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Impact of Land-use Land-cover Change during Five Decades on UHI Intensities and Thermal Comfort over a Sub-tropical Region in India

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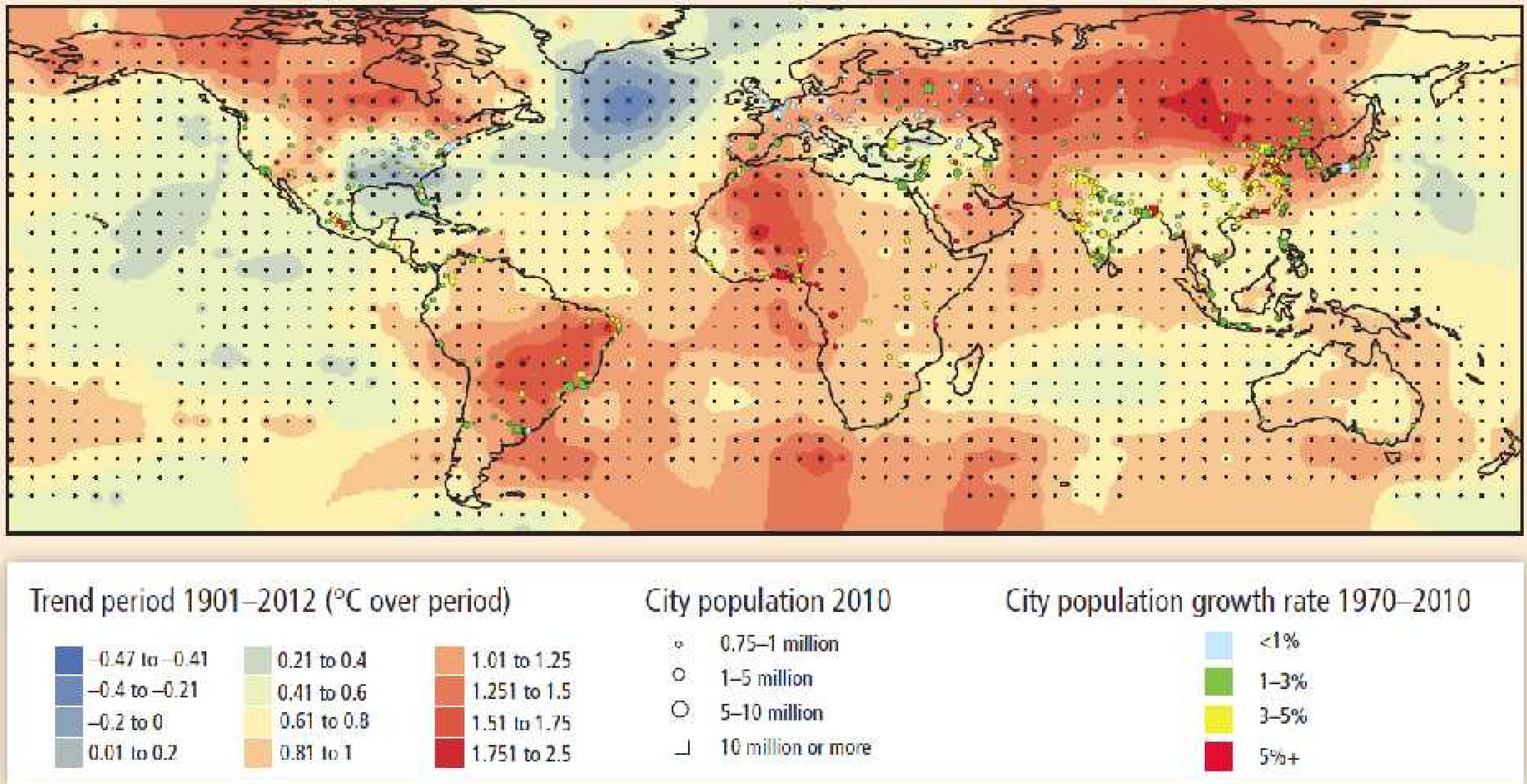
IPCC WGII AR5:Chapter 8. Urban Areas

- Urbanization alters local environments via a series of physical phenomena that can result in local environmental stresses. Much of key and emerging global climate risks are concentrated in urban areas.
- In the past, long-term trends in surface air temperature in urban centers have been found to be associated with the intensity of urbanization.
- More than half the world's population in 2008 was living in urban centers and the proportion continues to grow (UN DESA Population Division, 2012)
- Three-quarters of the world's urban population and most of its largest cities are now in low- and middle income nations implying stronger adaptation measures
- The spatial, temporal, and sustainability-related qualities of urbanization are important for understanding the shifting complex interactions between climate change and urban growth.



Large urban agglomerations with observed climate change
Trend period 1901–2012

Source: IPCC AR5

Urbanization, Air Quality and Health

- Urbanization reduces the wind speed in its vicinity which reduces both heat and pollutant flushing capacity of the region resulting in stagnation and exacerbating pollution levels.

- Along with various heat related illness.

- Urbanization leads to higher temperature and increase in thermal stress leading to health complications and reduction in work efficiency.

- Key inference: Climate Change is proved to be very closely related to urbanisation affecting significant population and key to CC impacts reduction lies with mitigation and adaptation at city level.

IPCC WGII AR5:Chapter 8. Urban Areas

- Anthropogenic heat fluxes across large cities can average within a range of approximately 10 to 150 W m–2 but over small areas of the city can be three to four times these values or even more (Flanner, 2009; Allen et al., 2011).
- Projections suggest that by 2050, London's nocturnal UHI in August could rise another 0.5°C, representing a 40% increase in the number of nights with intense UHI episodes(Wilby, 2007).
- Climate change in NewYork City is expected to increase extended heat waves, thus exacerbating existing UHI conditions (Rosenzweig et al., 2009). Increased nighttime minimum temperatures are associated with increased cooling demand and health-related stresses. Similarly for Tokyo and other cities, affects are more severe. Likewise for India.

IPCC has recognized* connections between urbanization and the development of UHI in several cities of the world including Delhi . Further, it states that for cities in India, the implications of future climate for connections between urbanization and the development of UHI have been defined (Mohan et al., 2011a,b, 2012)

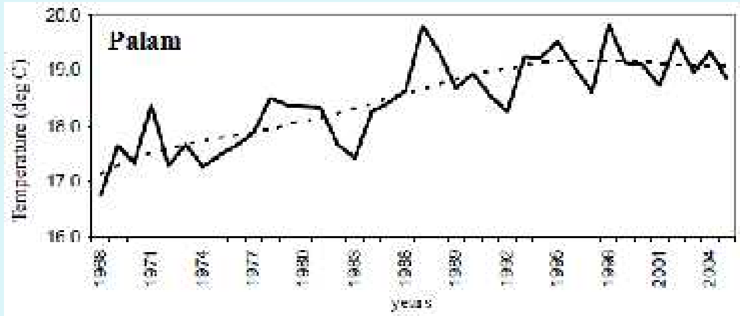
The report includes above studies in Delhi which have explored this relationship

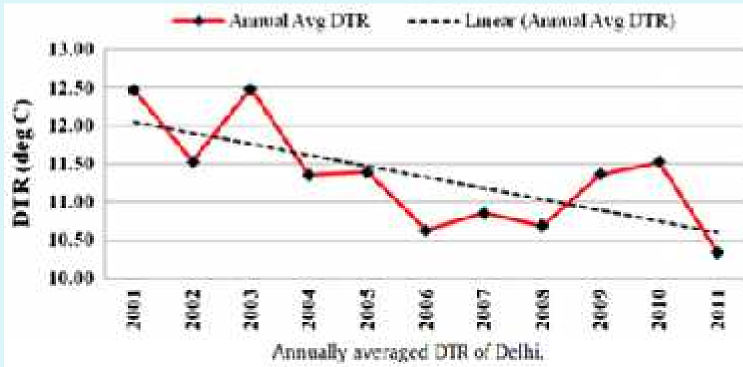
- *Dynamics of Urbanization and LULC (Mohan et al, 2011)*: shows there has been significant change in LULC which is expected to have led to changes in temperatures (ISRO, RESPOND Project; 2007-2010).
- *Urban Heat Island and Temperature Trends* (Mohan et al, 2011) wherein some signatures of heat island 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).

