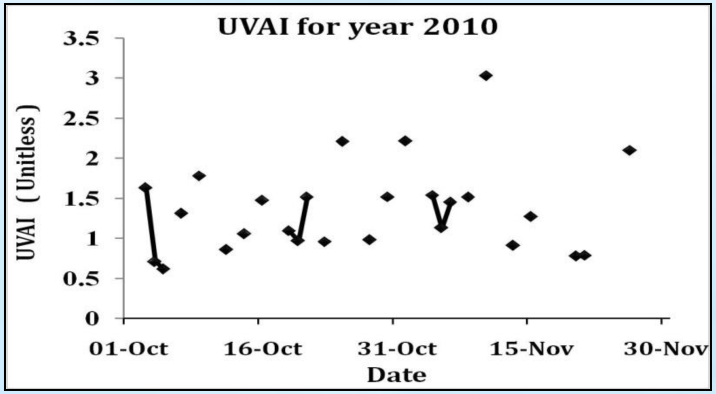
Observed Changes in Precipitation →



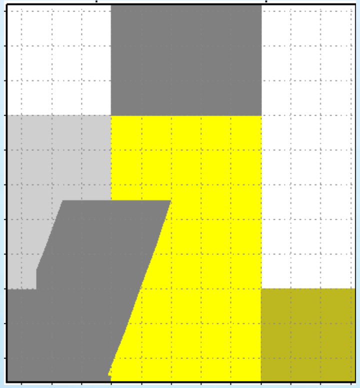
*Paul et al, 2016, Scientific Reports | 6:32177



(*a*)

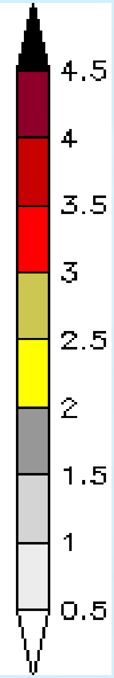


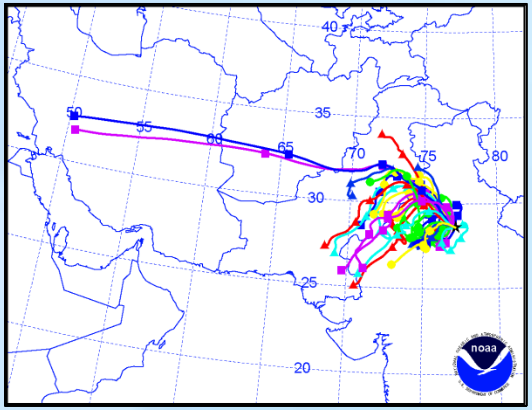
(*b*)



(*c*)

Sati and Mohan, 2014; IJRS





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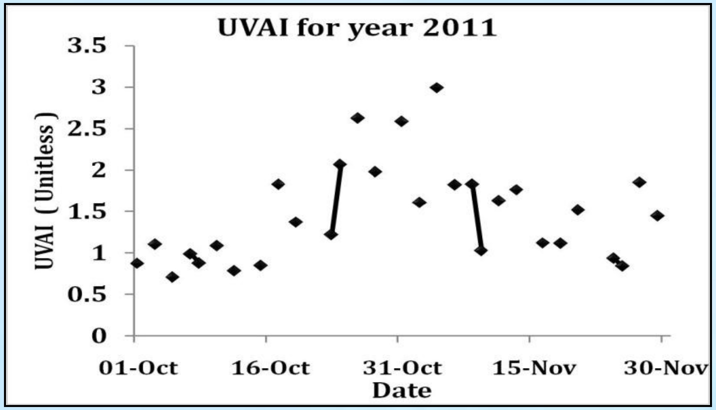

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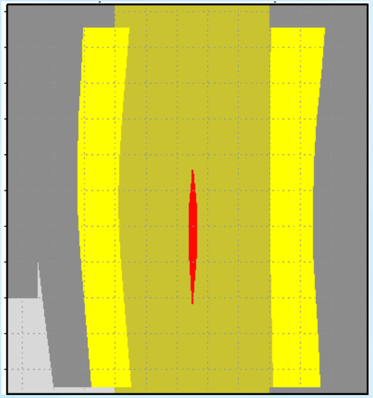

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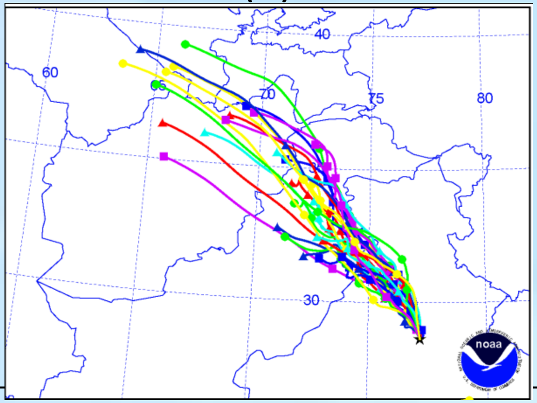
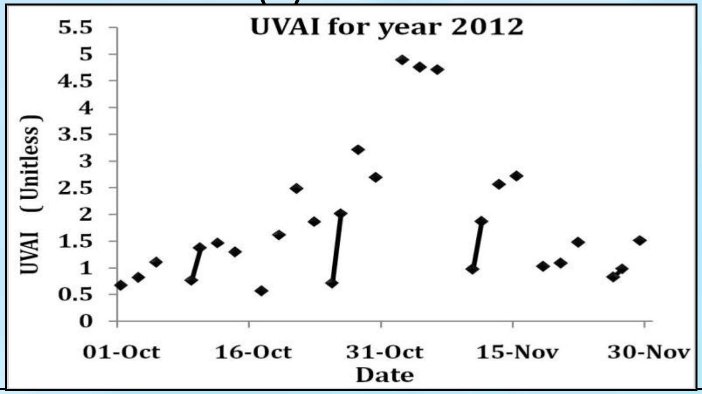
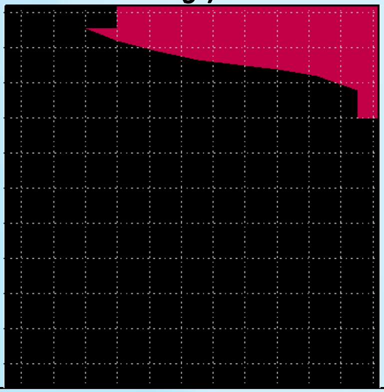






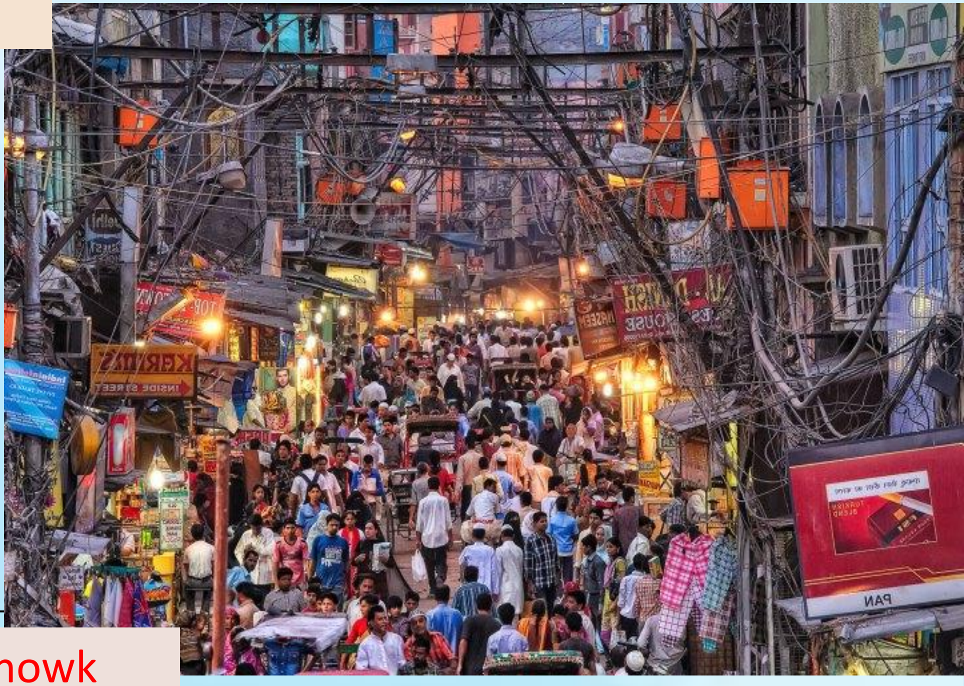
Prof M Mohan
IIT Delhi, India

(*g*) (*h*) (*i*)

LULC Changes and Impacts
Case Study: Delhi

1930 Connaught place 2010

Delhi



Chandni chowk

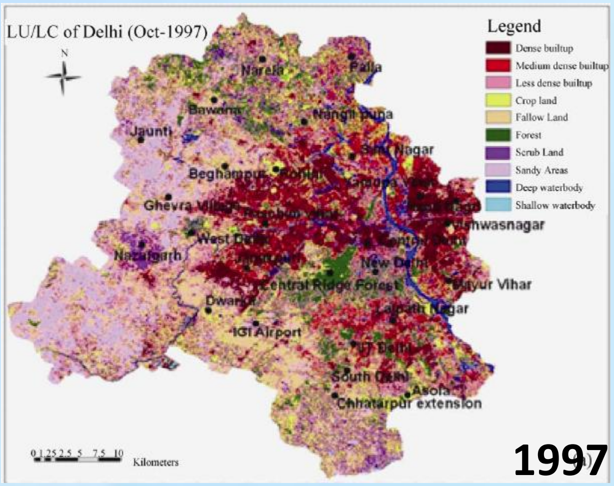
IPCC has recognized* connections between urbanization and the development of UHI in several cities of the world including Delhi . The report includes above studies in Delhi which have explored this relationship

