Connecting Changes in the Local Urban Fabric to Intra-Urban Summer Heat

Eric Brown de Colstoun[1], Stacia Harper[2], Eleanor Horvath[3], Martin Meister[4], and Diana Muller[5]

1 Biospheric Sciences Laboratory, NASA/GSFC; 2 West Virginia University; 3 Boston University; 4 Centennial High School, HCPSS; 5 Arundel High School, AACPS

ABSTRACT

New, more detailed, and more accurate remotely sensed data on urban areas and associated built-up surfaces can provide a foundation for a better understanding of the impacts of cities on their environment and inhabitants, as well as potential improvements in the modeling of the impacts of urbanization on the energy, water, and carbon cycles. In this project, we use Landsat and MODIS-derived surface temperature and land cover data to investigate the relationship between the changing urban fabric and temperature-related threats to urban populations. We then harmonize remotely sensed data with socioeconomic variables from the U.S. Census in support of the derivation of a novel urban heat vulnerability index.

INTRODUCTION

The urban fabric referred to in this research is the physical form of towns and cities (figure 1); it includes materials like trees, grass, pavement, and buildings, as well as the people that live there. The United Nations projects that more than 2/3 of the global population will live in within this urban fabric by 2050 (figure 2).

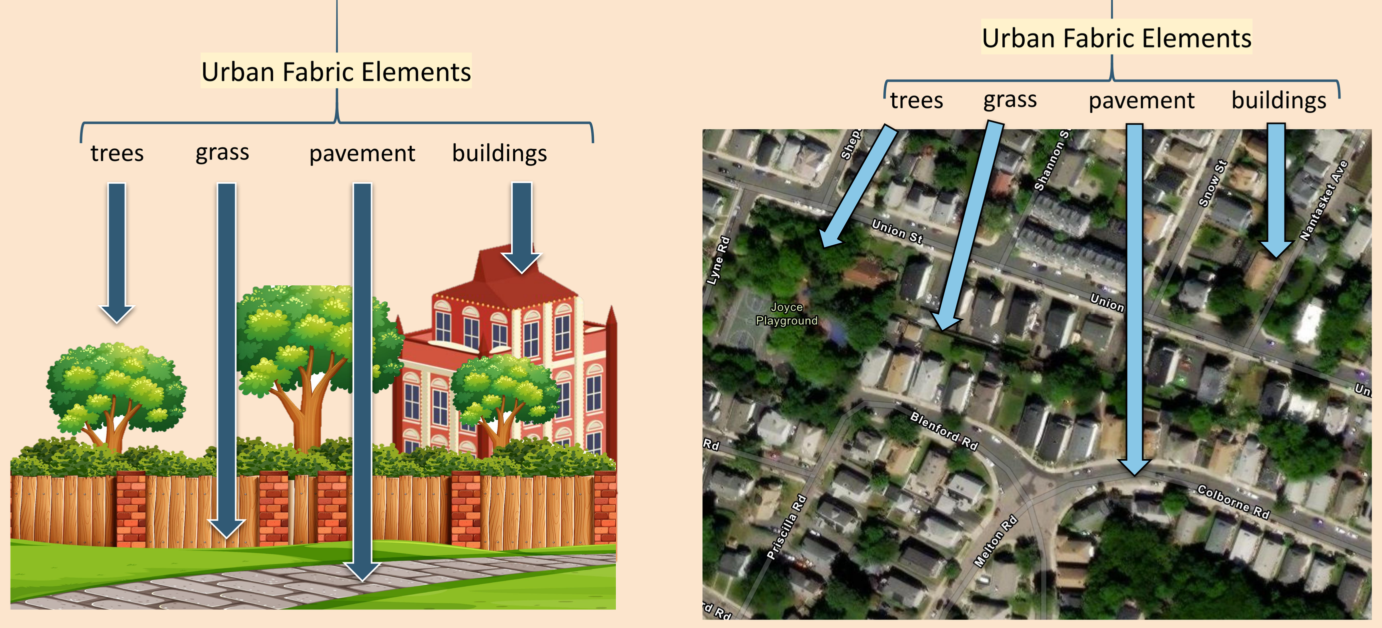


Figure 1. Materials of the urban fabric (diagram and high-resolution satellite imagery)

The changes associated with both historic and projected urban growth has significant impacts on hydrology, air pollution, water quality, local meteorology, human wellbeing, and more. In recent years, the development of high-quality remote sensing instruments have offered researchers a new perspective with which to study urban expansion and intra-urban changes due to growing urban populations. In order to better understand the impacts of urban growth on vulnerable residents of the urban fabric, this research focuses on the effects of rising urban temperatures on those most at risk from heat-related threats. Although we focus on the Baltimore - Washington, D.C. metropolitan area, the methodologies and implications of this research have the potential to be applied to urban areas around the world.

