Urban Heat Island & its' Mitigation

Presenter :

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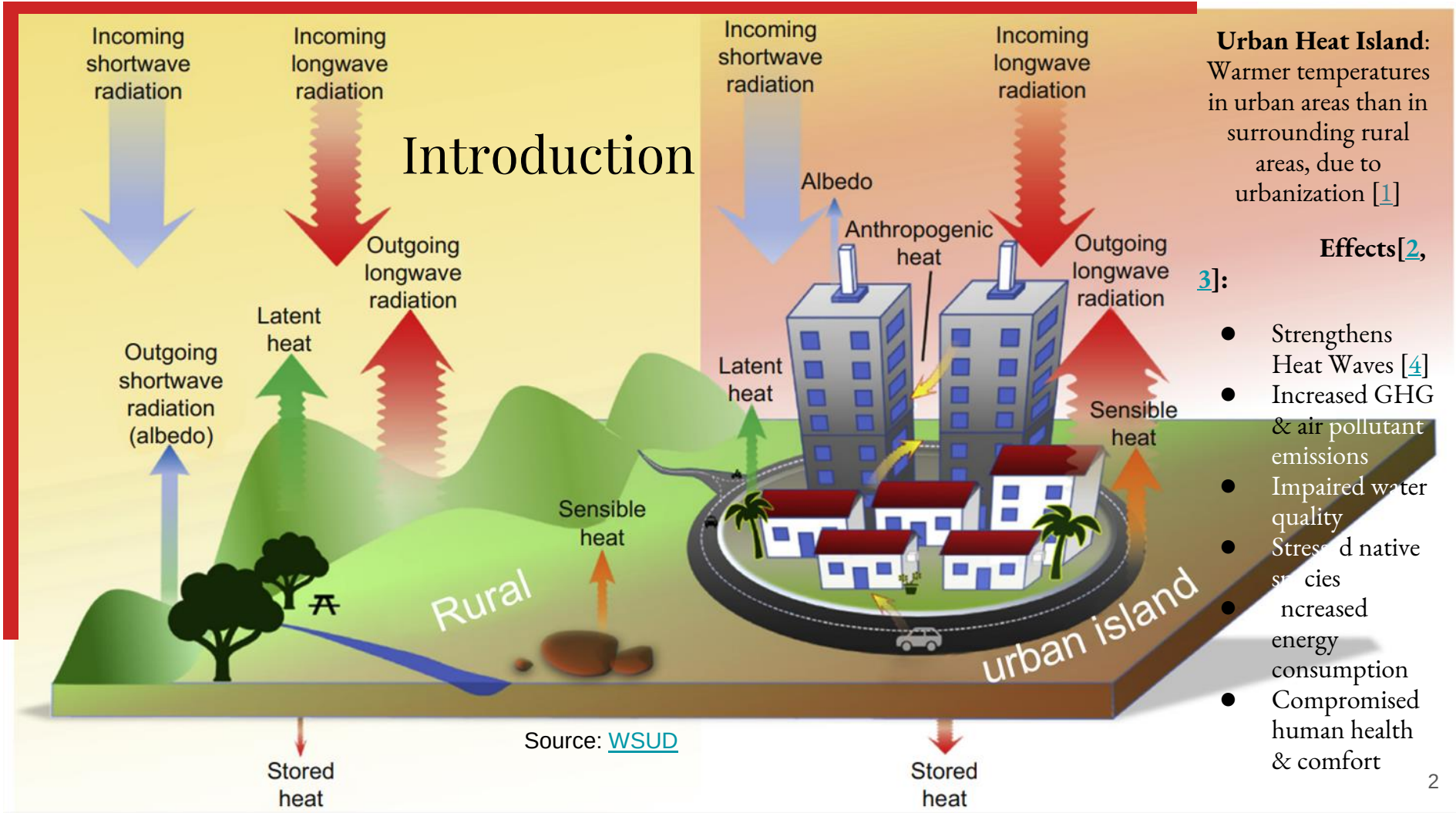
Project Proposal

EES - 502: Contemporary Environmental Issues

Introduction



Source: WSUD

Urban Heat Island: Warmer temperatures in urban areas than in surrounding rural areas, due to urbanization [1]

Effects[2, 3]:

- Strengthens Heat Waves [4]
- Increased GHG & air pollutant emissions
- Impaired water quality
- Stressed native species
- Increased energy consumption
- Compromised human health & comfort

Parameter & Index Analysis

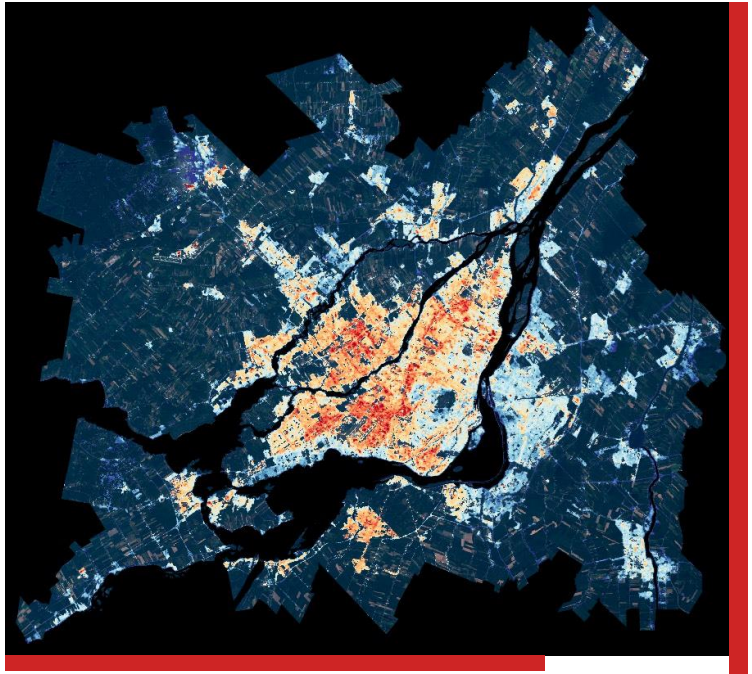
Urban Canopy Module (UCM) and the Local Climate Zones (LCZ) Approach