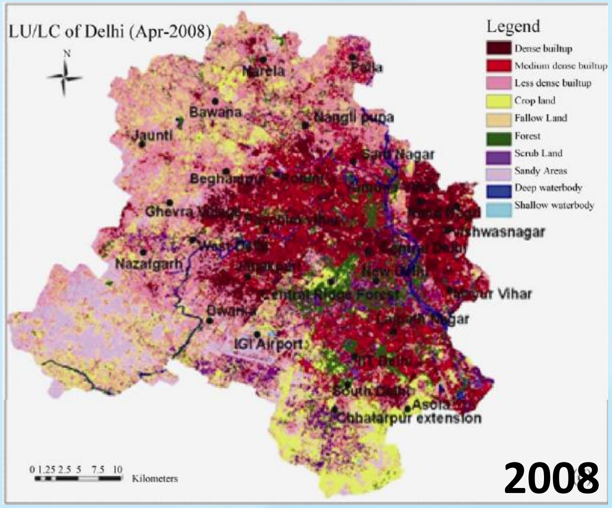
- ***Dynamics of Urbanization and LULC** (Mohan et al, 2011)*: **shows there has been significant change in LULC which is expected to have led to changes in temperatures (ISRO, RESPOND Project; 2007-2010).**
- ***Urban Heat Island and Temperature Trends*** **(Mohan et al, 2011) wherein some signatures of heat island effect were obtained to relate urbanisation with change in temperature trends (ISRO, RESPOND Project; 2007-2010).**
- ***UHI based on ambient and satellite derived temperatures*** **(Mohan et al, 2012) in which systematic field campaign was carried out to estimate existing UHI effect (Indo-Japanese Cooperative Project on Heat Island Effect 2008-2015).**

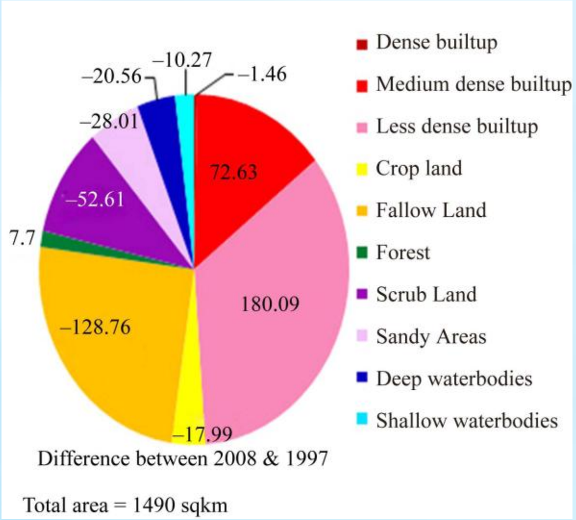
***IPCC WGII AR5 Chapter 8, 2014**

Dynamics of Urbanization for Megacity Delhi

- **Changes in LULC and urban expansion in Mega city Delhi were evaluated based on satellite data.**
- **Major impacts of rapid urbanization and population growth on the land cover changes which needs immediate attention were highlighted.**







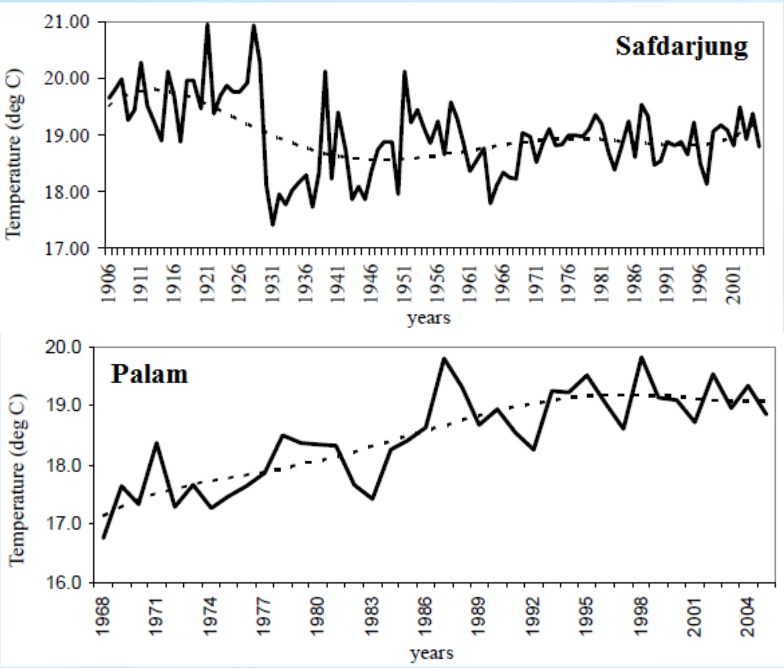
Land use/Land cover distribution over Delhi for the years 1997 and 2008.

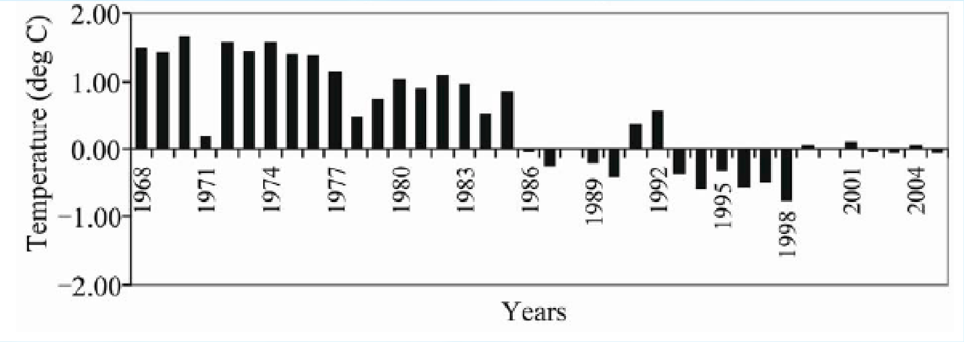
Land Cover changes (km^2) in Delhi for different classes from 1997-2008

Mohan, M., S. K., Pathan, K. Narendrareddy, A. Kandya, and S. Pandey (2011), Dynamics of Urbanization and Its Impact on Land-Use/Land-Cover: A Case Study of Megacity Delhi. Journal of Environmental Protection, 2, 1274-1283.

Urban Heat Island and Temperature Trends

- A consistent increasing trend was seen in the annual mean minimum temperatures indicating an overall warming trend over the NCR especially after 1990.





Annual Mean Minimum Temp difference between Safdarjung and Palam during 1968 - 2005.

- Increasing warming trends in the night-time temperatures reflect the contribution of changing land-use patterns and additional anthropogenic heat that may enhance the urban heat island intensities in the city.

Mohan, M., A. Kandya, and A. Battiprolu (2011b). Urban Heat Island Effect over National Capital Region of India: A Study using the Temperature Trends.journal of Environmental Protection, 2, 465-472

Diurnal Temperature Range*

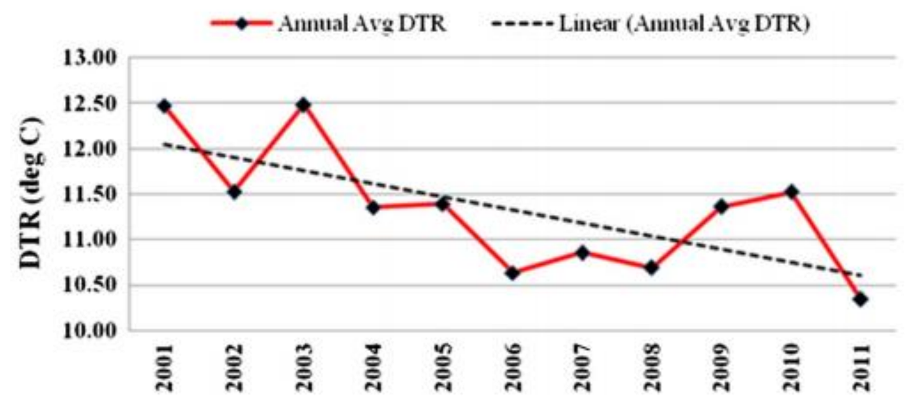
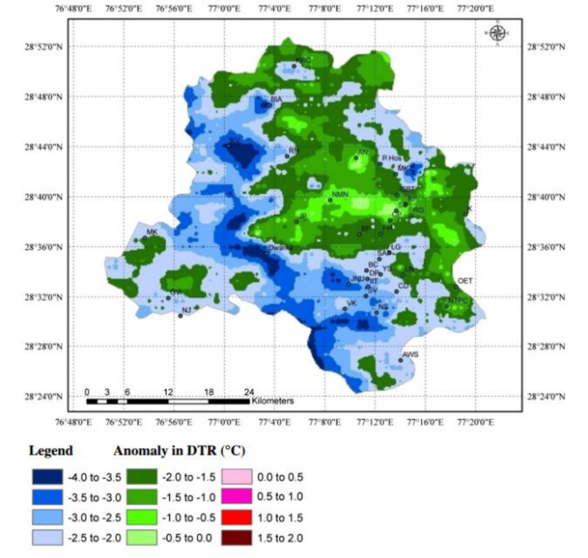
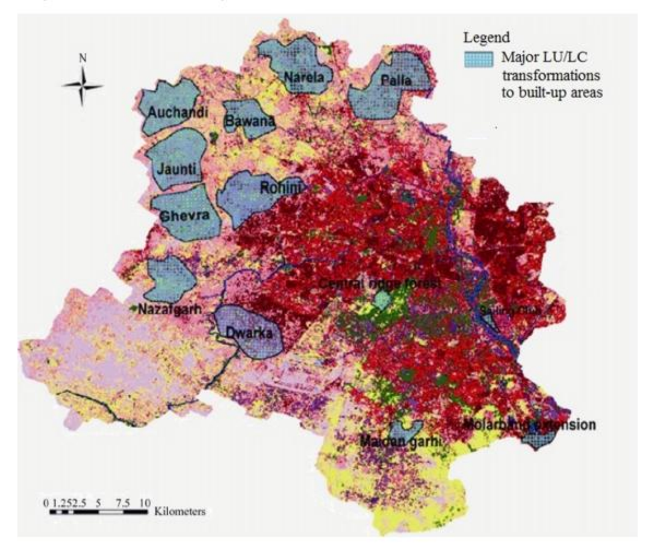


Fig. 2. Annually averaged DTR of Delhi.