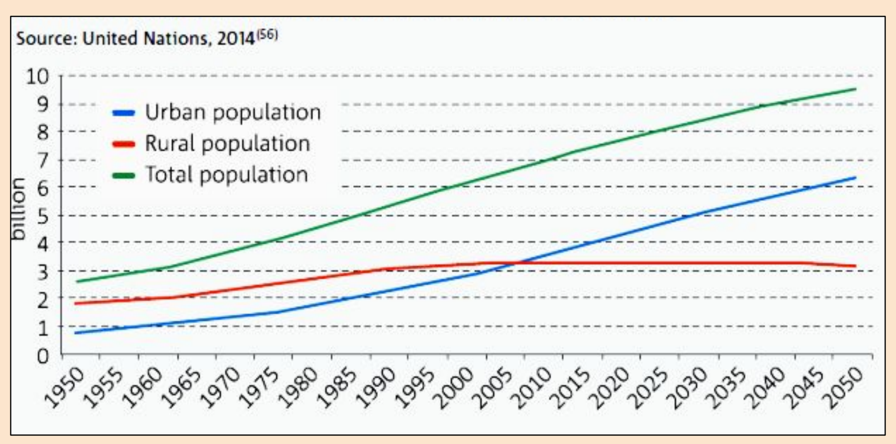


Figure 2. United Nations global, urban, and rural population estimates.

METHODS

Data for temperature composites were collected by various generations of Landsat satellites and pre-processed by the U.S. Geological Survey. To calculate a metric of maximum summer heat for this analysis, the two maximum summer temperatures for each pixel were calculated and averaged using the Google Earth Engine JavaScript API. The data was then clipped by 0.25% from the maximum and minimum of the composite to remove anomalies. For comparison, "MODIS LST - daily daytime LST" data are collected by Terra MODIS and are filtered by quality and cloud cover using MODIS quality bits. Dates are filtered based on Landsat overpass dates. Field measurements of LST were collected around Landsat pixel centers in conjunction with Landsat overpasses and compared to real Landsat data. Land cover data were taken from the Multi-Resolution Land Characteristics Consortium's National Land Cover Database. Temperature composite data, land cover classifications and percent impervious cover data, Normalized Difference Vegetation Index data, and other indicators were aggregated to U.S. Census geometries in ArcGIS for future harmonization with Census-derived variables.