- Morphological Parameters
  - Building and road dimensions
  - Shadowing due to buildings
  - Street orientation
  - Diurnal variation of azimuth angle
- Wind profile in the canopy layer
- Urban Land Cover
  - Imperviousness
  - Vegetation cover
  - Surface energy budget of roofs, walls & roads
  - Radiation trapping

- Optical Parameters
  - Albedo
  - Emissivity
  - Cloud Cover
- Thermal Parameters
  - Conductivity
  - Capacity
  - Vertical thermal gradient
- Temporal Parameters
  - Diurnal temperature variations
  - Seasonal temperature variations
- Anthropogenic Heat Emission Parameters
  - Global anthropogenic heat flux
  - Particulate Emissions

Land Surface Temperature changes over urban areas

- Deriving Land Surface Temperature (LST) form thermal infrared satellite measurements has already been performed for several decades using Landsat and MODIS, and now Sentinel images are also been used for their high resolution capability.
- These types of *studies mainly been carried out for the agricultural purposes to estimate evapotranspiration(ET)*.
- **Another interesting application is to gain insights into the day- and night LST evolution over urban areas.**
- **Thus, these high resolution LST data provide valuable information for the city planners and climate modelers to gain detailed insights about the effects and susceptibility nature of the extreme heat conditions and how to mitigate these effects.**
- In addition to that we will also see the Land Use Land Cover changes and the dynamicity of it in the different time periods of the year to estimate the temperature dynamics.



Satellite imagery and land surface temperature.
Photo : Google Earth Engine, NASA

Anthropogenic Effects and Aerosol Analysis

Main sources:

1.Manufacturing of building , cooling and heating of building-1) the dark materials with canyon like configurations of buildings and pavements collects more sun's energy(fig)- 2) Because of impermeable and water tight urban construction materials, to dissipate sun's heat moisture is not available .

2.Air pollution results from emission of particulates like co2,h20 vapour etc. By anthropogenic ae

Change the urban net all wave radiation by 1) Reducing the incident shortwave flux of solar radiati

2)Re-emission of longwave (ie,infrared) from urban surface 3) absorbing long wave radiation from

These 3 contribute to warming the ambient air. AAUHI pronounced in areas with high level of indus

And vehicular emissions. From this equation :

$$Qf = Qfv + Qfh + Qfm$$

Qfv: heat release by vehicles ; Qfh:stationary sources ; Qfm:metabolism

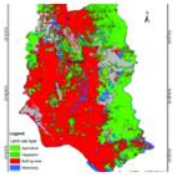
Qf is the flux of latent heat of anthropogenic energy release within that urban control volume.

While the urban heat island effect is a well known phenomenon, the AAUHI effect is still not well understood and requires further research

Model Building

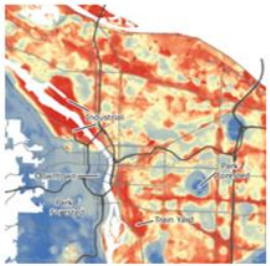
Footprint

3D Model



City LULC

UHI Index



Aerosol Data

Material Data

Vegetation Data

- Is Aerosol concentration a factor?
- What will change if different materials are used?
- What is the effect of micro-scale vegetation?
- Is building height also a factor?
- Does geometry matters?

Mitigation Strategies and Case Studies

Mitigation of urban heat islands refers to actions taken to reduce the temperature difference between urban areas and surrounding rural areas caused by human activity. Strategies include:

1. Increasing the amount of green space in cities through the use of green roofs.
2. Implementing reflective surfaces on buildings and pavements.
3. Increasing energy efficiency in buildings promoting more walkable, compact urban designs

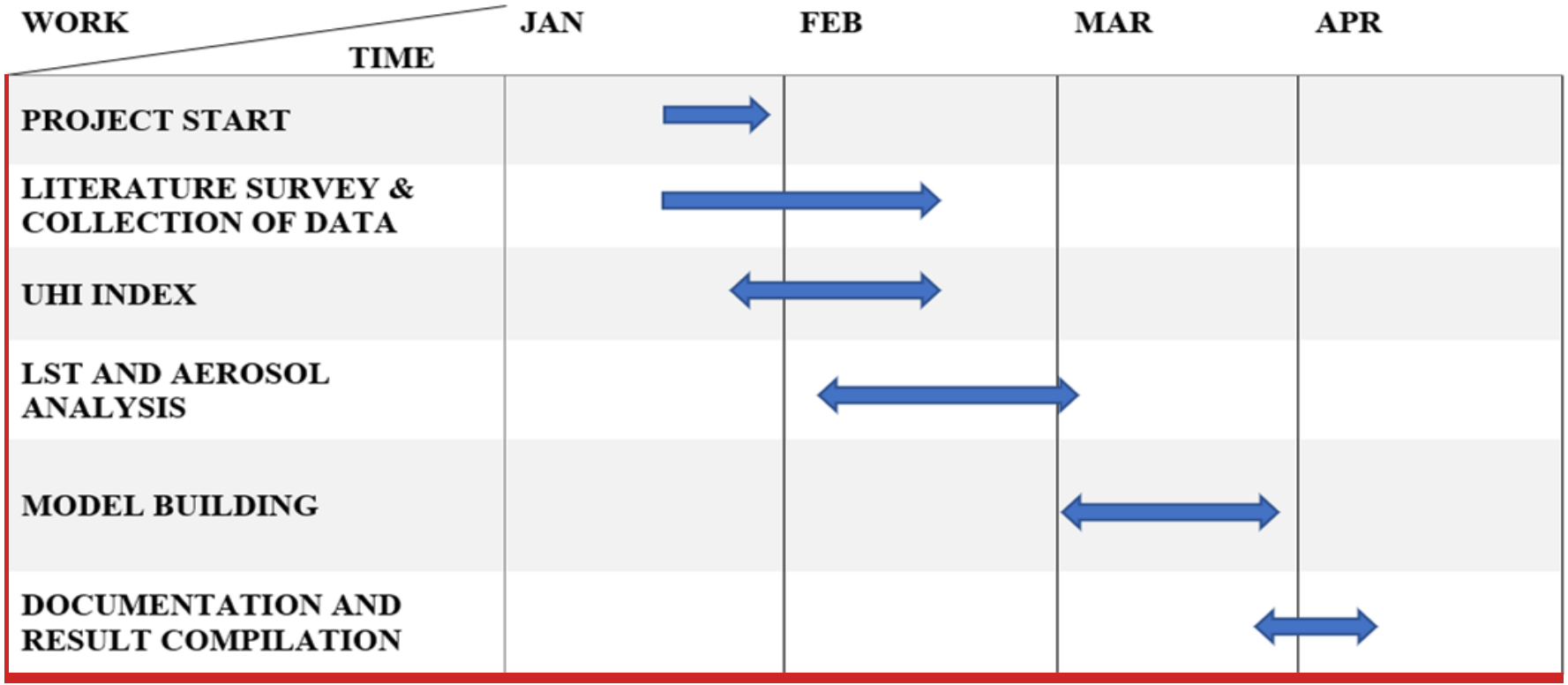
Different cases can help to see the efficiency of our model:

Compact Settlement

Slum Settlement

Planned modified Settlement

Future Timeline



WRF/UCM Model

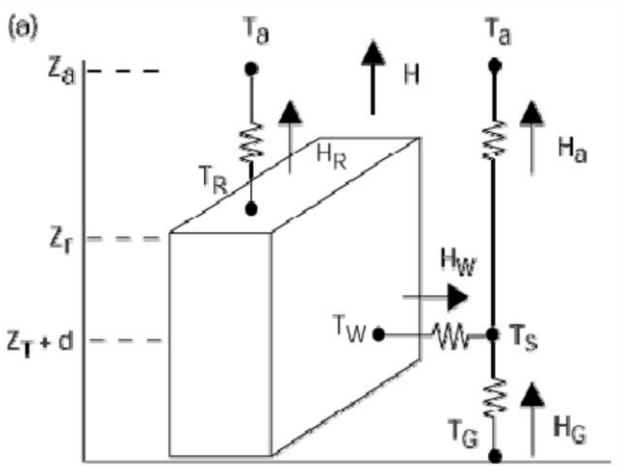
- Weather Research & Forecasting coupled with Urban Canopy Module
- Single Layer Model, Version 3.7.1
- Developed by the National Centre for Atmospheric Research (NCAR), USA

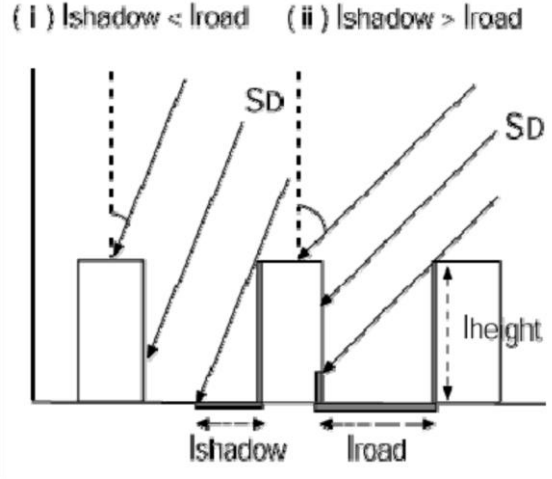
Advantages:

- High spatial and temporal resolution

Disadvantages:

- Ineffective urban-rural comparison due to grid selection biases
- Suboptimal detection of local temperature differences
- Heat transfer by convection mechanisms and vertical imperviousness of land structures are not well studied.
- Cannot account for water bodies.





Local Climate Zones (LCZ) Model

- Regions of uniform surface cover, structure, material, and human activity that span hundreds of meters to several kilometers in horizontal scale.
- Classifies urban and rural environments into 10 “built” and 7 “natural” classes, where each class has a set of characteristic parameter values (e.g., sky view factor, built-up surface fraction, and vegetation surface fraction).

Advantages:

- Facilitates metadata collection and description of measurement sites
- Widely acknowledged as a global standard for urban temperature studies
- Accounts for altitude corrections in temperature measurements

Disadvantages:

- Microscale temperature heterogeneity can still be observed within the same LCZs or neighborhoods

Initial Assumptions & Index Equations

$$T_s = FRC\_URB \times T_{s(impervious)} + (1 - FRC\_URB) \times T_{s(vegetation)}$$

$$SH = FRC\_URB \times SH_{(impervious)} + (1 - FRC\_URB) \times SH_{(vegetation)}$$

$$T_{2m} = T_s - \frac{SH}{\rho C_{h2m} U_{2m}}$$

$$T_{2m} = FRC\_URB \times \left(T_{s(impervious)} - T_{s(vegetation)} - \frac{SH_{(impervious)} - SH_{(vegetation)}}{\rho C_{h2m} U_{2m}}\right) + T_{s(vegetation)} - \frac{SH_{(vegetation)}}{\rho C_{h2m} U_{2m}}$$

UHII $T_{2m(vegetation)}$

$$\Delta T = T - \frac{1}{N} \sum_{k=1 \ldots N} T_{b,\,k}$$

- Clear Sky: Cloud fraction < 12.5%
- Calm Winds: Daytime < 3 m/s, Nighttime < 2 m/s
- Standardized time interval for modelling iterations = 90 seconds (tentatively)

Index Equations

- City Area[8]: $\Delta T_{u-r(\max)} = 2.01 \log P - 4.06$
- Height / Width ratio (building and road dimensions)[9]: Air Temperature = 1.3459 * (H/W) - 30.634
- Total Heat Flux (including anthropogenic heat flux)[10]: $\Delta T_{UHI} = \frac{Q_F l}{C_p \rho h_{UHI} V}$
- Thermal Inertia[11]: $P = \sqrt{\rho \cdot c \cdot K}$
- Net Surface Shortwave Radiation[12]: $\delta T(t) = J(t) \frac{\sin[\omega t - (\pi/4)]}{\omega^{\frac{1}{2}} \cdot P}$
- Emissivity & Longwave Radiation[13]: $\varepsilon_b = 0.2122 \cdot \varepsilon_{29} + 0.3859 \cdot \varepsilon_{31} + 0.4029 \cdot \varepsilon_{32}$
- Sky View Factor & Diurnal Temperature Range[14]: $UHI_{Theeuwes} = (2 - SVF - f_{veg}) \sqrt[4]{\frac{rsds\ DTR^3}{wind}}$