- **Satellite based annually averaged DTR of entire Delhi shows a significant decreasing trend.**
- **Areas of Rapid urbanization exhibited a highly decreasing trend in DTR.**



DTR anomaly across Delhi for year 2011 with reference to year 2001



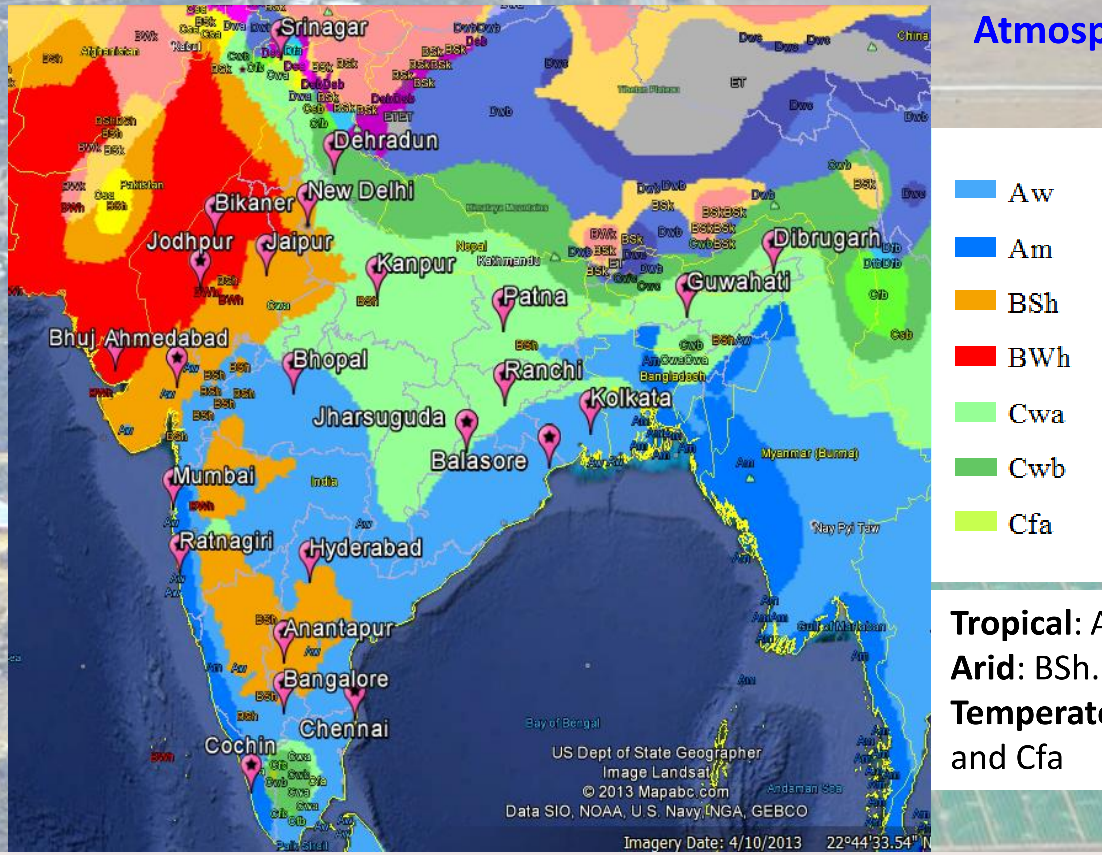
Major Land Use / Land Cover changes in Delhi during 1997-2008

** M Mohan and A Kandya 2015, Impact of urbanization and land-use/land-cover change on diurnal temperature range: A case study of tropical urban airshed of India using remote sensing data. Science of the Total Environment 506–507 (2015) 453–465*

Analysis of LULC Impacts using WRF Modelling System

Stations for Model Validation

Gunwani and Mohan;
Atmospheric Research, 2017

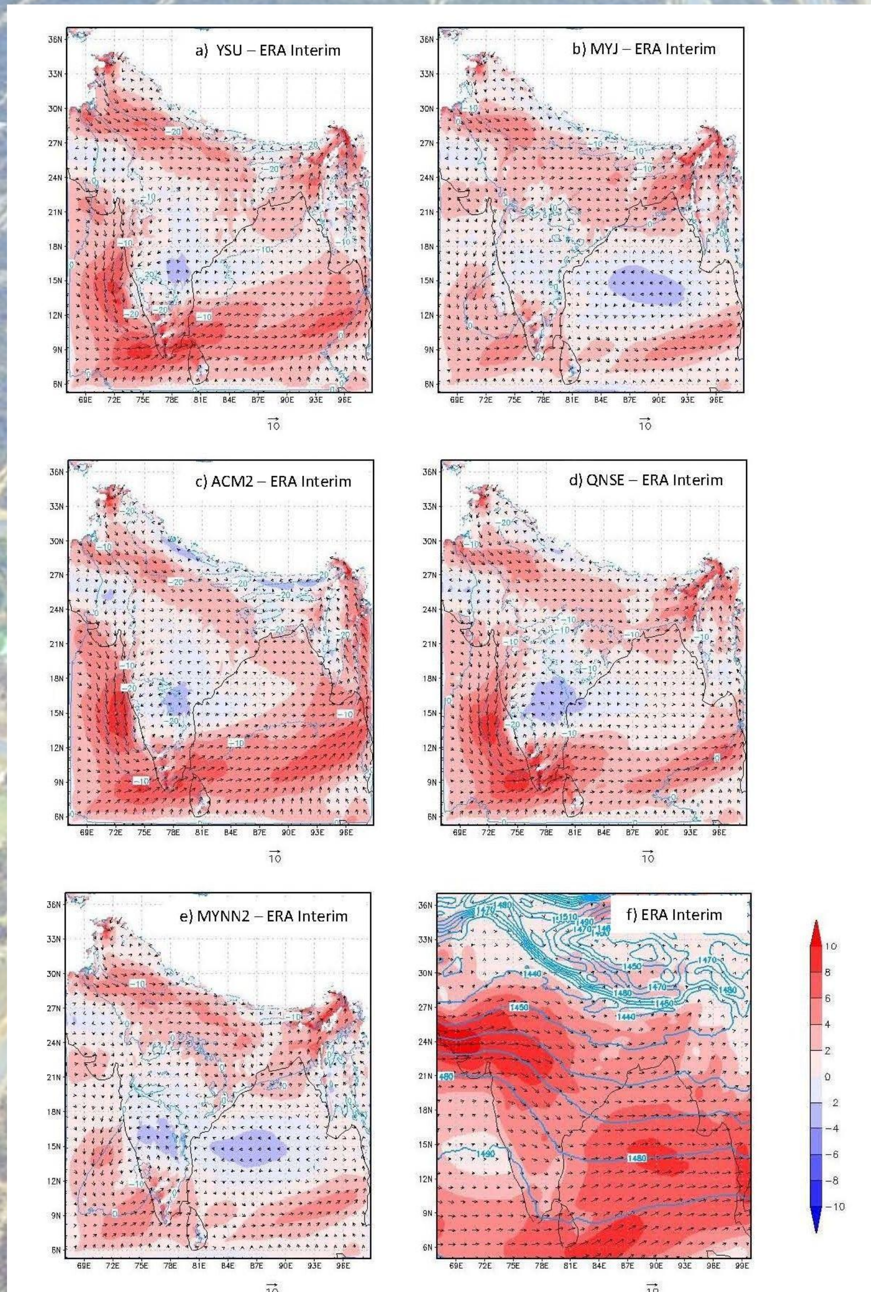


Tropical: Aw, Am
Arid: BSh. BWh
Temperate: Cwa,Cwb and Cfa

The different koppen climate classification (Peel et al., 2007) found in India are - Tropical Monsoon (Aw), Tropical Savannah (Am), Arid Steppe Hot (BSh), Arid Desert Hot (BWh), Temperate Dry winter Hot summer (Cwa), Temperate Dry winter Warm summer (Cwb), Temperate without dry season Hot summer (Cfa). The climate classes have been broadly divided into three zones namely - Tropical, Arid, and Temperate.

Reference: Gunwani and Mohan 2017

Synoptic weather conditions – wind and geopotential height at 850hPa



Reference: Gunwani and Mohan 2017; Atmospheric Research

- ERA Interim shows strong westerly winds of the order of 6–12 m/s over India during summer period.
- The simulated geopotential height almost overlaps with the ERA Interim during winter period and maximum difference ranging between 10 and 20m is seen during summer.
- YSU, ACM2 and QNSE show positive bias (overestimation) for wind speed and higher differences for wind direction over sea compared to land.
- Higher positive bias over land area is seen around northern and north eastern India during
summer.
- Overall ACM2 and MYNN show lower wind and geopotential bias at 850 hPa during summer, whereas YSU and MYNN work better in winter.