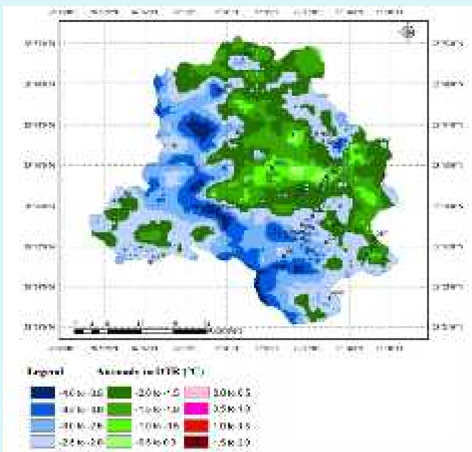
***IPCC WGII AR5 Chapter 8, 2014**

Urban Heat Island and Temperature Trends

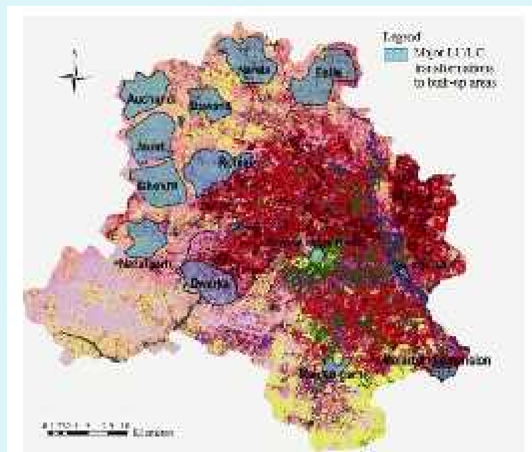
- A consistent increasing trend was seen in the annual mean minimum temperatures indicating an overall warming trend over the NCR especially after 1990.
- Satellite based annually averaged DTR of entire Delhi shows a significant decreasing trend.
- Areas of Rapid urbanization exhibited a highly decreasing trend in DTR.
- Increasing warming trends reflect the contribution of changing land-use patterns and additional anthropogenic heat that may enhance the urban heat island intensities in the city







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

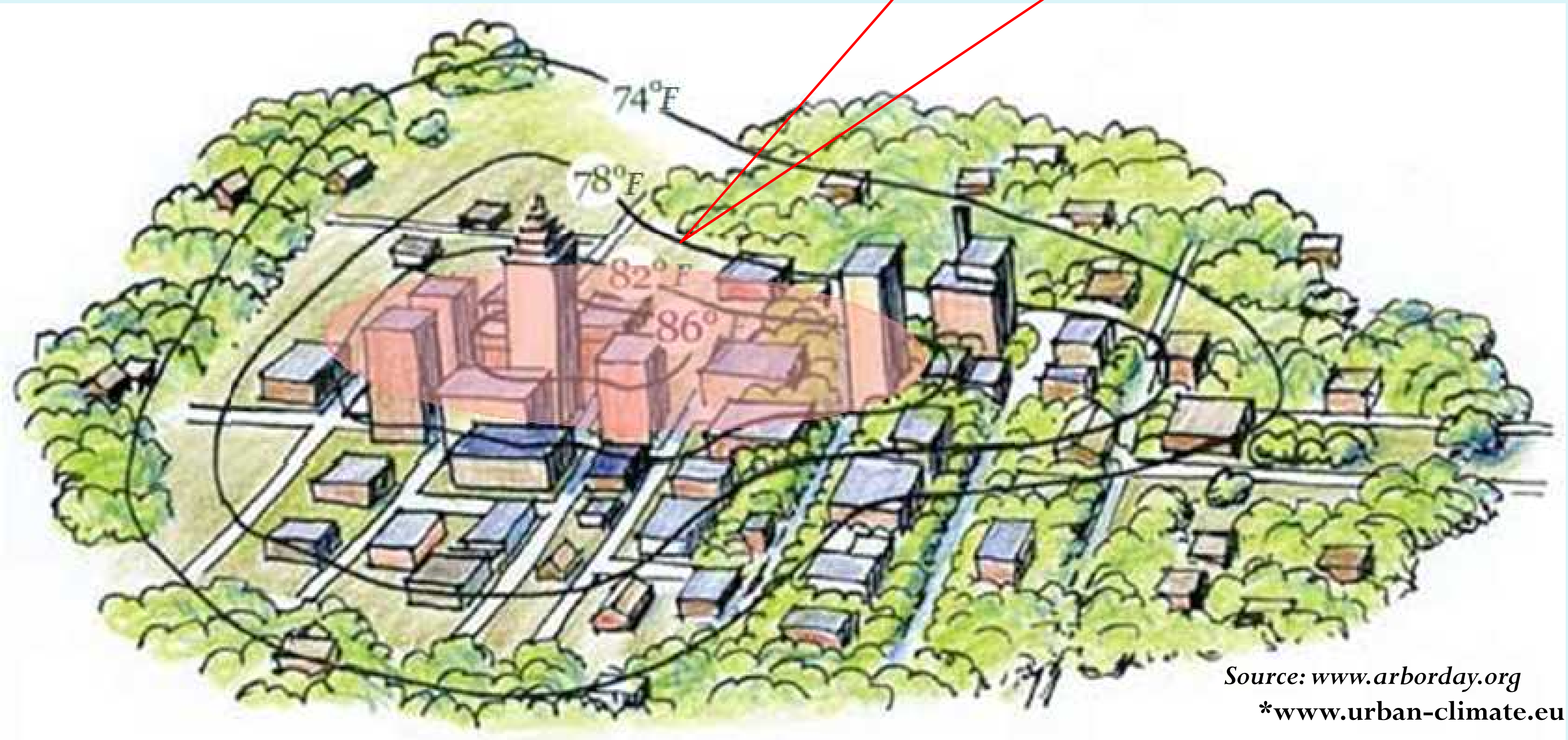


Major Land Use / Land Cover changes in Delhi during 1997-2008

Mohan and Kandya, 2015, Science of the Total Environment

Urban Heat Island

An urban heat island (UHI) is defined as any urban area which has a tendency to be warmer than a surrounding rural/lesser developed area.



Urban Heat Island Effect over Delhi: Field Experiments

Objective:

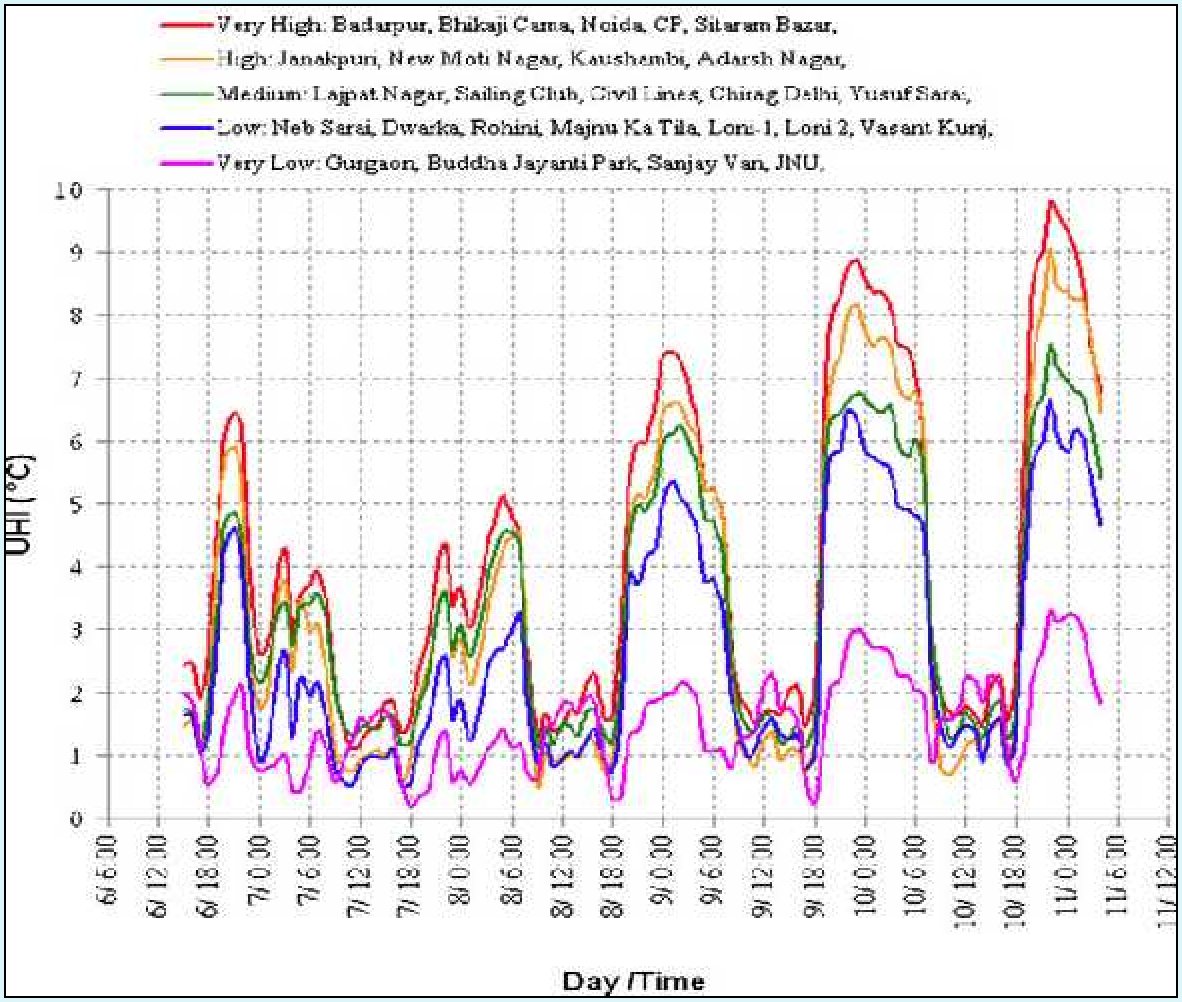
- to understand the present scenario of heat-island phenomena in Delhi through surface meteorological observations in Delhi

In-situ Observations through Field Campaigns

- UHI-I : 25 May 2008 – 28 May 2008, and,
- UHI-II : 6-10 March 2010

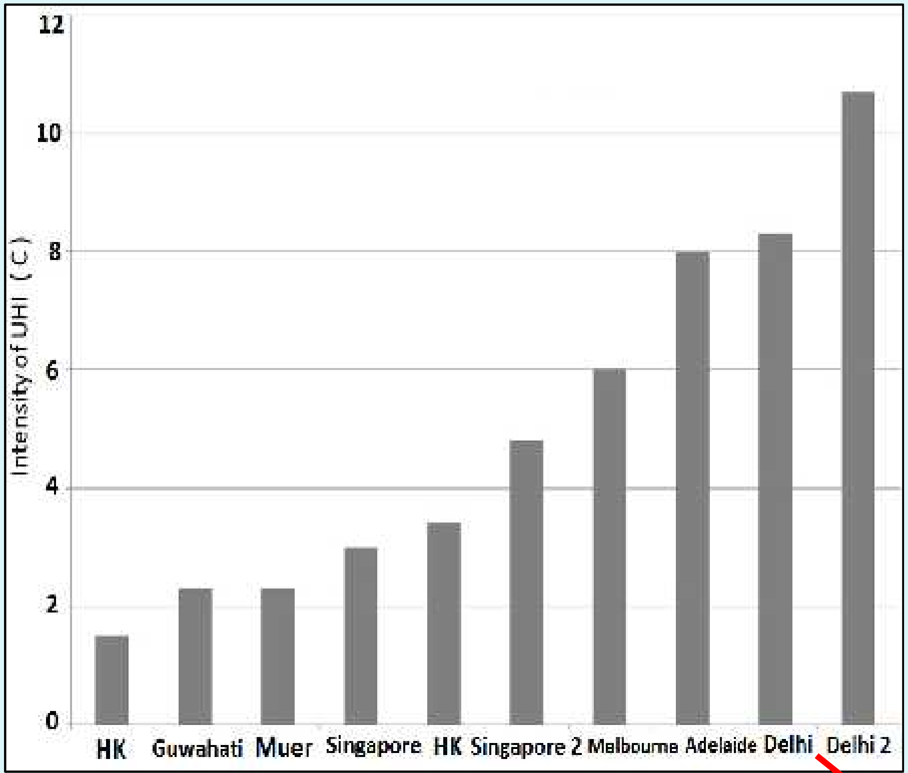
- 30 sites (27 surface stations, 3 weather stations)

Diurnal Variation of grouped UHI



Ref: Theor Appl Climatol (2013) 112:647–658

UHI Comparison with other cities



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

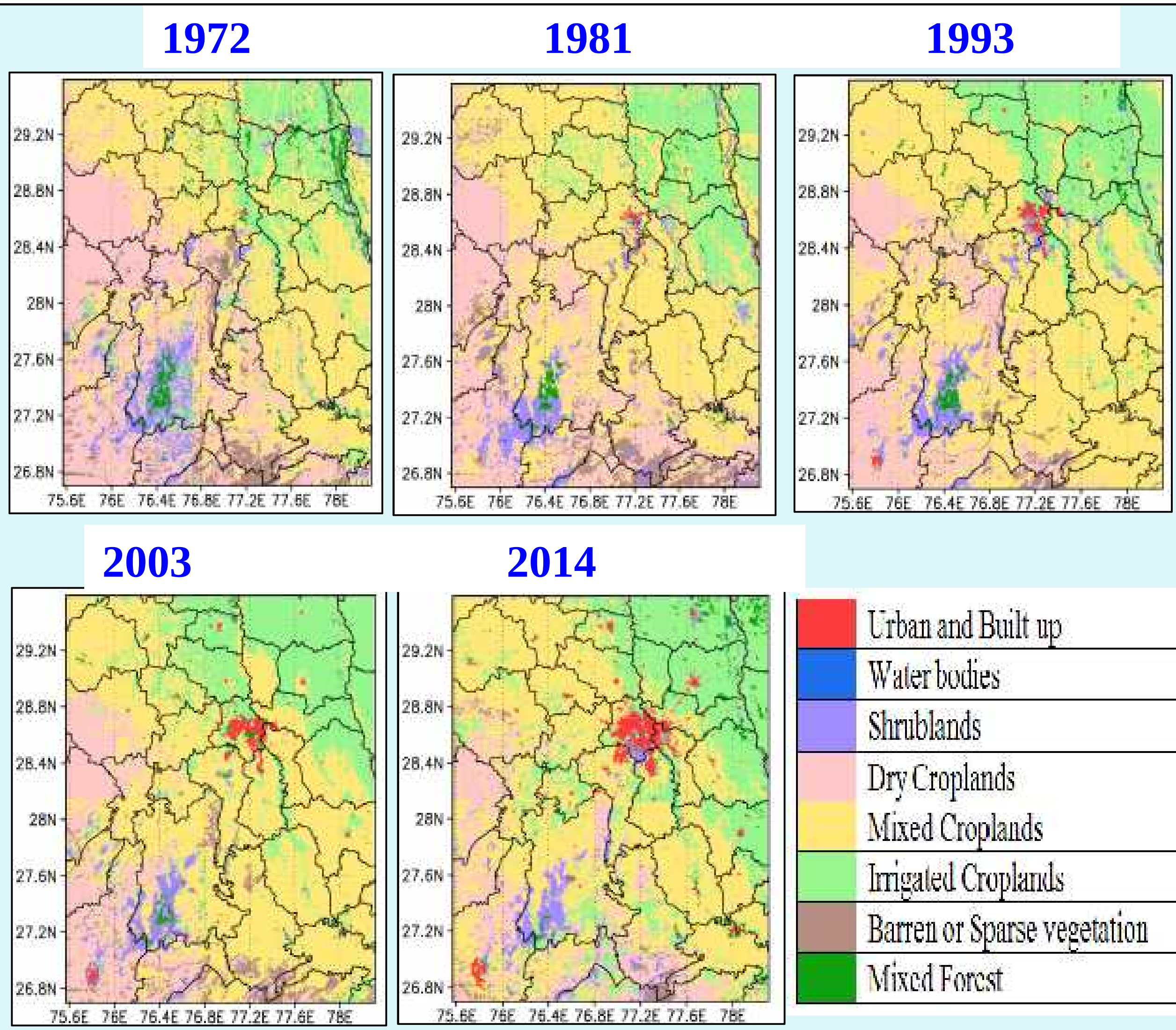
*Fig from **Santamouris, 2015, Sci Total Env**

