Overview and Access of Land Surface Temperature (LST)

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Learning Objectives

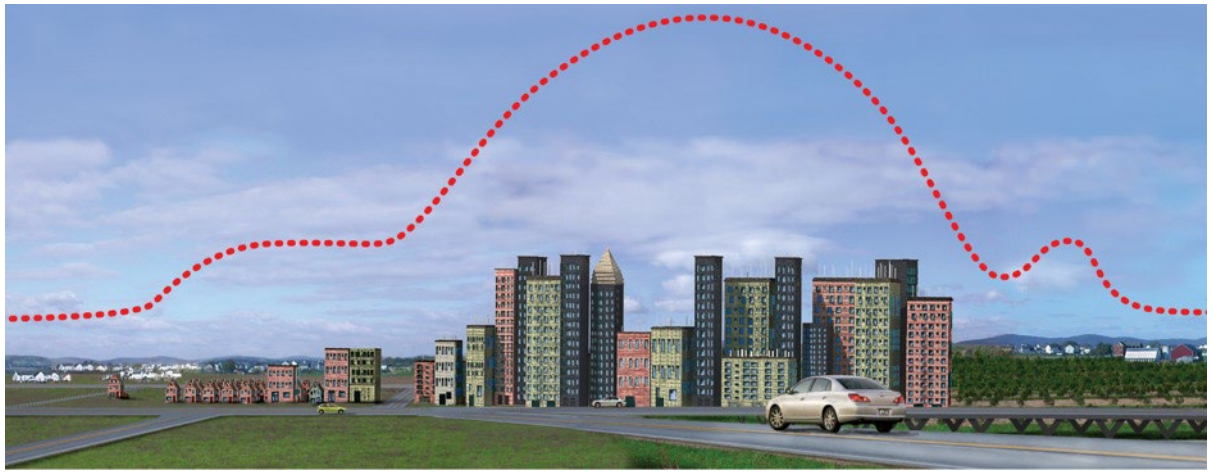
After participating in today's training, attendees will be able to:

- Define what an urban heat island (UHI) is and why it matters to urban planners and public health experts
- Identify which satellites and sensors can be used for assessing UHI
- Analyze land surface temperature from Landsat 8 and 9 and Aqua MODIS using Google Earth Engine
- Summarize the limitations of satellite data for understanding UHI

Land surface temperature for Baltimore, Maryland (USA) collected by Landsat ETM+ on August 1, 2001. The highest temperatures are shown in yellow, while cool temperatures are shown in deep purple.
Credit: NASA

Urban Heat Islands

- Urban areas experience higher temperatures than outlying areas. This difference in temperature is what constitutes an urban heat island (UHI).
- Difference in temperature has to do with changes in radiative and thermal properties of impervious surfaces i.e., heat-absorbing buildings and pavement.
- Temperatures vary within cities due to the spatial distribution of water, soil, vegetation, and impervious surfaces.



Land surface temperatures in cities, particularly densely-developed cities, tend to be elevated in comparison to surrounding areas. Credit: NASA

Causes of Urban Heat Islands

- Albedo & Infrastructure
  - Asphalt, concrete, and brick absorb— rather than reflect— the sun's heat, causing surface temperatures and air temperatures to rise due to their thermal storage capacity.
- Reduced vegetation in urban areas
  - Minimizes the natural cooling effects of shading and evapotranspiration from soil and vegetation.
- Anthropogenic heat
  - Vehicles, air-conditioning units, buildings, and industrial facilities all emit heat into the urban environment.

Credit: Anthony Quintano

Causes of Urban Heat Islands

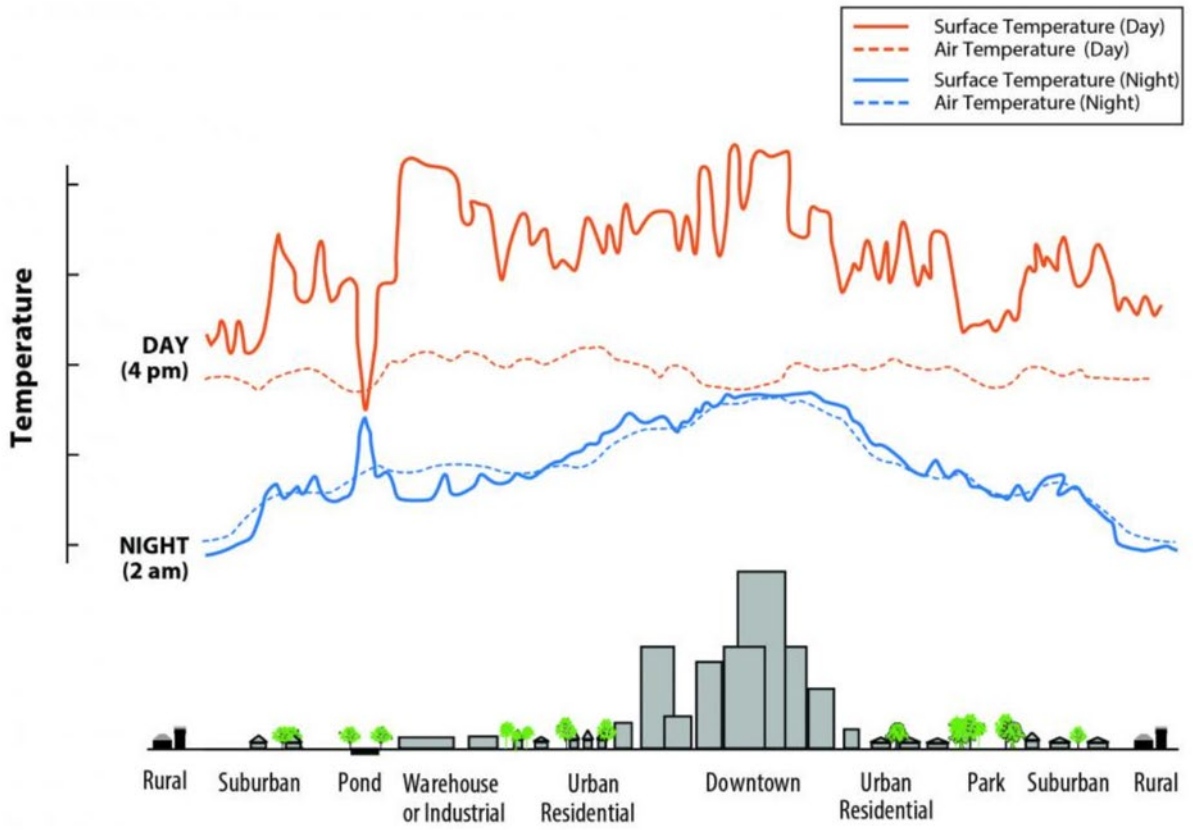
- Urban geometry
  - Tall buildings act as obstacles and reduce wind flow which would bring cooling effects.
- Weather
  - Calm and clear weather conditions maximize the amount of solar energy reaching urban surfaces. Conversely, strong winds and cloud cover suppress heat island formation.
- Geography
  - Large bodies of water can moderate temperature while nearby mountains can block wind or create wind patterns that pass through a city.

Credit: Pikrepo

https://www.epa.gov/heat-islands/heat-island-compendium

Urban Heat Islands

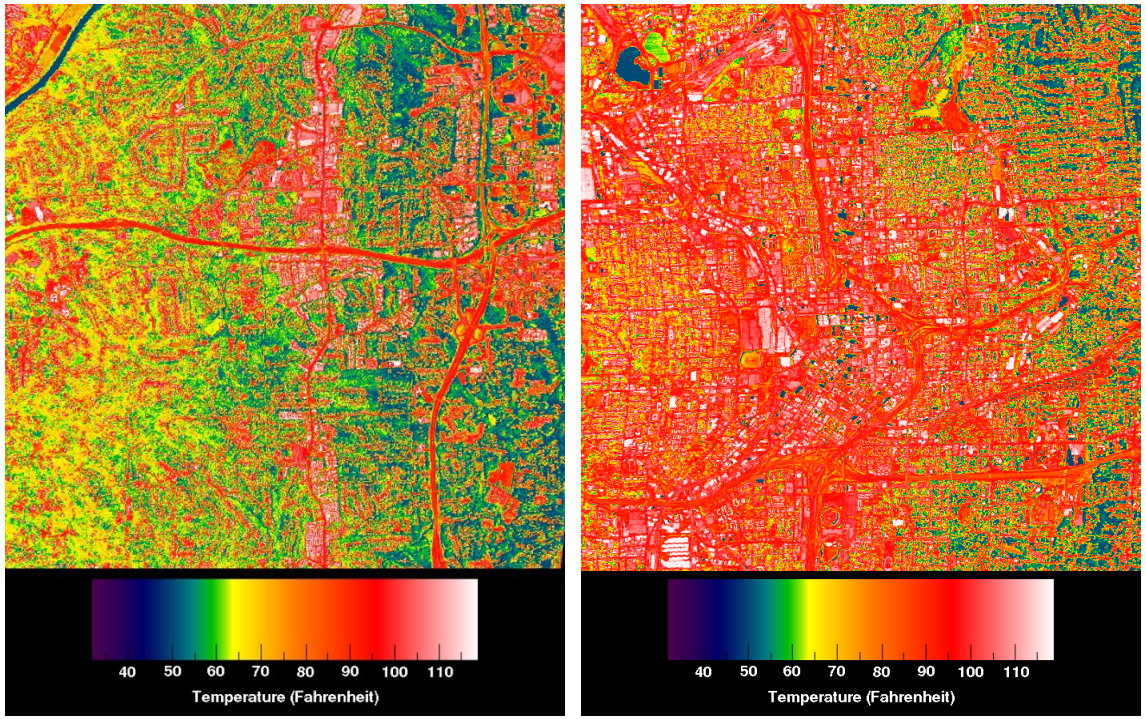
- Urban heat islands can form during the day or night, in small or large cities, and in any season.
- There are two types of urban heat islands:
  - Surface Urban Heat Islands
  - Atmospheric (i.e., air) Urban Heat Islands
- Surface temperatures vary more than air temperatures during the day, but they are generally similar at night



Parks, open land, and bodies of water can create cooler areas within a city. Temperatures are typically lower at suburban-rural borders than in downtown areas. Credit: EPA

Surface Urban Heat Islands

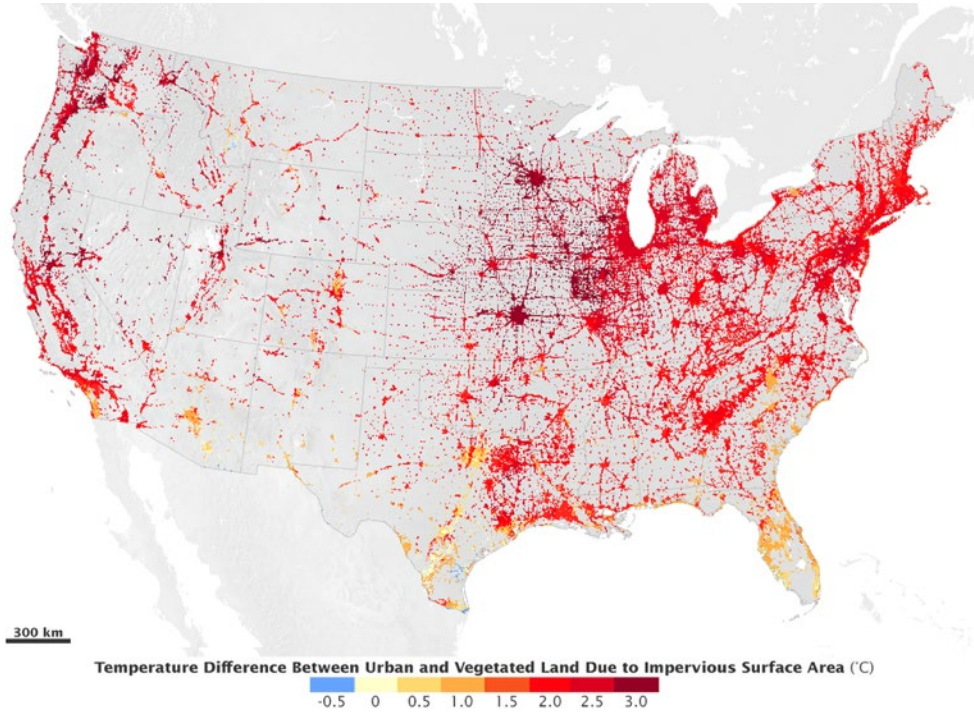
- Surface Urban Heat Islands (SUHI) represent the radiative temperature difference between impervious and natural surfaces.
  - SUHIs tend to be most intense during the day when the sun is shining.
  - Magnitude varies with seasons, but it is typically largest in the summer.
  - SUHIs are primarily measured by remote sensing in the thermal infrared (TIR) region of the electromagnetic (EM) spectrum.



Satellite imagery of suburban (left) and urban (right) Atlanta, Georgia (USA) shows the differences in daytime heating, as caused by the urban heat island effect.
Credit: NASA Goddard Scientific Visualization Studio

Monitoring Urban Heat Islands – SUHI

- Satellite thermal remote sensing measures SUHI and provides consistent and repeatable observations of the Earth's surface.
- Remote sensing offers the ability to study the urban thermal environment at various spatial (from local to global) and temporal (diurnal, seasonal, and inter-annual) scales (Weng, 2009).



Credit: NASA

Monitoring 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.

$$\Delta T_{U-r} = T_U - T_r$$

- Where ΔT_{U-r} is UHI intensity, T_U is urban temperature and T_r is rural temperature.

- The intensity of the heat island is the simplest quantitative indicator of the thermal modification imposed by urban relative to non-urban areas.

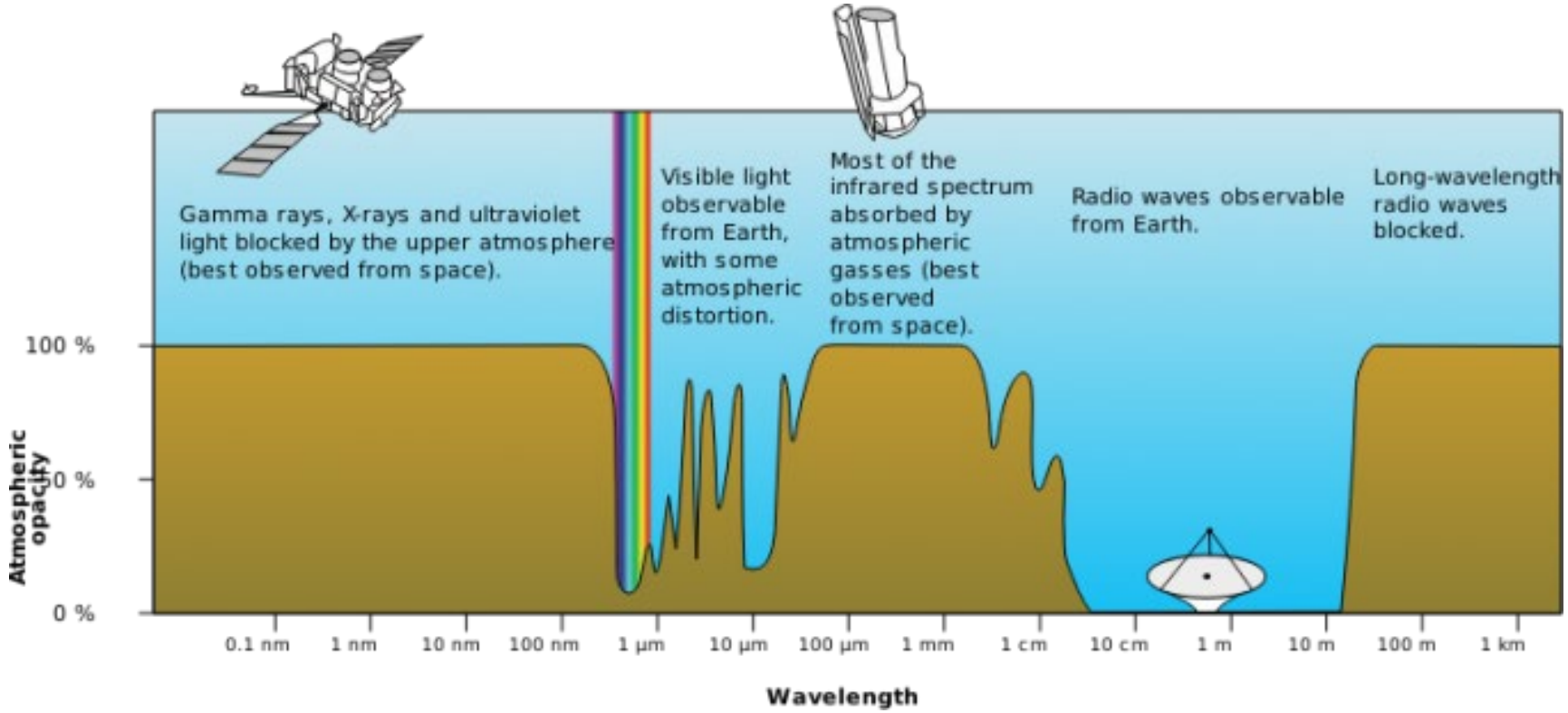
Why are Urban Heat Islands a Problem?

- Increased risk of heat-related mortality and morbidity
  - Children, older adults, and those with existing health conditions are particularly at risk.
  - UHIs contribute to respiratory difficulties, heat cramps and exhaustion, non-fatal heat stroke, and heat-related mortality.
- Increased energy consumption
  - Heat islands increase both overall electricity demand as well as peak energy demand.
  - During extreme heat events, demand for cooling can overload systems and require a utility to institute controlled, rolling brownouts or blackouts to avoid power outages.

Credit: NIEHS

Remote Sensing of Land Surface Temperature

- Atmospheric window: Between approximately 10–12 micrometers (μm) the atmosphere has relatively low absorption of IR radiation emitted by the land surface. Therefore, this spectral region is used to derive land surface temperature (LST).



Absorption spectrum during atmospheric transition of electromagnetic radiation. Credit: GIS Geography

Remote Sensing of Land Surface Temperature

Satellite	Sensor	Temporal Coverage	Orbit & Swath	Spectral Bands (µm)	Spatial Resolution	Temporal Resolution
Landsat 4 Landsat 5 Landsat 7 Landsat 8 Landsat 9	Thematic Mapper (TM) Thematic Mapper (TM) Enhanced Thematic Mapper Plus (ETM+) Thermal Infrared Sensor (TIRS) Thermal Infrared Sensor-2 (TIRS-2)	07/1982 –12/1993 03/1984 – 01/2013 04/1999 – Present 02/2013 – Present 11/2021 – Present	Landsat 4–9 Orbit: Polar, 10 am/pm (local time) Swath: 185 km	10.40 – 12.50 10.40 – 12.50 10.60 – 11.19 11.50 – 12.51 11.50 – 12.51	120 m 60 m 100 m 100 m	16 days
Terra Aqua	Advanced Spaceborne Thermal Emission and Reflection Radiometer(ASTER) & MODIS MODerate-resolution Imaging Spectroradiometer (MODIS)	12/1999 – Present 04/2002 – Present	Terra/Aqua Orbit: Polar, 10:30 (Terra) am/pm & 13:30 (Aqua) am/pm (local time) Swath: 2330 km	10.78 – 11.28 11.77 – 12.27	1 km	12 hours

* Landsat 1, 2, and 3 carried a Multi Spectral Scanner that did not have thermal IR bands.

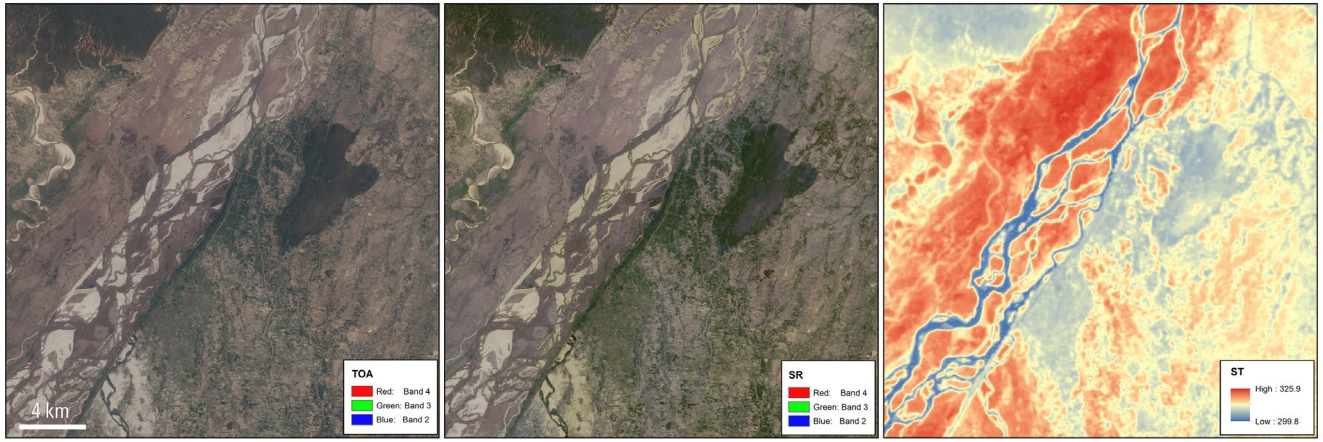
Refer to the previous ARSET training for a comprehensive list of satellites and sensors used for monitoring UHI: https://appliedsciences.nasa.gov/join-mission/training/english/arset-satellite-remote-sensing-urban-heat-islands

Landsat Collection 2

Second major reprocessing effort of the Landsat archive

- Global Level-2 Science and Atmospheric Auxiliary Products
  - Surface reflectance
  - **Surface temperature**
- Improved Geometric Accuracy
- Improved Digital Elevation Modeling
- Improved Radiometric Calibration
- Consistent Quality Assessment Bands
- Updated and Consistent Metadata Files
- Cloud Optimized File Format

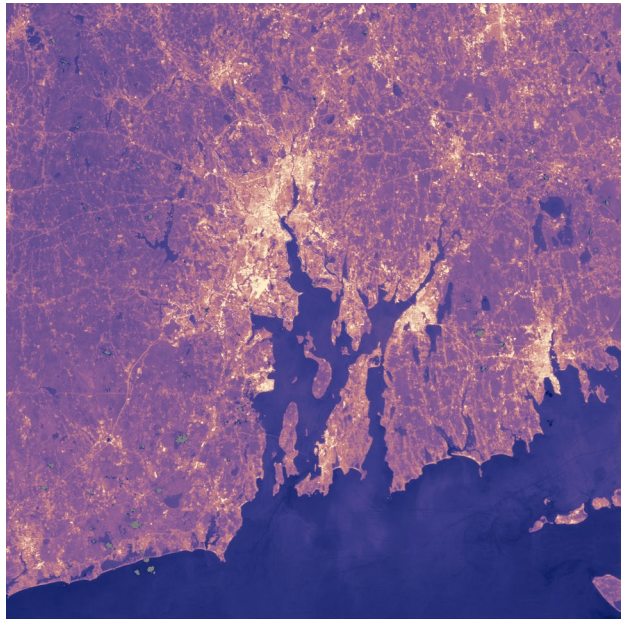
https://www.usgs.gov/landsat-missions/landsat-collection-2



Left: Landsat 8 Collection 2 level-1 top of atmosphere reflectance image, Center: Landsat 8 Collection 2 level-2 atmospherically corrected surface reflectance image, and Right: Landsat 8 Collection 2 level-2 surface temperature image for an area over the Sapta Koshi River in Bairawa, Nepal acquired on May 3, 2013. Credit: USGS

Landsat Collection 2 – Surface Temperature

- Measures the Earth's surface temperature in Kelvin
- Useful for monitoring:
  - crop and vegetation health
  - heat waves
  - natural disasters (e.g., volcanic eruptions, wildfires)
  - urban heat island effects
- Product availability:
  - Landsat 9: February 2022 to present
  - Landsat 8: April 2013 to present
  - Landsat 7: July 1999 to April 2022
  - Landsat 5: March 1984 to May 2012
  - Landsat 4 : August 1982 to December 1993



Land surface temperature for Providence, Rhode Island (USA) collected by Landsat ETM+ on July 31, 2002.
The highest temperatures are shown in yellow, while cool temperatures are shown in deep purple.
Credit: NASA

MODIS Surface Temperature

https://lpdaac.usgs.gov/products/myd11a1v061/

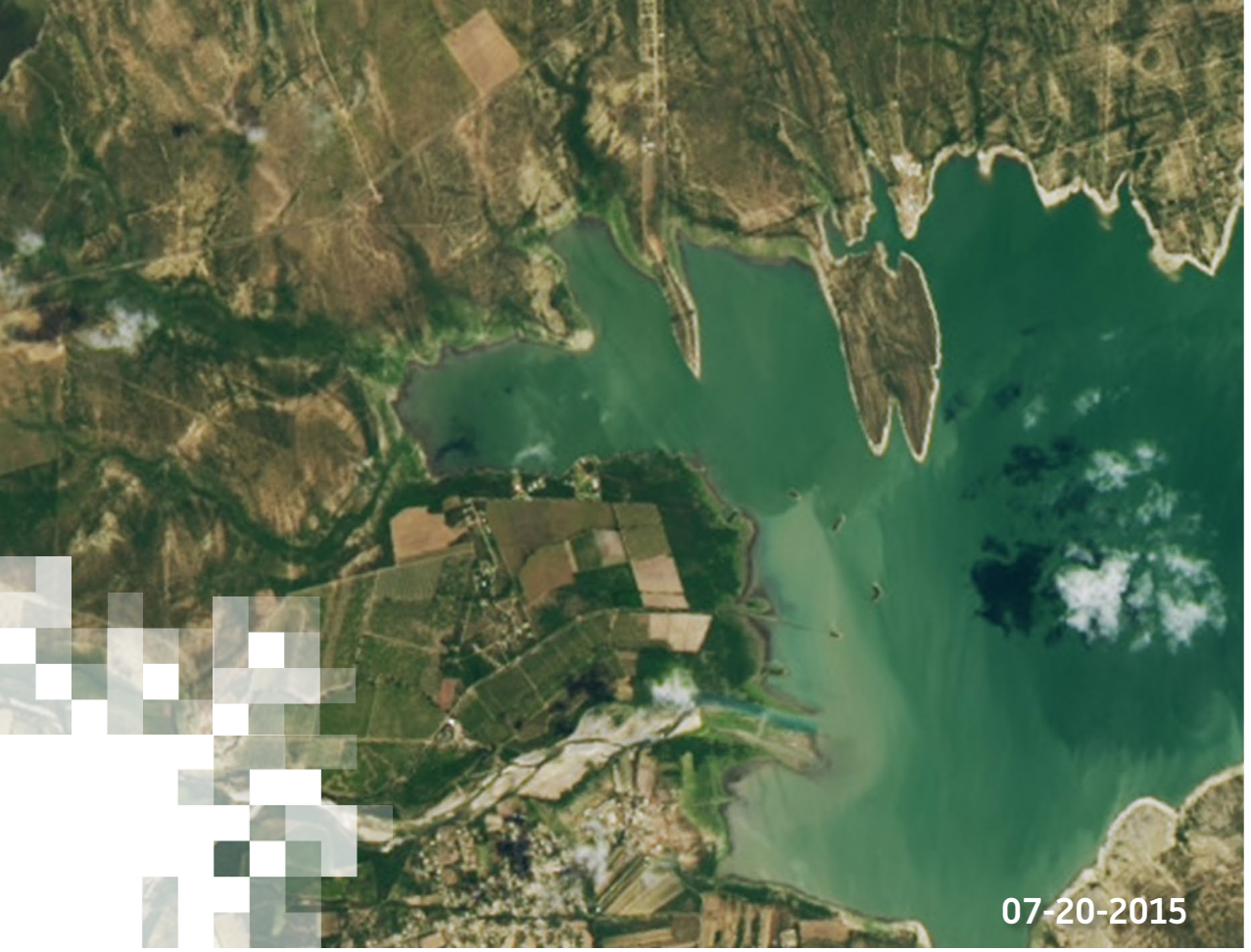
- A physics-based algorithm to retrieve the LST and Emissivity simultaneously
- Based on TIR bands at a spatial resolution of 1 km
- Based on the ASTER Temperature Emissivity Separation (TES) algorithm
- An improved Water Vapor atmospheric correction scheme
- Global data available since 2002

Benefits of Satellite Remote Sensing for Urban Heat Islands

- Continuous spatial coverage compared to in situ data
- Provides data where no systematic in situ measurements are available and augments where they are
- Simultaneous observations of LST, surface emissivity, and land cover from various satellites (e.g., Landsat/TM, ETM+, OLI & TIRS, MODIS, VIIRS, AVHRR)
- Global, consistent, data coverage from many satellites
- Availability of open-source data

Limitations of Satellite Remote Sensing for Urban Heat Islands

- Data acquisition times of sun-synchronous satellites usually do not coincide with the time of day where the SUHI is at a minimum or maximum.
- Most widely used satellite for SUHI detection (i.e., Landsat) only has daytime data.
- Optical sensors cannot penetrate clouds or vegetative cover, which can lead to data gaps or a decrease in data utility.
- The accuracy of land surface temperature (LST) estimates depends strongly on corrections for atmospheric effects and an accurate estimate of surface emissivity.
- Radiances received by sensors are influenced by the sensor-viewing angle.
- It is difficult to obtain high spectral, spatial, and temporal resolution with the same instrument.
- A large amount of data exists in various spatial and temporal resolutions, file formats, sizes, and from multiple sources.



