Impacts of Increased Urbanization on Surface Temperature, Vegetation, and Aerosols over Bengaluru, India

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Background on Urbanization

- As cities expand, urbanization has the ability to:
  - Reduce the area of green spaces (Andersson, 2006)
  - Impact local and regional climate (Kishtawal et al., 2010; Wang et al., 2012)
  - Deteriorate air quality (Ramachandran et al., 2012)
  - Increase the number of heat-related deaths (Raghavendra et al., 2019)
- Urban heat island (**UHI**) phenomenon: cities tend to have higher temperatures than their non-urban surroundings

Background on Bengaluru, India

- Bengaluru is located in southern India and is the third most populous city in India with a population of ~10 million (Census Report of India, 2011), which is a 47.18% increase from the Census in 2001
- Known to as the *"Garden City"* of India, bot now more commonly known as the *"Silicon City"* (Sudhira et al., 2007)
- Bengaluru's UHI has not been studied in terms of its seasonality and diurnal cycle, which are critical UHI factors for tropical Asian cities (Hung et al., 2005)

Objectives

- Bengaluru's population is increasing, thus making more people susceptible to heat-related illnesses
  - **What is the city's UHI intensity in terms of seasonality (monsoon/wet vs. dry season) and diurnal cycle with respect to surface temperature, vegetation, and aerosols?**
- Bengaluru's urbanization is unique due to:
  - Vegetation: low vegetation = less evapotranspiration = higher temperatures, and vice versa
    - **How much has the vegetation greenness in Bengaluru declined in recent years?**
  - Aerosols: black carbon aerosols, which absorb solar radiation and thereby decrease temperatures, are increasing in urban cities in India due to increased vehicular pollution, especially during the dry season (Ramachandran et al., 2012)
    - This effect has cancelled and exceeded the UHI effect in New Delhi, India during the dry months and has induced an urban cool island (Pandey et al., 2014) – **Does an urban cool island exist in Bengaluru?**

Study Region and Data

- Study region: 50 km × 50 km region surrounding the Bengaluru city center (12.97°N, 77.59°E)
- Climate Prediction Center global unified gauge-based daily precipitation data from NOAA/OAR/ESRL/PSD at 0.5° resolution from 2003-2018 to determine wet vs. dry season
- Satellite products from the MODerate Resolution Imaging Spectroradiometer (**MODIS**) for 2003–2018 at 1 km:

Variable	Product(s)
Land surface temperature (**LST**)	8-day composite from Terra and Aqua, day and night measurements
Land cover	Terra and Aqua combined annual product
Enhanced vegetation index (**EVI**)	16-day composite from both Terra and Aqua
Aerosol Optical Depth (**AOD**)	Terra and Aqua combined daily product

Methods

1. Preliminaries

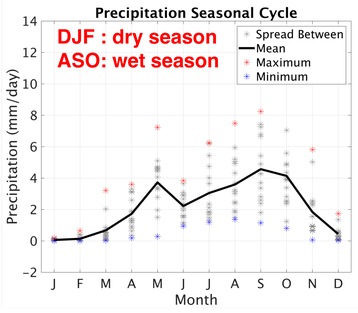

Fig. 1: Seasonal cycle of daily precipitation averaged over Bengaluru from 2003–2018 and its statistics.

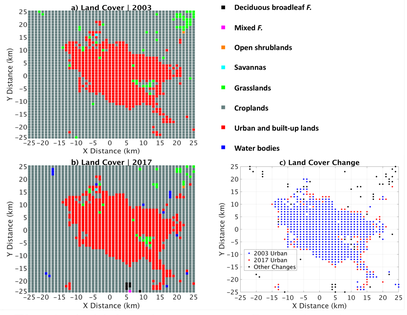

Fig. 2: *(a,b) Land cover over Bengaluru in 2003 and 2017. (c) Urban pixel locations in 2003, 2017, and other changes in land cover in 2017 compared to 2003. Forest abbreviated as* ***F.***

2. Analysis

1. Calculated rate of urbanization and amount of urban area from 2003–2018
2. Calculated spatial patterns and trends in LST from 2003–2018 for day and night
3. **UHI Intensity = LST_{urban} – $LST_{non\text{-}urban}$**
   - If a non-urban (cropland) pixel < 5 km from an urban or water body pixel, it was removed from the calculation
   - Calculated for each year
4. Calculated spatial patterns and trends in EVI from 2003–2018
5. Calculated trends in AOD from 2003–2018
   - Computed correlation between AOD and LST in DJF (not shown) due to significant increasing trend (Fig. 8a)

Results

1. Daytime and Nighttime LST in DJF and ASO

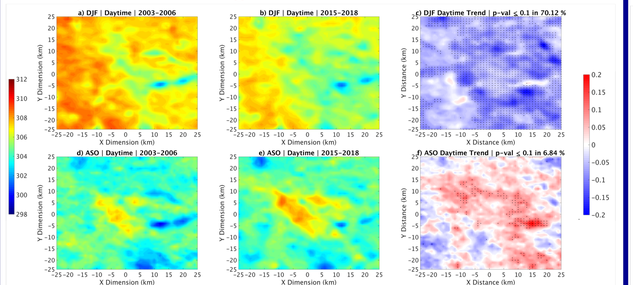

Fig. 3: *(a,b,d,e)* Daytime LST for the 2003–2006 mean and 2015–2018 mean (in K). *(c,f)* 2003–2018 linear trends (in K yr^{-1}), where stippling indicates significance at the 10% level by the Student's t-test.

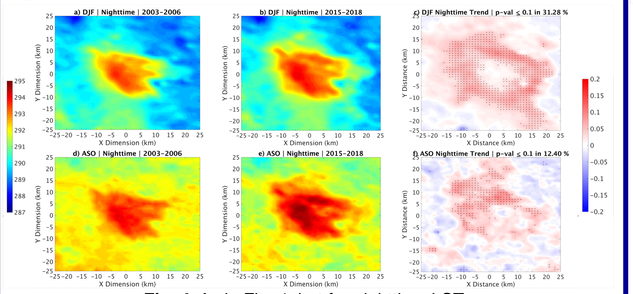

Fig. 4: As in Fig. 4, but for nighttime LST.

2. UHI Intensity

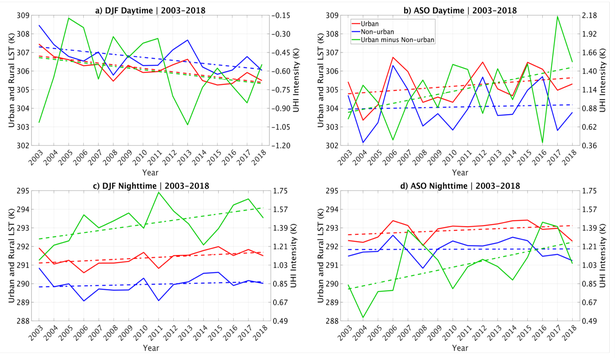

Fig. 5: UHI intensity from 2003–2018.

	2003–2018 Mean UHI Intensity (in K)
DJF Daytime	-0.60
ASO Nighttime	1.02
ASO Daytime	1.14
DJF Nighttime	1.43

3. EVI Trends

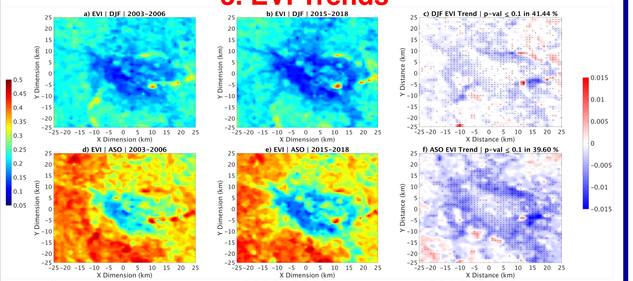

Fig. 6: *(a,b,d,e)* EVI for the 2003–2006 mean and 2015–2018 mean. *(c,f)* 2003–2018 linear trends per year, where stippling indicates significance at the 10% level by the Student's t-test.

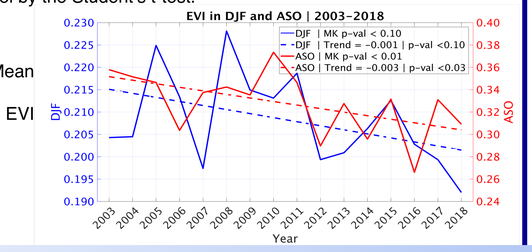

Fig. 7: Mean temporal change in EVI over Bengaluru.

4. AOD Trends

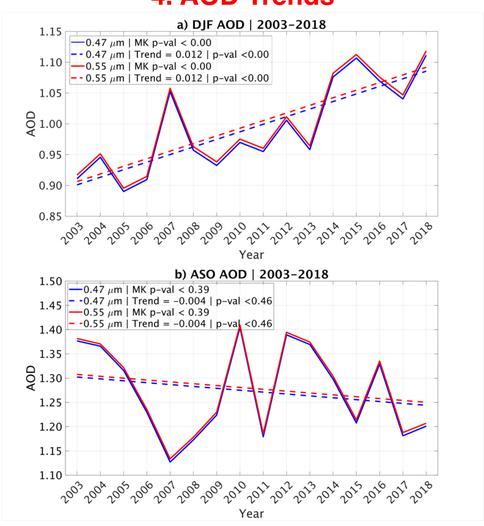

Fig. 8: Mean temporal change in AOD during DJF and ASO over Bengaluru.

Conclusions

- UHI intensity is increasing in Bengaluru during the wet season daytime and nighttime and dry season nighttime
- UHI intensity is decreasing in Bengaluru during the dry season daytime due to an increase in AOD limiting surface warming, and thus inducing an urban cool island
- EVI has significantly decreased in the locations of urbanization, likely amplifying the UHI effect

Reference: Sussman, H.S., Raghavendra, A., Zhou, L., 2019. Impacts of increased urbanization on surface temperature, vegetation, and aerosols over Bengaluru, India. *Remote Sensing Applications: Society and Environment*. 16, 100261. doi: **10.1016/j.rsase.2019.100261**

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