Land use distribution of NCR India for various decades

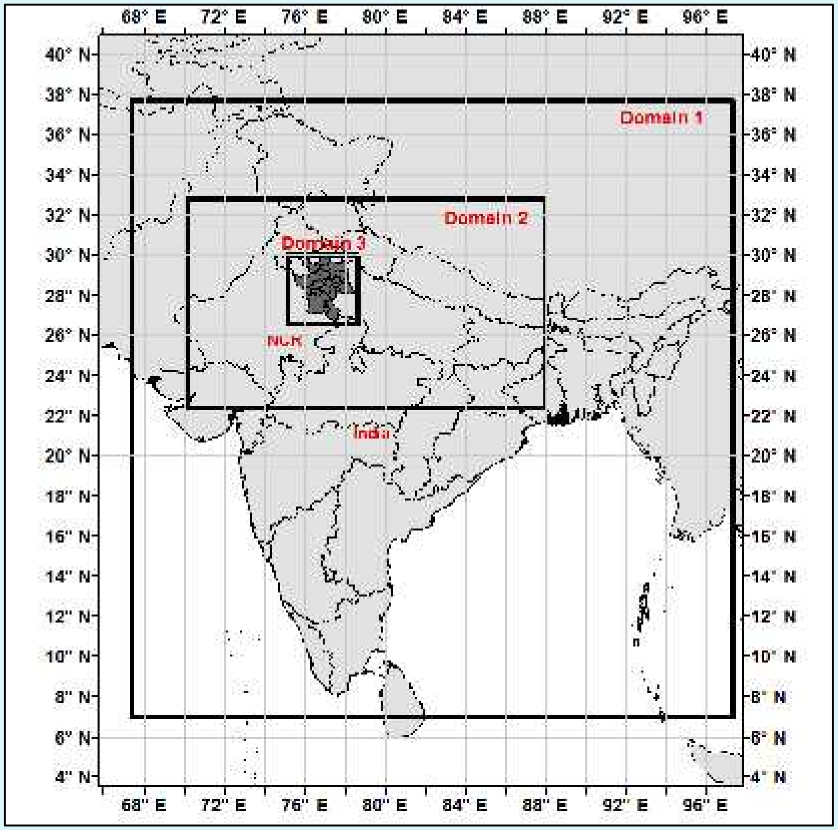
Total NCR area: 86,991 km^2

- Almost 17 fold increase in the urban and built up areas (126 km^2 of urban built up in 1972 to 2180 km^{2}in 2014). This is 38 fold in Central NCR region.
- Conversion of dry croplands to irrigated and mixed croplands.
- Substantial decrease (40%) in water bodies is noticed.

Reference: Sati and Mohan, 2017; Theore. Appl. Climato.



Domain and Methodology



Cases of LULC	**D1972**	LULC of the year 1972
	D1981	LULC of the year 1981
	D1993	LULC of the year 1993
	D2003	LULC of the year 2003
	D2014	LULC of the year 2014

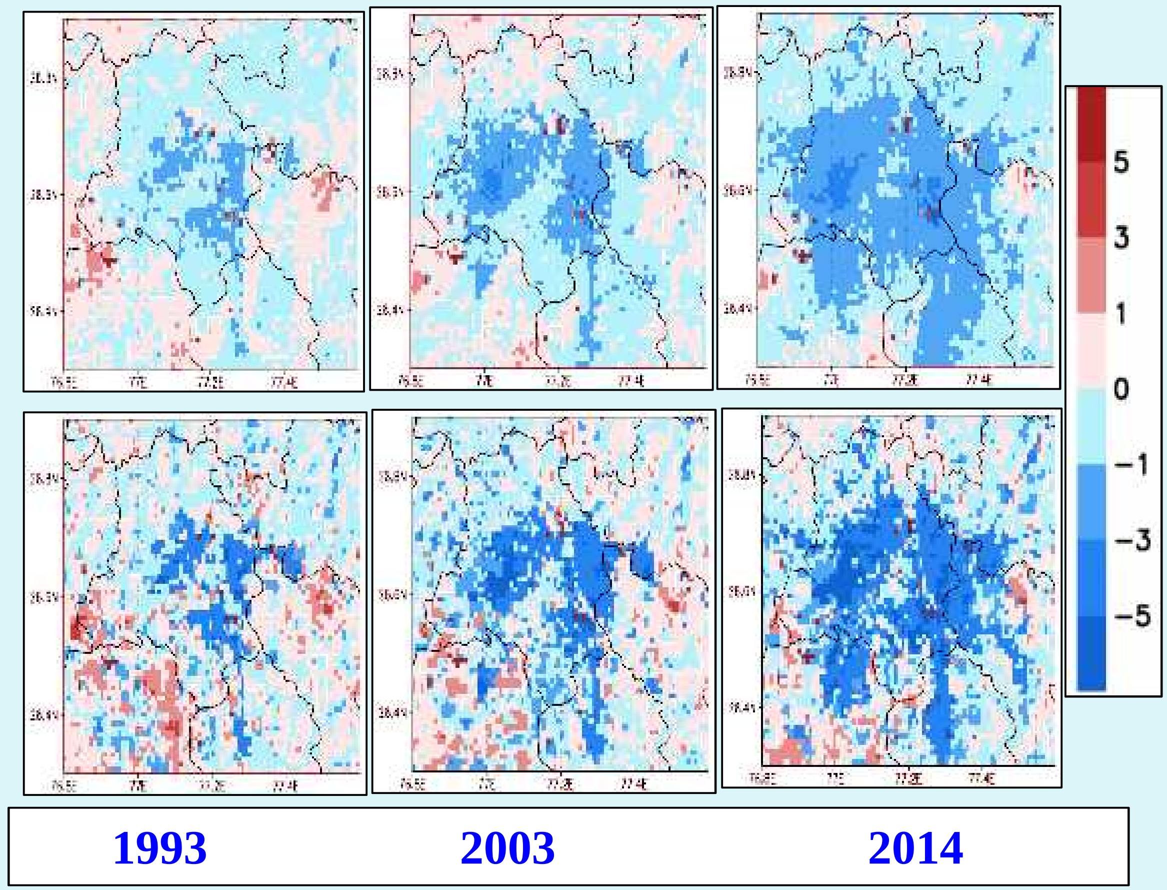
Physics Options	
Microphysics	Lin
Cumulus	Kain Fritsch
Shortwave radiation	Goddard
Longwave radiation	RRTM
PBL scheme	YSU
Land surface model	Noah
Surface Physics	MM5

Model :Weather Research and Forecasting Model (WRF)

Simulation Period :
01 May 2012 – 15 May 2012

Effect on Diurnal Temperature range

- The difference in DTR of LST shows that it has decreased in the expanding urban area from 1972-2014.
- The differences in DTR of surface temperature show a noticeable decrease (2- 3 K) in these regions.
- The urban area show maximum decrease in the LST values (≈5 K).