Parameter and Dataset Analyses

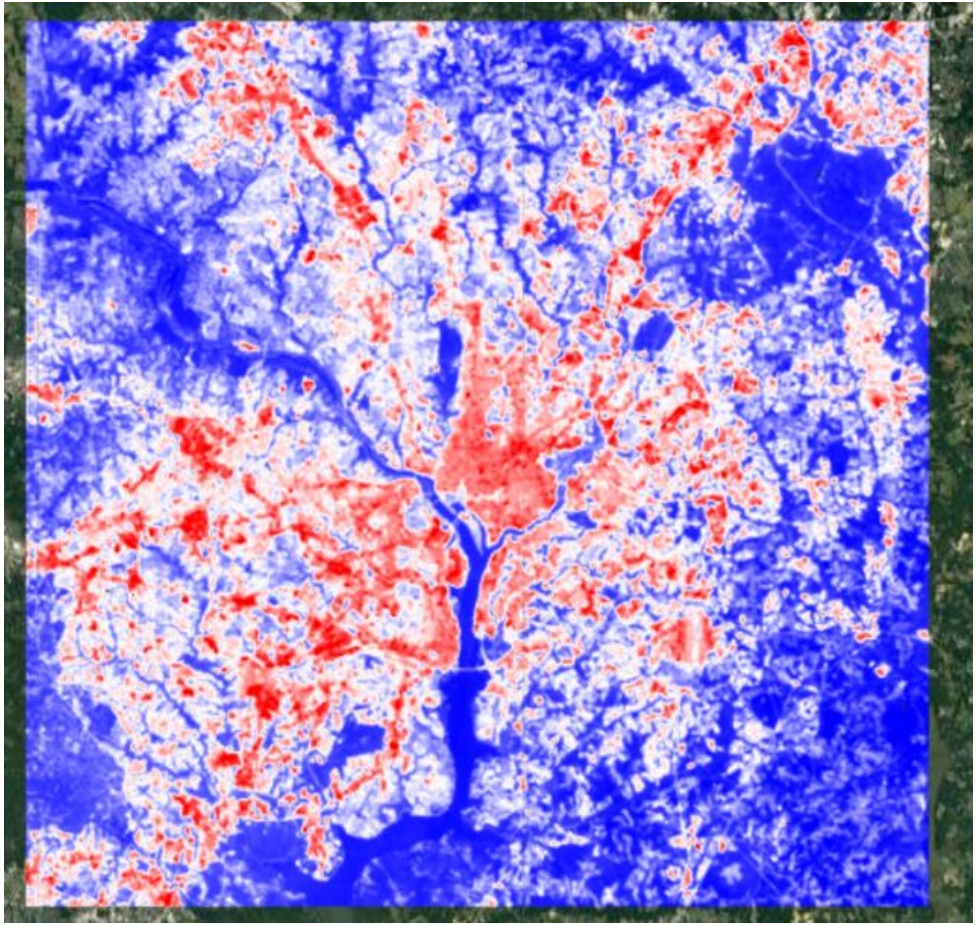
- **Morphological Parameters:-**
  - **Building and road dimensions, shadowing due to buildings, street orientation, diurnal variation of azimuth angle:** 3D City Model, Visualization of Earth Observation and Archival System (VEDAS), Space Applications Centre; ISRO
  - **Land Cover Fractions:**
    - Copernicus Global Land Cover Data
    - OpenStreetMap
    - Sentinel - II
- **Anthropogenic Heat Emissions (AHE)**: Dong et al (2017)
- **Optical Parameters:-**
  - **Material Reflectances:** Defense Technical Information Center (DTIC), U.S. Department of Defence
  - **Albedo & Emissivity:**
    - Meteosat Surface Albedo
    - Bhuvan
    - Copernicus
    - MODIS
- **Thermal Parameters (Conductivity & capacity):** Thermophysical properties database of materials for light water reactors and heavy water reactors, International Atomic Energy Agency
- **Land Surface Temperatures:** ARSET, USGS Earth Explorer
- **Initial and Lateral Boundary Conditions:** Reanalysis data from Global Forecast System, National Centre for Environment Prediction

Urban Heat Islands – SUHI

• Surface Urban Heat Islands (SUHI) represent the difference of land surface temperature (LST) in urban relative to non-urban areas, as well as “hot spots” within urban areas, and are usually measured using satellite data.

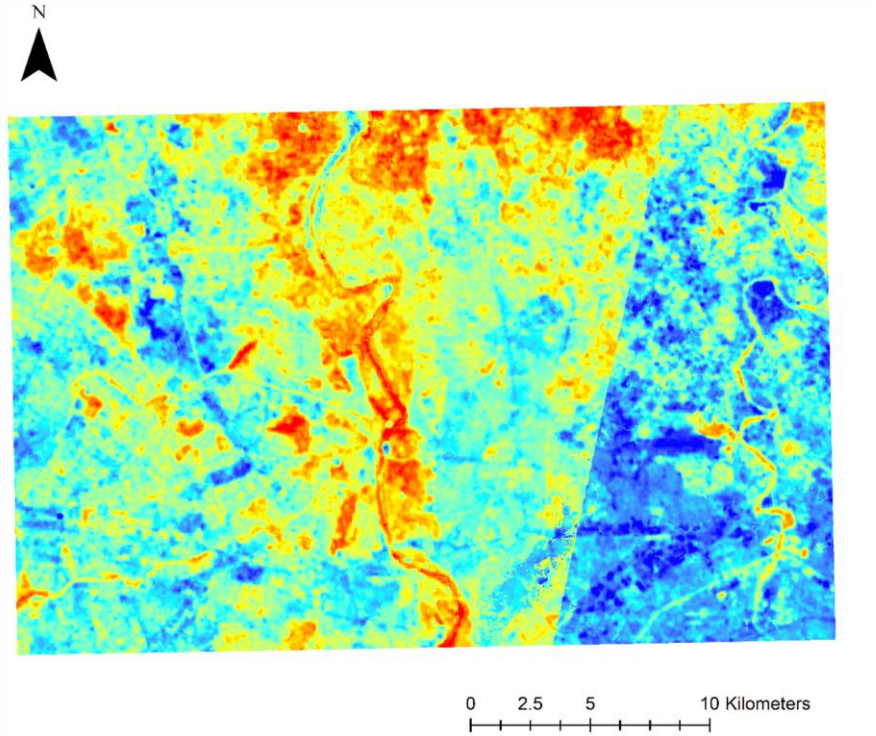
$$\Delta\, Tu{-}r = Tu - Tr$$

• where $\Delta\, Tu{-}r$ is UHI intensity, Tu is urban temperature and Tr is rural temperature.