Statistical Performance, T2, Summer

Climatic zones		YSU	MYJ	ACM2	QNSE	MYNN	Acceptable values	Best option
Tropical	IOA	0.85	0.88	0.84	0.88	0.80	>0.8	MYJ, QNSE
	Bias	1.55	0.68	1.23	0.74	2.45	<±0.5	
	FB	-0.0051	-0.0022	-0.0041	-0.0024	-0.0079	<±0.5	
	RMSE	3.12	2.83	3.47	2.80	4.18	<2	
Arid	IOA	0.62	0.73	0.73	0.74	0.65	>0.8	ACM2, QNSE
	Bias	4.98	3.25	3.15	3.20	4.75	<±0.5	
	FB	-0.0162	-0.0106	-0.0103	-0.0104	-0.0155	<±0.5	
	RMSE	7.04	5.60	5.75	5.51	6.99	<2	
Temperate	IOA	0.73	0.82	0.85	0.84	0.73	>0.8	ACM2
	Bias	5.96	4.23	3.24	3.79	6.14	<±0.5	
	FB	-0.0196	-0.0139	-0.0107	-0.0125	-0.0201	<±0.5	
	RMSE	7.33	5.57	5.23	5.36	7.59	<2	
All Stations	IOA	0.71	0.80	0.81	0.81	0.72	>0.8	QNSE, ACM2
	Bias	3.94	2.53	2.46	2.43	4.22	<±0.5	
	FB	-0.0129	-0.0083	-0.0081	-0.0080	-0.0138	<±0.5	
	RMSE	5.99	4.76	4.89	4.65	6.27	<2	

- Similarly QNSE and ACM2 also show good performance during winter period

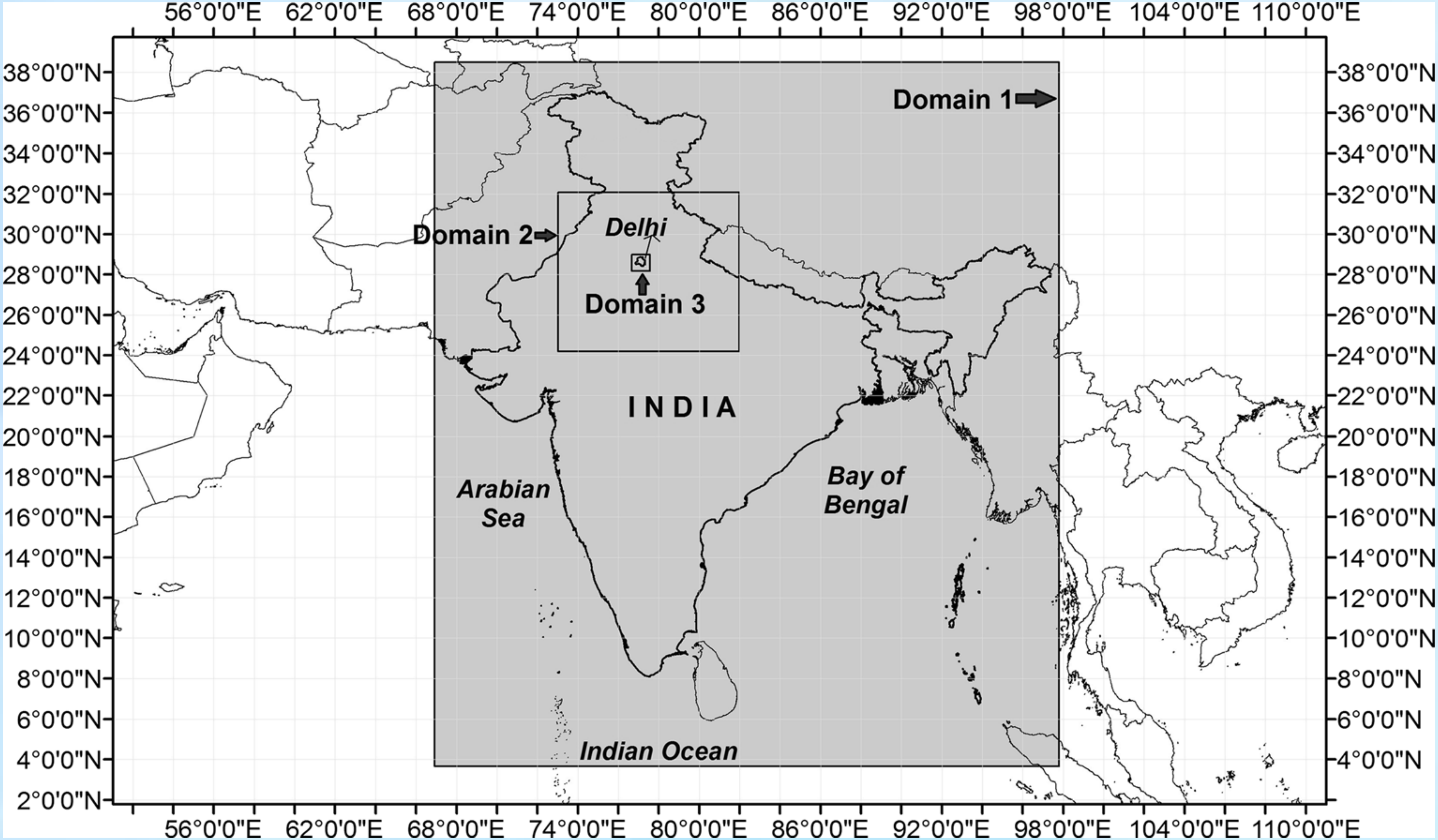
Reference: Gunwani and Mohan 2017; Atmos. Res.

Simulation Details

- **Simulations over the study area of Delhi were carried out using WRF modeling system (v 3.5).**

- **Simulation Details**
  - **Time Period: 5 Mar 2010 0000 UTC – 11 Mar 0000 UTC**
  - **Analysis: 6 Mar 2010 0600 UTC – 11 Mar 0000 UTC**
  - **No. of Domains: 3 ; Resolution: 18 km, 6km, 2km**

- **Physical Schemes (*Mohan and Bhati, 2011, Advances in Meteorology*)**
  - **Microphysics: Lin**
  - **NOAH LSM**
  - **ACM 2 Boundary Layer**
  - **Kain Fritsch cumulus parametrisation**



Model Domains

LULC Categories

- **The built-in USGS 24 category land-use data in WRF is based on AVHRR satellite data spanning April 1992 through March 1993 using a resolution of ˜ 1 km (Schicker, 2011; Sertel et al, 2009).**

- **Major differences, specially in terms of urban land cover, have been observed in USGS data and present LULC.**

- **Present study is aimed at analyzing impact of change in input land cover on model outputs such as air temperature and land surface temperature.**

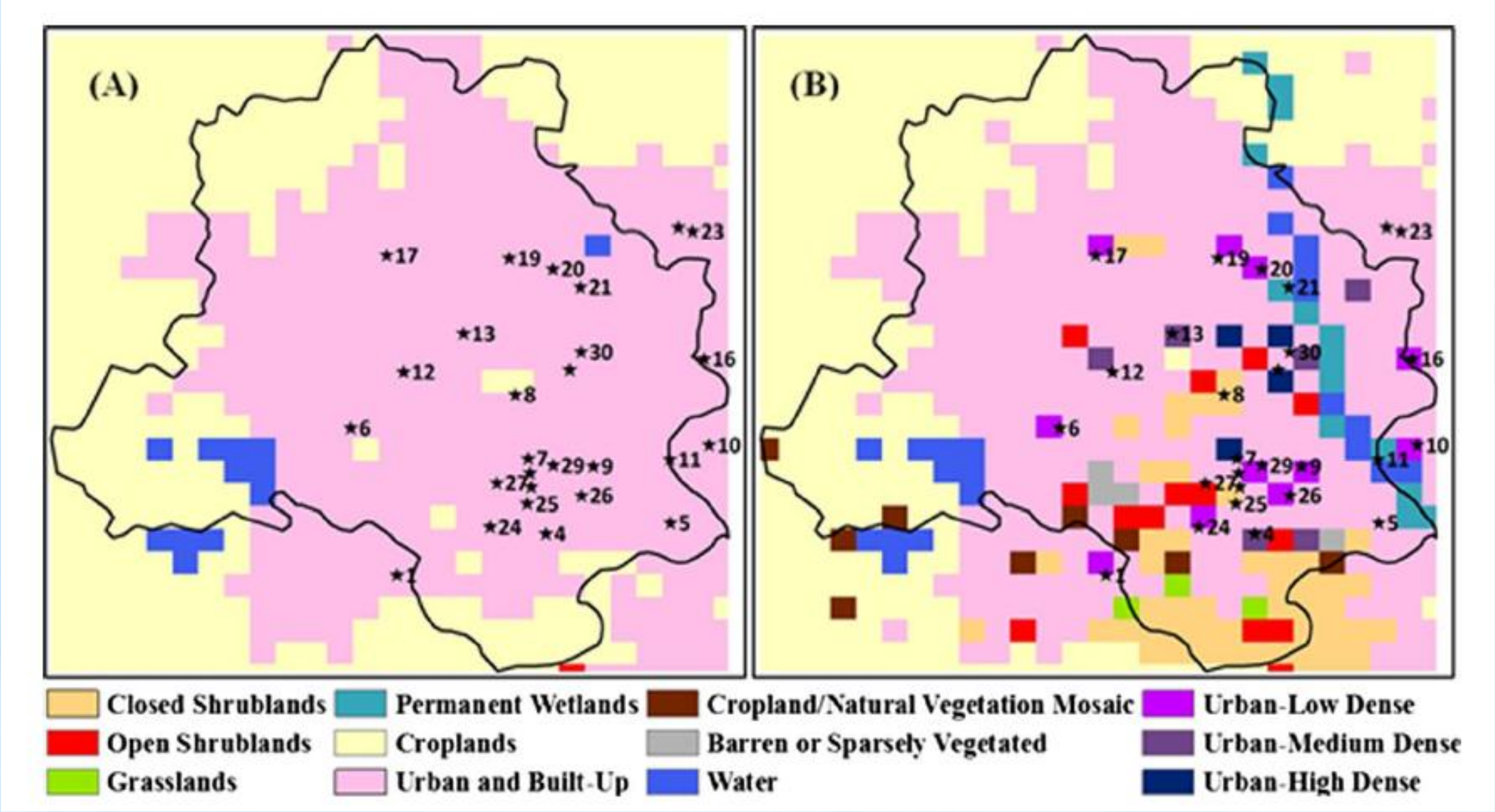
- **MODIS IGBP is a 20 category land use data based on MODIS satellite data collected during years 2001-2005.**

