National Aeronautics and Space Administration

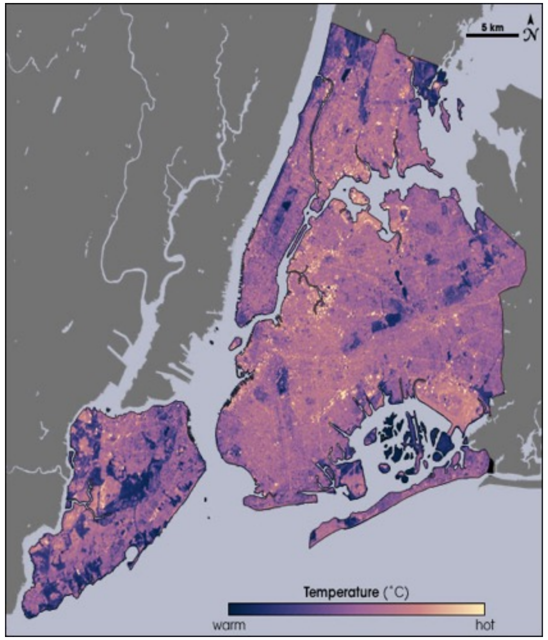
Satellite Remote Sensing for Urban Heat Islands

Sean McCartney & Amita Mehta

November 10, 2020

Training Outline

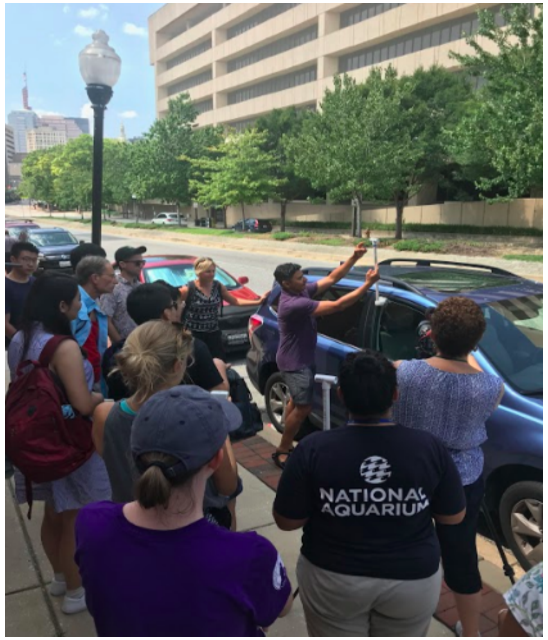
10 November 2020



Credit: NASA Earth Observatory

Land Surface Temperature-based Urban Heat Island Mapping

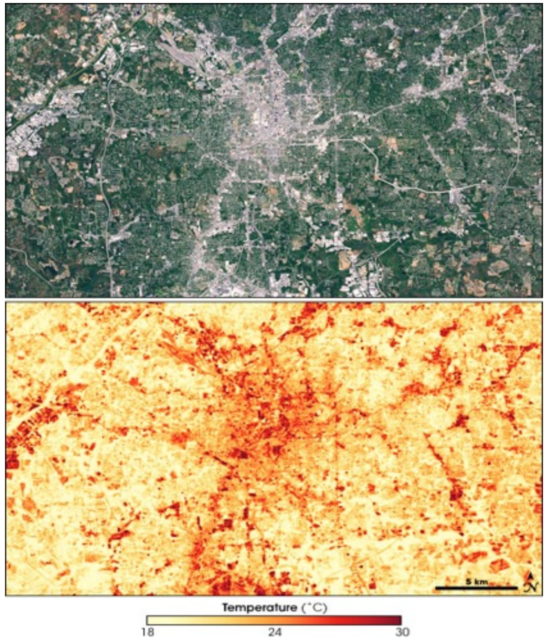
17 November 2020



Credit: Frank Niepold/NOAA

Integrating In-situ Observations with Satellite Imagery for Mapping Urban Heat

24 November 2020



Credit: NASA Earth Observatory

Mitigating Urban Heat Islands via Long-term Climate Monitoring

Course Structure and Materials

- Three, 1.5-hour sessions including presentations and question and answer sessions
- The same content will be presented at two different times each day:
  - Session A: 10:00-11:30 ET (UTC-4)
  - Session B: 16:00-17:30 ET (UTC-4)
- **Please only sign up for and attend one session per day.**

Course Structure and Materials

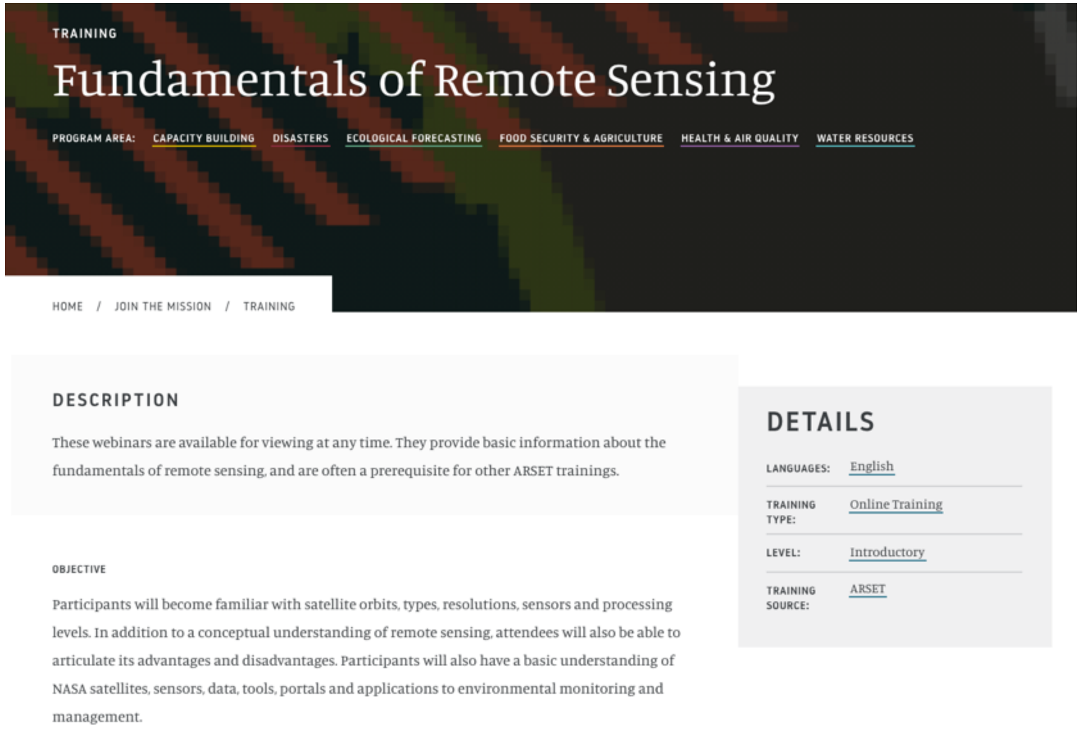
- Webinar recordings, PowerPoint presentations, and the homework assignment can be found after each session at:
  - https://appliedsciences.nasa.gov/join-mission/training/english/satellite-remote-sensing-urban-heat-islands

Homework and Certificate

- One homework assignment:
  - Homework submitted via Google Forms
  - Due date: December 1, 2020
- A certificate of completion will be awarded to those who:
  - Attend all live webinars
  - Complete the homework assignment by the deadline (access from website)
  - You will receive a certificate approximately two months after the completion of the course from: marines.martins@ssaihq.com

Prerequisites

- Create an account with Google Earth Engine: https://earthengine.google.com/
- Fundamentals of Remote Sensing: https://appliedsciences.nasa.gov/join-mission/training/english/fundamentals-remote-sensing



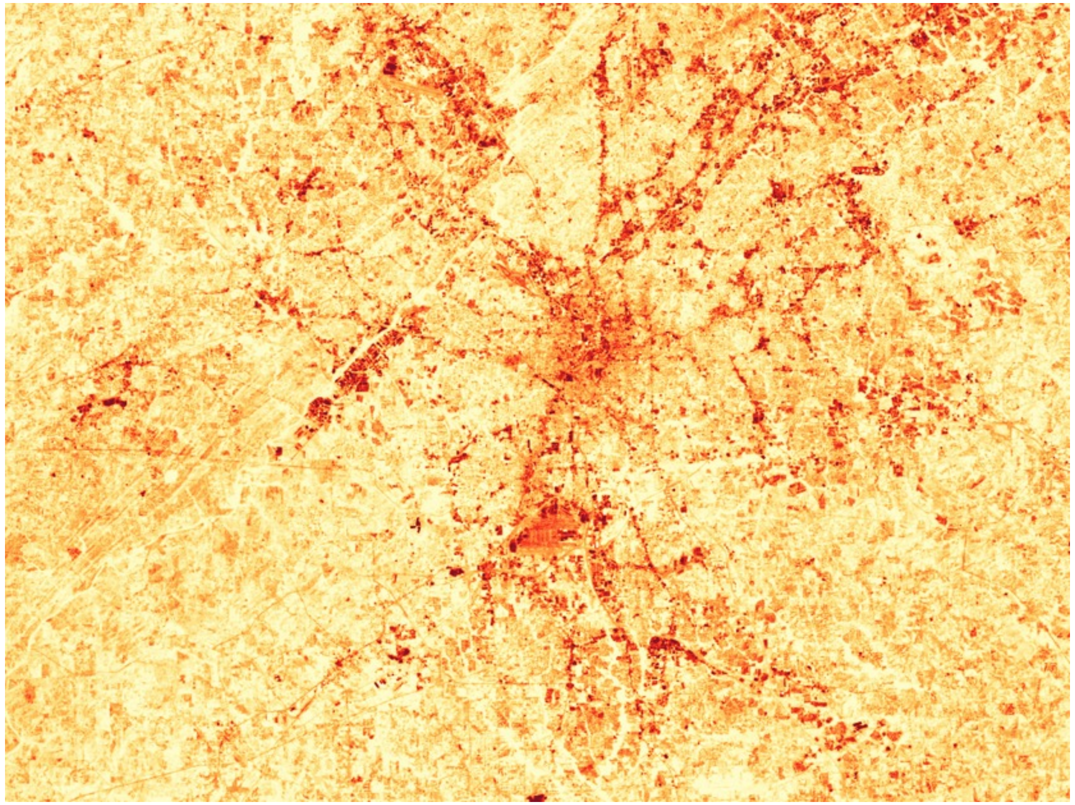
Optional:

- Google Earth Engine Tutorials: https://developers.google.com/earth-engine

Learning Objectives

After participating in this training, attendees should be able to:

- Summarize the characteristics, causes, and impacts of Urban Heat Islands
- Identify the satellites and sensors used in analyzing Urban Heat Islands
- Replicate the steps of converting data from the Landsat series of satellites to Land Surface Temperature estimates using Google Earth Engine
- Recognize the limitations of satellite data for Urban Heat Island analysis



Credit: NASA Earth Observatory

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

CM-SAF – Climate Monitoring Satellite Application Facility

EM – Electromagnetic

ETM+ – Enhanced Thematic Mapper Plus

GEE – Google Earth Engine

JPL – Jet Propulsion Laboratory

LST – Land Surface Temperature

NASA – National Aeronautics and Space Administration

NCAR – National Center for Atmospheric Research

NCEP – National Center for Environmental Prediction

OLI – Operational Land Imager

SMW – Statistical Mono-Window

SUHI – Surface Urban Heat Island

TOA – Top of Atmosphere

TIRS – Thermal Infrared Sensor

TM – Thematic Mapper

TIR – Thermal Infrared

UHI – Urban Heat Island

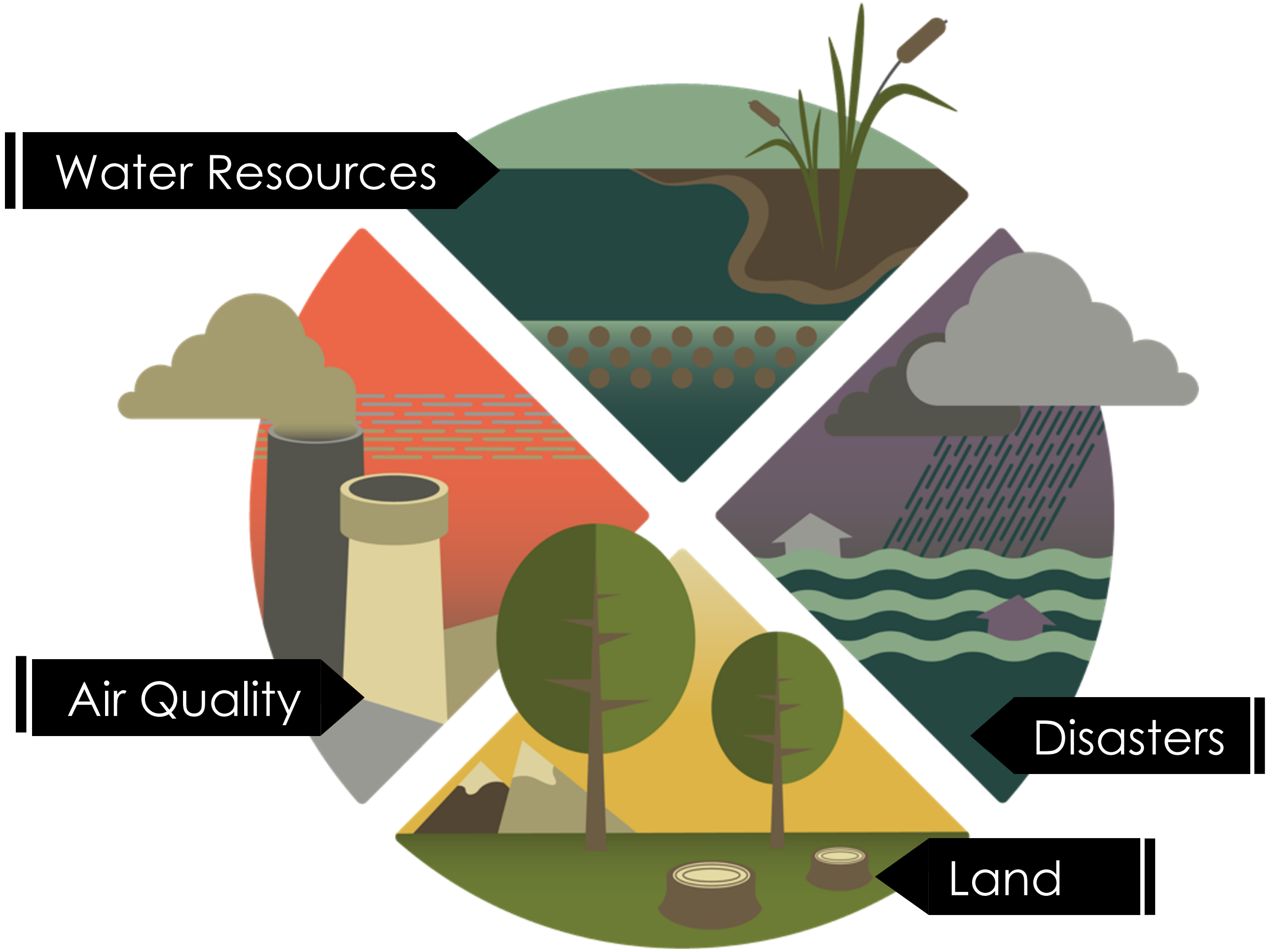
USGS – U.S. Geological Survey

About ARSET

NASA's Applied Remote Sensing Training Program (ARSET)

https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset

- Part of NASA's Applied Sciences Capacity Building Program
- Empowering the global community through online and in-person remote sensing training
- Topics for trainings include:
  - Water Resources
  - Air Quality
  - Disasters
  - Land



NASA's Applied Remote Sensing Training Program (ARSET)

https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset

- ARSET's goal is to increase the use of Earth science in decision-making through training for:
  – Professionals in the public and private sector
  – Environmental managers
  – Policy makers

All ARSET materials are freely available to use and adapt for your curriculum. If you use the methods and data presented in ARSET trainings, please acknowledge the NASA Applied Remote Sensing Training (ARSET) program.