Measuring Surface Temperature from Landsat and MODIS Using Google Earth Engine

Computing Land Surface Temperature in GEE

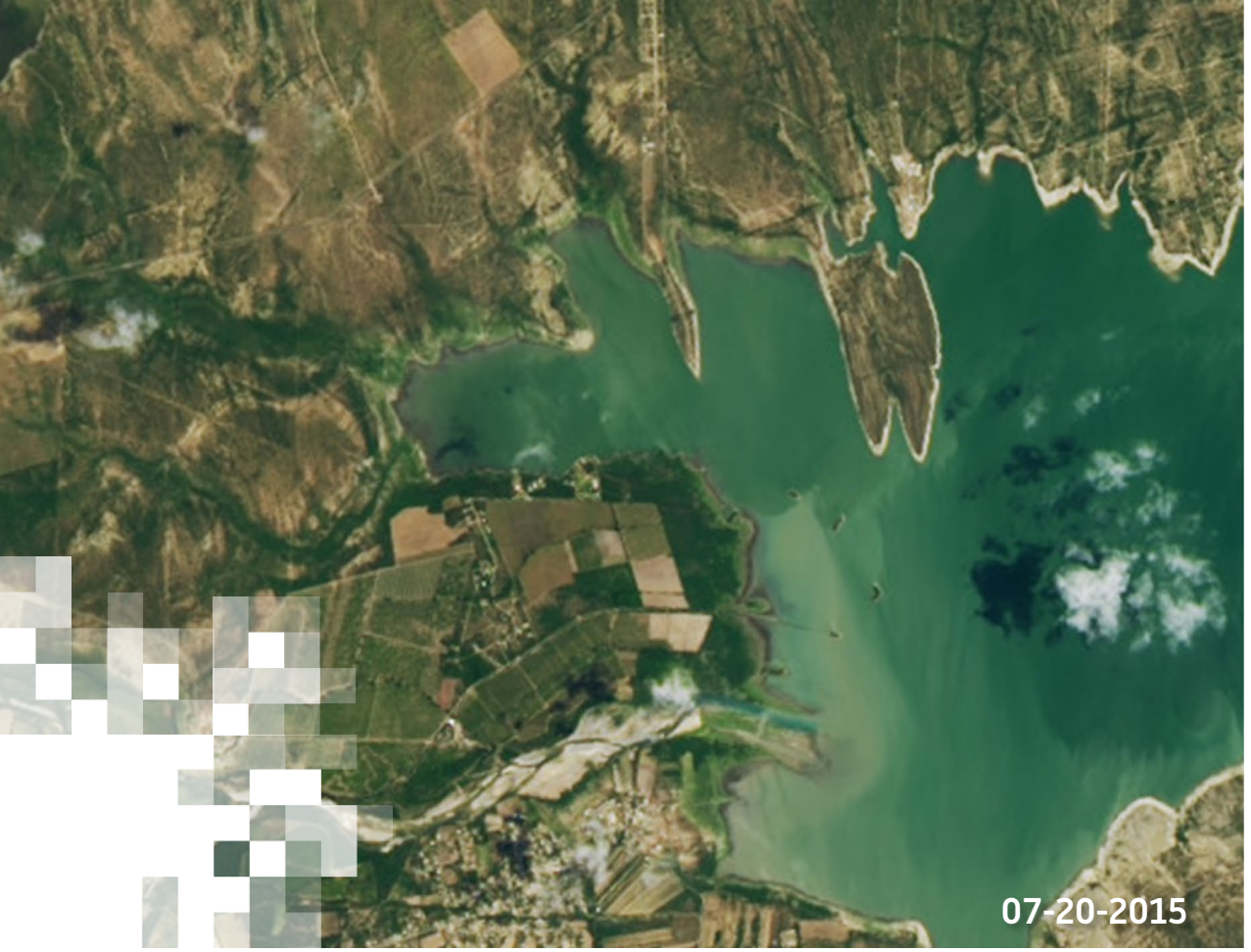
Below are 3 scripts for assessing urban heat islands using satellite data.

- **Landsat_LST_Time_Series_Pixel.js**
  - Example code showing how to graph a **LST time series** from Landsat 8 & 9
  - https://code.earthengine.google.com/2eae305edb229ae171391b341094fa81
- **Landsat_LST_SUHI.js**
  - Example code showing how to process **Landsat-derived SUHI** over Washington, DC (USA)
  - https://code.earthengine.google.com/8f8a363aa18fa9d16c1fe84991aa4154
- **MODIS_LST_Day_Night.js**
  - Example code showing how to process **MODIS-derived SUHI** for **day** and **night** over Washington, DC (USA)
  - https://code.earthengine.google.com/63c37316806efa35321f7e8651429bb2

Computing Land Surface Temperature in GEE

- To modify the different scripts for your study area, users will need to change the following parameters:
  - DATE_RANGE
  - YEAR_RANGE
  - STUDYBOUNDS
  - DISPLAY
  - point: longitude/latitude for area of interest
  - aoi: delineated rectangle for area of interest
  - Rural: delineated polygon(s) for rural areas
  - Urban: delineated polygon(s) for urban areas

```
// Assign a variable to filter the day of year from July 1 t
// Adjust the DATE_RANGE for your own UHI study.
var DATE_RANGE = ee.Filter.dayOfYear(182, 243);
// Assign a variable to filter years from 2010 – 2022.
// Adjust the YEAR_RANGE for your own UHI study.
var YEAR_RANGE = ee.Filter.calendarRange(2010, 2022,'year');
// Assign a variable to delineate your area of interest
// Create your own aoi using the Geometry tools in the map w
var STUDYBOUNDS = aoi;
// Assign a variable to display images in the map window
var DISPLAY = true;
```



Demonstration – Measuring Land Surface Temperature from Landsat and MODIS

References

Anniballe, R.; Bonafoni, S.; Pichierri, M. Spatial and temporal trends of the surface and air heat island over Milan using MODIS data. Remote Sensing of Environment, 2014, 150, 163–171.

Cook, M. (2014). Atmospheric Compensation for a Landsat Land Surface Temperature Product. Thesis. Rochester Institute of Technology. Accessed from http://scholarworks.rit.edu/theses/8513

Freitas, S.C.; Trigo, I.F.; Macedo, J.; Barroso, C.; Silva, R.; Perdigão, R.; Freitas, S.C.; Trigo, I.F.; Macedo, J.; Barroso, C.; et al. Land surface temperature from multiple geostationary satellites. Int. J. Remote Sens. 2013, 1161, 3051–3068.

García, D.H. Analysis of Urban Heat Island and Heat Waves Using Sentinel-3 Images: a Study of Andalusian Cities in Spain. Earth Syst Environ 6, 199–219 (2022). https://doi.org/10.1007/s41748-021-00268-9

IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp

NASA Earth Science Data Systems (ESDS) Program, Extreme Heat Data Pathfinder, https://www.earthdata.nasa.gov/learn/pathfinders/disasters/extreme-heat-data-pathfinder

NASA Earth Sciences & Science Museum of Virginia, ClimateBits: Urban Heat Island, (En) https://www.youtube.com/watch?v=Od2d1bYQVHs&ab_channel=ClimateBits (Sp)https://www.youtube.com/watch?v=V2Cf6ahbAus&ab_channel=ClimateBits

Rozenstein, O.; Qin, Z.; Derimian, Y.; Karnieli, 2014, Derivation of Land Surface Temperature for Landsat-8 TIRS Using a Split Window Algorithm, Sensors. 4(4):5768-5780, DOI 10.3390/s140405768

Tomlinson, C.J., Chapman, L., Thornes, J.E. and Baker, C., 2011, Remote sensing land surface temperature for meteorology and climatology: a review. Met. Apps, 18: 296-306. doi:10.1002/met.287.

U.S. Environmental Protection Agency. 2008. Reducing urban heat islands: Compendium of strategies. Draft. https://www.epa.gov/heat-islands/heat-island-compendium

U.S. Environmental Protection Agency. *Heat Island Effect.* 2020, https://www.epa.gov/heatislands

U.S. Geological Survey. Landsat 8-9 Collection 2 Level 2 Science Product Guide. 2022, https://www.usgs.gov/media/files/landsat-8-9-collection-2-level-2-science-product-guide

U.S. Geological Survey. Landsat Collection 2 Level-2 Science Products, https://www.usgs.gov/landsat-missions/landsat-collection-2-level-2-science-products

Weng, Q. Thermal infrared remote sensing for urban climate and environmental studies: Methods, applications, and trends. ISPRS Journal of Photogrammetry and Remote Sensing. 2009, 64, 335–344.

Zhou, Decheng, et al. "Satellite Remote Sensing of Surface Urban Heat Islands: Progress, Challenges, and Perspectives." *Remote Sensing*, vol. 11, no. 1, 2018, p. 48., doi:10.3390/rs11010048.

Zhou S., and J. Cheng, 2020, An Improved Temperature and Emissivity Separation Algorithm for the Advanced Himawari Imager, in IEEE Transactions on Geoscience and Remote Sensing, 58, 7105-7124, doi: 10.1109/TGRS.2020.2979846.

List of Abbreviations

ARSET – Applied Remote Sensing Training Program

ASTER GED – Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Emissivity Database

AUHI – Atmospheric Urban Heat Island

BLHI – Boundary Layer Heat Island

CLHI – Canopy Layer Heat Island

ETM+ – Enhanced Thematic Mapper Plus

GEE – Google Earth Engine

JPL – Jet Propulsion Laboratory

LP DAAC – Land Processes Distributed Active Archive Center

LST – Land Surface Temperature

MODIS – Moderate Resolution Imaging Spectroradiometer

MOD – MODIS Terra

MYD – MODIS Aqua

NASA – National Aeronautics and Space Administration

NCAR – National Center for Atmospheric Research

OLI – Operational Land Imager

QA_PIXEL – Pixel Quality Assessment

SUHI – Surface Urban Heat Island

ST – Surface Temperature

TOA – Top of Atmosphere

TIRS – Thermal Infrared Sensor

TM – Thematic Mapper

TIR – Thermal Infrared

UHI – Urban Heat Island

USGS – U.S. Geological Survey