- **Urban areas are more dominant in MODIS data.**

Distribution of different land use types in input terrestrial data sets for WRF model

Type	USGS	MODIS	UCM	Satellite *(Mohan et al, 2011)*
Urban (built up/high-low residential/commercial/industrial)	25.17%	90.66%	49.83%	52%
Cultivated (Cropland and Pastures)	59.03%	6.08%	27.43%	20%
Natural (Grassland/Scrubland/ Woodland)	14.58%	0.83%	18.92%	14%
Water	1.22%	2.43%	3.13%	12%
Barren/Sparsely vegetated/Sandy	0.00%	0.00%	0.69%	2%

Representation of different landuse/land cover



Land use of Delhi as simulated by WRF based on MODIS land use data with (a) WRF (b) modified LULC with UCM. * symbols followed by number indicate location of micrometeorological stations and their station code in the field campaigns

Bhati, S. and Mohan, M., 2015. WRF model evaluation for the urban heat island assessment under varying land use/land cover and reference site conditions. Theoretical and Applied Climatology, pp 1-16. 10.1007/s00704-015-1589-5

UHI Field Campaigns*1,2

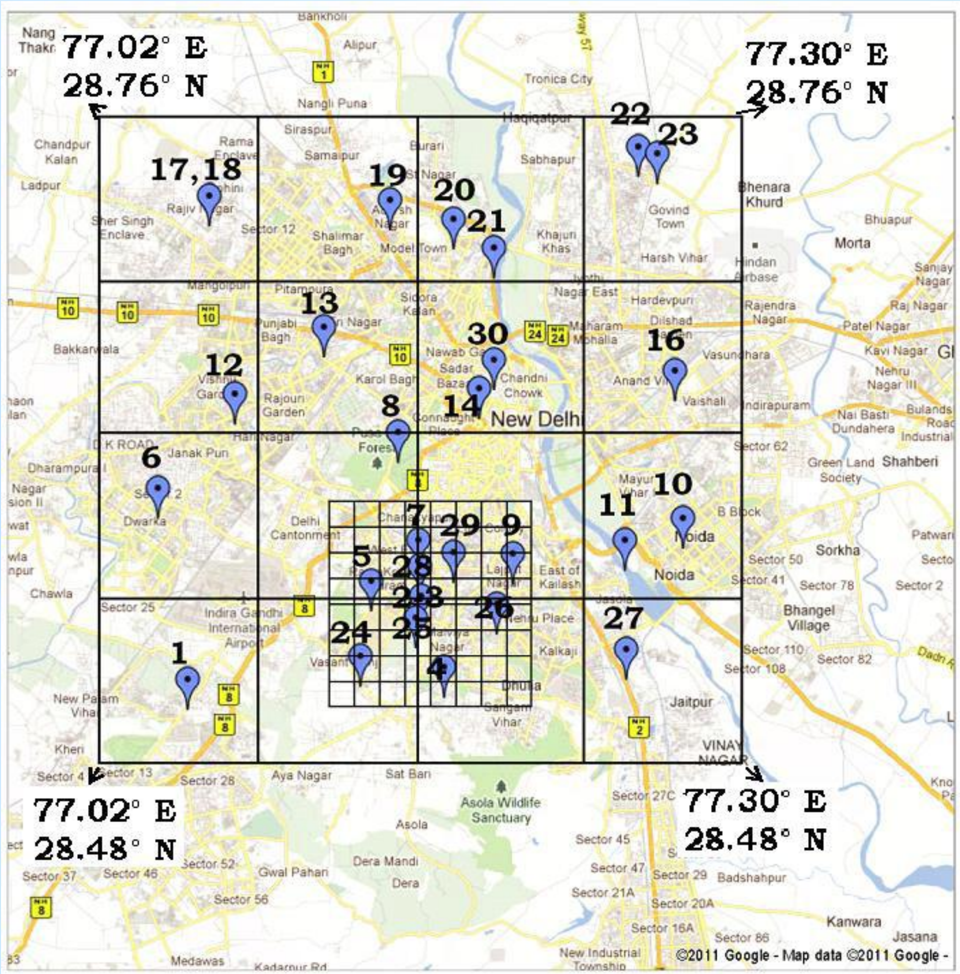
- DELHI (Delhi Experiments for Learning Heat Island)
  - DELHI-1 (23-28 May 2008)
  - DELHI-2 (4-10 March 2010)

- Urban heat islands in Delhi were assessed based on both air temperature as well as land surface temperature.

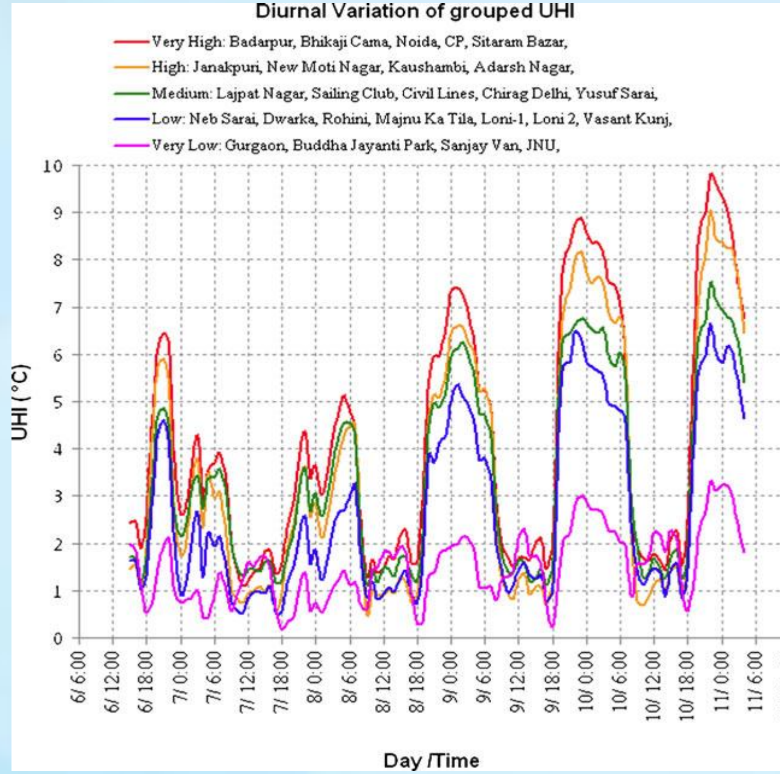
- The studies revealed temperature hotspots in densely populated and commercial areas.

1 Mohan, M., Y. Kikegawa, B. R. Gurjar, S. Bhati, A. Kandya and N. T. Kolli** *(2013), Assessment of urban heat island effect for different land use–land cover from micrometeorological measurements and remote sensing data for megacity Delhi,* ***Theoretical and Applied Climatology*, 112, 647-658.*

2 Mohan M, Yukihiro Kikegawa, B.R. Gurjar, S. Bhati, A. Kandya and K. Ogawa:** *Urban Heat Island Assessment for a Tropical Urban Airshed in India, Atmospheric and Climate Sciences,* ***2012*, Volume 2, pages 127-138. doi:10.4236/acs.2012.22014*



Set up of micrometeorological stations across the study area of Delhi. A 12 × 12 km sub domain with greater station density is shown in lower part of the grid network.



Diurnal variation of various categories of UHI intensities across Delhi city (March 2010)

Mohan et al, , 2012, Atmospheric and Climate Sciences, 2, doi:10.4236/acs.2012.22014

HINDUSTAN TIMES, NEW DELHI
SATURDAY, SEPTEMBER 26, 2009

metro

Local warming is here, and growing

VICIOUS CYCLE Hot zones use more ACs, become hotter still

HT Correspondent
htreporters@hindustantimes.com

NEW DELHI: You have always felt it, and now there is scientific evidence to show that the heavily commercialised belt from Connaught Place to Sitaram Bazaar is the hottest zone in Delhi.

The results follow from a study carried out by Indian Institute of Technology (IIT), Delhi.

The project, which mapped the temperatures of 30 different locations in the National Capital Region over a period of four days in May 2008, found Connaught Place along with Bhikaji Cama Place and Sitaram Bazaar to be the hottest zones of the Capital.

IIT, Hauz Khas District Park, Sanjay Van and Buddha Jayanti Park are on the other end of the temperature spectrum — the coolest.

And there's a reason why people in CP, Bhikaji Cama Place and Sitaram Bazaar are feeling the heat more than people in other parts of the city.

Professor Manju Mohan, who carried out the research in collaboration with Meisei University (Japan) and IIT, Roorkee, attributes it to a phenomenon called the Urban Heat Island (UHI) Effect.

An urban heat island is a metropolitan area which is warmer than its surroundings.