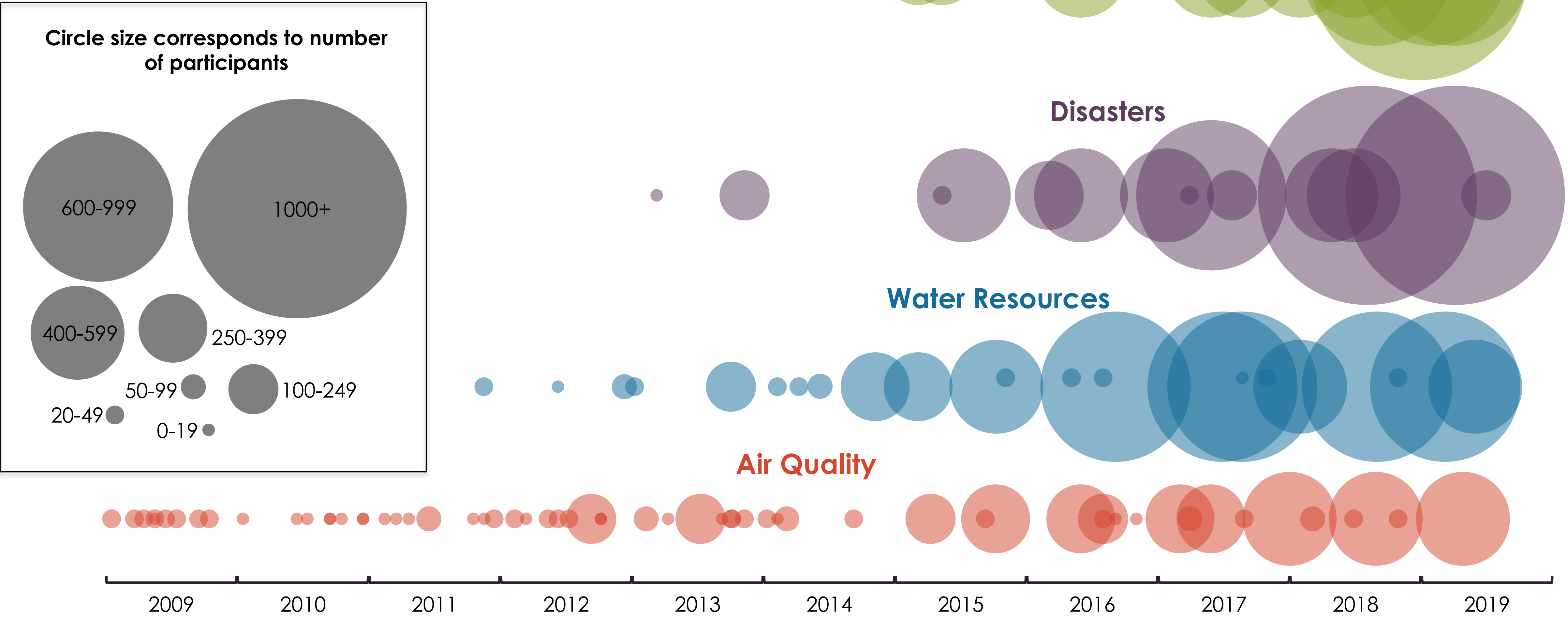
ARSET Trainings

40,000+ participants

170+ countries

140+ trainings

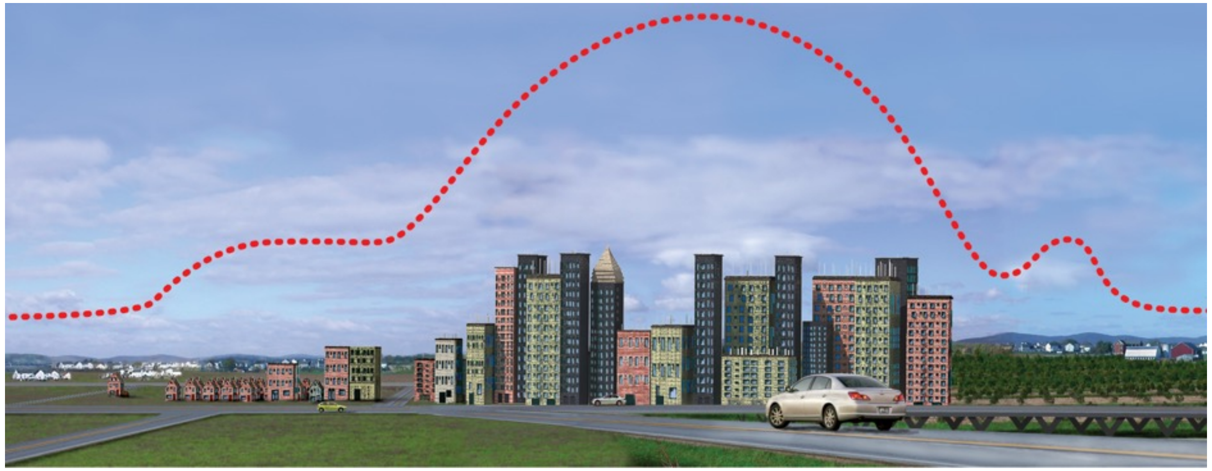
9,000+ organizations



Overview of Urban Heat Islands

Urban Heat Islands

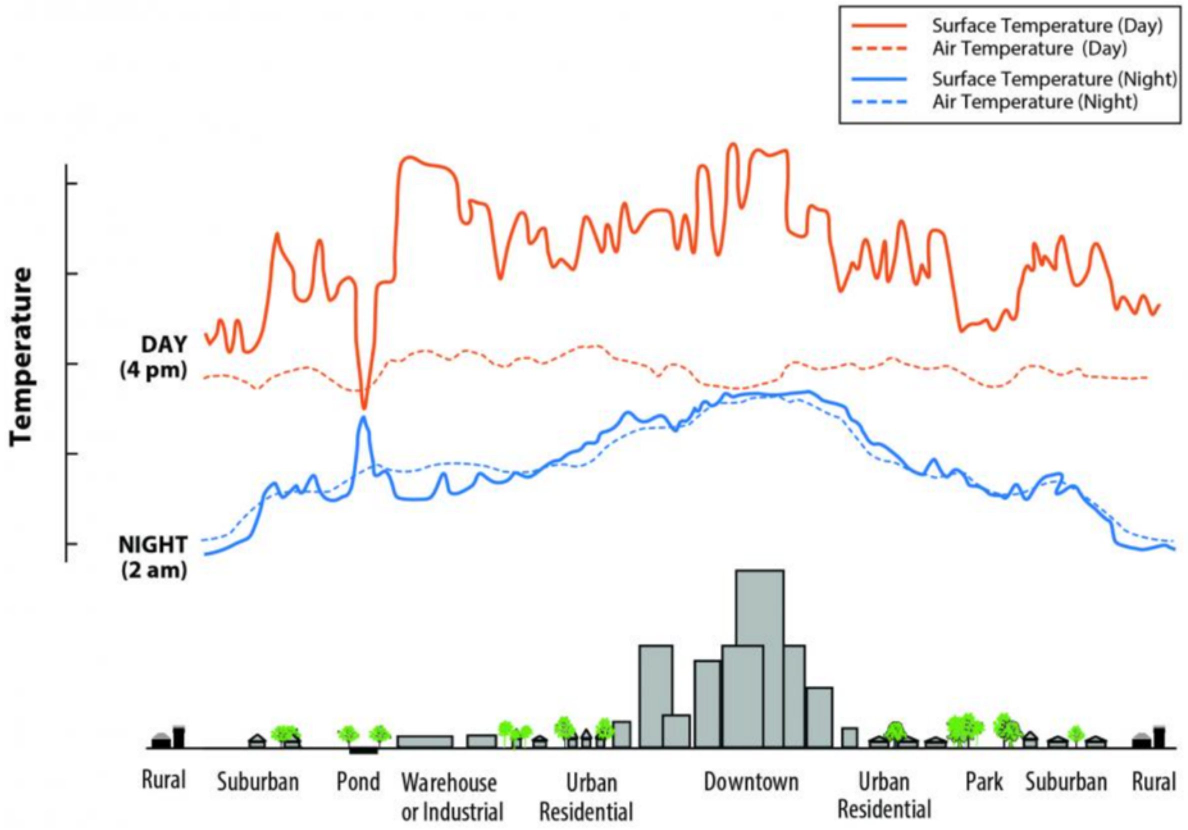
- Urban areas experience higher temperatures than outlying areas. This difference in temperature is what constitutes an urban heat island (UHI).
- Difference in temperature has to do with changes in radiative and thermal properties of impervious surfaces (i.e. heat-absorbing buildings and pavement).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



Credit: NASA

Urban Heat Islands

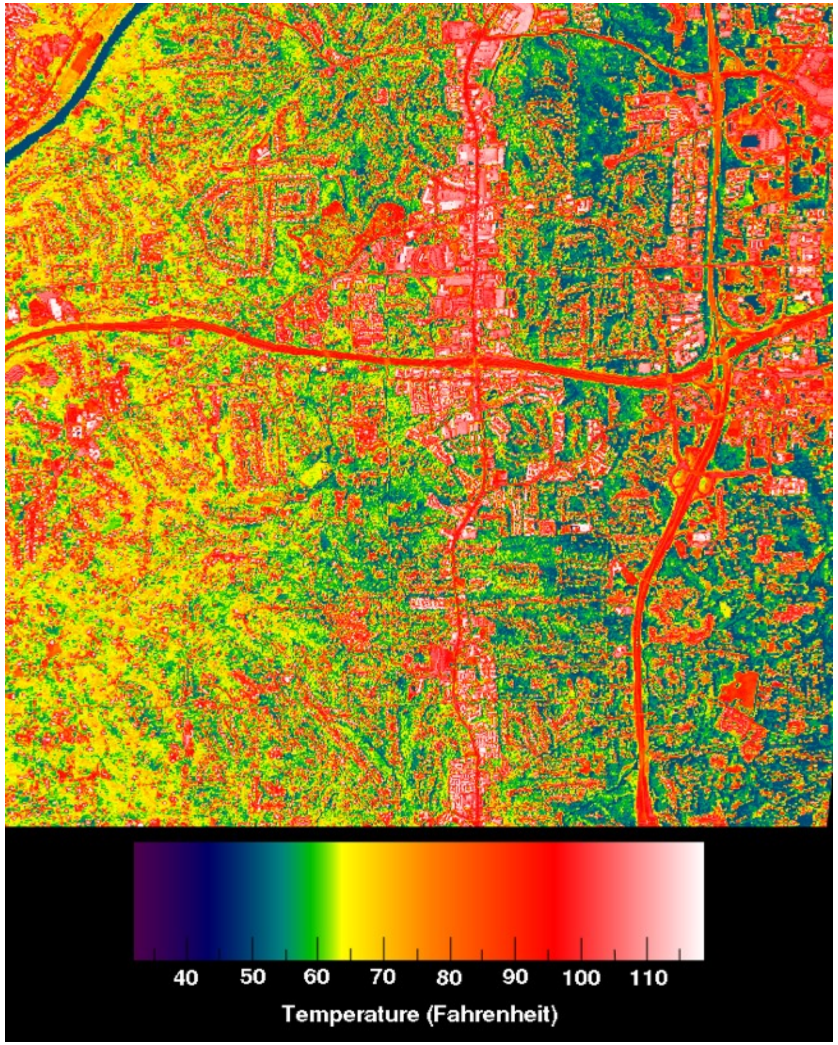
- Urban heat islands can form during the day or night, in small or large cities, and in any season.
- There are two types of urban heat islands:
  - Surface Urban Heat Islands
  - Atmospheric (i.e. air) Urban Heat Islands
- Surface temperatures vary more than air temperatures during the day but are more pronounced after sunset due to the slow release of heat from impervious surfaces.



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.



Credit: NASA Goddard's Scientific Visualization Studio

Atmospheric Urban Heat Islands

- Atmospheric Urban Heat Islands (AUHI) refer to effects in the **canopy layer** or **boundary layer**.
  - **Canopy layer** heat island (CLHI) is the layer of air from the surface to treetops/rooftops.
    - Measured by in situ sensors mounted on fixed meteorological stations or mobile traverses.
  - **Boundary layer** heat islands (BLHI) extend from treetops/rooftops to where urban landscapes no longer influence the atmosphere (~1.5 km).
    - Measured by tall towers, radiosondes, and aircraft.

Credit: NOAA

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 result in maximizing amounts 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

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

Why are Urban Heat Islands a problem?

- Elevated emissions of air pollutants and greenhouse gases
  - Electricity suppliers typically rely on fossil fuel power plants to meet demand.
  - Elevated air temperatures increase the rate of ground-level ozone formation.
- Water quality
  - Surface urban heat islands degrade water quality, mainly by thermal pollution.
  - Water temperature affects all aspects of aquatic life, especially the metabolism and reproduction of many aquatic species.