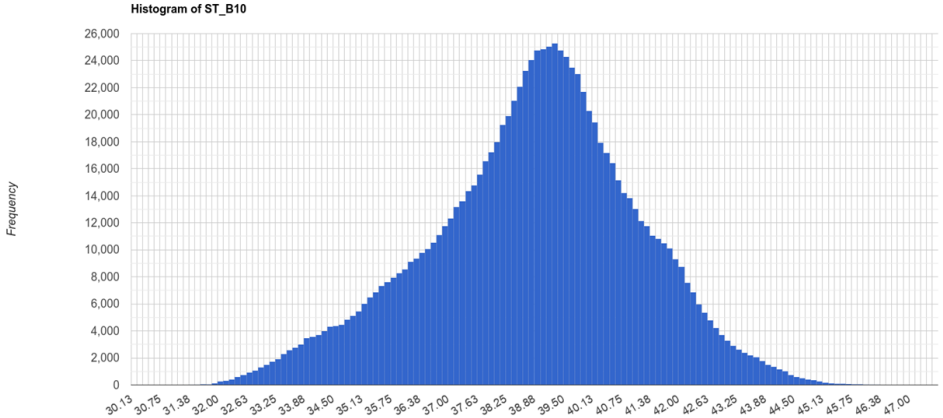
Preliminary Results for the region Washington, Old Delhi and Athens(Greece)

- The first thing that we have to remember is that these results purely depends upon the region you select and geometry used in the code itself.
- The results can be fine tuned upon the features and the datasets has been used.
- For these results we relied upon the Landsat 8-9 images with 30 meter resolution but with the high resolution images we can see better results.