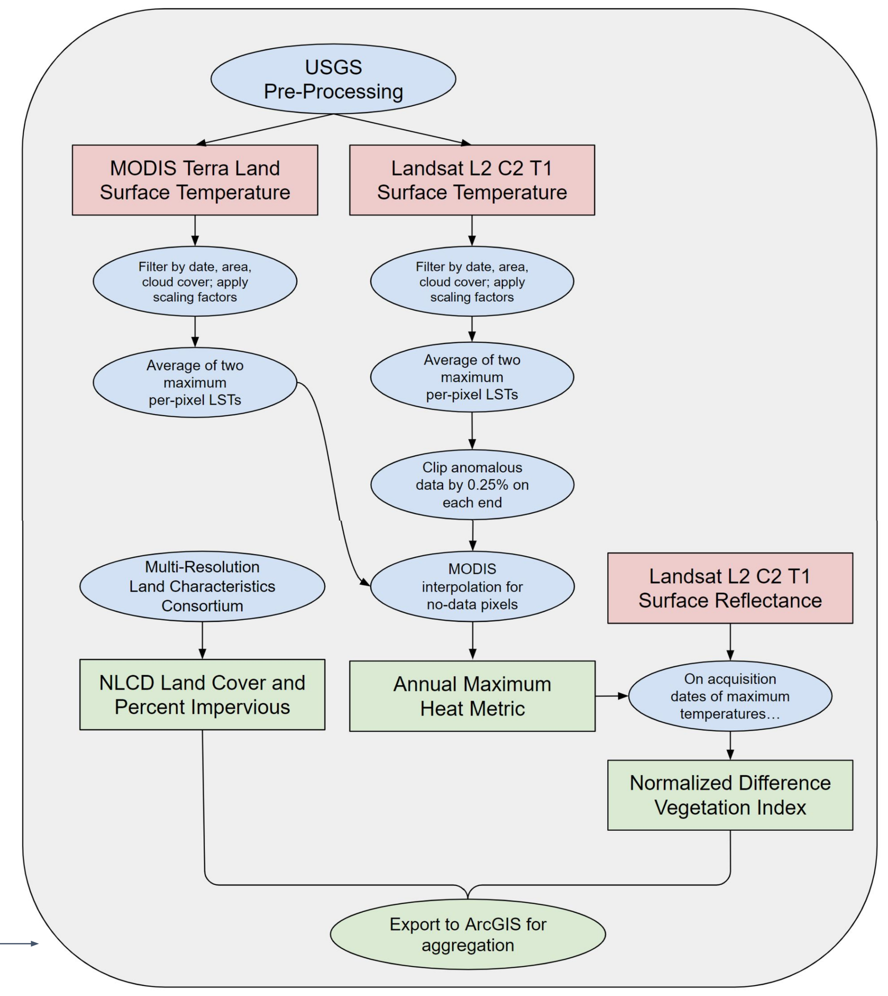


Figure 3. Flowchart of temperature- and land cover-related methodology in Google Earth Engine.

RESULTS

Similar spatial patterns can be found between the annual summer heat metric described above and land cover data from the National Land Cover Database. In areas experiencing significant urban development, land surface temperatures increased dramatically (figure 4). The greatest increases in land surface temperature were found in areas converted from dense vegetation (e.g., forest or shrubs) to high-intensity development (figure 5).

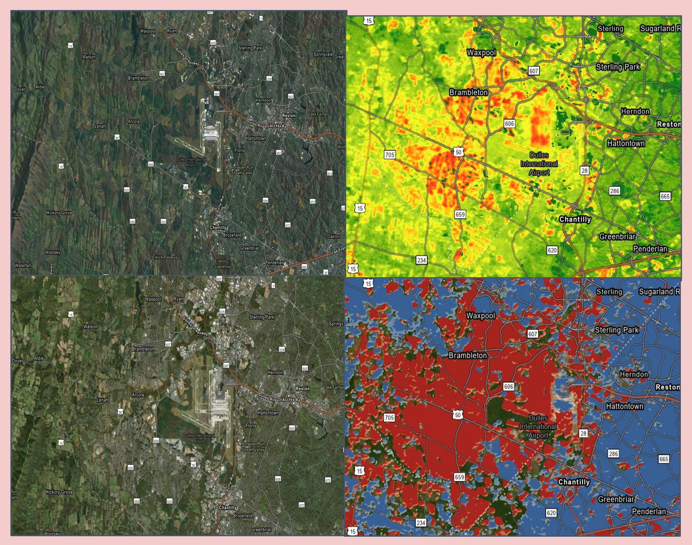


Figure 4. (Left) High-resolution satellite imagery of the area surrounding Dulles International Airport in 2001 and 2019. (Top right) Change in summer temperature from 2001-2019. (Bottom right) Hotspot analysis results for change in temperature from 2001-2019.

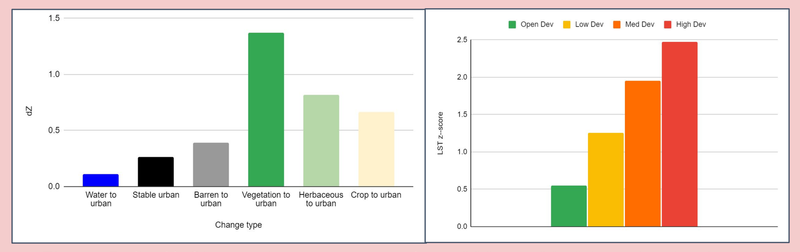


Figure 5. (Left) Change in temperature from 2001 to 2019 by urbanization type. (Right) Normalized intra-urban temperatures from summer heat composite by development intensity in 2019.