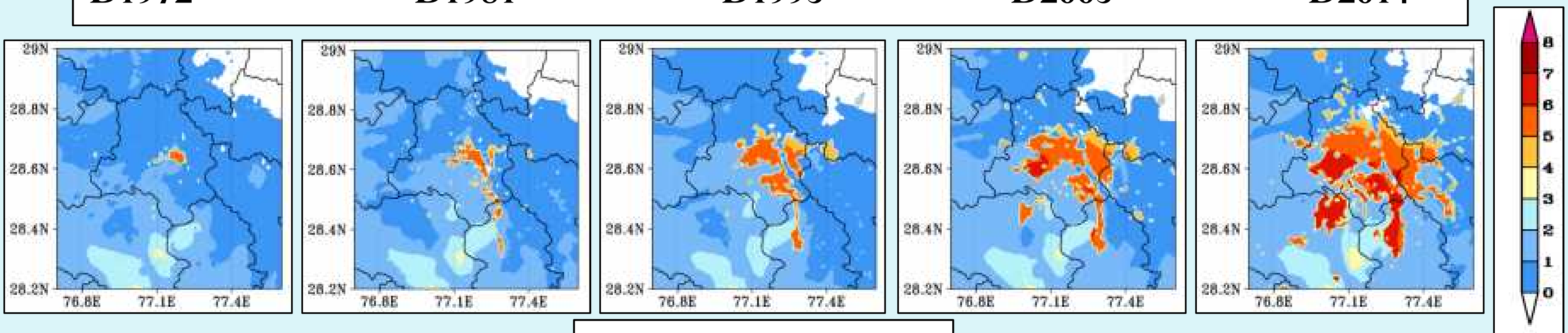


Difference in DTR values of AT (upper panel) and LST (lower panel) between the corresponding decades and values in 1972