"The UHI effect is a problem faced as a result of rapid industrialisation and urbanisation of the cities. Densely populated regions generate more anthropogenic heat, that is heat generated by human activity. That increases the temperature of an area even further," she said.

"The results compiled over four days showed that three hot zones are hotter than the mentioned 'cool' zones by 2.8 to 8.3 degrees C, around 9 pm. The range in temperature variation arises from changing weather conditions — from rainy to moderately hot," Mohan said.

But why should CP or the other two areas register higher temperatures in comparison with, say, Dwarka, which has a larger human population residing there?

"This is because these are commercial areas which make the maximum use of cooling devices such as air conditioners and also have some of the busiest traffic intersections. These primarily lead to the building up of these heat islands," said Mohan.

Apart from these highly commercialised pockets, it is residential areas such as Dwarka, Noida, Janakpuri, Kaushambi and Adarsh Nagar which have turned out to be among the hotter zones in the Capital.

So what does living in a heat island really mean for a regular Delhiite?

As a natural consequence, you will feel a greater need for air-conditioning and in all probability start running up greater electricity bills. Water consumption, too, will increase.

The more cooling devices you use the more heat you generate and that sets off a vicious cycle, making it difficult to mitigate the UHI effect.

"The best mitigation solution is to stop the use of such electrical devices and vehicles which pollute. But that is not practical. We are now soon going to conduct a research on the best possible ways of mitigating this problem in Delhi," said Mohan.

HOT FLUSHES

METHODOLOGY

- 30 locations across the NCR were selected.
- Weather stations were installed on roof tops of buildings to collect data such as temperature, wind speed, wind direction and atmospheric pressure.
- Temperature and humidity measurements were taken from May 25 to May 28.

EFFECTS OF LIVING IN AN URBAN HEAT ISLAND

- Greater energy consumption due to increased use of cooling devices, which in turn generate more heat.
- Greater consumption of water.

HOT – EVEN AT NIGHT

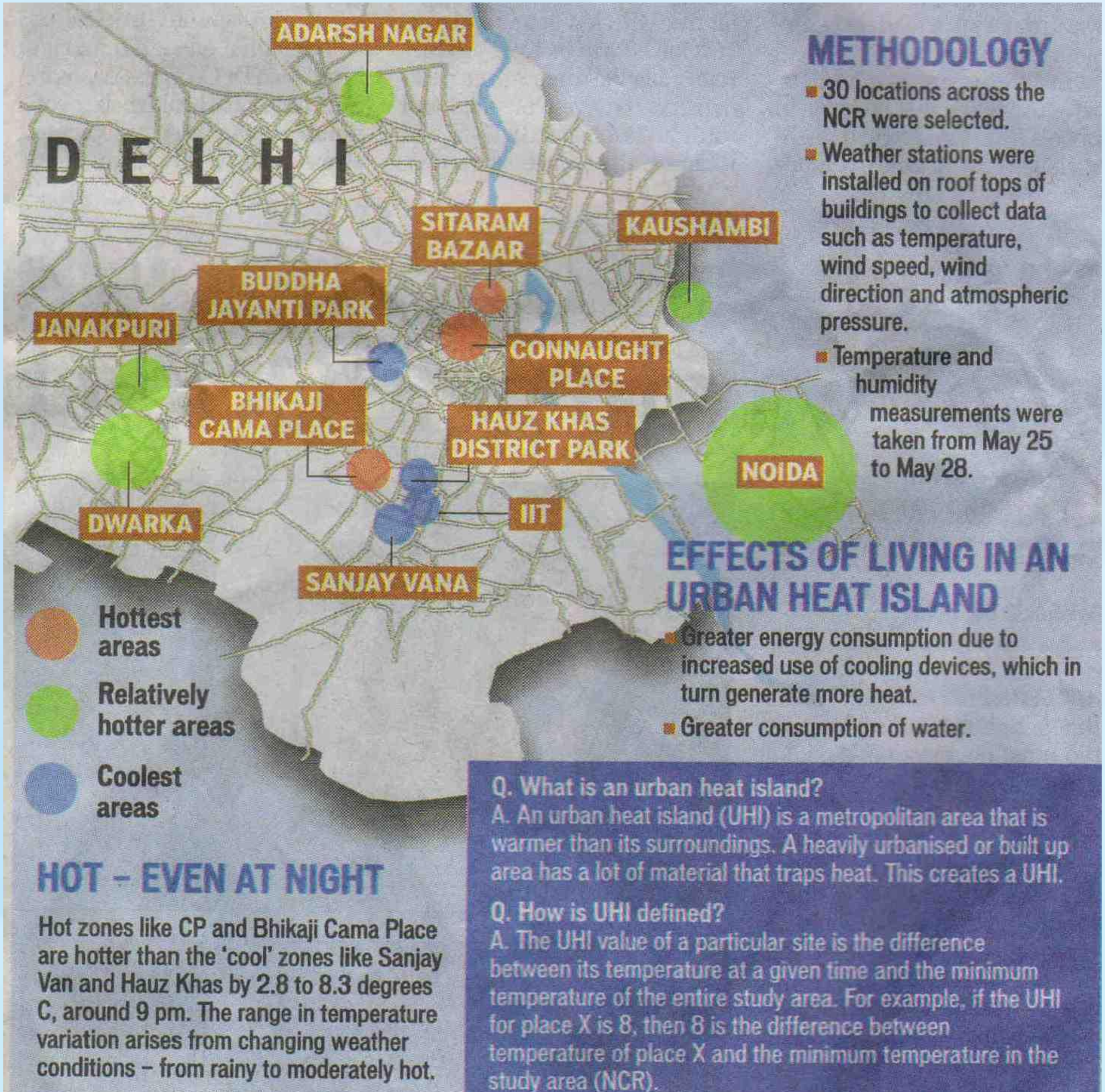
Hot zones like CP and Bhikaji Cama Place are hotter than the 'cool' zones like Sanjay Van and Hauz Khas by 2.8 to 8.3 degrees C, around 9 pm. The range in temperature variation arises from changing weather conditions – from rainy to moderately hot.

Q. What is an urban heat island?
A. An urban heat island (UHI) is a metropolitan area that is warmer than its surroundings. A heavily urbanised or built up area has a lot of material that traps heat. This creates a UHI.

Q. How is UHI defined?
A. The UHI value of a particular site is the difference between its temperature at a given time and the minimum temperature of the entire study area. For example, if the UHI for place X is 8, then 8 is the difference between temperature of place X and the minimum temperature in the study area (NCR).

GRAPHIC: VINEY, TEXT:RITIKA CHOPRA

The Hindustan Times, 26 September, 2009



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Sites Under Urban Built Up Area


Neb Sarai


Bhikaji Cama


Dwarka


Noida Sec-19


Lajpat Nagar


Janakpuri

Green Areas

Hauz Khas Distt Park
Natural + Cultivated Green Area

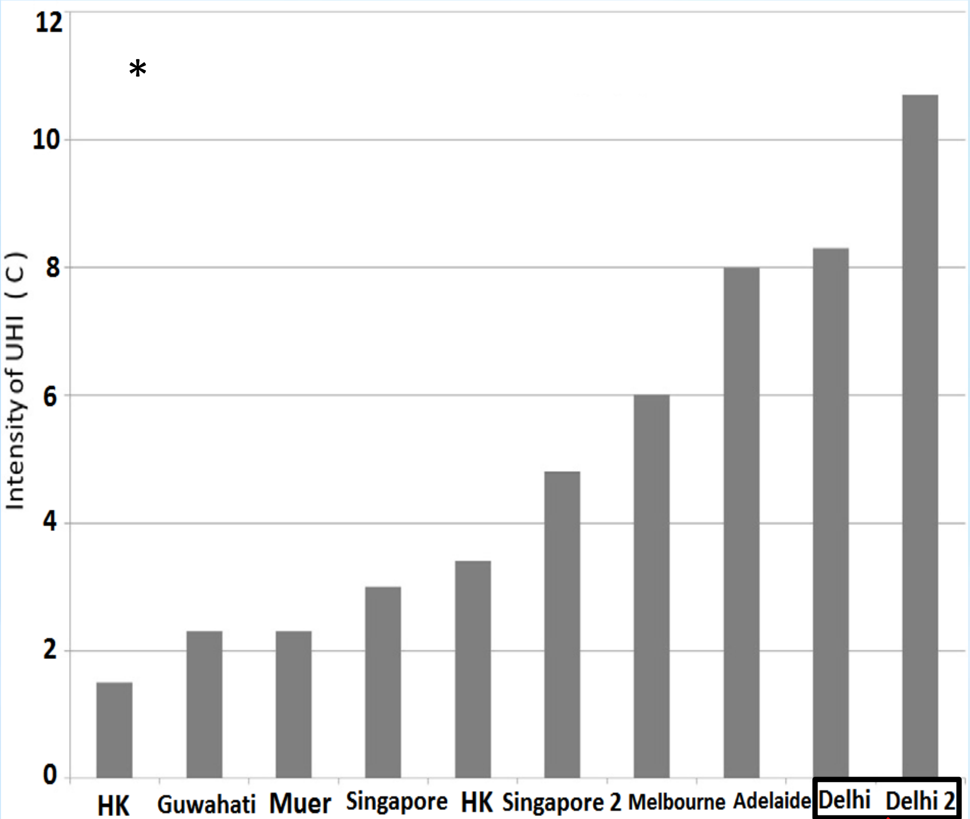
Buddha Jayanti Park
Natural Green Area
(Medium Dense Forest)