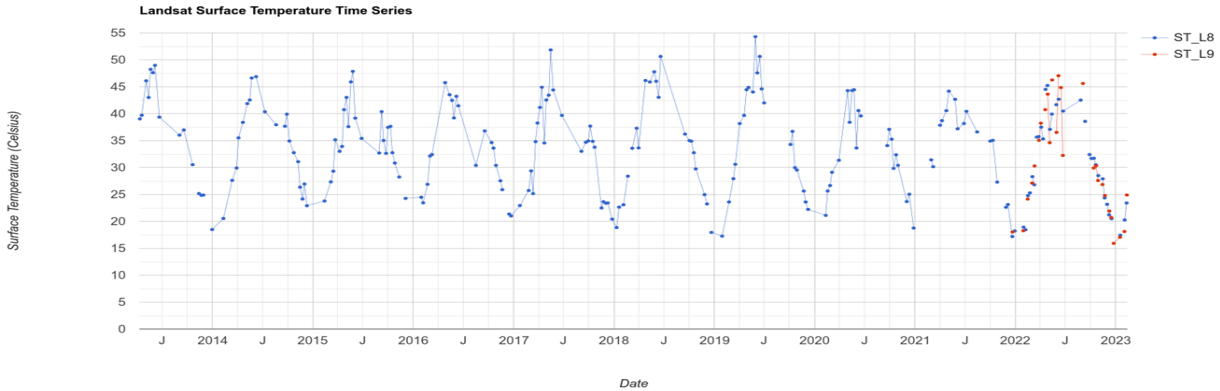


Delhi data at 30m resolution

For Old Delhi

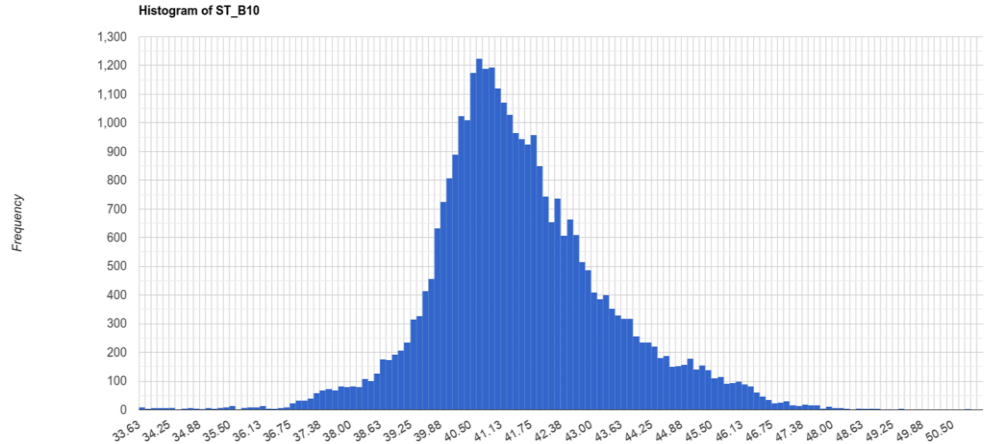


Histogram of Surface Temperature

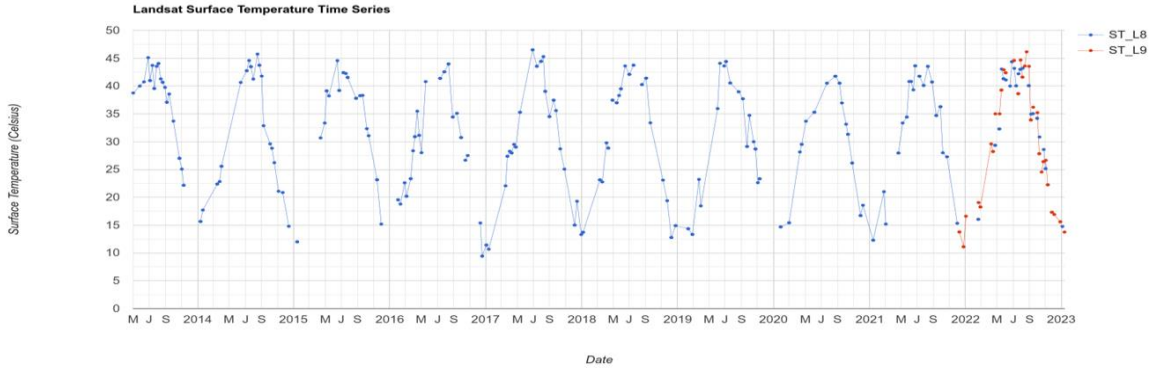


Time Series Plot of LST

For Athens-Greece

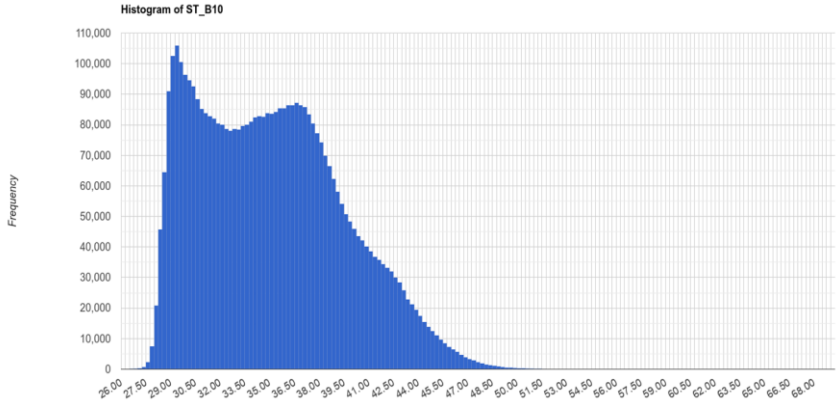


Histogram of Surface Temperature

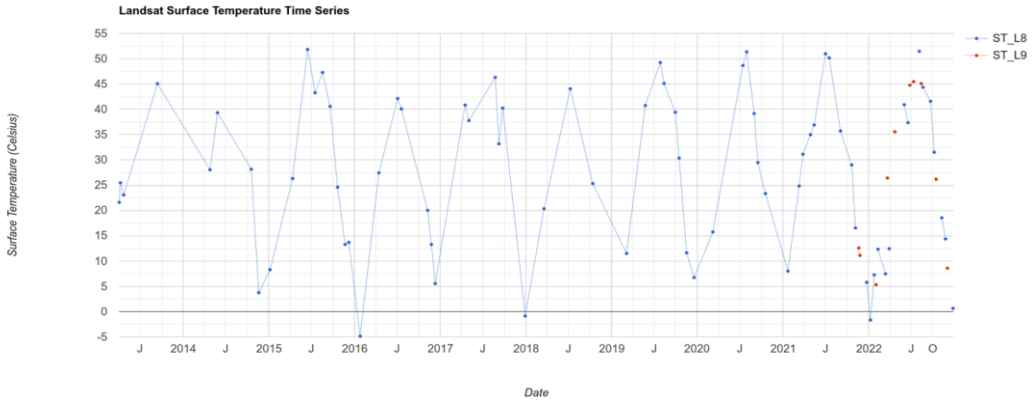


Time Series Plot of LST

For Washington



Histogram of Surface Temperature



Time Series Plot of LST

Drivers of the Urban Heat Island

Loss of Vegetation

Impervious Materials

Waste Heat

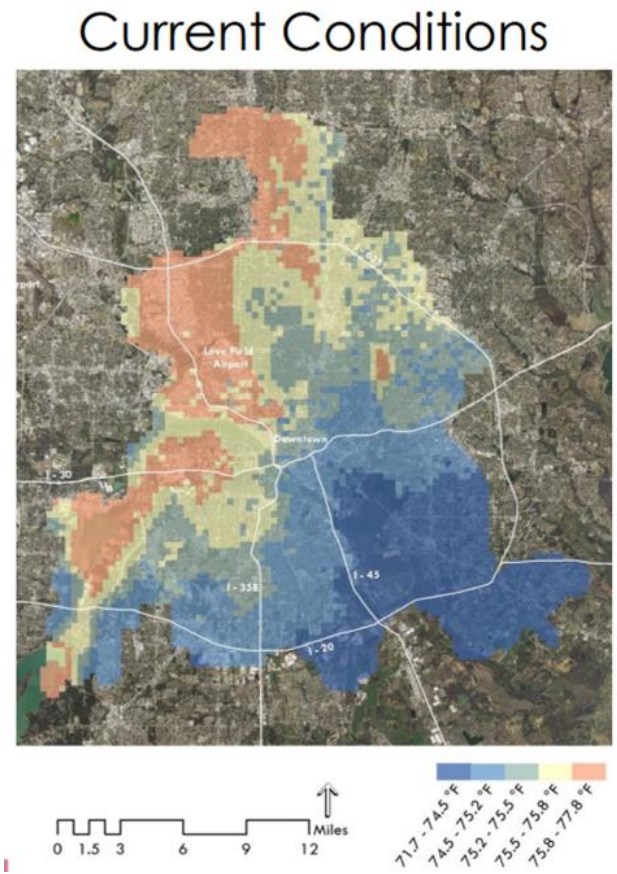
Urban Morphology

Why Use HVIs?

• Urban heat is exacerbated by the urban heat island and varies by microclimate, but can be mitigated via neighborhood-specific interventions

• Interventions should be located in areas where they will be most effective, efficient, and equitable

• Heat-related health outcomes and comprehensive, high-resolution air temperature data are difficult to obtain and model

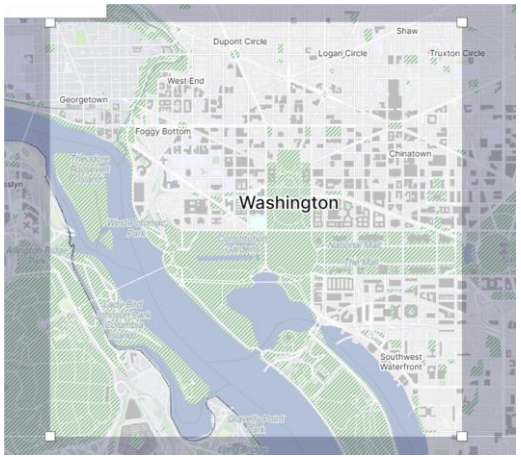


AOI and data-selection

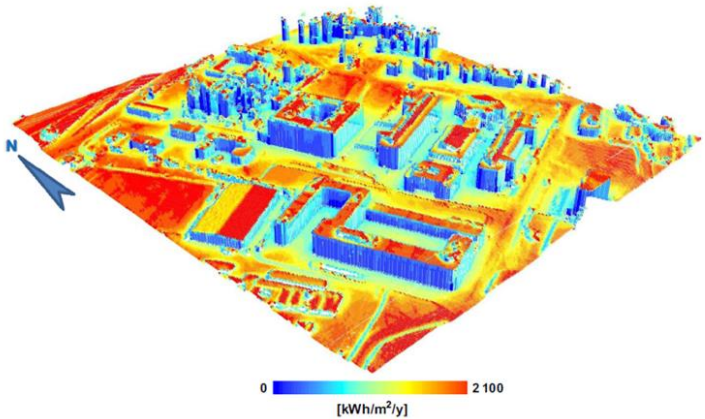
Rural Area

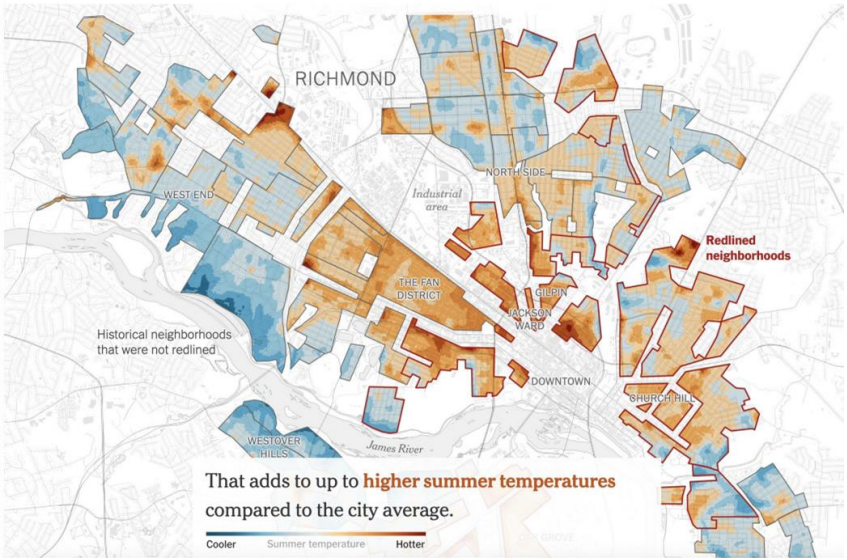
Urban Area

3D model


Dupont Circle
Shaw
Logan Circle
Truxton Circle
West End
Georgetown
Foggy Bottom
Chinatown
Washington
Southwest Waterfront

3D model-LST


N
0
2 100
[kWh/m²/y]


RICHMOND
WEST END
Industrial area
NORTH SIDE
Redlined neighborhoods
THE FAN DISTRICT
GILPIN
JACKSON WARD
Historical neighborhoods that were not redlined
DOWNTOWN
CHURCH HILL
WESTOVER HILLS
James River
That adds to up to higher summer temperatures compared to the city average.
Cooler
Summer temperature
Hotter

Anthropogenic heat effects of UHI

Urban areas are the sources of anthropogenic carbon dioxide emissions from the burning of fossil fuels for heating and cooling; from industrial processes; from transportation of people and goods which contributes to change the pre urban environment.

The main sources for this are:
1)cooling and heating of buldings
2)manufacturing
3)transportation
4)lightning
5)human and animal metabolism these warm the ambient atmosphere by conduction,convection and radiation.

Anthropogenic heat and Urban energy balance = latitude + season of year

For eg:- **Temperate city** anthro heat signifiant component of the **energy balance in winter .** Negligible component in summer

It involves Air pollution results from emissions of particulates, water vapour, and carbon dioxide from industrial, domestic, and automobile combustion processes , which reducing the
1) incident flux of short-wave (i.e., solar) radiation
2)re-emitting long-wave (i.e., infrared) radiation from the urban surface downward to where it is retained by the ground
3) absorbing long-wave radiation from the urban surface

To determine how much anthropogenic heat is produced in any region, all energy use (commercial, residential, industrial, and transportation) must be estimated. The sum is then divided by the region's area to enable comparisons of different cities to be made

To understand and simplify the complexity, *(Foley et al 2005, Oke 2006)* has suggested an equation called the "energy balance" in which the heat generated by and 4 Urban Studies Research contained in an area could be calculated by this equation:

$$Q* + QF = QH + QE + \Delta QS + \Delta QA$$

where, Q∗: the net all-wave radiation; QF : the anthropogenic heat QE: the turbulent latent heat flux
QH: the turbulent sensible heat flux ΔQS: the sensible heat storage ΔQA: the net heat advection

QF: means heat generated from stationary and mobile sources of an area. QF must either be converted to radiations, sensible heat flux, or latent heat flux, or it is stored . This component is usually modelled as sum of heat generated by the buildings vehicle and people.