3 day averaged Night Time (1:30 am) UHI for various Decadal LULC over NCT

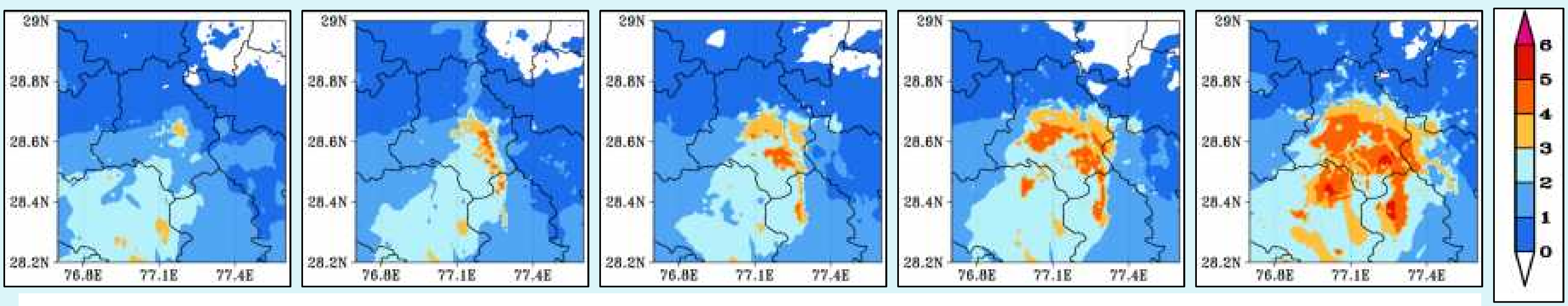
Surface UHI

D1972 | D1981 | D1993 | D2003 | D2014



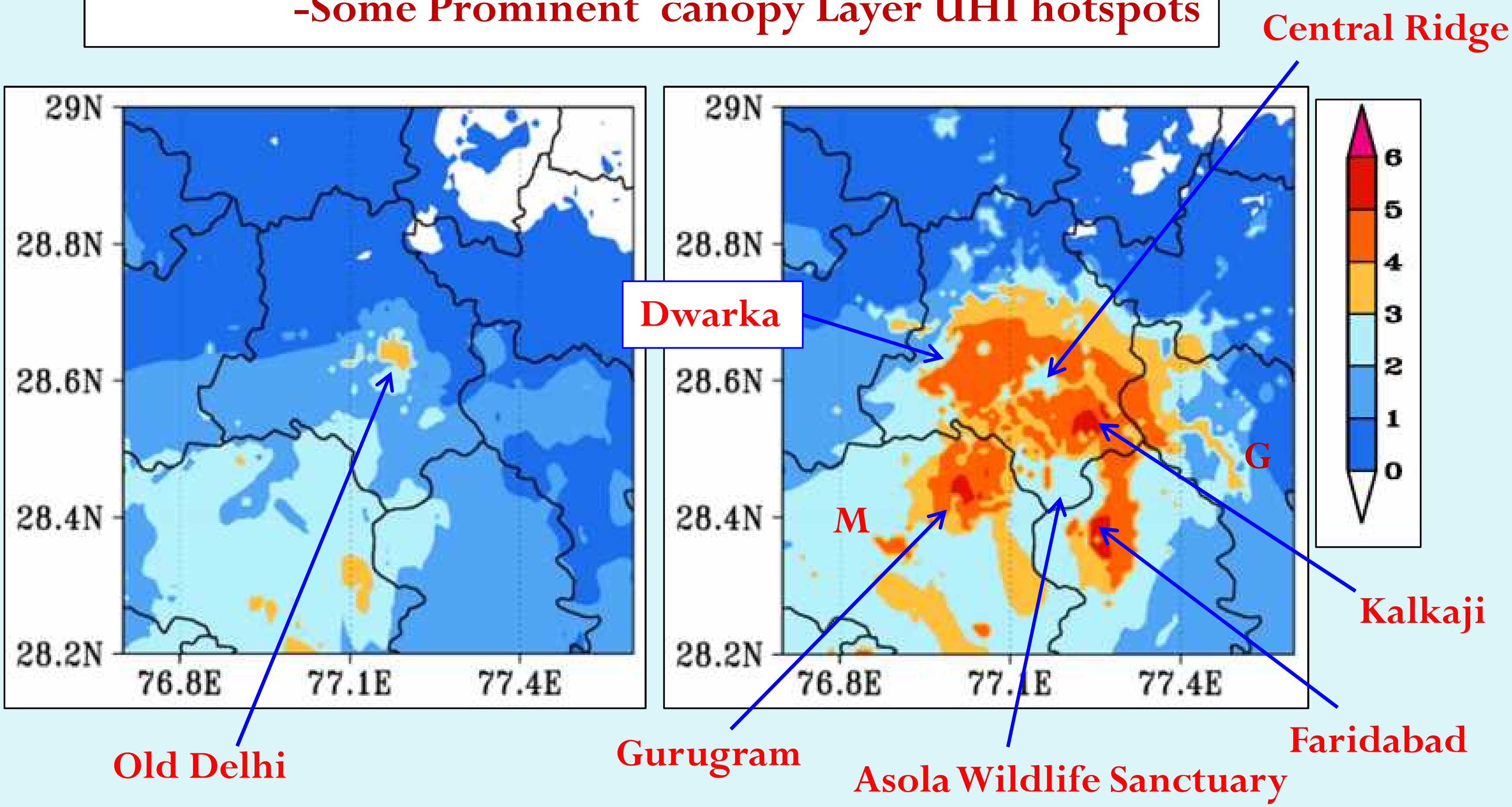
Canopy Layer UHI

D1972 | D1981 | D1993 | D2003 | D2014



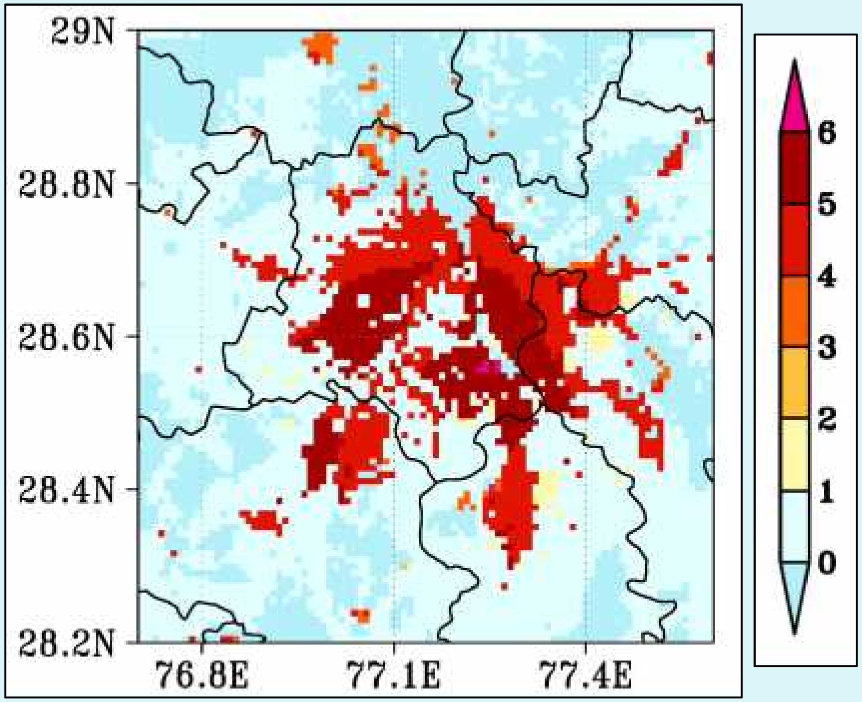
- Spatial Increase in night time UHI with increasing Urbanization
- 1-2 degree strengthening of night time UHI

What changed between 1972-2014!!
-Some Prominent canopy Layer UHI hotspots



- The Prominent Hotspots are the densely urbanized area such as Gurugram, Kalkaji, Old Delhi, Faridabad.
- The localities which have urbanized recently such as Manesar(M) and Greater Noida (G) also show development of UHI

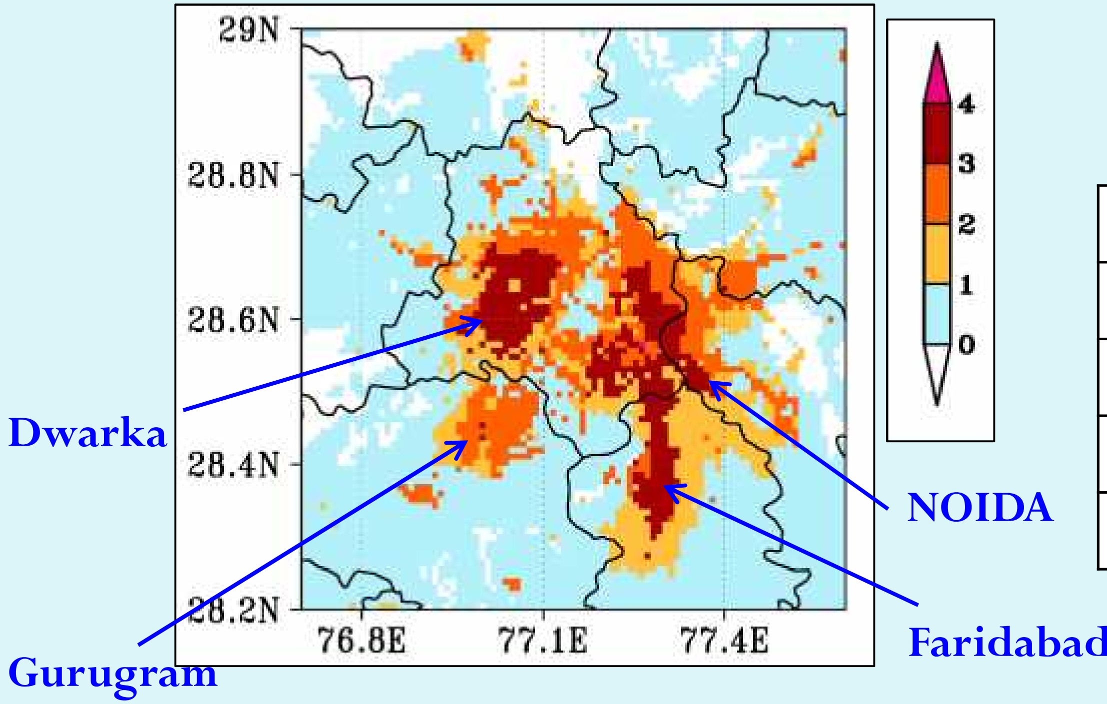
What changed between 1972-2014!!
-Difference in nocturnal Surface UHI intensity



Increase (K)	Area (sq Km)
6+	9
5-6	667
4-5	794
3-4	68
1-3	80

- The maximum increase in UHI intensity corresponds to the underlying urbanization which has been maximum in the current (2014 LULC) decade.
- Maximum increase in SLHI is 4-5 K followed closely by 5-6 K.
- This increase is majorly in the expanded urban region in the NCR.
- 1-3 K increase is visible in the locations adjacent to/covered by the urban built up area.

What changed between 1972-2014!!
-Difference in nocturnal Canopy layer UHI intensity



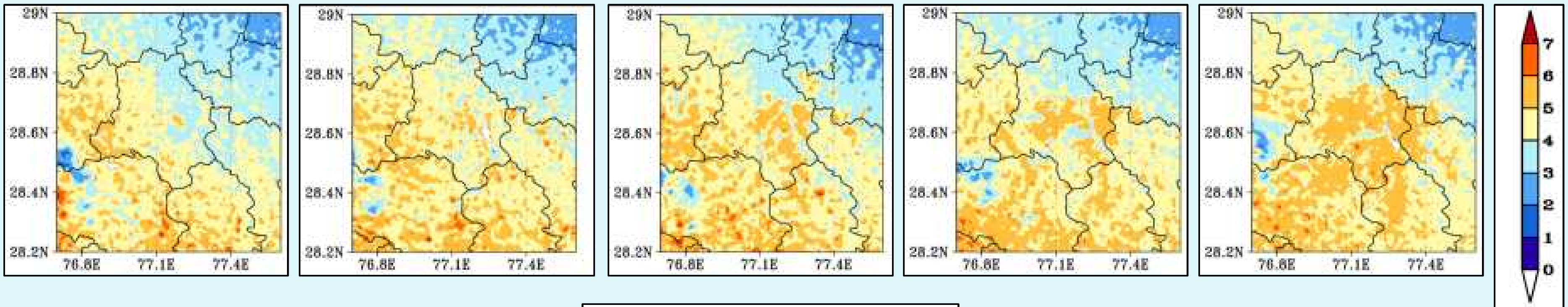
Increase (K)	Area (sq Km)
4+	3
3-4	573
2-3	787
1-2	816

- 3-4 K increase is visible in the densely built up region prominently in satellite cities viz., Faridabad, NOIDA, Gurugram and Dwarka.
- Most of the area (816 sq km) experience an increase of 1-2 K in night time UHI followed closely by 2-3 K rise (787 sq km).
- This increase is majorly in the expanded urban region in the NCR.

3 day averaged Day Time (1:30 pm) UHI for various Decadal LULC over NCR

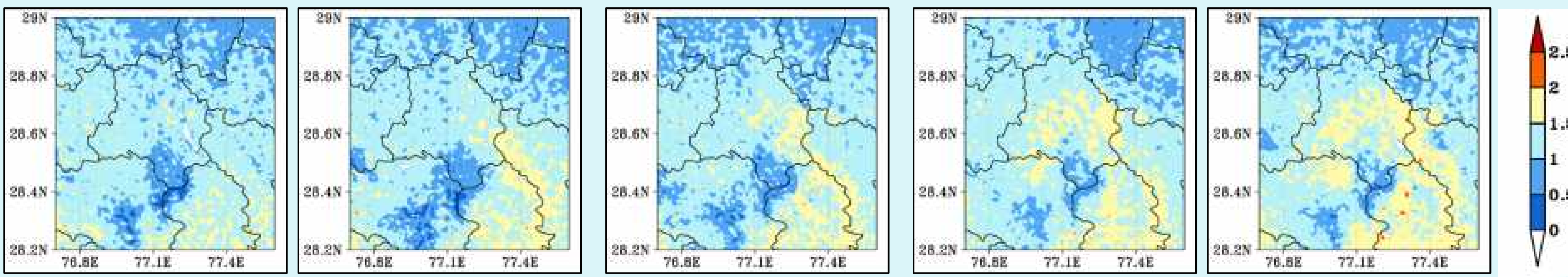
Surface UHI

D1972	D1981	D1993	D2003	D2014



Canopy Layer UHI

D1972	D1981	D1993	D2003	D2014



Prominent development of daytime UHI visible in latter decadal LULC of 2003 and 2014

Urban Areas and Thermal Comfort

- The urban heat island effect has a direct relation with thermal comfort. It has the potential to prevent the city from cooling down, maintaining night-time temperatures at a level that affects human health and comfort (Tan et al. 2009; Lo et al. 2003; Tomlinson et al. 2011; Mavrogianni et al. 2011).