Sailing Club *(River Bank)*

Riverside Areas

Majnu Ka Tila *(Near River Bank)*

Calibration Set Up of all Micro-Meteorological Instruments



City	UHI	Source	Remarks
New York	Max: 5.4°C Mean: ~3°C	Gaffin 2008	UHI in summer 2002
Paris	Max: 6°C Mean: 2.6°C	Sarkar and Ridder 2011	12 Day experiment in June 2006
London	8°C - 9°C	GLA 2006	MaxUHI in summer 2003 heat wave episode
Beijing	7.9°C	Wang and Hu 2006	Max UHI in July 2002
Tokyo	Max: 8.1°C Mean: 5.3°C	Saitoh *et al.* 1996	Nocturnal UHI in March 1992

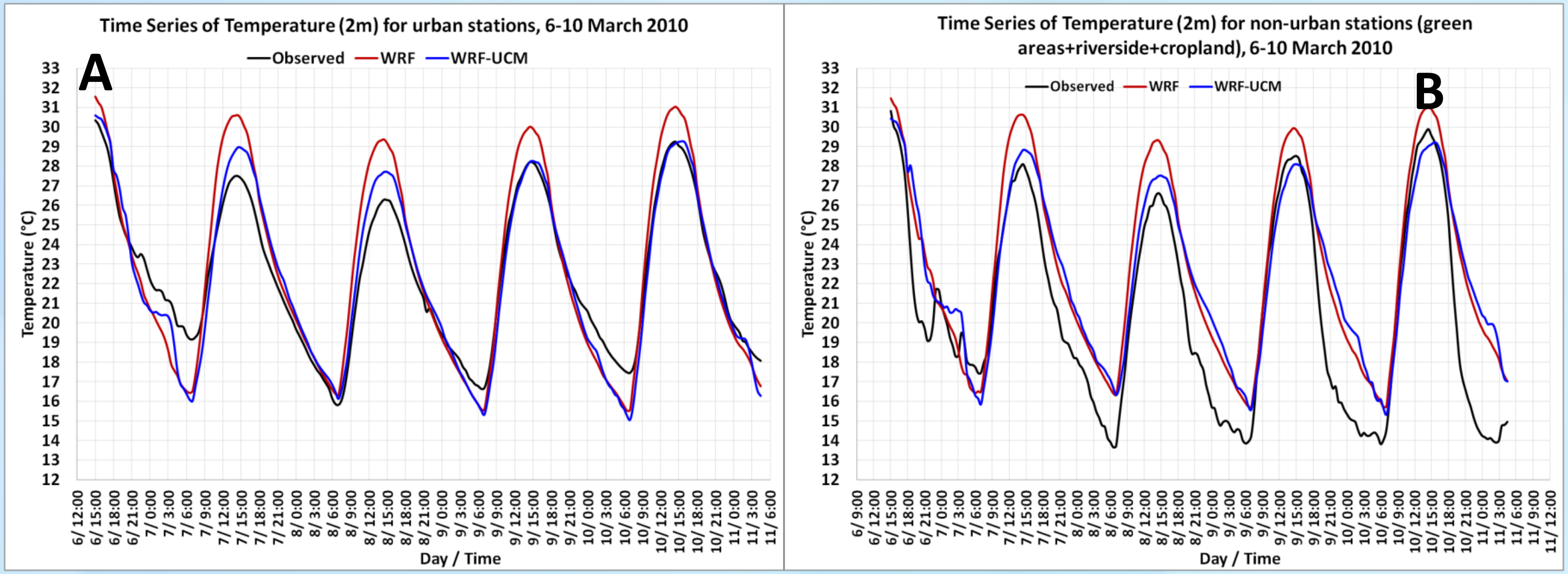
Mohan et al, 2012, 2013

Reported intensity of the urban heat island in various cities across the world

*Fig from **Santamouris, 2015, Sci Total Env**

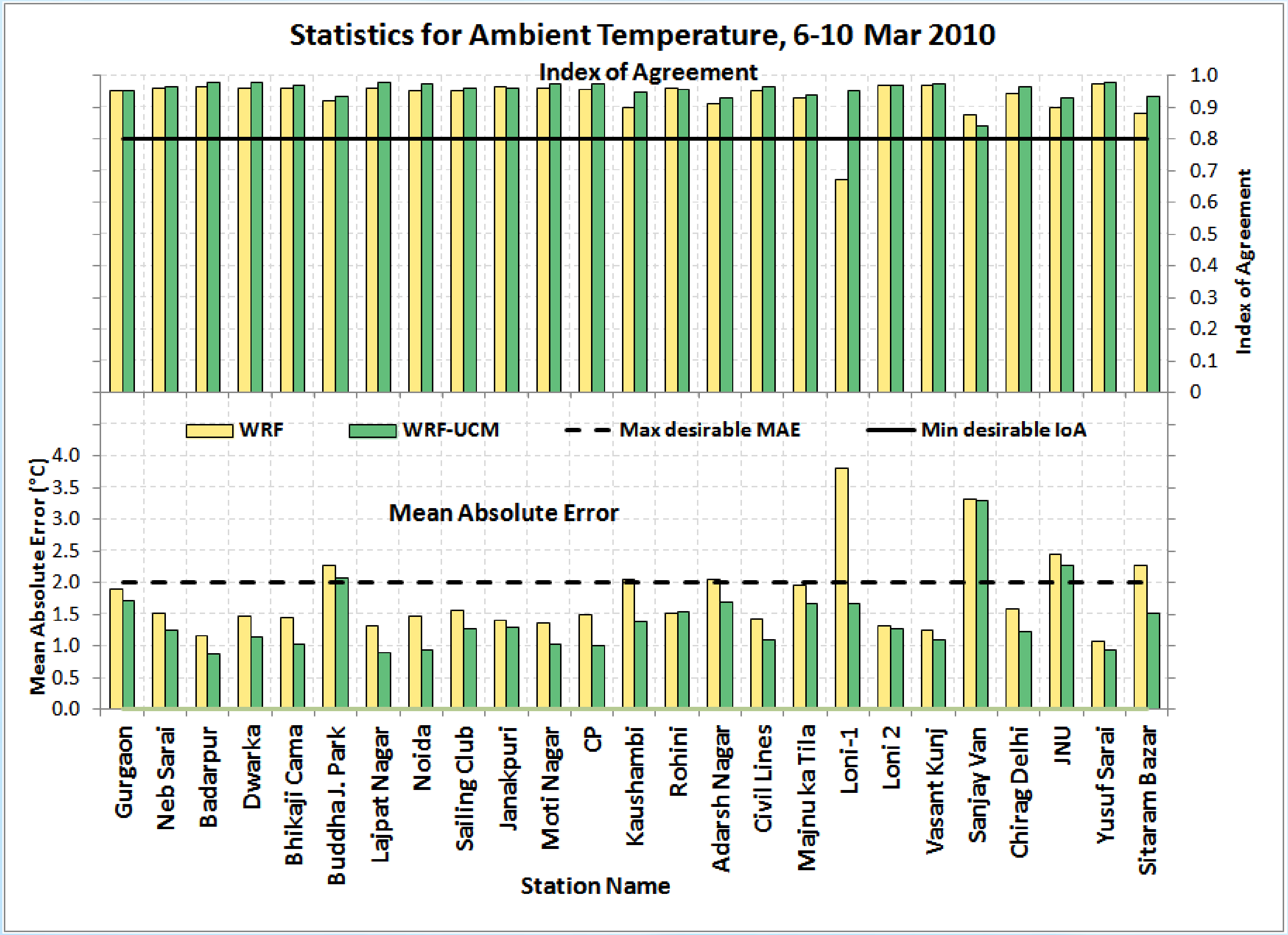
Time Series of Surface Temperature (2m) [A: Urban stations, B: Non-urban stations

2010



Incorporation of urban canopy features in WRF has shown improvement in both ambient temperatures as well as urban heat island intensity distribution.