Credit: NOAA

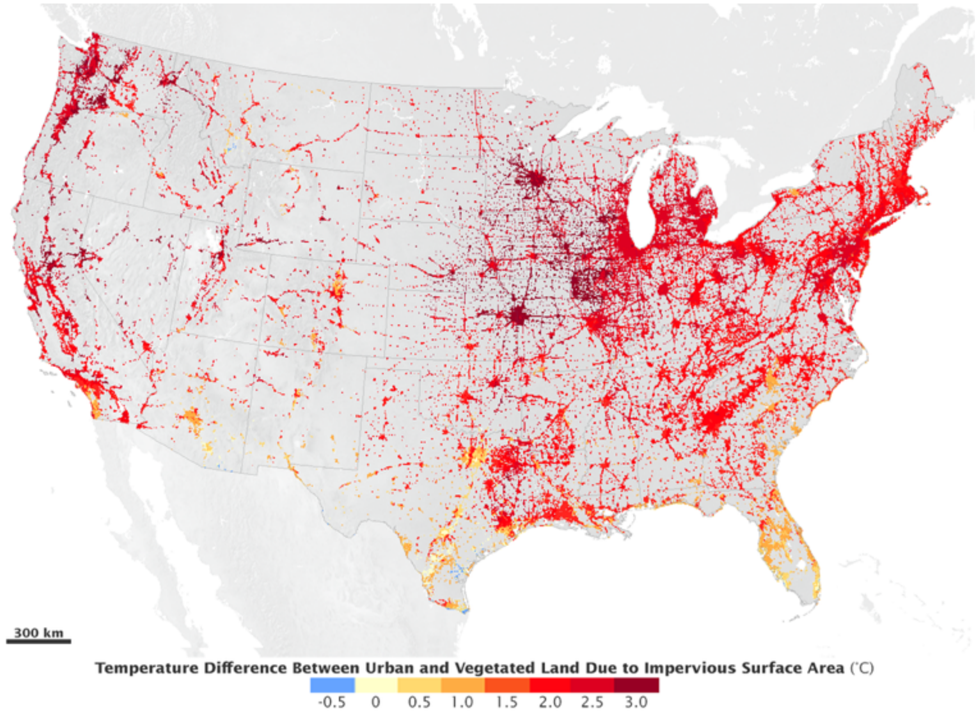
Monitoring Urban Heat Islands – CLHI

- Canopy layer heat island (CLHI) is the layer of air from from ground to the tops of trees and buildings.
- Useful in mitigating public health risks since it is the best indicator of conditions experienced by people.
- Measured by in situ sensors on fixed meteorological stations or traverses, and by climate models to estimate temperatures in places where no field data are available.
- Due to limited monitoring stations, measured CLHI provides insufficient spatial detail for urban planning (Anniballe et al., 2014).

Credit: David Sailor/Edison-Eastlake Measurement Campaign/Associated Press

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.
- 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

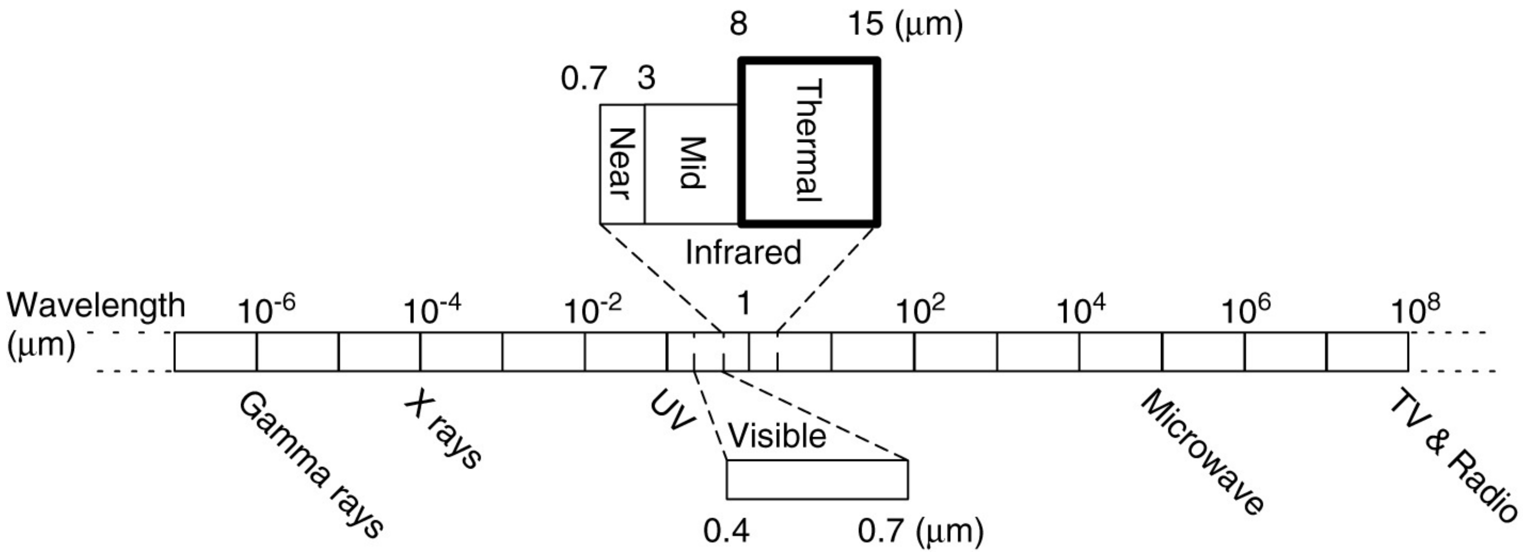
Satellites and Sensors Used in Analyzing Urban Heat Islands

Outline

- Remote Sensing of Land Surface Temperature (LST) for Surface Urban Heat Island (SUHI) Monitoring
- Satellites and Sensors for Estimating LST
- LST Data Products
- Ancillary Data for UHI Vulnerability and Impact Analysis
- Benefits and Limitations of Satellite Measurements for Monitoring UHI

Remote Sensing of LST

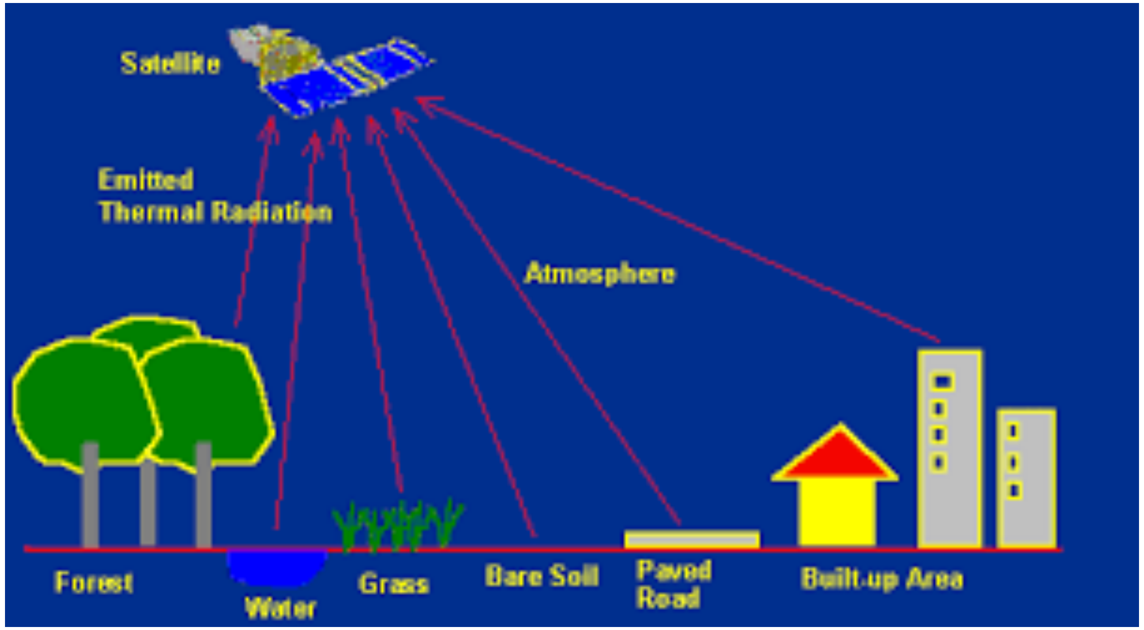
- Thermal Infrared (TIR) wavelengths between 8 to 15 micrometers (µm) are commonly used for LST estimation.



Tomlinson et al., (2011)

Remote Sensing of LST

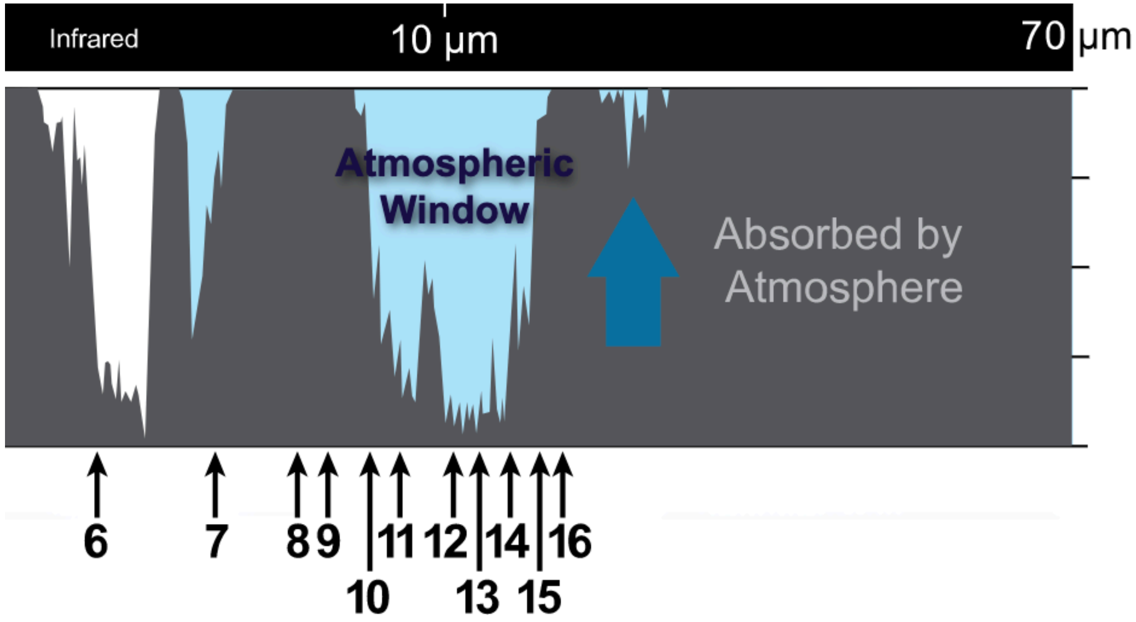
- Satellite TIR sensors measure top of the atmosphere (TOA) radiance emitted by the Earth's surface and atmosphere.
- The TOA radiances are affected by:
  - Surface emissivity (built-up areas, vegetation, bare soil, etc.)
  - Atmospheric attenuation (water vapor and aerosols)
  - Angle at which a satellite sensor receives the radiation.



https://crisp.nus.edu.sg/~research/tutorial/infrared.htm

Remote Sensing of LST

- Atmospheric Window: Around 10-12 micrometers the atmosphere has relatively low absorption of IR radiation emitted by the land surface. Therefore, this spectral region is used to derive LST.
- Using either one or multiple IR bands, techniques are developed to obtain LST (Rosenstein et al, 2014).
- A review of methodologies for retrieving LST and land surface emissivity can be found in Zhou and Cheng (2020).



GOES-R IR Channels

https://www.weather.gov/jetstream/satellites

Several polar orbiting and geostationary satellites have sensors observing in one or multiple bands in this IR spectral range.

Satellites and Sensors for Estimating LST

Satellite	Sensor	Temporal Coverage
*Landsat 4 Landsat 5 Landsat 7 Landsat 8	Thematic Mapper (TM) Enhanced Thematic Mapper (ETM+) [1]Operational Land Imager (OLI) Thermal Infrared Sensor (TIRS)	7/1982 -12/1993 3/1984 - 01/2013 4/1999 - Present 02/2013 - Present
Terra Aqua	Advanced Spaceborne Thermal Emission and Reflection Radiometer(ASTER) & MODIS MODerate-resolution Imaging Spectroradiometer (MODIS)	12/1999 - Present 04/2002 - Present
International Space Station/ ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS)	Prototype HyspIRI Thermal Infrared Radiometer (PHyTIR)	06/2018 - Present

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

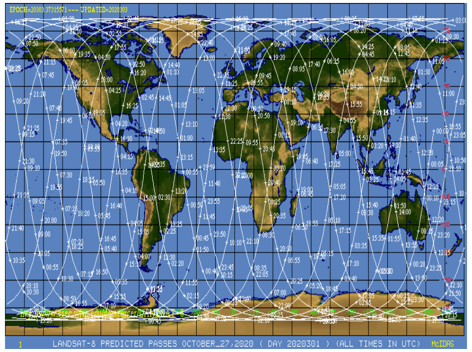
[1]Used for land cover/NDVI/impermeable surface

Satellites and Sensors for Estimating LST

Satellite	Sensor	Temporal Coverage
*Suomi National Polar Partnership (NSPP) Joint Polar Satellite System-1 (NOAA 20)	Visible Infrared Imaging Radiometer Suite (VIIRS)	10/2011 - Present 11/2018 - Present
NOAA Operational Series Current: NOAA 15,18,19 ESA- Metop-A & B	Advance Very High-Resolution Radiometer (AVHRR)	1979 - Present
NOAA Geostationary Operational Environmental Satellites (GOES) Current: GOES-16 & GOES-17	Imager & Sounder Advance Baseline Imager (ABI)	1975 - Present
ESA - Sentinel 3A & 3B	Sea and Land Surface Temperature Radiometer (SLSTR)	O2/2016 - Present 04/2018 - Present
ESA - Sentinel 2A & 2B	[1]MultiSpectral Instrument (MSI)	07/2015 - Present 03/2017 - Present

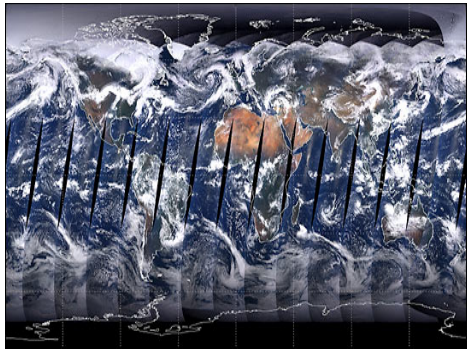
*NOAA Prime PM mission since 05/2014
[1]Used for land cover

Satellites and Sensors for Estimating LST



Credit: University of Wisconsin-Madison Space Science and Engineering Center

Landsat series: TM, ETM+, OLI, TIRS:
Orbit: Polar, 10 am/pm
Swath: 185 km



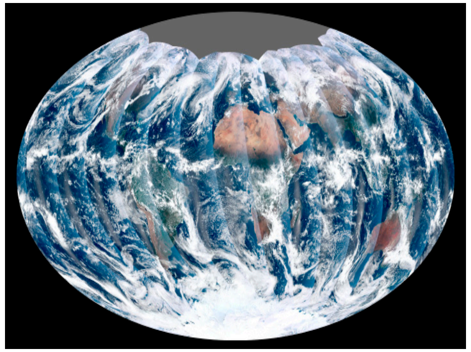
Credit: Earth Observatory

Terra & Aqua: MODIS
Orbit: Polar, 10:30 (Terra) & 1:30 (Aqua) am/pm
Swath: 2330 km