- Thermal stress is most relevant to people who spend a substantial time outdoors during a day such as pedestrians, cyclists, vendors, shopkeepers near roadside and most people from the lower strata of society who live in makeshift houses (Mohan et al. 2014).

Ramifications of UHI induced Thermal Discomfort

- Urban heat island induced thermal discomfort affects people both with and without access to cooling amenities.
- Higher temperatures have a serious impact on the electricity consumption due to building sector increasing considerably the peak leading to an additional electricity penalty of about 21 (±10.4) W per degree of temperature increase and per person (Santamouris et al.,2015). Further, heat released due to operation of electrical cooling devices further exacerbates the heat island effect in the city.
- This increase greatly outweighs the otherwise small beneficial decrease in heating demand in winter especially for sub-tropical/tropical cities.
- Hence, analysis of UHI vis-a-vis thermal comfort is essential with regards to both economic as well as environmental concerns.
- An increase of upto 2.5°C in heat index has been found at dense built up areas in comparison to non urban areas due to urban heat island effect. (Bhati and Mohan, 2018, Geoscience Letters)

Thermal Indices

- There are many indices devised for assessing thermal comfort such as
  - Heat Index (Rothfusz,1990)
  - physiological equivalent temperature (PET) (Hoppe 1999),
  - Universal Thermal Climate Index (UTCI) (Blazejczyk et al. 2012),
  - Wet Bulb Globe Temperature (Yaglou and Minard 1957).
  - Robba Index(RI) (Robba 2011)

- Numerical weather prediction models like WRF and UCM help in assessing thermal comfort by means of providing a continuous distribution of spatial and temporal data.

Thermal Comfort with Robaa Index

Robaa proposed formula accounting for the combined effect of the three weather elements (dry air temperature, humidity and wind speed) on human discomfort. His formula, RI, is expressed as follows;

$$\mathbf{RI = 1.53\ T_d - 0.32\ T_w - 1.38V + 44.65}$$

Where,

T_d = dry temperature (°C) of surface air

T_w = wet bulb temperature in °C

V = wind speed (m/s)

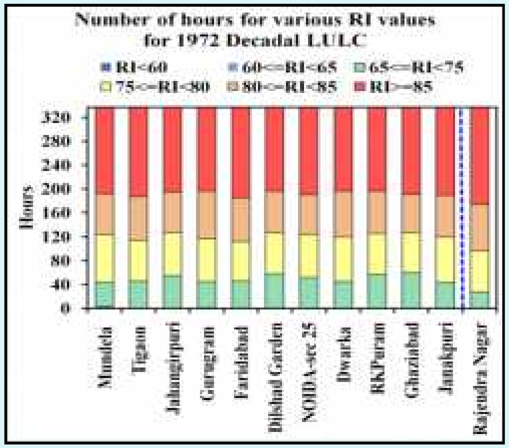
The range of applicability of this formula is wide and adequate for subtropical climatic region (Egypt's climate). The criterions of RI are given in **Table 1.**

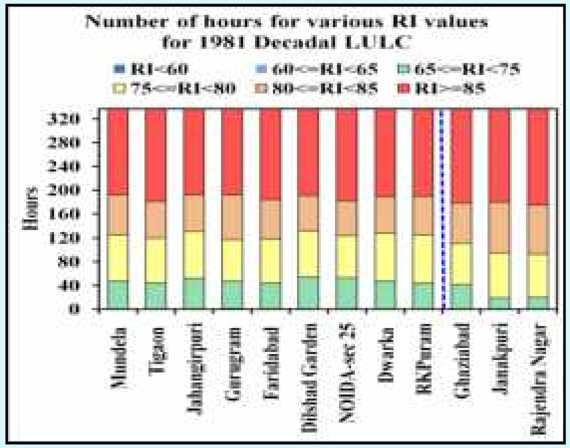
Table 1. Criterions of, RI, at different discomforts.

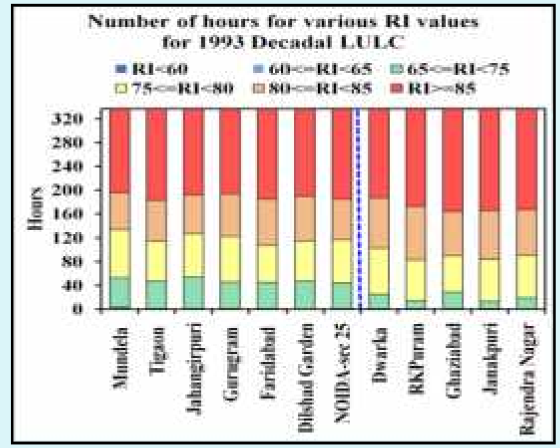
RI values	Human feeling
RI < 60	All people feel quite uncomfortable cooling.
60 ≤ RI < 65	50% of people feel partial uncomfortable cooling.
65 ≤ RI < 75	All people feel quite comfortable.
75 ≤ RI < 80	50% of people feel partially uncomfortable heat.
80 ≤ RI < 85	All people feel uncomfortable heat.
85 ≤ RI	All people feel extreme serious uncomfortable heat.

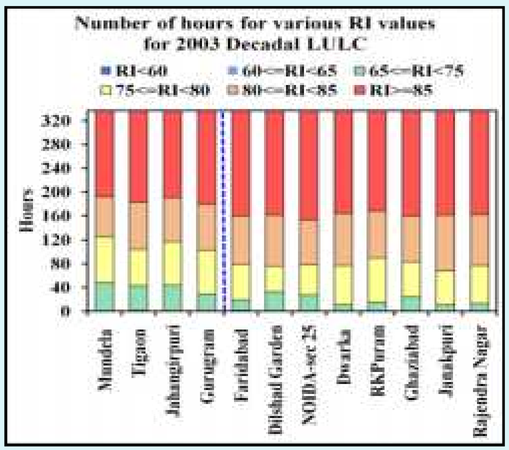
Reference: Robaa SM (2011*Atmospheric and Climate Sciences*, **1**,

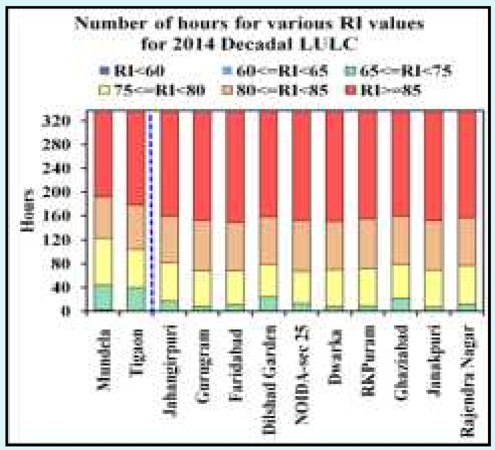
Number of Hours for various RI values at the stations across Delhi-NCR for various decadal LULC











	RI values	Human feeling
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Blue line separates rural-cropland(left) and urban (right) stations. **When the station converts to Urban ,decrease in green comfortable hours with each decade is observed.**