Anthropogenic heat release relates to human population and percapita energy use. *(Oke 2006)*

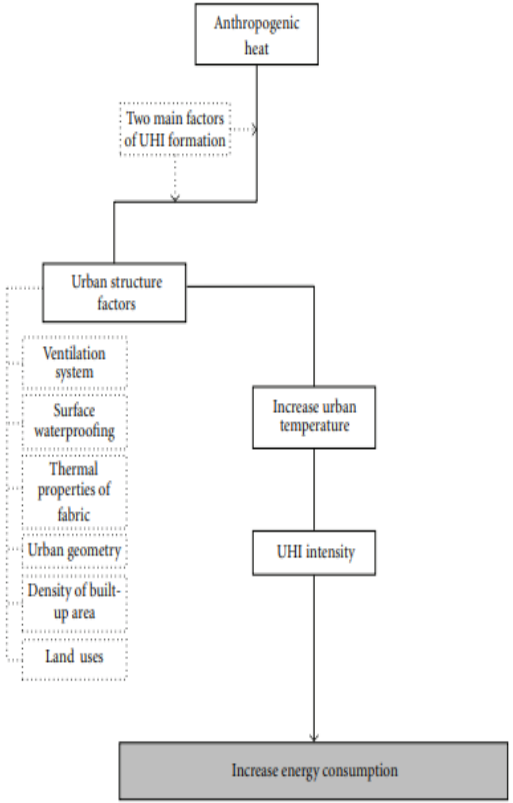
Anthropogenic heat has smaller effect than albedo and vegetation cover, and that it is negligible in commercial and residential areas (*taha et al 1992*).

Turbulent Heat Fluxes (QE, QH): comprised of the sensible and latent heat fluxes. These can be directly derived from eddy correlation, or measured using appropriate equipments.

The urban areas which are built heavy are responsible for increased sensible heat flux which is vary as per the built surface

Storage Heat Flux (ΔQS) : Due to the complicated configuration of surface materials, orientations, and their interactions, the direct measurement of storage heat flux in an urbanized area is almost impossible.

Increase in the net all-wave radiation directly increases the stored heat flux.



Aerosol effects on UHI

Aerosol particles can affect the UHII by air pollution through:

(1)change in the surface energy balance by Aerosol Radiative Effect (ARE)

(2) PBL(planetary boundary layer) [fig-1] stability and air flow intensity by modifying thermodynamic structure which is referred to as Aerosol Dynamic Effect (ADE). impact of aerosols on UHII differ by different strengths of the ARE and ADE between summer and winter.

ARE on UHII is dominant over the ADE, cooling down surface temperature more strongly in urban areas than in rural areas because of much higher aerosol loading and offsets the urban heating, therefore weakening UHII.

Interaction between urban heat and air pollution can be anlysed by aerosol studies
Which also plays important role in scattering radiation.

Aerosol Optical Depth (AOD) : is **the measure of aerosols (e.g., urban haze, smoke. particles, desert**
sea salt distributed within a column of air from the instrument.
Its value ranges from 0 to 1.
Means high AOD high AOD values indicate **a relatively hazy atmosphere** while low values of AOD indicate a relatively clear atmosphere and it is wavelength dependent.

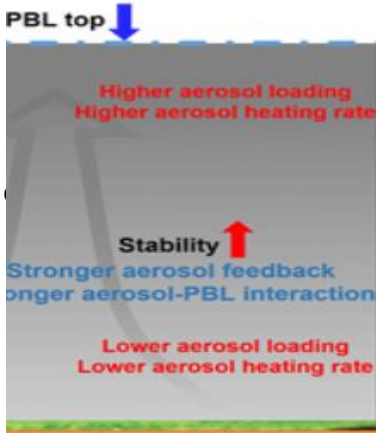
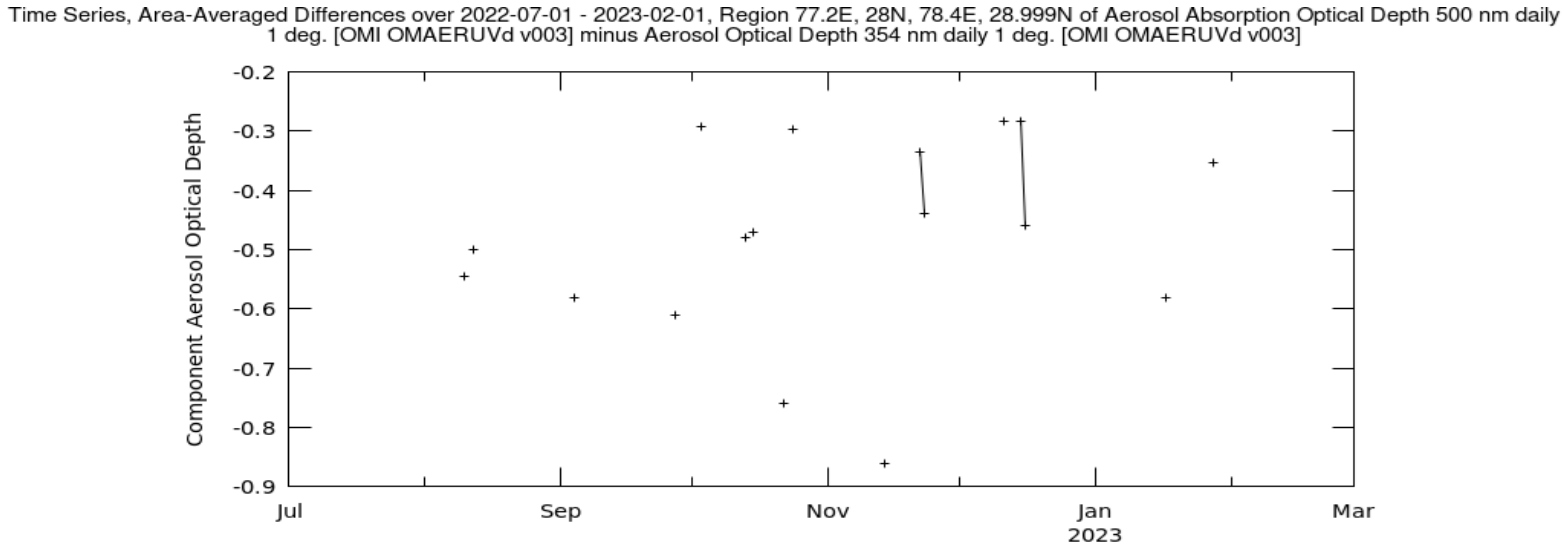


Fig-1

In the present analysis **average optical depth data** from giovanni shows area averaged difference 500nm and 354 nm from july of 2022 to february of this year of **New delhi** ;



Lowest AODcomponent area averaged difference was observed in the initial days of october 2022 may be due to rainfall settled down the particulate matte and highest was observed around mid november of that year (WINTER) . most aod component between 0.4-0.7.

Questions?

Thank You.