Terra: ASTER
Swath: 60 km

Credit: NASA JPL

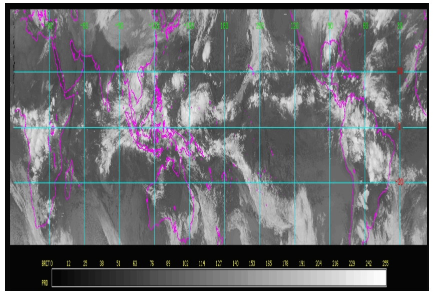
ISS: ECOSTRESS
Swath: 385 to 415 km
Varying temporal samplings



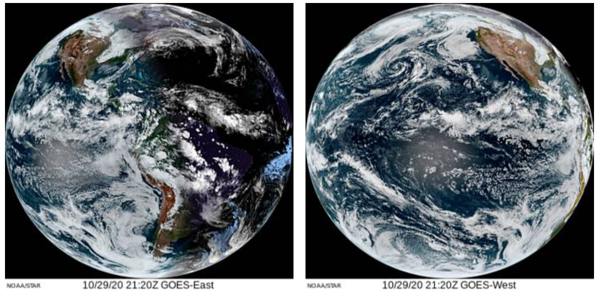
Credit: NASA Earth Observatory

SNPP & JPSS: VIIRS
Orbit: Polar, 1:30 am/pm
Swath: 3000 km

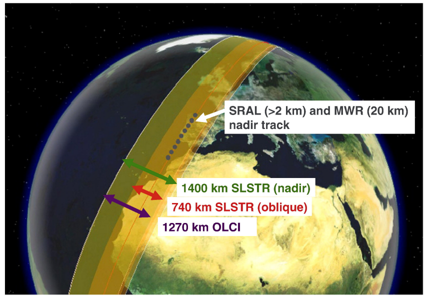
Satellites and Sensors for Estimating LST



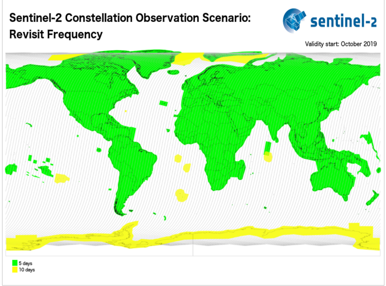
Credit: NOAA



Credits: NOAA



Credit: ESA



Credit: ESA

NOAA 19: AVHRR
Orbit: Polar, 2:00 am/pm
Swath: 2900 km

GOES: East (16) & West (17)
Orbit: Geostationary
10-minute Image Updates

Sentinel 3: SLSTR
Orbit: Polar, 10 am/pm
Swath: > 740 km

Sentinel 2: MSI
Orbit: Polar, 10:30 am/pm
Swath: 290 km

Spectral Bands for LST

- Each sensor (TM, ETM+, OLI/TIRS, MODIS, VIIRS, ABI, LSLTR, and PHyTIR) has **TIR spectral bands.**

Sensor	Spectral Bands (µm)	Spatial Resolution	Temporal Resolution	Sensor	Spectral Bands (µm)	Spatial Resolution	Temporal Resolution
TM **ETM+** **TIRS**	10.40 - 12.50 10.40 - 12.50 10.6 - 11.19 11.50 - 12.51	120 m (30 m resampled) 60 m (30 m) 100 m 100 m	16 days	**VIIRS**	10.26 - 11.26 11.54 - 12.49	750 m	12 hours
MODIS	10.78 - 11.28 11.77 - 12.27	1 km	12 hours	**AVHRR**	10.30 - 11.30 11.5 - 12.50	1 km & 4 km	
ASTER	10.25 - 10.95 10.95 - 11.65	90 m	12 hours	**VISSR** **ABI**	10.10 - 10.60 **10.80 - 11.60** **11.80 -12.80** 13.0 - 13.6	2 km CONUS and Full Disk	minutes, hours, day/night
PHyTIR	8.28, 8.79, 9.06, 10.5, 12.05	60 m CONUS only	varies/every few days	**SLSTR**	10.45 - 11.24 11.57 - 12.48	1 km	12 hours

Satellite Radiance Data Access

Landsat TIRS & OLI: https://earthexplorer.usgs.gov/

Terra & Aqua MODIS: https://modis.gsfc.nasa.gov/tools/

Terra ASTER: https://lpdaac.usgs.gov/products/ast_09tv003/

ECOSTRESS: https://ecostress.jpl.nasa.gov/data

SNPP/JPSS VIIRS: https://ladsweb.modaps.eosdis.nasa.gov/

NOAA AVHRR: https://www.ncdc.noaa.gov/cdr/fundamental/avhrr-radiances-nasa

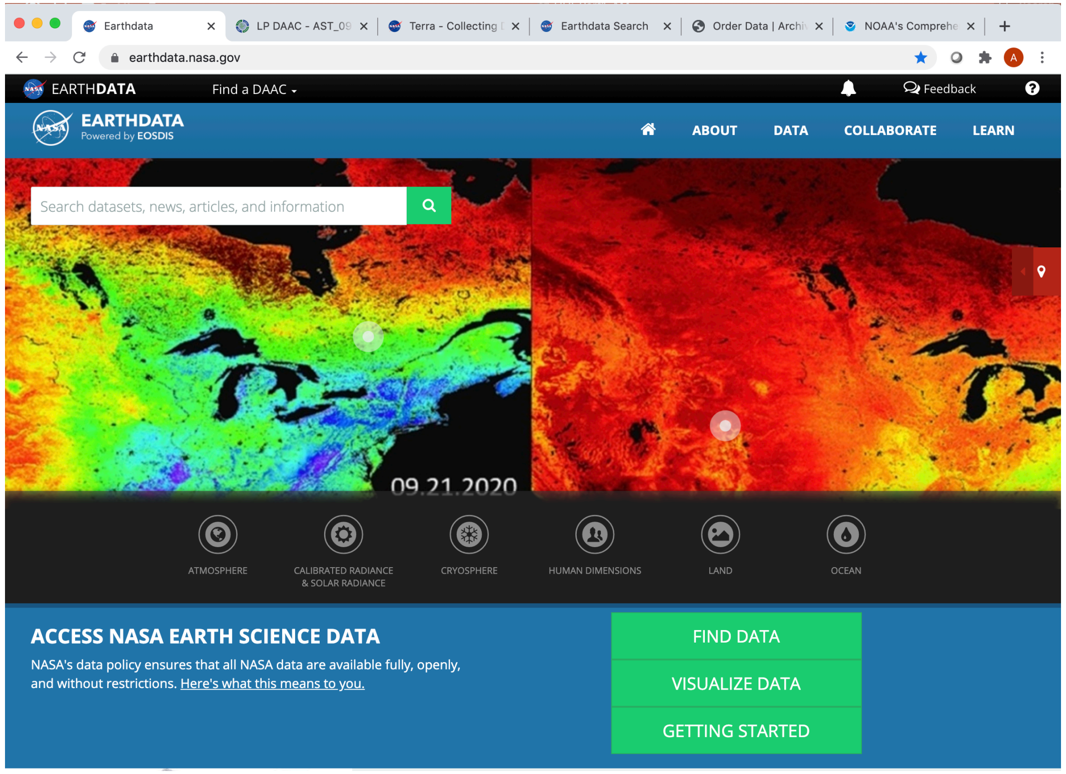
GOES: https://www.bou.class.noaa.gov/saa/products/search?datatype_family=GRABIPRD

Sentinel-3 SLSTR & Sentinel-2 MSI: https://scihub.copernicus.eu/dhus/#/home

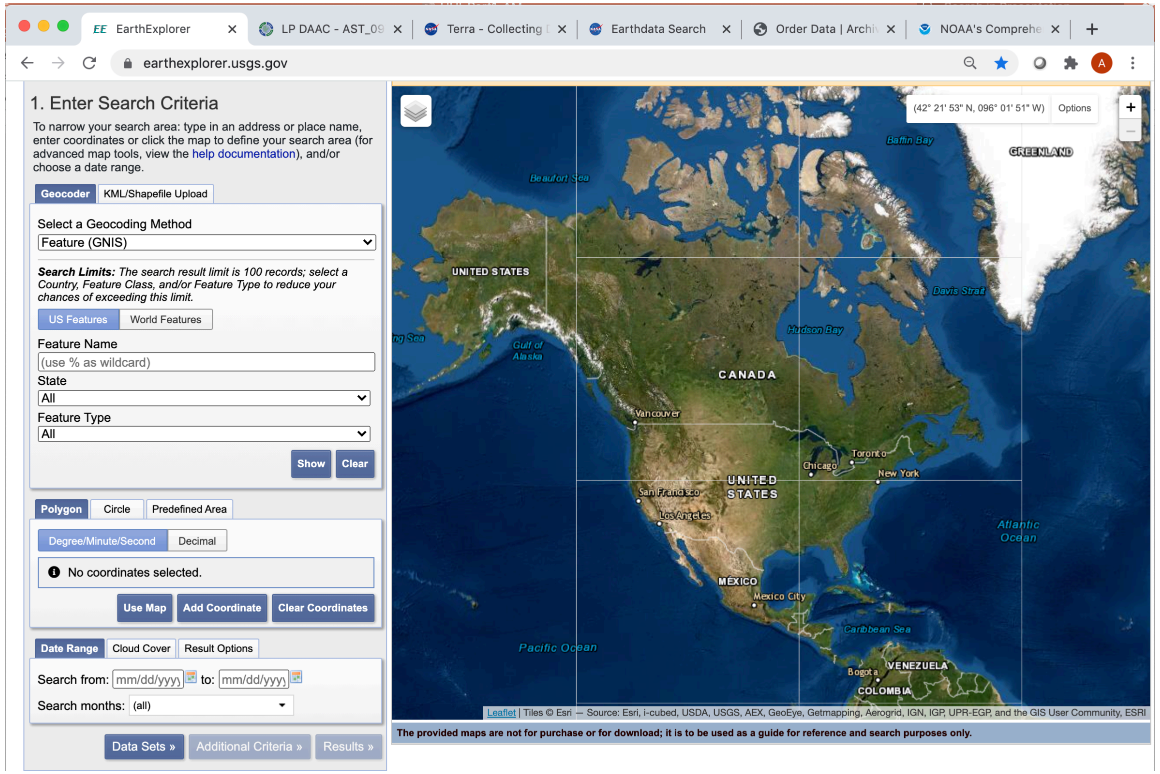
Satellite Radiance and Derived Products Data Search

All NASA satellite data can be searched though the following sites

https://earthdata.nasa.gov/ https://earthexplorer.usgs.gov/



NASA EarthData

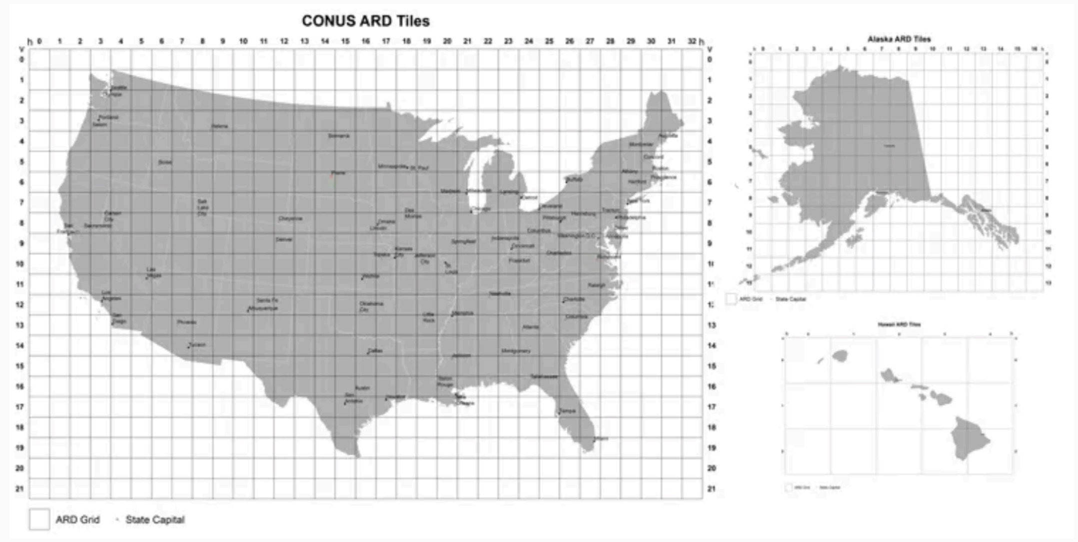


USGS EarthExplorer

Land Surface Temperature Data Products

Landsat LST Data

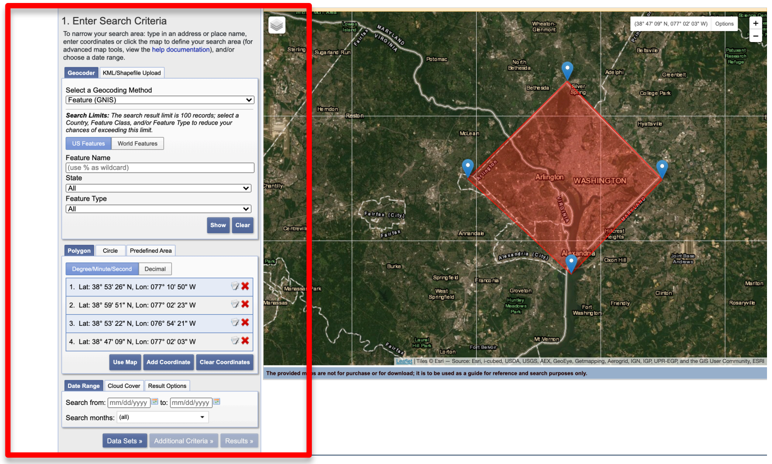
- https://www.usgs.gov/media/files/landsat-provisional-surface-temperature-product-guide
- Provisional Land Surface Temperature based on Landsat 4-8 missions' TIR
- Part of U.S. Landsat Analysis Ready Data (ARD) products (1982 to present)
- ASTER Global Emissivity Database (GED) and NDVI data are used
- Atmospheric profiles of geopotential height, specific humidity, and air temperature extracted from reanalysis data
- Data available **for the U.S.** at 30 m resolution



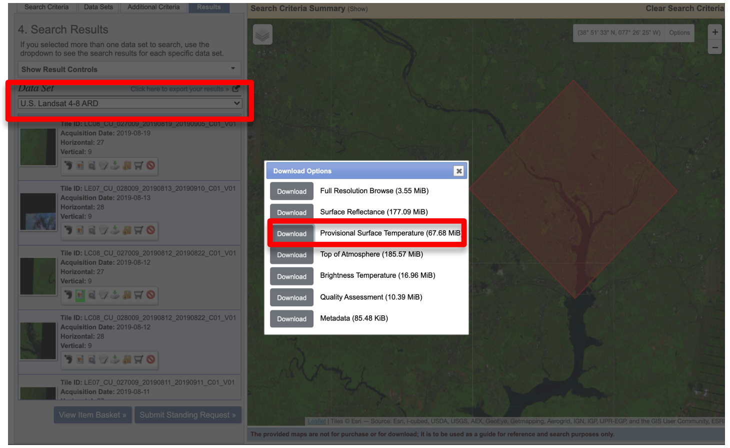
CONUS Landsat ARD Tile Maps.