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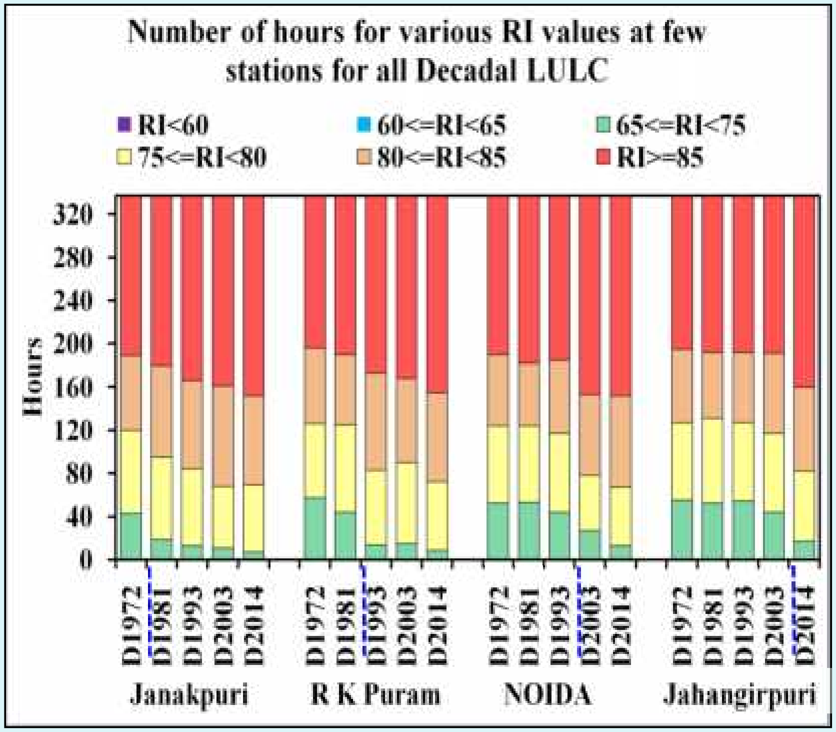
Number of Hours for various RI values at few stations across Delhi-NCR for all decadal LULC



	RI values	Human feeling
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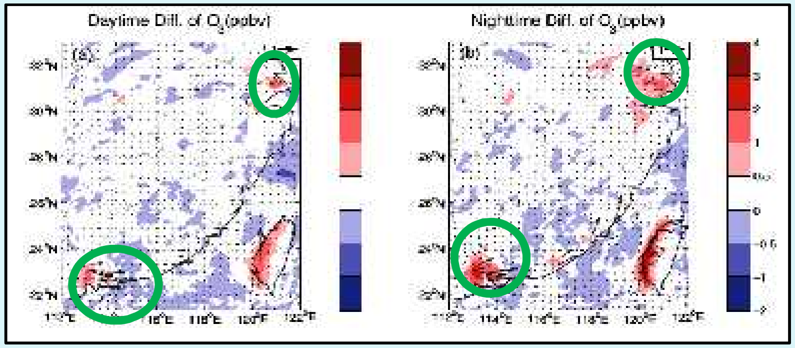
Table : No of hours (in %) for various RI values for different decadal LULC

			D1972	D1981	D1993	D2003	D2014
Janak puri		65<=RI<75	**13**	**6**	**4**	**3**	**2**
		75<=RI<80	23	23	21	17	18
		80<=RI<85	20	25	24	28	25
		RI>=85	**44**	**47**	**51**	**52**	**55**
RK Puram		65<=RI<75	**17**	**13**	**4**	**4**	**3**
		75<=RI<80	20	24	20	22	19
		80<=RI<85	21	19	27	23	25
		RI>=85	**42**	**44**	**49**	**50**	**54**
NOIDA		65<=RI<75	**15**	**16**	**13**	**8**	**4**
		75<=RI<80	21	21	22	15	16
		80<=RI<85	20	17	20	22	25
		RI>=85	**44**	**46**	**45**	**55**	**55**
Jahangir puri		65<=RI<75	**16**	**15**	**16**	**13**	**5**
		75<=RI<80	21	23	22	22	19
		80<=RI<85	20	18	19	22	23
		RI>=85	**42**	**43**	**43**	**43**	**53**

Blue line separates rural-cropland(left) and urban (right) stations in various decadal LULC. When the station converts to Urban it can be seen:

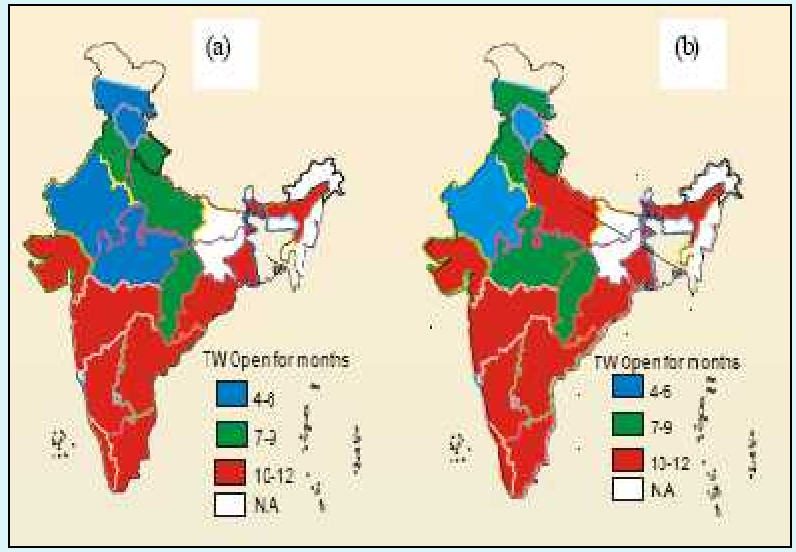
- Decrease in comfortable hours with each decade.
- Increase in uncomfortable hours.

Impact of Urbanization on Air Quality and Health



Urbanization increases surface ozone concentrations by about 4.7%–8.5% for the nighttime and by about 2.9%–4.2% for the daytime.
Wang et al (2009).Advances In Atmospheric Sciences

Increasing temperature has projected growth in transmission window of malaria on an average by two months in many regions of India.
Patwardhan and Harit, 2007



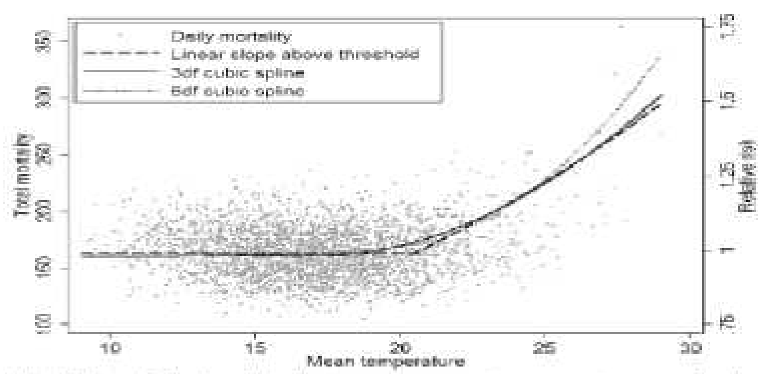


FIGURE Relationship between mean temperature and relative risk of mortality (righthand axis) in London estimated using 3 model specifications. Dots represent individual observations of daily mortality (lefthand axis).

Studies have shown exponential increase in mortality risk with increasing mean temperatures
Hajat et al.,(2006). Epidemiology

Effective Space Utilization in Construction

Energy Conservation and Efficiency

Appropriate Heating and Power Plant Fuel Choices

Mitigation Strategies

On-Site Renewable Energy Technologies

Green Buildings

Sustainable Transportation Solutions

Recommendation

- Significant investment in sustainable cities development is needed as part of Climate Change Action Plan

- The emissions are accounted in terms of carbon emissions from cities and industries. However, LULC has significant impact

- The majority of Urbanisation in past few decades (as illustrated with NCR India example) is going to take place in middle and low income countries and thereby affecting most vulnerable population; it is therefore required to focus greater attention on adaptation strategies due to urbanisation and implement mitigation with best available technology with greater investments.

with Contributions from

Mr. Ankur P. Sati

Dr. Shweta Bhati

Urbanization Across the World

Dubai (1990-2007)

Shanghai (1990-2010)

Panama (1930-2009)

THANKS

Tokyo (1960 -2010)

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