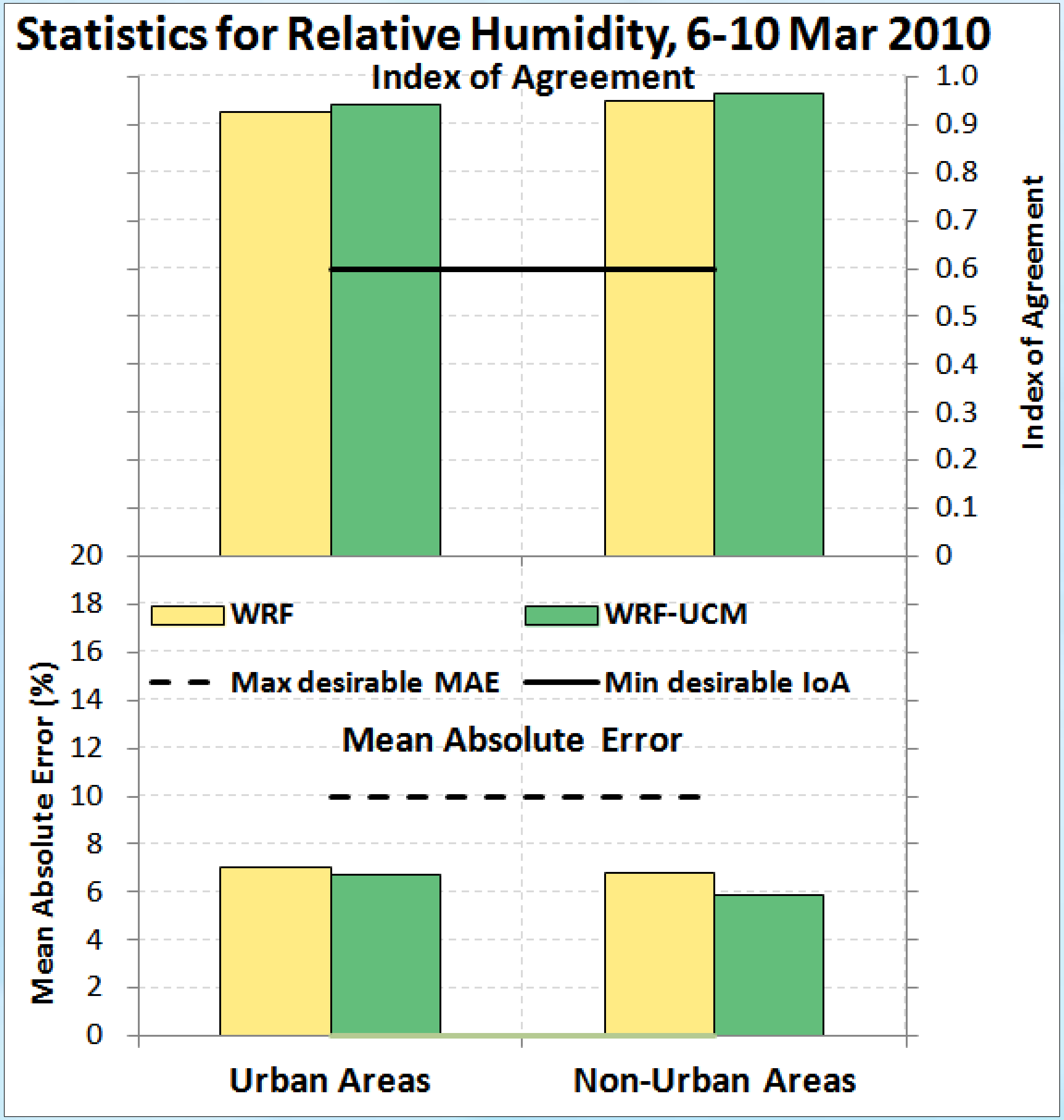
Bhati, S. and Mohan, M., 2015. WRF model evaluation for the urban heat island assessment under varying land use/land cover and reference site conditions. Theoretical and Applied Climatology, pp 1-16. 10.1007/s00704-015-1589-5



•**All stations show an index of agreement above 0.8 for WRF-UCM temperatures.**

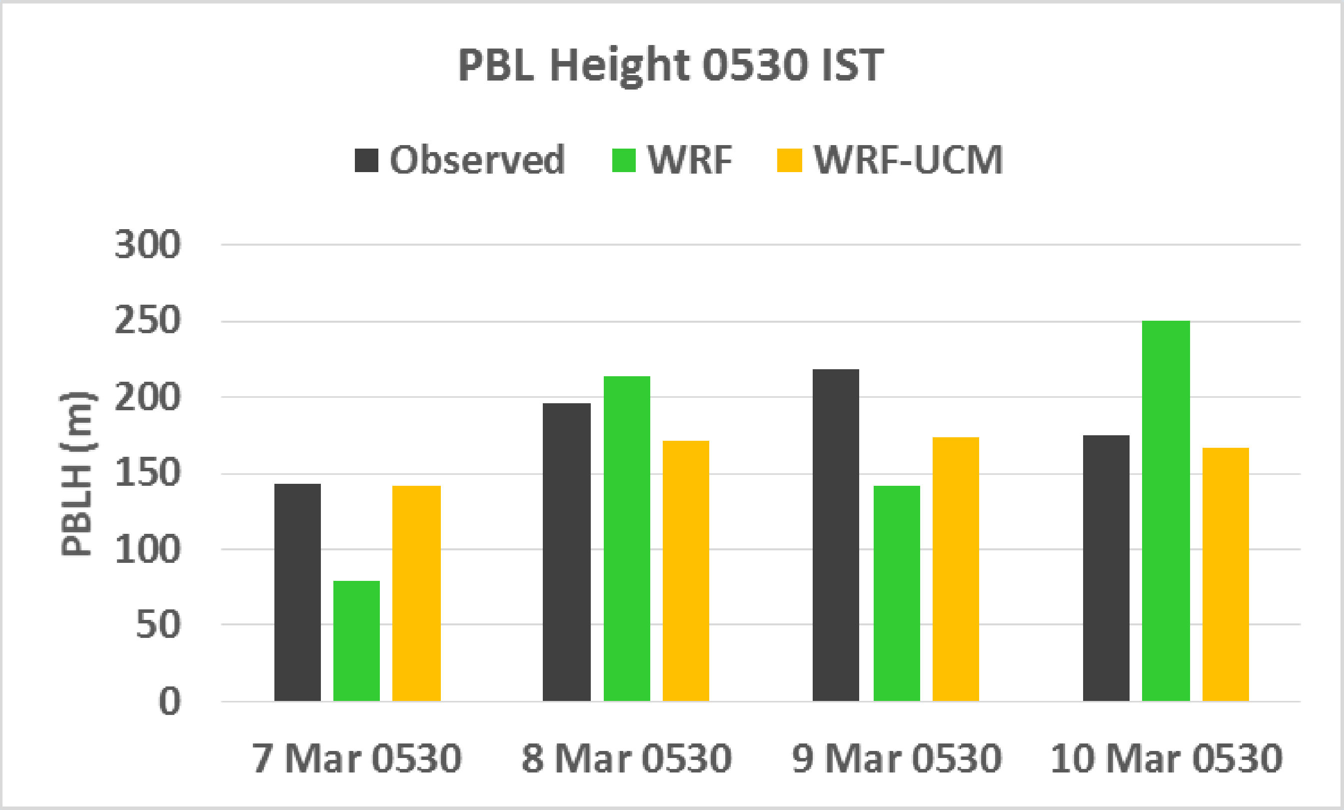
•**Mean absolute errors for WRF-UCM temperatures are also lower than WRF for all temperatures**

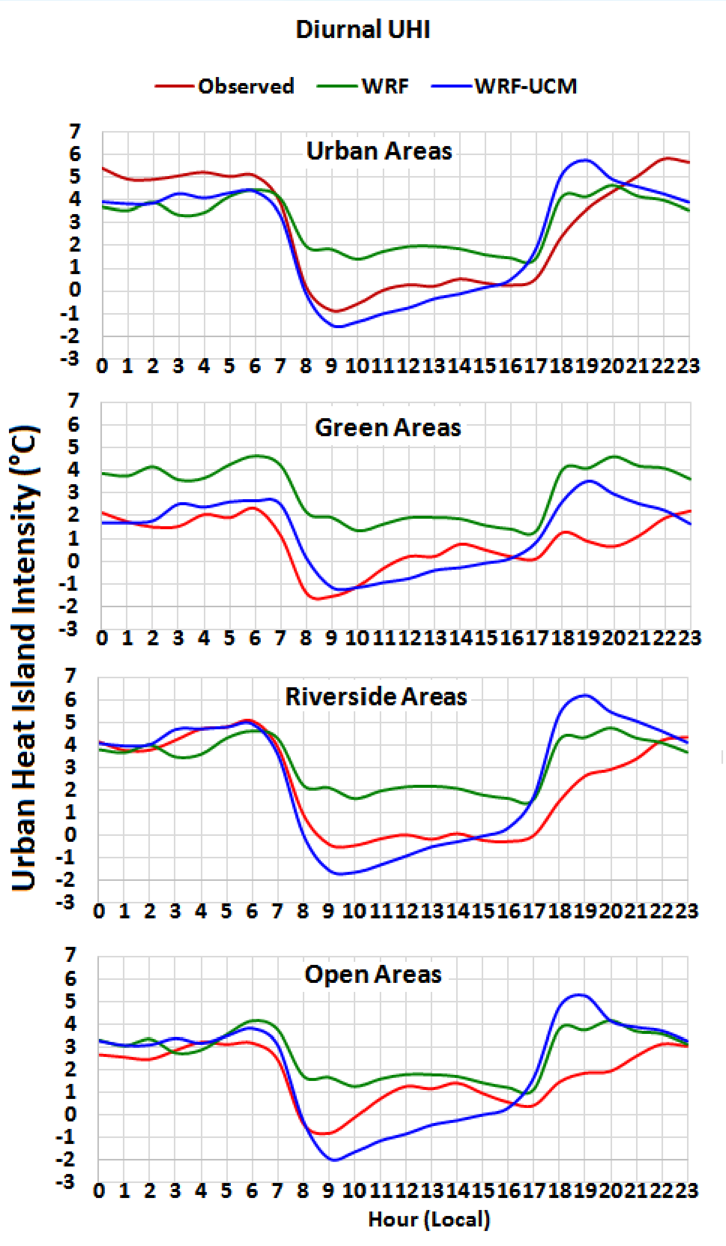
Bhati and Mohan, 2015, Theoretical and Applied Climatology, pp 1-16. 10.1007/s00704-015-1589-5



Bhati and Mohan, 2015, Theoretical and Applied Climatology, pp 1-16. 10.1007/s00704-015-1589-5

PBL height


PBL Height 0530 IST
Observed
WRF
WRF-UCM
PBLH (m)
300
250
200
150
100
50
0
7 Mar 0530
8 Mar 0530
9 Mar 0530
10 Mar 0530



Diurnal range of UHI for different land use land cover types

Bhati and Mohan, 2015, Theoretical and Applied Climatology, pp 1-16. 10.1007/s00704-015-1589-5

Conclusions

- **Significant changes in LULC observed across the globe due to urbanisation and developmental activities.**

- **NWP modelling shows significant impacts on temperature and air quality due to change in LULC across the globe**

- **Performance of mesoscale numerical models can be significantly altered by appropriate incorporation of LULC and urban canopy features.**

Acknowledgements

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Mr. Ankur P. Sati


THANKS