Landsat LST Data Access

https://earthexplorer.usgs.gov/

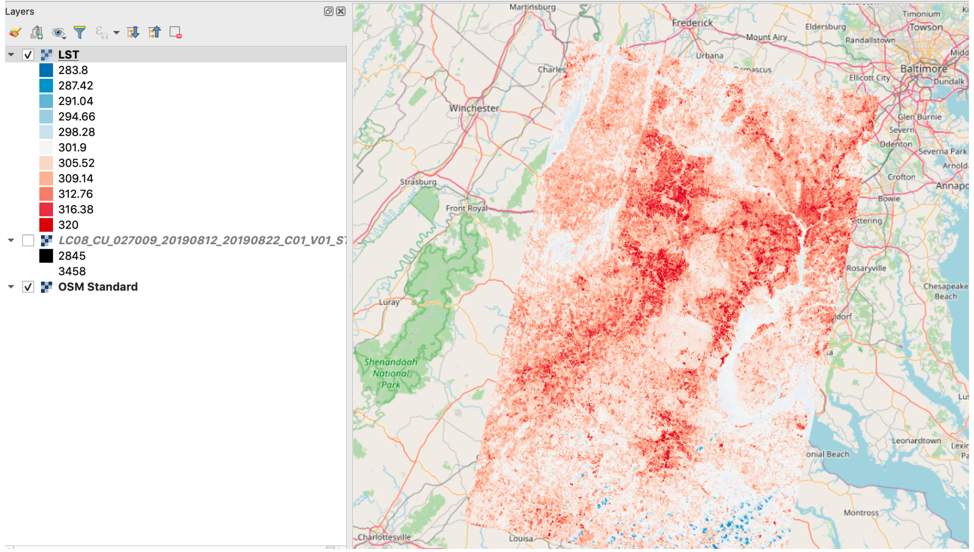


Spatial and Temporal Sub-setting



Search Landsat ARD data. Select 'surface temperature', select tiles, and download tiff images.

LST for Washington DC on 22 August2019



LST Viewed in QGIS:
There is a scale factor of 0.1

MODIS LST Data

https://modis.gsfc.nasa.gov/data/dataprod/mod21.php

- 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 2000

Product Name	Terra Product ID	Aqua Product ID
LST & Emissivity (E) Daily 5-Min L2 Swath 1km	MOD21_L2	MYD21_L2
LST & E Daily L3 Global 1km Day	MOD21A1D	MYD21A1D
LST & E Daily L3 Global 1km Night	MOD21A1N	MYD21A1N
LST & E 8-Day L3 Global 1km	MOD21A2	MYD21A2

VIIRS LST Data

https://viirsland.gsfc.nasa.gov/Products/NASA/LSTESDR.html

- The VIIRS Land Surface Temperature (LST) & Emissivity (E) are developed synergistically with the MODIS product.
- The same algorithmic approach is used in order to ensure data product continuity from MODIS to VIIRS.

Product Name	Product ID
LST & E Twice-Daily 6-min L2 Swath 750 m	VPN21_L2
LST & E Day L3 Global 1 km	VNP21A1D
LST & E Night L3 Global 1 km	VNP21A1N
LST & E 8-day L3 Global 1 km	VNP21A2

ECOSTRESS LST Data

https://lpdaac.usgs.gov/products/eco2lstev001/

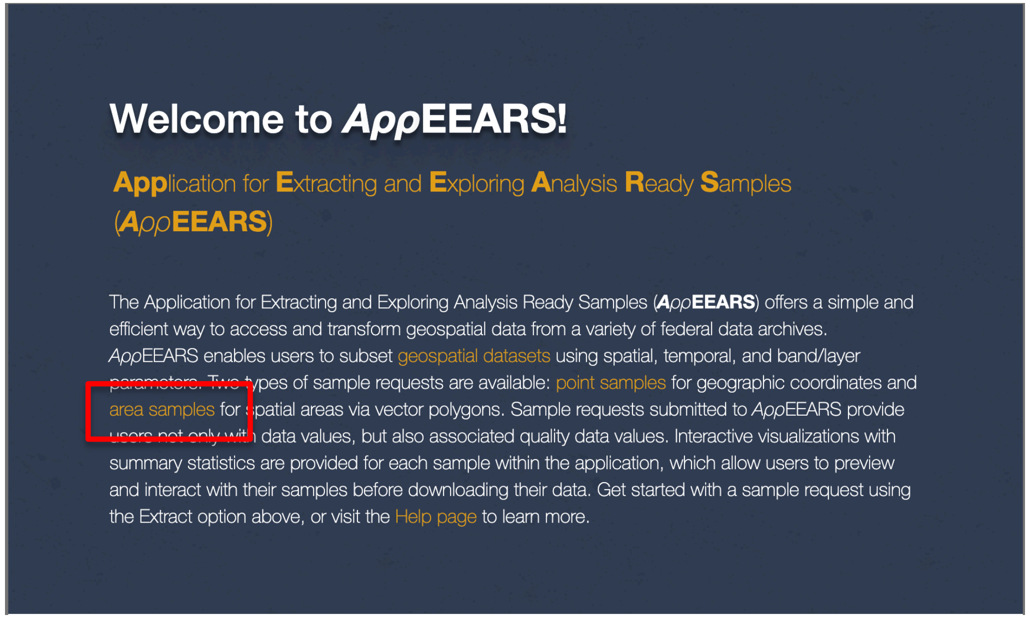
- The ECOSTRESS collects data over the conterminous U.S. as well as key biomes and agricultural zones around the world, and at selected FLUXNET sites.
- Available in swaths with 70 m resolution.
- Atmospherically corrected LST&E values derived from five TIRS bands.
- A physics-based Temperature/Emissivity Separation (TES) algorithm is used.
- Available since 7/2018-07-09 to present at variable temporal resolution.

Product Name	Product ID
LST & E	ECO2LSTE

MODIS, VIIRS, ECOSTRESS Data Access

https://lpdaacsvc.cr.usgs.gov/appeears/

USGS AppEEARS



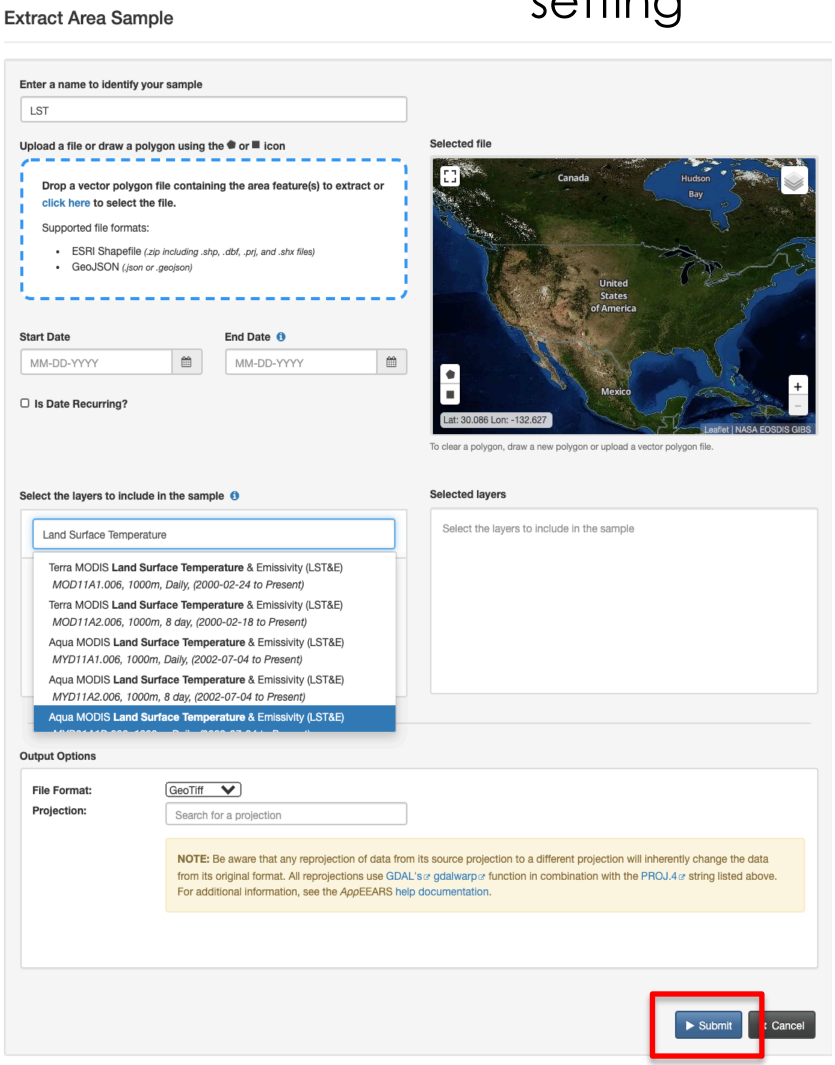
For more information on details of using AppEEARs review this ARSET webinar: **https://www.youtube.com/watch?v=KJTyMDyvBik**

Spatial Sub-setting

Temporal Sub-setting

Product Search

Format and Projection



ASTER LST Data

https://lpdaac.usgs.gov/products/ast_08v003/

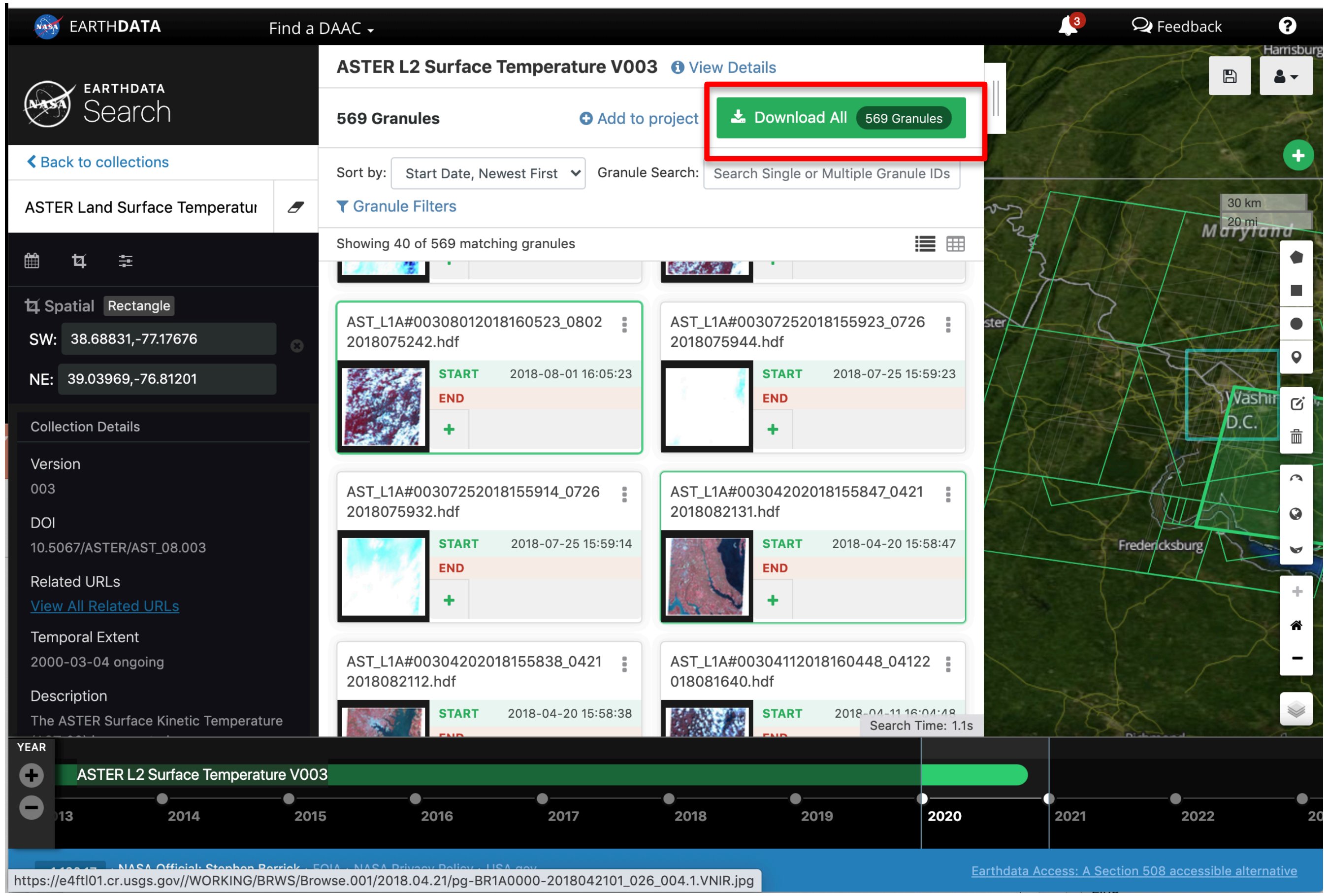
- The ASTER Surface Kinetic Temperature is generated from five TIR bands. (Global LST are available at 90 m spatial resolution.)
- Available since 03/2000 with variable temporal resolution
- Using the TIR, emissivity and LST are derived iteratively.
- Temperature/Emissivity Separation (TES) algorithm along with atmospheric correction is used

Product Name	Product ID
LST	AST_08
Emissivity	AST_03

Access ASTER LST

- https://search.earthdata.nasa.gov/search/granules?p=C1299783630-LPDAAC_ECS&pg[0][gsk]=-start_date&q=C1299783630-LPDAAC_ES&tl=1588271332!4!!