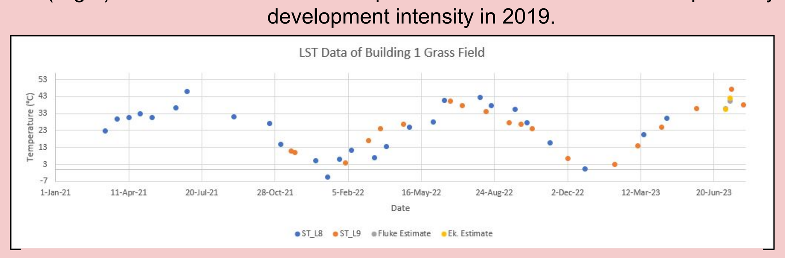
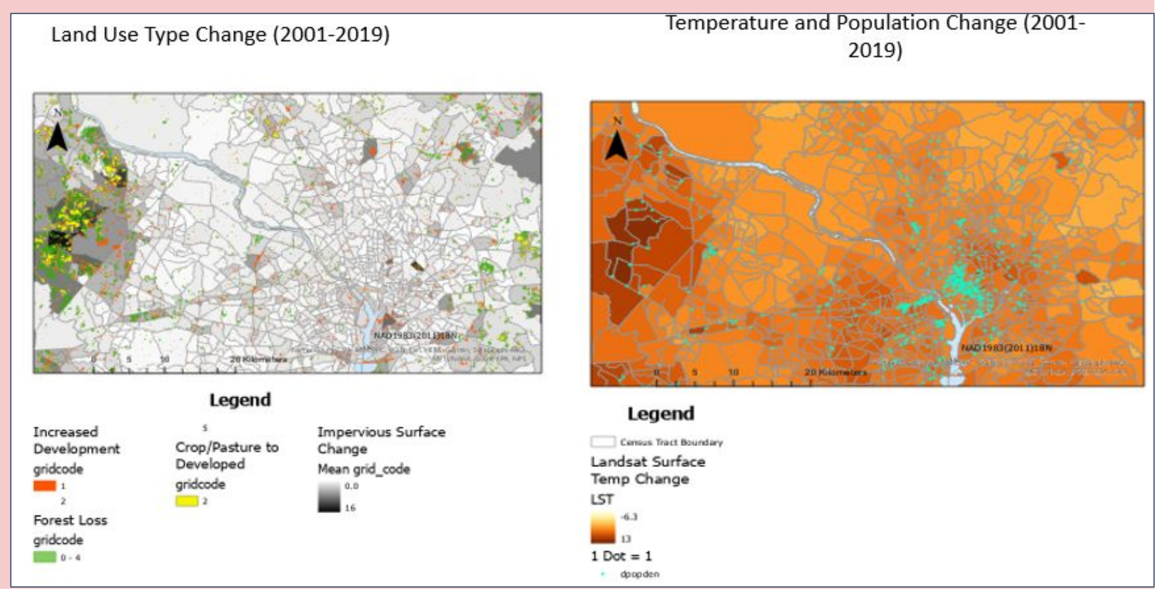


Figure 6. Field measurements of LST were collected in a Landsat pixel in a grass field and are graphed with Landsat data.

The measurements of a grass field near building 1 on the Goddard Space Flight Center campus were taken near the date of a Landsat overpass and graphed in figure 6. The averaged value of the measurements within the pixels were plotted with the the Landsat LST data and are very close together. This process was applied to other pixels and gave similar results.

Urban temperature increases are highly correlated to increases in impervious areas and loss of forests or green spaces to accommodate urban driven growth (figure 7, right).



CONCLUSIONS

- The signal of LST change due to land cover/use change (urban fabric) is strong and unequivocal.
- Despite regional climatic variations in temperature, urban development is always significantly hotter than other land cover classes.
- Urban growth can lead to significant increases in surface temperature not only locally but also regionally, **in addition** to local and regional climate change. It also leads to significant modifications of the spatio-temporal behavior of the temperature domain in, near and around urban centers.
- Urban growth exacerbates heat sensitivity of residents and also vulnerability of communities. In a future climate with increasing/stronger heat waves (like this year!), this has implications locally but also globally.

NEXT STEPS

1. Investigate discrepancies between Landsat and MODIS temperatures and artifacts in data due to pre-processing issues
2. Develop more robust way to standardize temperature data over time
3. Isolate the effects of global climate warming on temperature data
4. Further identify indicators of urban heat vulnerability through lenses of exposure, sensitivity, and adaptive capacity

DATA SOURCES

NASA DATA

- Landsat Level 2, Collection 2, Tier 1 Surface Temperature
- Landsat Level 2, Collection 2, Tier 1 Surface Reflectance
- MOD11A1.061 Terra Land Surface Temperature
- NASA Prediction of Worldwide Energy Resources
- National Land Cover Database (Landsat-based)
- GISS Station Temperature Data

NON-NASA DATA

- U.S. EPA EJScreen
  Criteria air pollutants
- US Census Bureau Decennial Survey - 10yr release
  2000, 2010, 2020
  Population, income, household value, geographic units
  2000, 2010, 2020
- US Census Bureau American Community Survey
  5 Year 2019-2015
  Population, household income, home value, poverty