Product Search



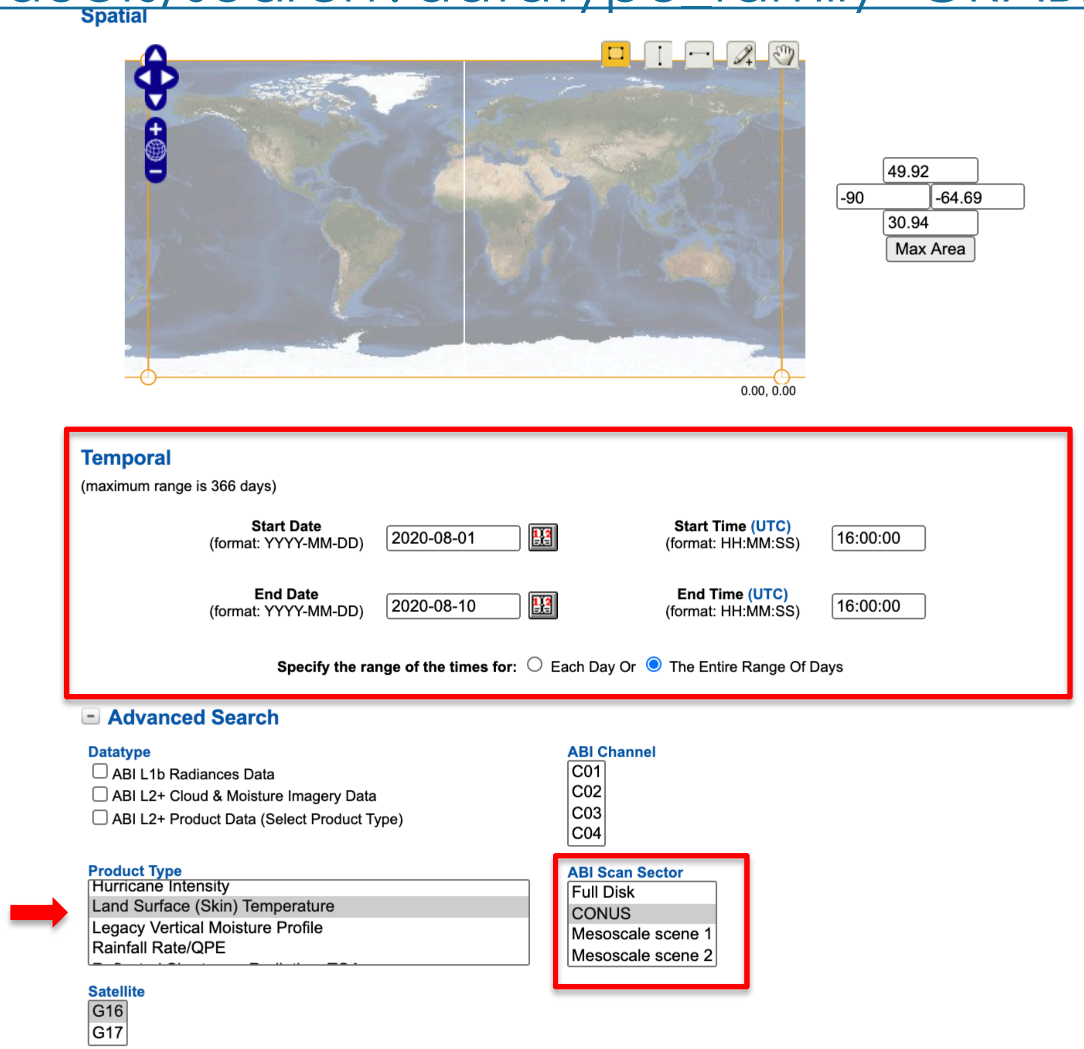
Spatial Sub-setting

Temporal Selection

GOES LST Data

https://www.avl.class.noaa.gov/saa/products/search?datatype_family=GRABIPRD

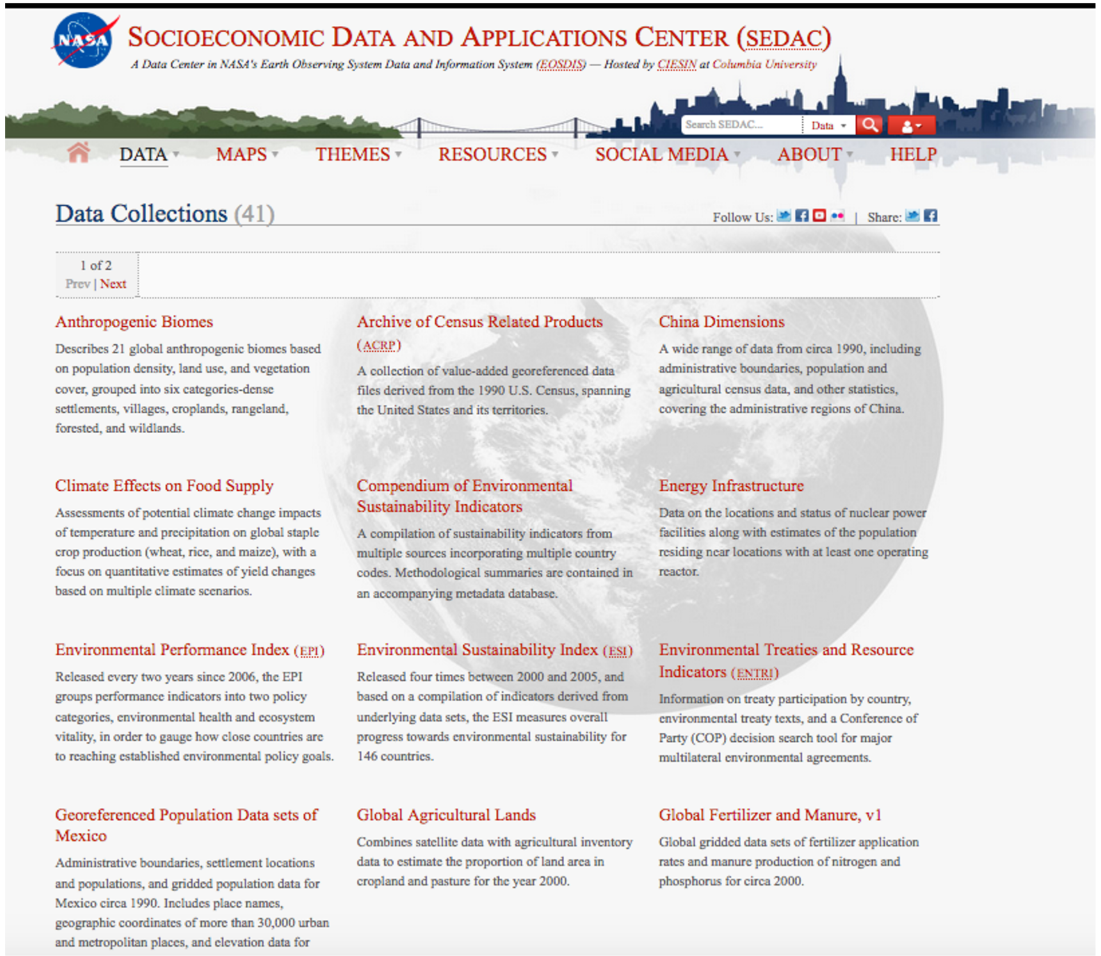
- The GOES-16 & 17 LST contains images with instantaneous pixel values.
- Available at 10 km resolution for Full Disk and 2 km resolution for CONUS.
- Available from NOAA CLASS site starting in 5/2017 with time interval of 60-minute.

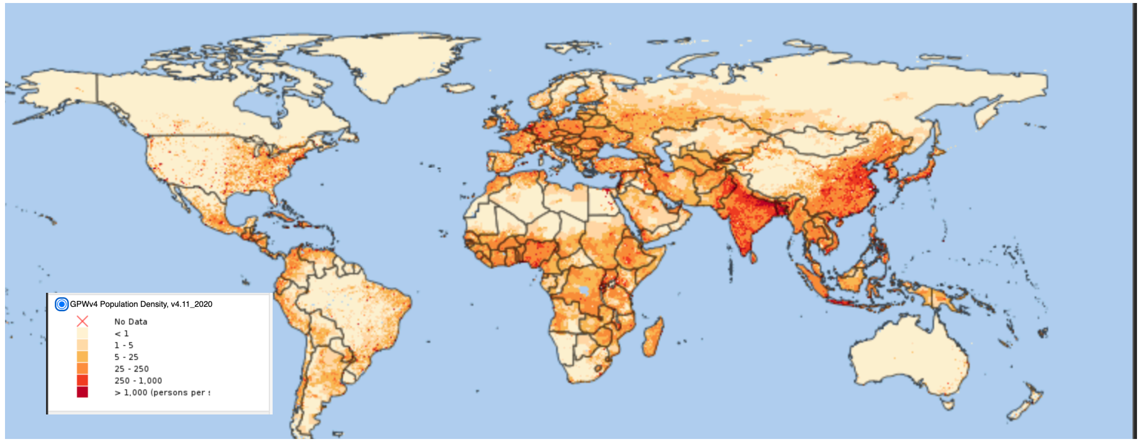


Ancillary Data Products for Urban Heat Island Vulnerability and Impact Analysis

Population Data

http://sedac.ciesin.columbia.edu





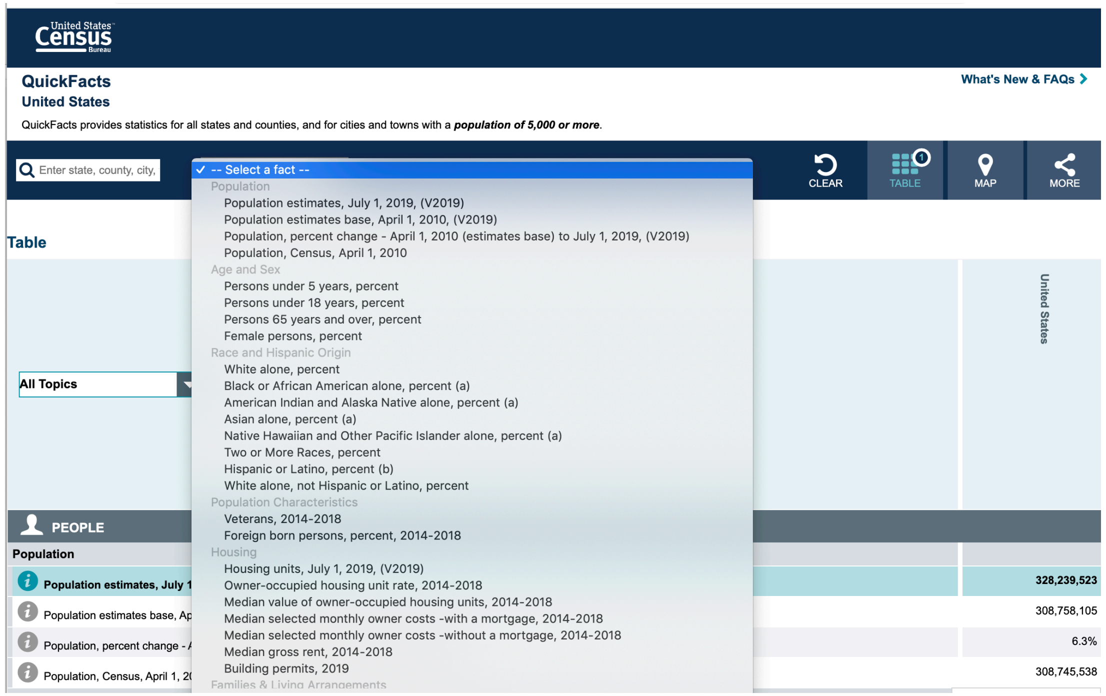
Other Useful Datasets:

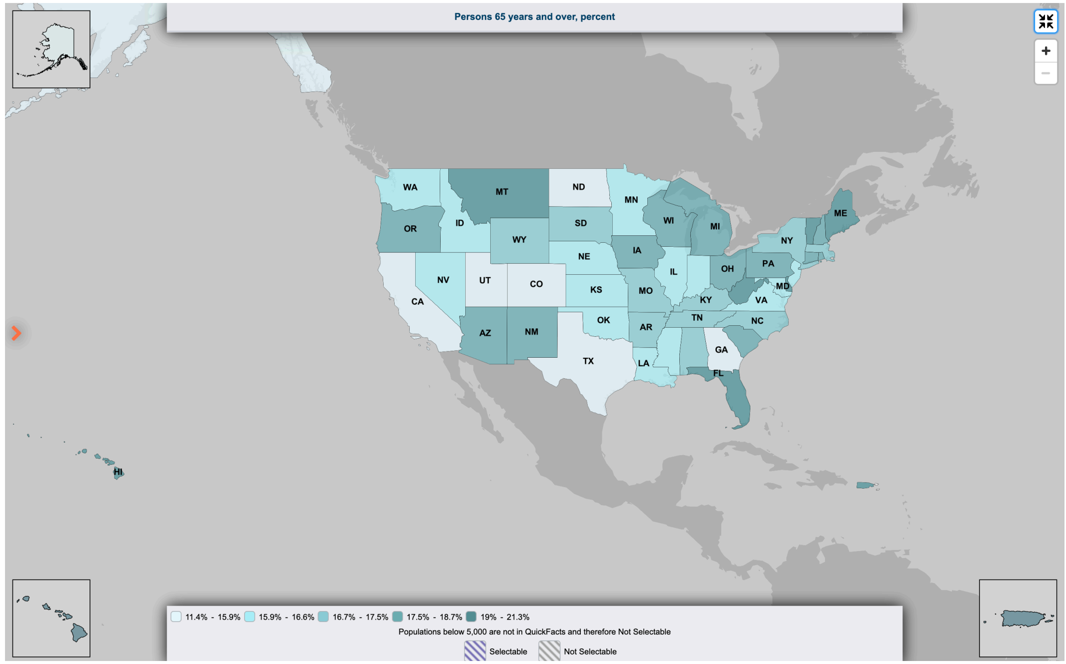
- Global Human Built-up And Settlement Extent (HBASE) Dataset From Landsat
- Global Grid of Probabilities of Urban Expansion to 2030, v1 (2000–2030)

United States Census Bureau Data

https://www.census.gov/data.html

A variety of socioeconomic data available by state, county, and city.



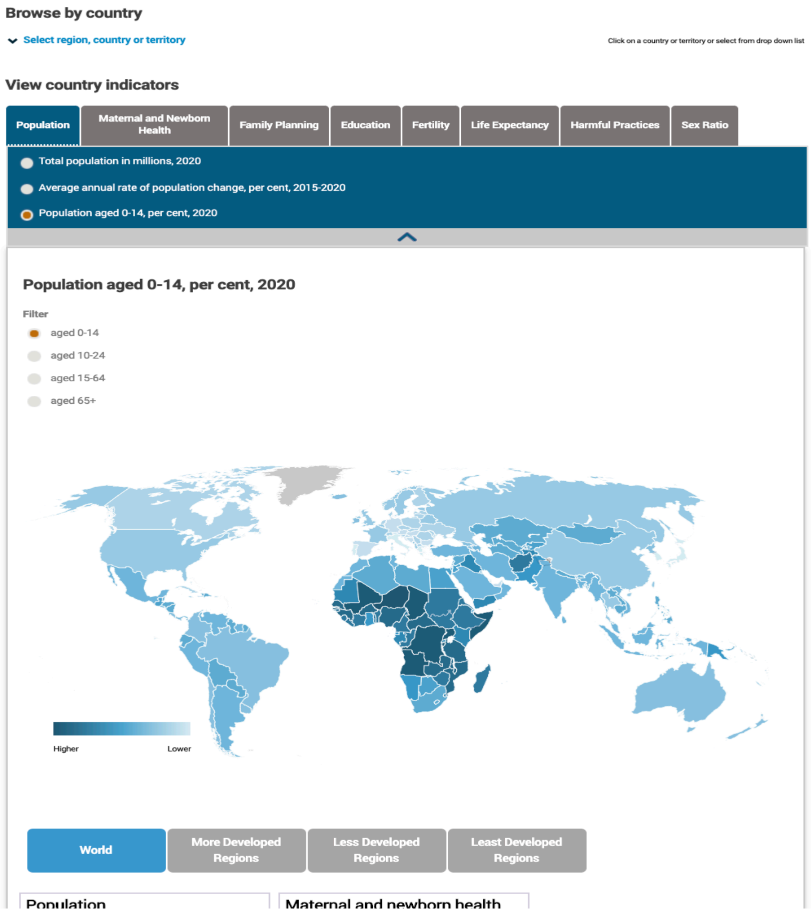


Population (%)above the age of 65 years

United Nations World Population Dashboard

https://www.unfpa.org/data/world-population-dashboard

Population data and development indicators



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.
- The 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.

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

Demo: Converting Thermal Infrared Data from the Landsat Series of Satellites to Land Surface Temperature Estimates Using Google Earth Engine

Google Earth Engine (GEE)

- Cloud based geospatial processing platform
- Available to scientists, researchers, and developers for analysis of the Earth
- Google’s computational power
- Application Programming Interface (API)
- JavaScript code editor (Python available)
- Contains a catalog of satellite imagery and geospatial datasets:
  - https://developers.google.com/earth-engine/datasets/catalog/
- Sign up for a free account:
  - https://earthengine.google.com/

Image Credit: Google

Google Earth Engine (GEE)

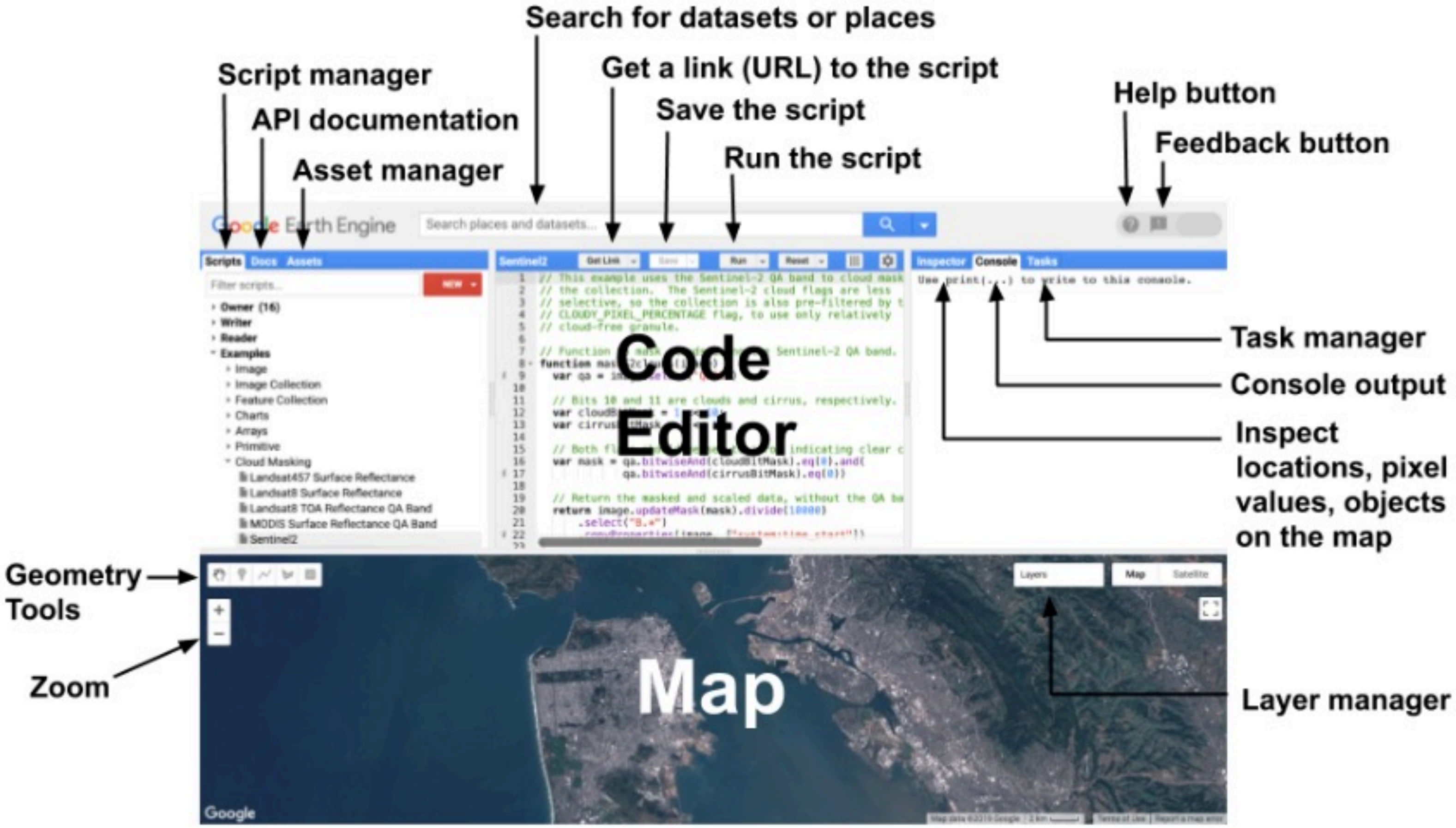


Image Credit: Google

Google Earth Engine (GEE)

- Resources to learn more about Google Earth Engine:
  - [Developer's Guide]
  - [Google Earth Engine Developers Group]

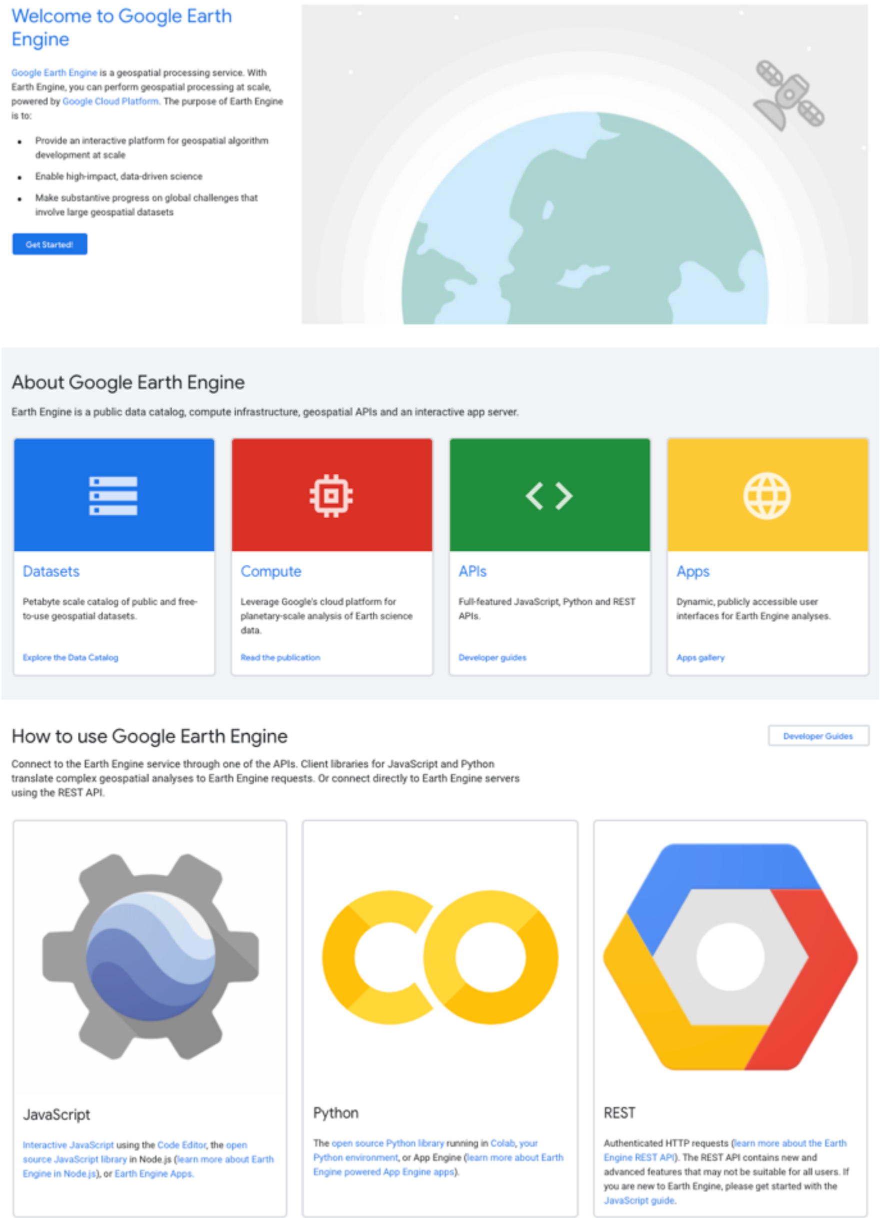


Image Credit: [Google]

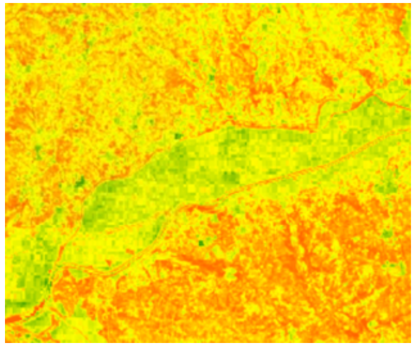
Computing Land Surface Temperature in GEE

- The production chain was fully coded in JavaScript by Ermida et al. (2020) using the Code Editor Platform.
- Repository is freely available from the following GEE or Git repositories:
- GEE: https://code.earthengine.google.com/?accept_repo=users/sofiaermida/landsat_smw_lst
- Git: https://earthengine.googlesource.com/users/sofiaermida/landsat_smw_lst

Ermida, S.L., Soares, P., Mantas, V., Göttsche, F.-M., Trigo, I.F., 2020. Google Earth Engine open-source code for Land Surface Temperature estimation from the Landsat series. Remote Sensing, 12 (9), 1471; https://doi.org/10.3390/rs12091471

Computing Land Surface Temperature in GEE

- Land Surface Temperature is computed from Landsat 4-8 (TM, ETM+, OLI, TIRS) data using the Statistical Mono-Window (SMW) algorithm developed by CM-SAF.
- The approach is based on an empirical relationship between TOA brightness temperatures in a single TIR channel and LST utilizing simple linear regression (Freitas et al., 2013).
- All inputs to the LST algorithm are obtained from the GEE Data Catalog.
  – Landsat Data (USGS)
  – Atmospheric Data (NCEP & NCAR)
  – Surface Emissivity from ASTER GED (NASA JPL)



Landsat Data Used for Estimating Land Surface Temperature

- Landsat satellite with instrument(s)
- Used bands from the instrument(s)
- Wavelength in micrometers (μm)
- GEE Dataset
- Spatial Resolution
- Equatorial Crossing Time
- Date Range

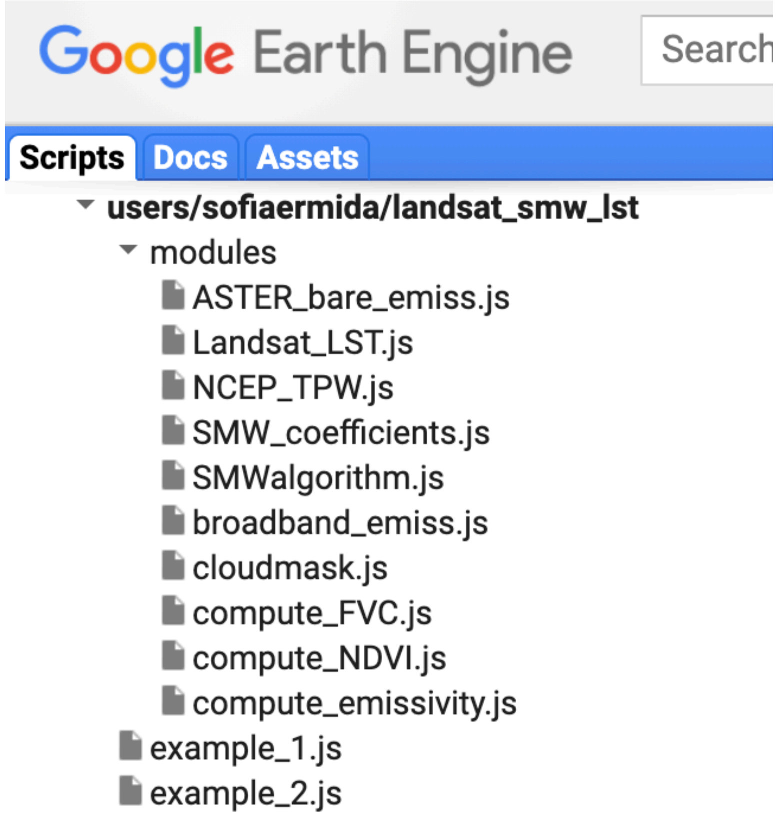
Satellite	Used Bands	Wavelength (μm)	Dataset	Spatial Resolution	E.C.T.	Date Range
Landsat 4 (TM)	Red: B3 NIR: B4 TIR: B6	0.63–0.69 0.76–0.90 10.4–12.5	C01/T1_SR C01/T1_SR C01/T1_TOA	30 m 30 m 120[2] m	9:45 am (16-day)	22 August 1982 to 14 December 1993
Landsat 5 (TM)	Red: B3 NIR: B4 TIR: B6	0.63–0.69 0.76–0.90 10.4–12.5	C01/T1_SR C01/T1_SR C01/T1_TOA	30 m 30 m 120[2] m	9:45 am (16-day)	1 January 1984 to 5 May 2012
Landsat 7 (ETM+)	Red: B3 NIR: B4 TIR: B6[1]	0.63–0.69 0.77–0.90 10.4–12.5	C01/T1_SR C01/T1_SR C01/T1_TOA	30 m 30 m 60[2] m	10:00 am (16-day)	1 January1999 to present
Landsat 8 (OLI; TIRS)	Red: B4 NIR: B5 TIR: B10	0.64–0.67 0.85–0.88 10.6–11.19	C01/T1_SR C01/T1_SR C01/T1_TOA	30 m 30 m 100[2] m	10:00 am (16-day)	11 April 2013 to present

Note: [1] low gain band (B6_VCID_1); [2] resampled to 30 m.

Source: Ermida et al., 2020

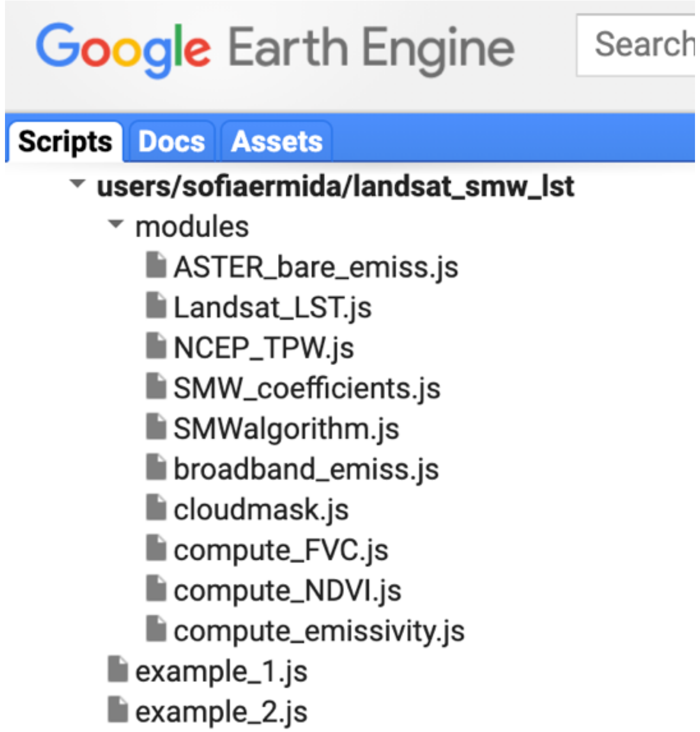
Computing Land Surface Temperature in GEE

- Launch the Google Earth Engine application.
- Add the repository from Ermida et al. (2020).
  - https://code.earthengine.google.com/?accept_repo=users/sofiaermida/landsat_smw_lst
- Confirm the repository and all associated modules have been added to your Scripts manager.



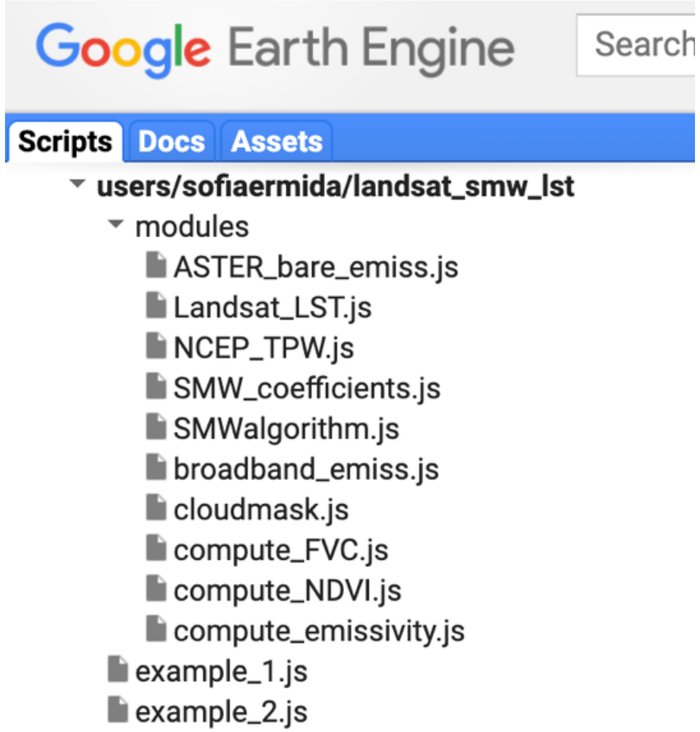
Computing Land Surface Temperature in GEE

- Each module contains reusable code (i.e. functions) that are shared between scripts to calculate LST.
- **ASTER_bare_emiss.js** – Applies a vegetation cover correction to ASTER emissivity in order to obtain a bare ground emissivity component at each pixel
- **Landsat_LST.js** – Selects the Landsat data based on user inputsand performs the LST computation
- **NCEP_TPW.js** – Matches the atmospheric water vapor data from NCEP reanalysis to each Landsat image
- **SMW_coefficients.js** – Coefficients for the Statistical Mono-Window Algorithm
- **SMWalgorithm.js** – Applies the Stastical Mono-Window algorithm to compute the LST



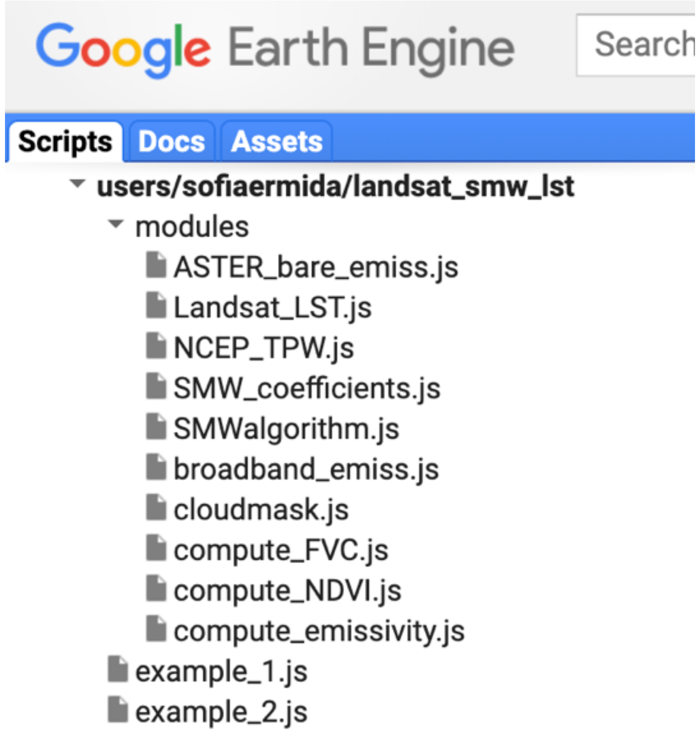
Computing Land Surface Temperature in GEE

- Each module contains reusable code (i.e. functions) that are shared between scripts to calculate LST.
- **Broadband_emiss.js** – Computes broad-band emissivity from ASTER GED
- **cloudmask.js** – Masks clouds and cloud shadow using the Quality band
- **compute_FVC.js** – Computes the Fraction of Vegetation Cover from NDVI
- **compute_NDVI.js** – Computes NDVI values for Landsat
- **compute_emissivity.js** – Computes surface emissivity for Landsat. Requires values from "compute_FVC.js"



Computing Land Surface Temperature in GEE

- **example_1.js**
  – Shows how to compute Landsat LST from Landsat-8 over Coimbra, Portugal
  – Corresponds to the example images shown in Ermida et al. (2020)
- **example_2.js**
  – Shows how to get LST time series at the SURFRAD DRA site
  – Corresponds to the method used to extract time series for comparison with station LST used in Ermida et al. (2020)



Computing Land Surface Temperature in GEE

- To modify the code for your study area, users need to specify the following inputs in example_1.js
  - geometry: <ee.Geometry>
    - Region of interest
  - landsat: <string>
    - The Landsat satellite id
    - Valid Inputs: 'L4', 'L5', 'L7' and 'L8'
  - date_start: <string>
    - Start date of the Landsat collection
    - Format: YYYY-MM-DD
  - date_end: <string>
    - End date of the Landsat collection
    - Format: YYYY-MM-DD
  - use_ndvi: <boolean>
    - If true, NDVI values are used to obtain a dynamic emissivity; if false, emissivity is obtained directly from ASTER.

```
// select region of interest, date range, and landsat satellite
var geometry = ee.Geometry.Rectangle([-8.91, 40.0, -8.3, 40.4]);
var satellite = 'L8';
var date_start = '2018-05-15';
var date_end = '2018-05-31';
var use_ndvi = true;
```

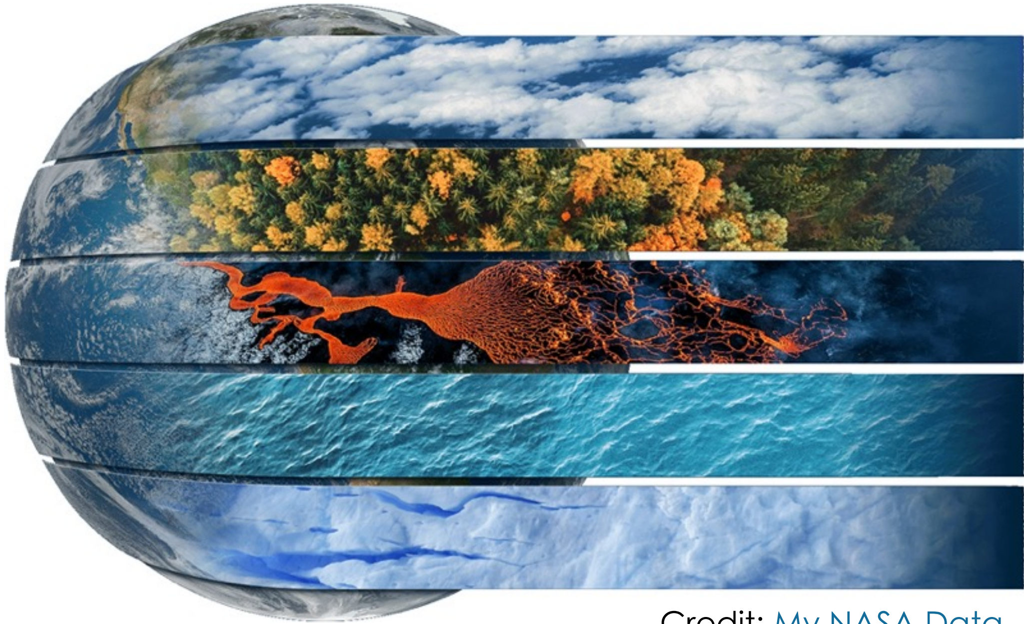
Get Involved – GLOBE Citizen Science

- The Global Learning and Observations to Benefit the Environment (GLOBE) Program is an international science and education program that provides students and the public worldwide with the opportunity to participate in data collection and the scientific process.
- GLOBE UHI Data Collection Campaign: https://www.globe.gov/web/surface-temperature-field-campaign
- GLOBE Surface Temperature Protocol eTraining: https://www.globe.gov/get-trained/protocol-etraining/etraining-modules/16867642/12267

Credit: GLOBE

Student Activities – My NASA Data

- My NASA Data provides grade 3-12 teachers access to NASA mission data through unique tools that help students learn about Earth system science. The project's value is providing Earth science data resources that are teacher- and student-friendly.
- My NASA Data UHI Phenomena Resources: https://mynasadata.larc.nasa.gov/phenomenon/creation-of-urban-heat-islands
- My NASA Data UHI Story Map: https://mynasadata.larc.nasa.gov/lesson-plans/creation-urban-heat-islands-story-map



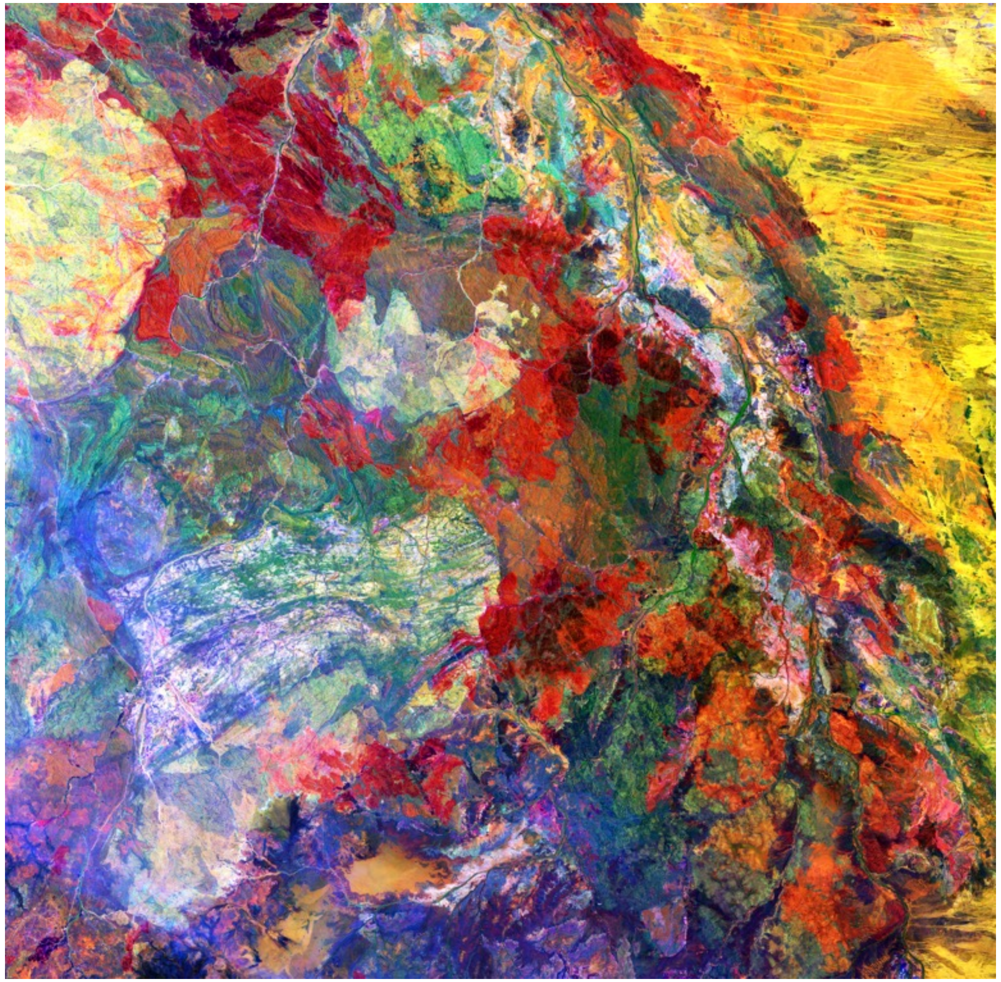
Credit: My NASA Data

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.
- Ermida, S.L., Soares, P., Mantas, V., Göttsche, F.-M., Trigo, I.F., 2020. Google Earth Engine open-source code for Land Surface Temperature estimation from the Landsat series. Remote Sensing, 12 (9), 1471; https://doi.org/10.3390/rs12091471
- 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.
- 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
- 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
- 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.

Questions

- Please enter your questions into the Q&A box. We will answer them in the order they were received.
- We will post the Q&A to the training website following the conclusion of the course.



Credit: NASA

Contacts

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  - Sean McCartney: sean.mccartney@nasa.gov
  - Amita Mehta: amita.v.mehta@nasa.gov

- Training Webpage:
  - https://appliedsciences.nasa.gov/join-mission/training/english/satellite-remote-sensing-urban-heat-islands

- ARSET Website:
  - https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset