DEVELOP Tutorial

GIS Tutorial

Boynton Beach Health & Air Quality

Assessing Urban Heat and Tree Canopy to Inform Urban Planning at Boynton Beach, FL

Spring 2025 | Virginia – Langley
April 4th, 2025

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Overview: This tutorial will enable users to acquire, process, and analyze NASA Earth observation data for urban heat mitigation. The tutorial will focus on Boynton Beach, Florida as a case study; however, the same methodologies can be applied to other projects focusing on the urban heat island (UHI) effect.

This tutorial aims to explain the GIS processes and methodology involved in the Boynton Beach Health & Air Quality project. The tutorial first includes instructions for creating daytime and nighttime UHI maps, using thermal bands from Landsat 8 Thermal Infrared Sensor (TIRS) and Landsat 9 TIRS-2. Second, this tutorial outlines how to generate a heat vulnerability index map, which combines UHI data with asthma data to reveal areas more vulnerable to heat stress. Additionally, this tutorial provides instructions for albedo maps, which depict surface reflectance and a bivariate of albedo and energy expenditure to examine a correlation between reflectance and energy use. Two types of vegetation maps are also covered: tree canopy and Normalized Difference Vegetation Index (NDVI) using aerial imagery from the National Agricultural Imagery Program (NAIP) as well satellite imagery from and Landsat 8 Operational Land Imager (OLI) and Landsat 9 OLI-2. Finally, we used ECOSTRESS to create an evapotranspiration map to depict the amount of moisture being released into the air. Being able to replicate and improve on our original maps will help the partners as their environmental and policy circumstances change. They may need to revisit the data and adjust results based off future decision-making processes, and this tutorial will provide a useful guide to the partners.

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Set up & Requirements

ArcGIS Pro Version 3.4.0

To use ArcGIS Pro, follow the [tutorial](#) to download ArcGIS Pro and create an account.[1] Make sure you have the appropriate licenses to use ArcGIS Pro. We used the Advanced ArcGIS Pro license and used the 3D analyst, geostatistical analyst, and spatial analyst extensions.

USGS – Earth Explorer

To access NASA Earth observation data and imagery, create an account with USGS EarthExplorer at https://earthexplorer.usgs.gov/.[2] EarthExplorer provides access to imagery from Landsat 8 and 9 satellites, which we used to generate maps of land surface temperature (LST), albedo, and NDVI. EarthExplorer also contains NAIP data which was used for mapping tree canopy.

NASA – AppEEARS

To access and process ECOSTRESS data, create an account with NASA's Application for Extracting and Exploring Analysis Ready Samples (AppEEARS) at https://appeears.earthdatacloud.nasa.gov/.[3] AppEEARS allows users to request and download analysis-ready datasets from a variety of NASA Earth science products. We used AppEEARS to obtain ECOSTRESS evapotranspiration and nighttime LST data. AppEEARS streamlines data processing by allowing users to clip and reproject data to their area of interest.

Methods

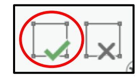
1. Data Acquisition and Processing

1.1 Study and Reference Area Shapefile

We created shapefiles for both our study area and our reference area to perform further analysis. The reference area shapefiles were created primarily for our heat analyses.

1. Open a new project in ArcGIS Pro.
2. Go to the **Catalog** pane. Under the **Project** tab, click **Databases** and right-click on the geodatabase for the project you are working on.
3. Select **New → Feature Class**. Name the file after the study or reference area for your project. Ensure that the Feature Class type is set to "Polygon."
4. Select **Finish**. In your contents pane, a new feature class should appear with the name of your shapefile.
5. On the **Edit** tab on the ribbon, click **Create** and select the feature class you just made. A variety of tools for creating and modifying shapefiles will appear in the Create Features pane.
6. Ensure that the first tool (Polygon) is selected: 

7. In your **Map**, zoom to the location of your reference area and click to place points around the boundary. Double-click on the first point you created to finish drawing the polygon. Click **Finish**.



8. To change the format of your polygon, select the symbol under your feature class in the **Contents** pane.

9. Within your project folder, create a new folder called "ReferenceArea" or "StudyArea." Export your feature class by right-clicking it in the **Contents** pane and selecting **Data → Export Features**.

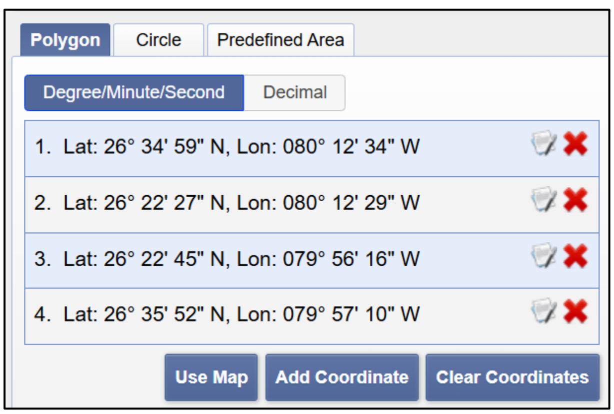
10. Select the folder next to Output Feature Class and navigate to the ReferenceArea or StudyArea folder in your project folder. This will save your shapefile so you can use it in other maps.

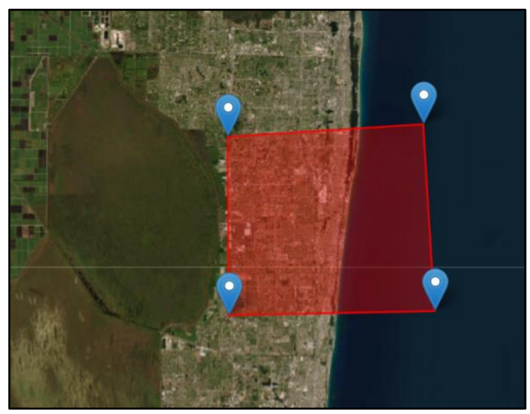
1.2 Acquiring Landsat Data from EarthExplorer

We used Landsat data to create maps displaying the UHI effect, NDVI, and albedo.

1. On the [USGS EarthExplorer website](), sign in or create an account if you have not already done so.[2]

2. In the **Search Criteria** tab, select the **Polygon** tab to define your area of interest. Set your area of interest by zooming to your study area on the map and draw a polygon by clicking to select points. For our project, we drew a quick polygon around the Boynton Beach area. Another way to define your area of interest is by uploading a zipped file into the KML/Shapefile Upload tab.





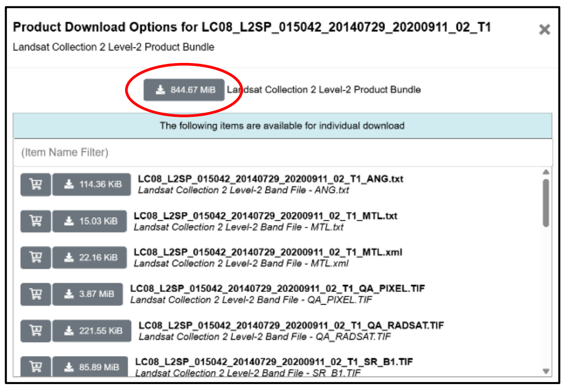
3. In the **Date Range**, set the time period of your study.

4. In the **Cloud Cover**, set the Cloud Cover Range to 25%.

5. In the **Data Sets** tab, select Landsat. Depending on what is being calculated, different levels will be used:
   a. UHI and NDVI
      Select **Landsat Collection 2 Level-2 → Landsat 8-9 OLI/TIRS C2 L2**. Select **Results**.
   b. Albedo
      Select **Landsat Collection 2 Level-1 → Landsat 8-9 OLI/TIRS C2 L1**. Select **Results**.

6. In the **Results** tab, all available scenes will appear for your set parameters. Click the Footprint to ensure that your study area is within the scene.

7. To download data, select the Download Options icon and select **Product Options**. Download the Product Bundle at the top. This will download GeoTIFF files for all the bands needed for daytime UHI, NDVI, and albedo analyses.

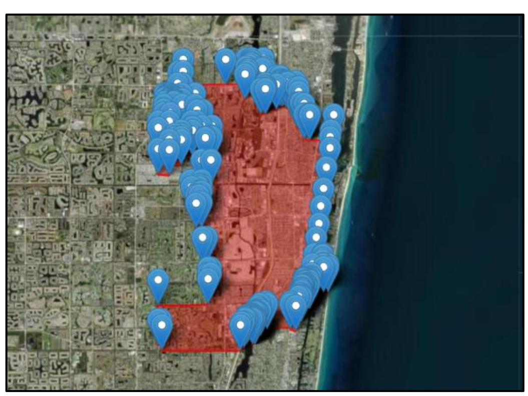


1.3 Acquiring NAIP Data from EarthExplorer

We acquired NAIP data to perform an analysis on tree canopy coverage in our study area.

1. On the USGS EarthExplorer website, sign in or create an account if you have not already done so.

2. In the **Search Criteria** tab, select **KML/Shapefile Upload**. This is another way to define your area of interest and is especially helpful with NAIP data because it minimizes the results to your specific study area. In the dropdown, change the upload from **KML/KMZ** to **Shapefile**. Upload a zipped file of the study area shapefile created in 1.1 Study and Reference Area Shapefile. Below is an example of the shapefile we uploaded of Boynton Beach.

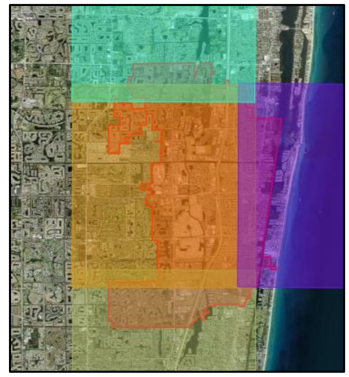


Basemaps credits: NASA–ESRI EULA

3. In the **Date Range**, set the time period of your study. Cloud cover does not need to be set for NAIP data.

4. In the **Data Sets** tab, select **Aerial Imagery → NAIP**.

5. Select the **Results** tab, all available scenes will appear for your set parameters. Six images are available for each year for the Boynton Beach area, but only four need to be downloaded for analysis. Click on the footprint to view each scene and ensure that the entire study area is covered, as shown on the right.



6. To download NAIP data, click the Download Options icon and download the Full Resolution image for each set of data that covers your study area.

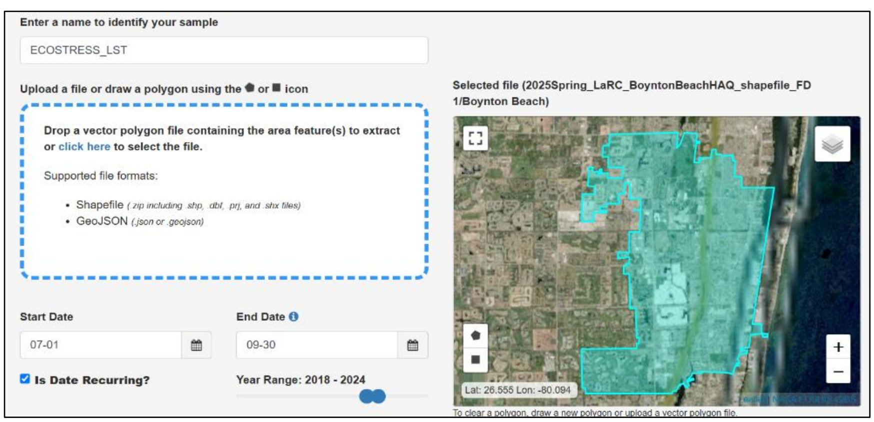
1.4 Acquiring ISS ECOSTRESS Data from NASA AppEEARS

We used ISS ECOSTRESS to calculate the nighttime UHI effect and to create an evapotranspiration map.

1. On the NASA AppEEARS website, select **Sign In** on the top right and log in to Earthdata.

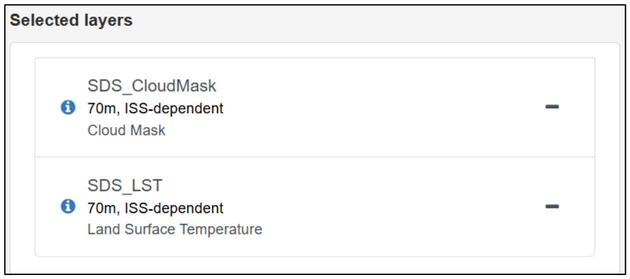
2. Select **Extract → Area**. Start a new request. Name your sample "LST" or "Evapotranspiration" depending on what you are requesting.

3. Input your study area by uploading your zipped shapefile in the polygon. To calculate the UHI effect, you will need to make a separate request to extract the reference area as well. Select the dates for your study period. Your study area or period may need to be broken up into separate requests if the download size exceeds the maximum allowed.

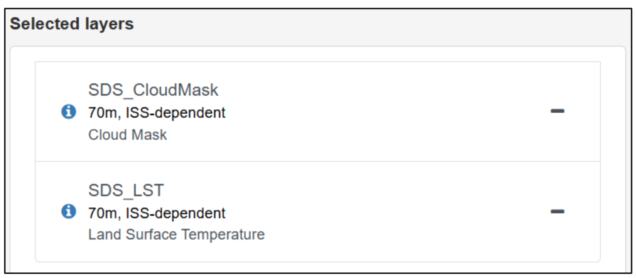


4. Select the layers to include in your extract depending on what you are calculating:
   a. UHI

When selecting layers, search **ECOSTRESS** and select **ECOSTRESS Land Surface Temperature and Emissivity (LST&E)**. Scroll down and add the **SDS_LST** layer. Search **ECOSTRESS** again and select **ECOSTRESS Cloud Mask**. Add the **SDS_CloudMask** layer.



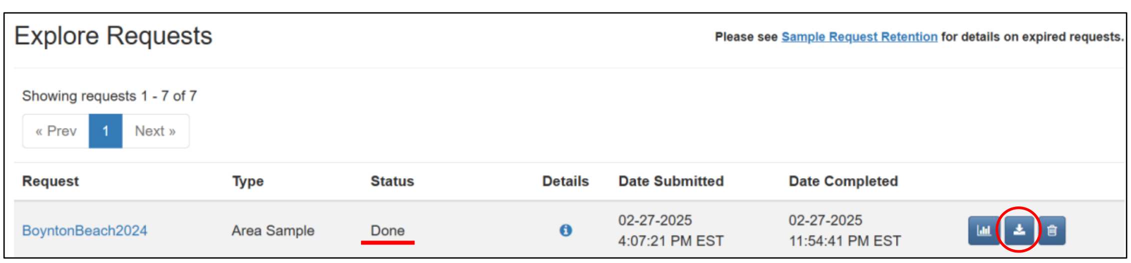
b. Evapotranspiration
Search **ECOSTRESS** and select **ECOSTRESS Evapotranspiration PT-JPL**. Add the **EVAPOTRANSPIRATION_PT_JPL_ETdaily** layer. This is the layer with evapotranspiration (ET) data. Search **ECOSTRESS** again and select **ECOSTRESS L3/L4 Ancillary Data Quality Assurance (QA) Flags**. Add the **L3_L4_QA_ECOSTRESS_L2_QC** layer. This is the quality control layer used to filter out the good pixels for further analysis.



5. Under **Output Options**, leave the **File Format** as a **GeoTiff**. In the **Projection** section, select **Geographic** and select **Submit**.

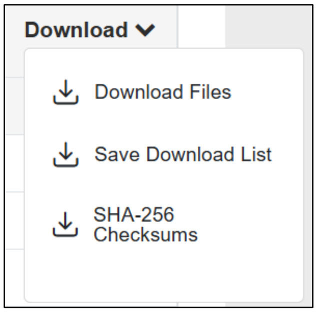
6. Select **Explore** to view your request. The time it takes for a request to be filled depends on how big of a request it is. You will receive an email when the request has been fulfilled.

7. After receiving the email, navigate back to the **Explore** requests page. The **Status** for your request should be listed as **Done**.



8. Select the **Download** button. This will bring you to the **Download Area Sample** page. Select the box to download all of the files on the left, or select the files you need.

9. After selecting all of your desired files, click the **Download** dropdown and select **Download Files**.



10. Once the download is complete, you can find the files in your downloads folder.

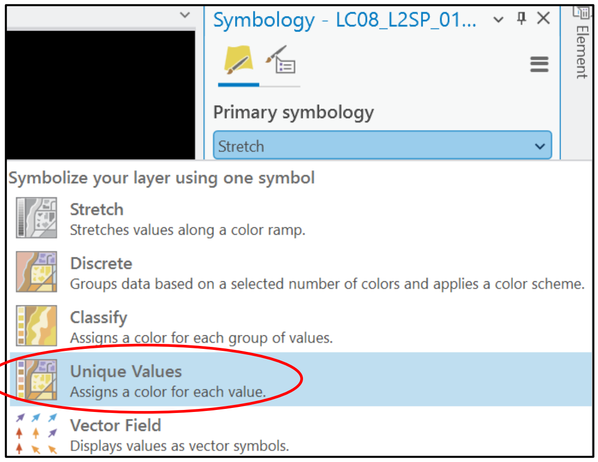
1.5 Cloud Mask (Landsat)

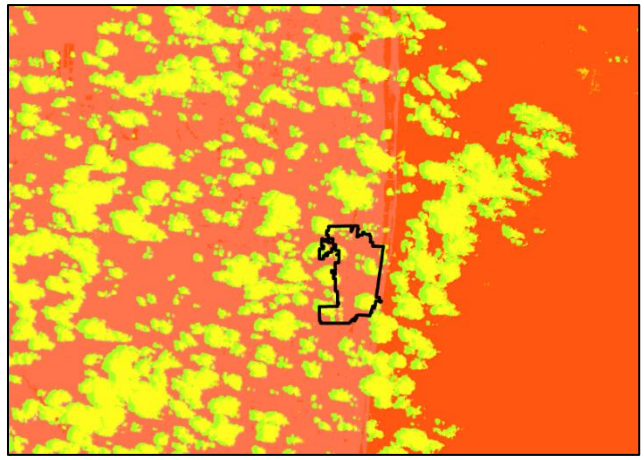
Clouds obstruct the view of Earth's surface and interfere with Landsat's data collection. When clouds block the sensors, temperature may appear cooler than it actually is. For this reason, we performed a cloud mask on the Landsat data for our daytime UHI and albedo analyses.

1. In ArcGIS Pro, open your project. Select **View** in the ribbon and open the **Catalog** pane. In the **Computer** tab, navigate to where your Landsat Product Bundle was saved.

2. Drag the QA_PIXEL band from the **Catalog** to the **Contents** pane to add it to the map.

3. Right-click the band and select **Symbology**. Under **Primary symbology**, select the dropdown menu to change it from **Stretch** to **Unique Values**. Select **Yes** when the warning box appears to build an attribute table. The image on the right is what the map should somewhat look like after changing the symbology.

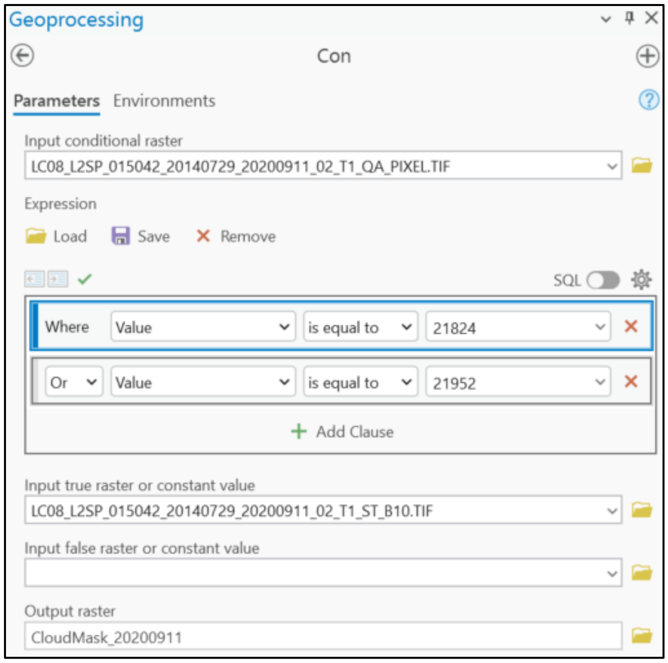




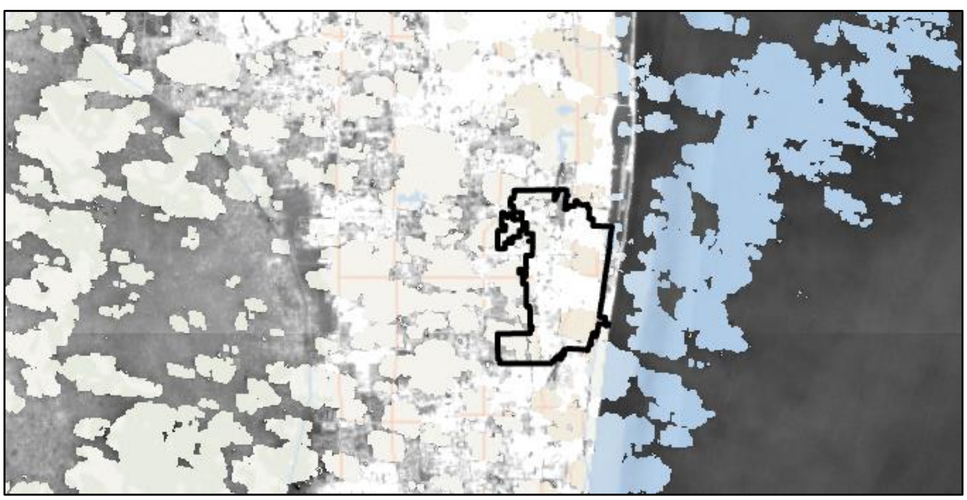
4. Select **View** in the ribbon and open the **Geoprocessing** pane. Search for the **Con** tool and open it. In **Input conditional raster**, select the QA_PIXEL layer of your dataset. In the **Expression** section, add the parameters where **Value is equal** to **21824** or **Value is equal** to **21952**. This will ensure that only pixels clear of clouds will be kept. In **Input true raster or constant value**, select the raster layer based on what you are calculating:
   a. **Daytime UHI**: Select Band 10.
   b. **Albedo**: Select the composite image you created in Step 6 of Basemaps credits: NASA–ESRI EULA

   c. 2.3 Albedo.

5. **Input false raster or constant value** can be left blank. In **Output raster**, name the new cloud-masked layer. In the example below, a cloud mask was performed for a daytime UHI analysis.



6. Select **Run**. This is what the cloud-masked image should look like.



Basemaps credits: NASA–ESRI EULA

1.6 Unit Conversion, Extracting Polygons, and Calculating the Median for UHI

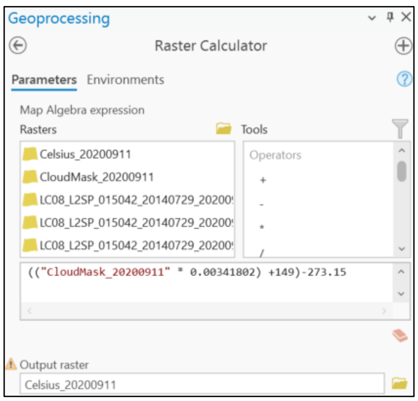
For our daytime UHI analysis, we performed these processing steps after cloud masking the entire scene each day. This ensured that the data were ready to make a composite image.

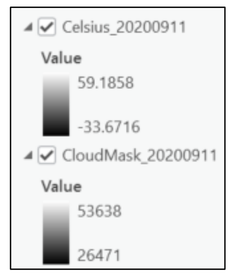
a. Unit Conversion

1. After cloud masking the Landsat data, the units will be in **Scaled Kelvin**. A unit conversion will be performed to convert these values to **Celsius**. In the Geoprocessing pane, open the **Raster Calculator** tool. In **"Band 10,"** insert your cloud-masked data. After typing out your equation, select **Run**.

$$\left(\left(\text{"Band 10"} \cdot 0.00341802\right) + 149.0\right) - 273.15$$

2. A new raster layer will be created in your **Contents** pane with the same data in **Celsius**. An example of the Raster Calculator calculation and the before and after of the conversion is shown below.

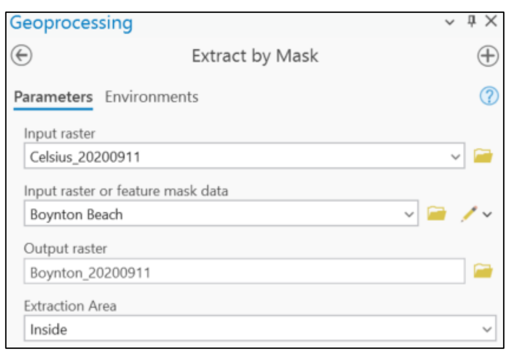




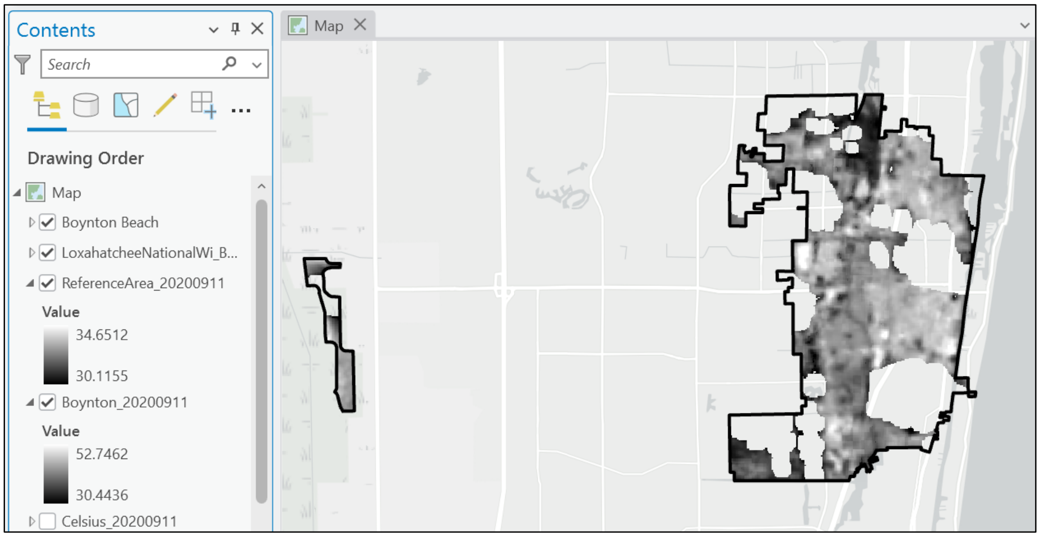
b. Extracting Polygons

1. To extract your study area and reference area, open the **Geoprocessing** pane and open the **Extract by Mask** tool.

2. In **Input raster**, select the data that were converted to Celsius. In **Input raster or feature mask data**, select the shapefile of the **study area** or **reference area**. The tool will need to be used twice to extract both areas. In **Output raster**, you can name your layer.

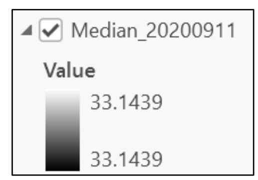


3. Select **Run**. An example is shown below of our extracted study area and reference area.



Basemaps credits: NASA–ESRI EULA

c. Calculating the Median of Reference Area
1. The **median** value of the reference needs to be taken for the UHI effect calculation. In the **Geoprocessing** pane, search for and open the **Zonal Statistics** tool.



2. In **Input Raster or Feature Zone Data**, select the shapefile of your reference area. In **Input Value Raster**, select the raster layer of the data for your reference area. You can name this layer under **Output Raster**. Under **Statistic Type**, select the dropdown and change it from **Mean** to **Median**.

3. A new layer will be created with a value showing the median of the reference area.

1.7 Filtering, Quality Control, Cloud Mask, and Unit Conversion (ECOSTRESS)
To create the nighttime UHI effect and evapotranspiration maps, we performed these steps to prepare the data for further analysis.

a. Filtering
1. We began by applying a filtering script in Python to remove extreme or nonphysical pixel values from LST and latent heat flux (LE) datasets. This involved removing:
    a. Pixels with LST values outside the expected ranges for Florida's climate (60–160°F)
    b. ET pixels with a value of zero or missing due to incomplete satellite retrievals or persistent cloud cover
    c. Saturated or an inconsistently high/low pixel values based on outlier detection

a. Quality Control (QC)
1. To filter out pixels with low-quality data for our analysis, we used a separate Python 3.13.1 script to apply pixel-level quality control using:
    a. The ECOSTRESS SDS_QC layer for LST
    b. The ECOSTRESS L3/L4 QC flag layer for ET

More details on ECOSTRESS QC filtering can be found at
https://ecostress.jpl.nasa.gov/downloads/tutorials/Applying_QC_Flags.pdf.[4]

2. The SDS_QC layer should be automatically applied when you acquire the cloud mask and LST layers from NASA AppEEARS.

3. The scripts filtered out any pixel flagged with retrieval errors, low confidence, or missing values based on ECOSTRESS documentation.

4. The pixels that passed these quality assurance checks were retained for unit conversion and spatial analysis.

b. Cloud Mask
1. Cloud masking was applied to LST products only. ECOSTRESS ET data did not have a dedicated cloud mask band and solely relied on QC filtering.

2. For the LST data, we used a script in Python to read the SDS_CloudMask layer and retain only pixels flagged as clear sky.

3. Pixels flagged as cloudy, cloud shadow, or uncertain were excluded using bitwise operations and conditional masking logic.

4. The resultant LST rasters were exported as GeoTIFFs and imported into ArcGIS Pro for mapping and UHI analysis.

c. Unit Conversion
1. During the quality control step, the ECOSTRESS data were converted into physical units, though it can also be done in ArcGIS Pro following the steps in **1.6**.
   a. LST was rescaled and converted from Kelvin to degrees Celsius using the equation:

$$LST_{Celsius} = (LST \cdot 0.02) - 273.15$$

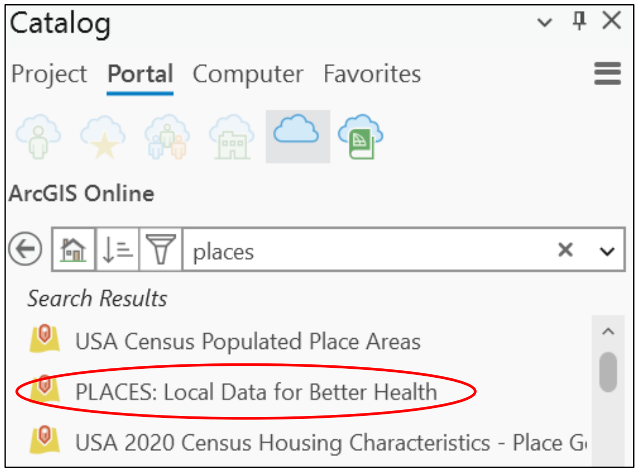
   b. ET was derived from LE and turned into mm/day using the Penman-Monteith relationship:

$$ET = \frac{LE}{\lambda}$$

   Where λ (latent heat of vaporization) is 2.45 MJ/kg.[5]

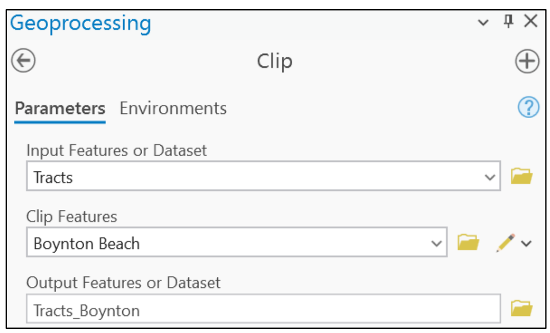
1.8 Acquiring CDC Health Data from the ArcGIS Online Portal
Health data were acquired to perform a further analysis comparing a health metric with urban heat. These data were used to create a heat vulnerability index.

1. In ArcGIS Pro, open your project. In the **View** tab, open the **Catalog** pane. Select **Portal**. In the search bar, search **PLACES**.



2. Right-click **PLACES: Local Data for Better Health** and select **Add to Current Map**.

3. To clip this data to your study area, open the **Geoprocessing** pane and select the **Clip** tool.



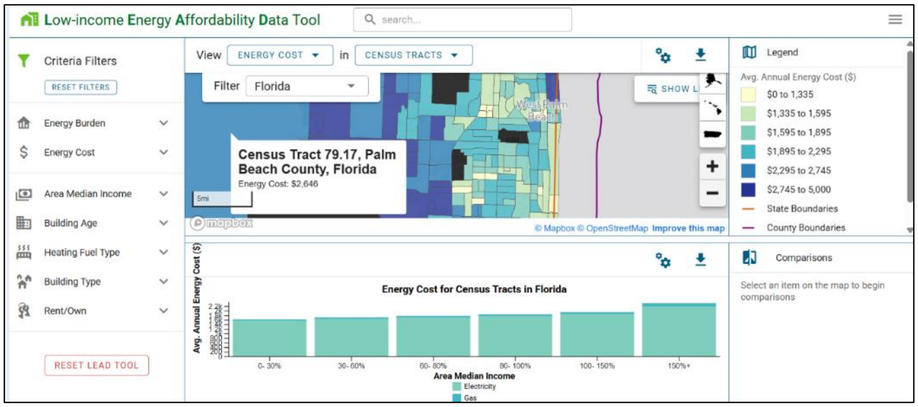
4. In **Input Features or Dataset**, select Tracts. In **Clip Features**, select the shapefile of your study area. Lastly, name the new feature layer in **Output Features or Dataset**.

5. Select **Run**. A new layer will be created in your **Contents** pane with the clipped health data.

1.9 Acquiring Energy Data from LEAD

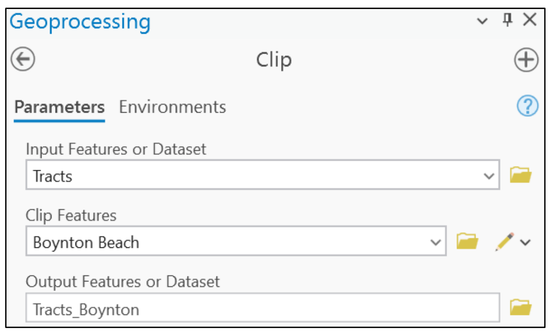
For our analysis, we acquired energy data to analyze the relationship between albedo and energy cost.

1. To acquire energy data, navigate to the Low-income Energy Affordability Data Tool **(LEAD)** to mine and download data.[6]



2. After locating the desired data and **filtering by location** and **census tracts**, import a data table with the average annual energy cost into ArcGIS Pro.

3. To clip this data to your study area, open the **Geoprocessing** pane and select the **Clip** tool.



4. In **Input Features or Dataset**, select Tracts. In **Clip Features**, select the shapefile of your study area. Lastly, name the new feature layer in **Output Features or Dataset**.

5. Select **Run**. A new layer will be created in your **Contents** pane with the clipped energy data.

2. Data Analysis

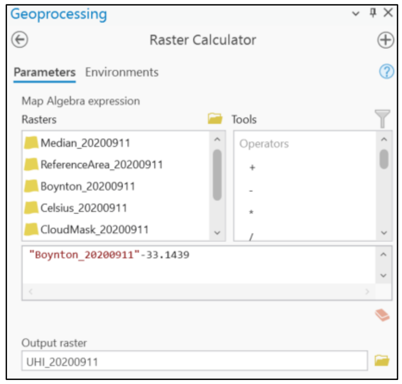
2.1 Composite Daytime UHI

After performing the processing steps for each day in our study period, we created a composite image combining all these days for our analysis. Our study was split into two periods: 2013–2019 and 2020–2024, so two composite images were created for daytime UHI.

1. After processing Landsat data, the UHI effect can be calculated using the following formula:

$$UHI = T_{Study\ Area} - T_{Reference\ Area}$$

2. In the **Geoprocessing** pane, open the **Raster Calculator** tool. Select the extracted study area LST map and subtract the **median** value of the **reference** area, which was calculated in 1.6 Unit Conversion, Extracting Polygons, and Calculating the Median for UHI.

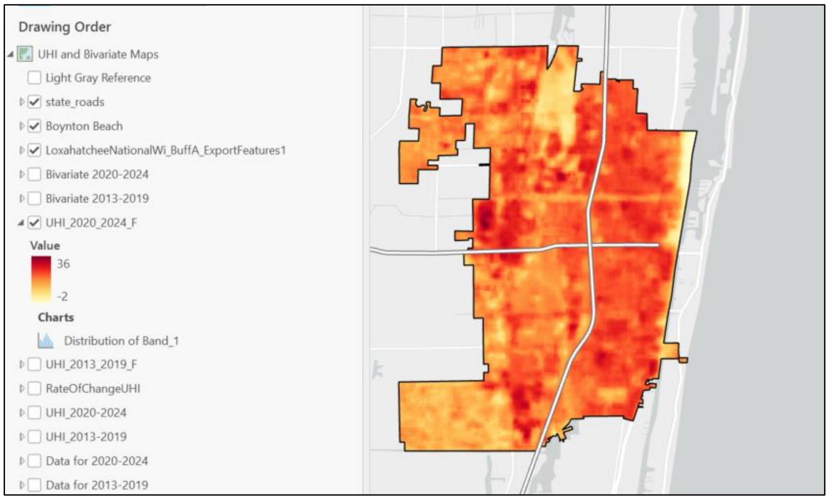


3. For our analysis, the UHI effect (along with each processing step) was calculated for every available day in our study periods (2013–2019, 2020–2024) during the hottest months (July 1st to September 30th).

4. After compiling all of the UHI data, a **composite** image was created combining each day in our study period by taking the median value of each pixel. In the Geoprocessing pane, open the **Cell Statistics** tool.

5. In **Input rasters or constant values**, select all the calculated UHI layers in your study period. In **Output raster**, name your new composite layer. In **Overlay statistic**, change the statistic from **Mean** to **Median**.

6. Select **Run**. This will produce a composite image of the median UHI value of each pixel in the study area.

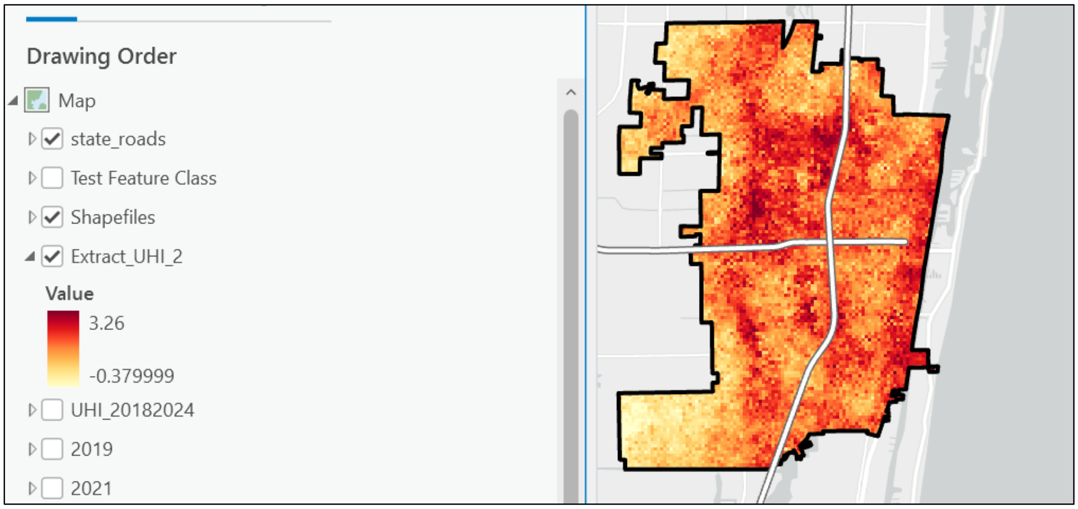


Basemaps credits: NASA–ESRI EULA

2.2 Composite Nighttime UHI

Similarly to our daytime UHI analysis, we created a composite image displaying nighttime UHI for comparison.

1. After the ECOSTRESS data are processed, the UHI effect can be calculated using the same formula used in 2. Data Analysis
2. 2.1 Composite Daytime UHI.
3. In the Geoprocessing pane, open the **Raster Calculator** tool. Select the extracted study area LST map and subtract the **median value** of the **reference** area, calculated in 1.6 Unit Conversion, Extracting Polygons, and Calculating the Median for UHI.
4. For our nighttime analysis, we calculated the UHI effect for each available day from 2018–2024 during the hottest months (July 1st to September 30th).
5. A composite image was created from the median value of each pixel from each day in the study period, similarly to the daytime analysis. In the **Geoprocessing** pane, open the **Cell Statistics** tool.
6. In **Input rasters or constant values**, select the calculated UHI data for each day in your study period. In **Output raster**, name your new composite layer. Change the **Overlay statistic** from **Mean** to **Median**.
7. Select **Run**. This is the **composite nighttime UHI map**. An example of ours is shown below.



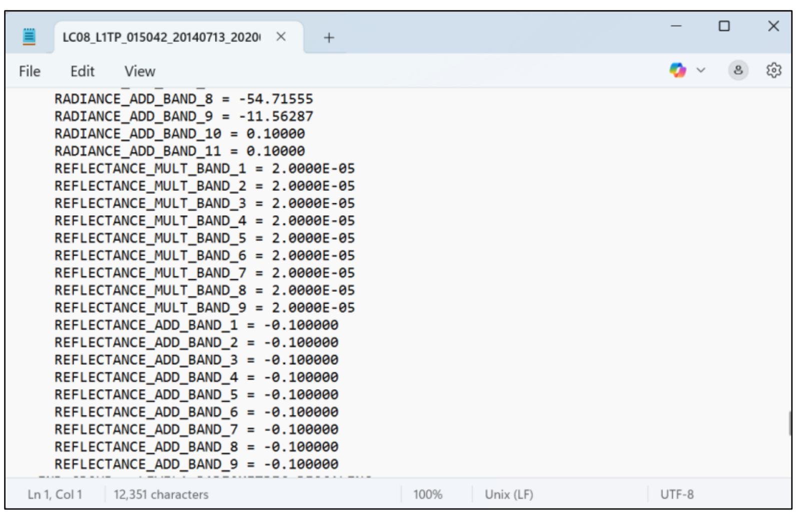
Basemaps credits: NASA–ESRI EULA

2.3 Albedo

We created maps displaying albedo to analyze the differences in reflectance in urban and surrounding areas.

1. Import the data into ArcGIS pro and save, separating by year (2014 and 2024).

2. To measure albedo, first calculate top of atmosphere (TOA) in the **Raster Calculator geoprocessing tool**. The variables are reflectance multi band value (M), raster band (Q), reflectance add band value (A), and sun elevation angle (SE), which can be found in the XML file of the respective product bundle.



```
RADIANCE_ADD_BAND_8 = -54.71555
RADIANCE_ADD_BAND_9 = -11.56287
RADIANCE_ADD_BAND_10 = 0.10000
RADIANCE_ADD_BAND_11 = 0.10000
REFLECTANCE_MULT_BAND_1 = 2.0000E-05
REFLECTANCE_MULT_BAND_2 = 2.0000E-05
REFLECTANCE_MULT_BAND_3 = 2.0000E-05
REFLECTANCE_MULT_BAND_4 = 2.0000E-05
REFLECTANCE_MULT_BAND_5 = 2.0000E-05
REFLECTANCE_MULT_BAND_6 = 2.0000E-05
REFLECTANCE_MULT_BAND_7 = 2.0000E-05
REFLECTANCE_MULT_BAND_8 = 2.0000E-05
REFLECTANCE_MULT_BAND_9 = 2.0000E-05
REFLECTANCE_ADD_BAND_1 = -0.100000
REFLECTANCE_ADD_BAND_2 = -0.100000
REFLECTANCE_ADD_BAND_3 = -0.100000
REFLECTANCE_ADD_BAND_4 = -0.100000
REFLECTANCE_ADD_BAND_5 = -0.100000
REFLECTANCE_ADD_BAND_6 = -0.100000
REFLECTANCE_ADD_BAND_7 = -0.100000
REFLECTANCE_ADD_BAND_8 = -0.100000
REFLECTANCE_ADD_BAND_9 = -0.100000
```


3. To convert the SE value from degrees to radians before plugging into the equation, find a degree to radian conversion tool online and use the radian value for the equation listed below. Repeat this step for bands 2,4,5,6,7 for each individual day of interest.

$$TOA = \frac{(MQ + A)}{\sin(SE)}$$

4. After calculating the TOA value for each desired day, we used the following equation to calculate albedo: [7]

$$Albedo = \frac{(0.365(b_2) + 0.130(b_4) + 0.373(b_5) + 0.085(b_6) + 0.072(b_7) - 0.0018)}{1.016}$$

5. Using the raster calculator geoprocessing tool, plug in each TOA value for the bands of interest (2,4,5,6,7) into the above equation.

6. After retrieving the albedo for each day, use the cell statistics geoprocessing tool to create a composite image. Select each desired day for that season and select median for the calculation.

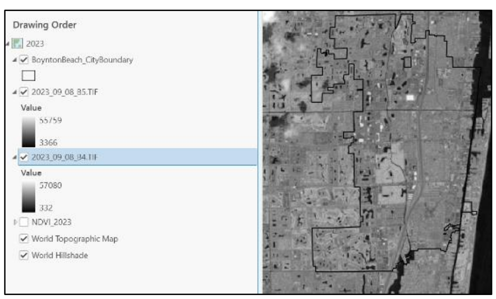
7. Refer to Section **1.5 Cloud Mas** to cloud mask this composite data.

8. After combining the yearly data, navigate to symbology and switch the stretch type to minimum maximum.

2.4. NDVI

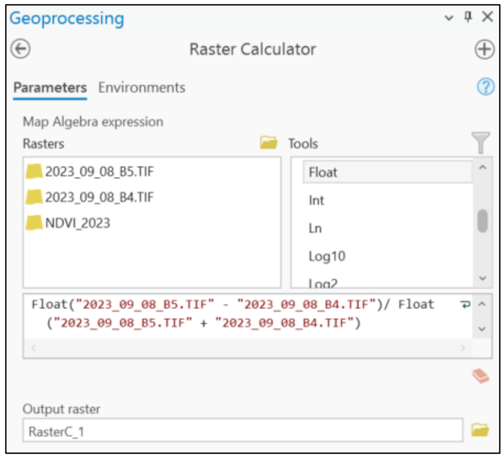
NDVI depicts the health and density of vegetation. It is important to consider when examining heat because vegetation often has a direct correlation with land surface temperature. In our team's results, we found that areas with healthier and denser vegetation often had the coolest land surface temperatures.

1. To add the data in Arc Pro, open the file and select the two file names that end with "B4" and "B5". You are selecting for bands 4 and 5, which is how to calculate NDVI. You can also rename these files for convenience (2023_09_08_B5)



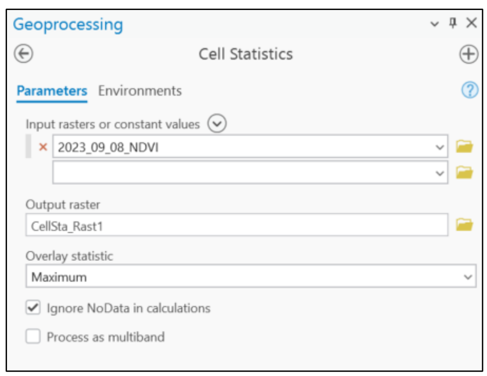
2. To calculate NDVI, open the raster calculate geoprocessing tool. The equation is as follows: [8]

$$NDVI = \frac{Float(Band5 - Band4)}{Float(Band5 + Band4)}$$



3. Once the NDVI is calculated for the day, repeat this process for all the days you would like to use for the year.

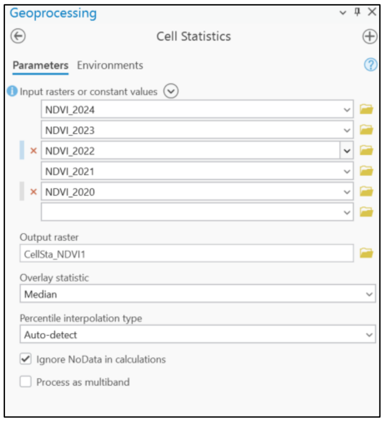
4. Use the **Cell Statistics** Geoprocessing tool to take the maximum of all the NDVI values for the year. There will be more days in your version, this image only shows one day.

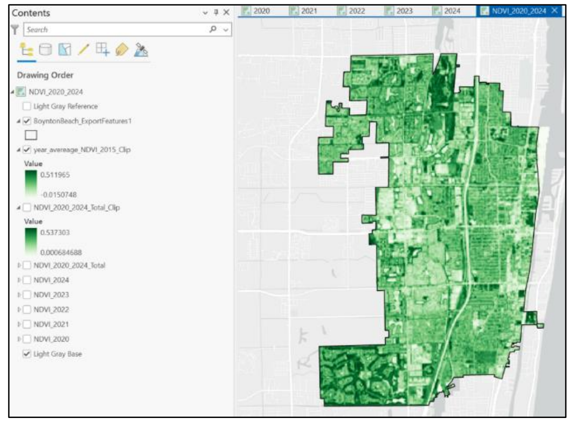


5. This should provide you with an annual NDVI map. The values should be between -1 and 1.

6. To get the raster in a more digestible format, navigate to the **Analysis** tab at the top of your screen. Under this tab, click **Tools**, and search for the **Clip Raster** tool in the geoprocessing window on the right side to size the raster to your study area, and change the symbology to a green color gradient.

7. Repeat this process for each year, and to get a 5-year map, use the **Cell Statistics** tool again. Upload all 5 NDVI maps and take the median of them. Select **Run**. This will provide the final NDVI map!





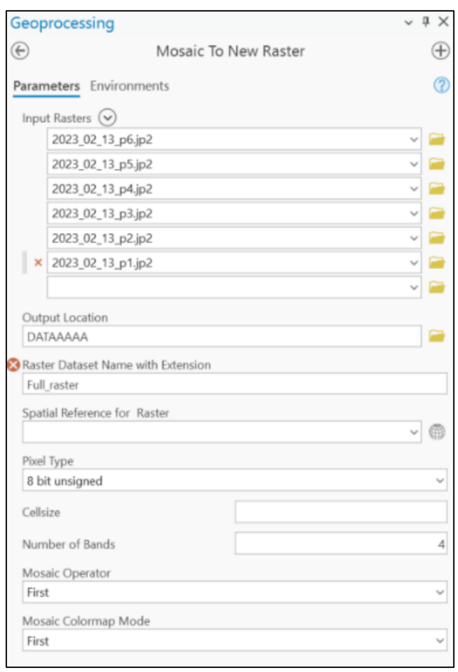
Basemaps credits: NASA–ESRI EULA

2.5 Tree Canopy

Tree Canopy is essential when breaking down the different factors of heat and LST. Our team's results found that tree canopy and shade were often associated with the coolest daytime land surface temperatures.

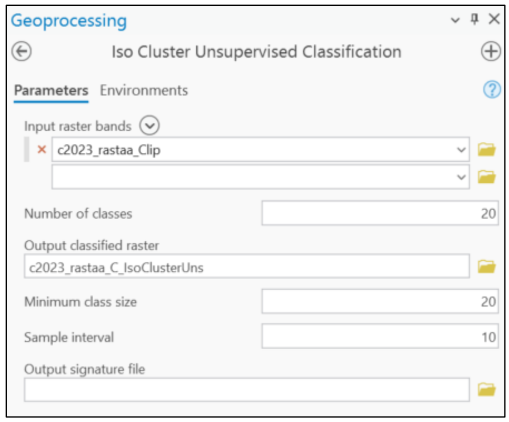
1. In EarthExplorer, under datasets and aerial imagery, select NAIP. Download the files that encompass your study area and unzip them. For Boynton Beach, there were 6 separate images that encompassed the city.

2. Upload into ArcGIS Pro (rename the files if desired) and use the **Mosaic to New Raster** tool to combine images from the same day, as shown in the image below. This will combine all 6 images into one raster. Make sure to double check the pixel type (8 bit unassigned) and check there are 4 bands.



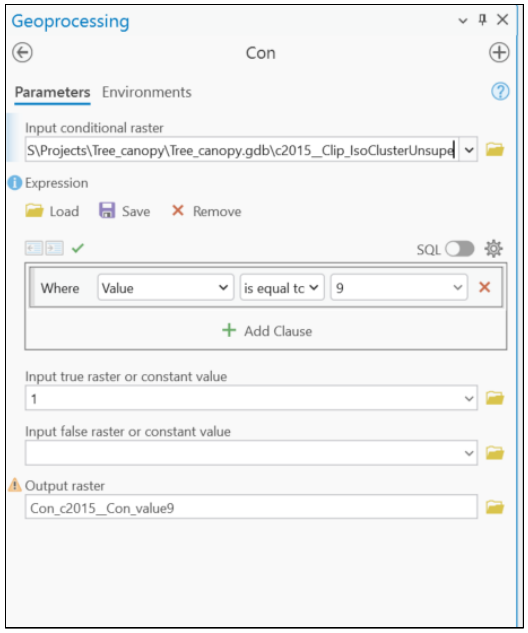
3. Clip the new raster to the parameters of Boynton Beach using the **Clip Raster** tool. That way only the data in Boynton Beach are processed.

4. Start classifying tree canopy by opening the **ISO Cluster Unsupervised Classification** tool. Upload the clipped raster file into the tool, and select the number of classes you are interested in. Even if eventually you only want two classes (tree and non-tree), it is best to start with a larger number and classify them yourself for better accuracy. For this project, we started with twenty classes.

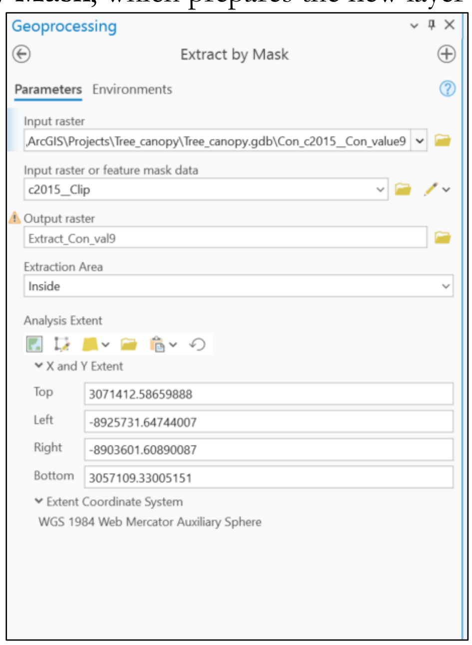


5. After running this tool, the result should be a very colorful map with 20 color classes ranging from 1 to 20. Zoom in, click around, and see if there are any classes that you can identify as tree or not tree. If there is a class that looks like it is comprised of roads or buildings, set it to grey and change the label to indicate what it is.

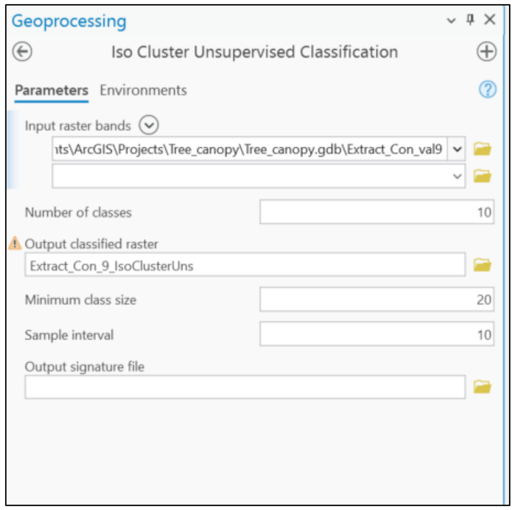
6. If there are classes mixed between trees and non-tree values (grass or shadow), you can perform a "cluster bust" to further sort them. This will re-classify a single class into 10 more sub-classes. There are a few steps needed to do this. First, identify which class you would like to re-sort. Then, use the **Con** tool to make a new layer with only this class. Set the value equal to the class number, and the input true raster equal to 1.



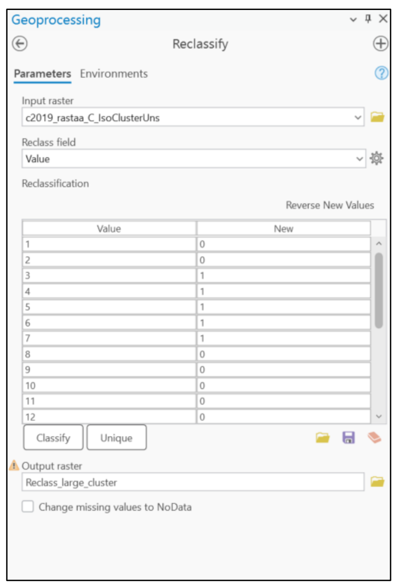
7. Next run a tool called **Extract by Mask**, which prepares the new layer to be re-sorted.



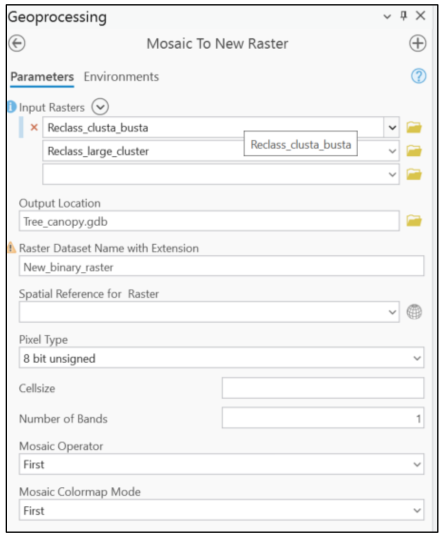
8. Now, it is time to re-classify the class. Run another ISO Unsupervised cluster, but this time you only need to make ten new classes. After this is created, again identify each sub-class as tree or not tree.



9. Now there should be two or more layers of classifications for tree and not tree. To make these layers you will need to convert them to Boolean values (true or false) by creating a binary. To do this, open the **Reclassify** geoprocessing tool, and reassign the values assigned tree or not tree with 1 or 0.



10. There should now be two or more (however many classes needed to be re-sorted) binary layers. You will need to combine these to get the most accurate data and perform overall calculations. To do this, open the **Mosaic to New Raster** geoprocessing tool. Make sure the pixel type and number of bands are correct. Input the cluster bust layer first, and then the larger classification layer. Then, at the bottom, make sure to select **First** for the mosaic operator.



11. Now your final tree canopy map is done! To perform calculations about total tree canopy cover, it may be easier to do in Excel. Open the attribute table for your tree canopy layer and look at the values. It should look simple with only two rows and look something like this:

	OBJECTID *	Value	Count
1	1	0	480135150
2	2	1	119163157
	Click to add new row.		

12. In Excel, calculate the count of the trees divided by the total count of pixels. For this example, it would look like (480135150 / (480135150 + 119163157)). This is used to calculate percent tree canopy by pixel.

13. If desired, the accuracy of this percentage can be determined by performing a confusion matrix.

2.6 Evapotranspiration

Evapotranspiration is a measurement of water moving from the Earth's surface and from plants into the atmosphere. We created a map displaying this in our study area to compare it with our vegetation maps.

1. Import the evapotranspiration data into ArcGIS Pro.

2. Compile each season's data of evapotranspiration, adding all data into a single map.

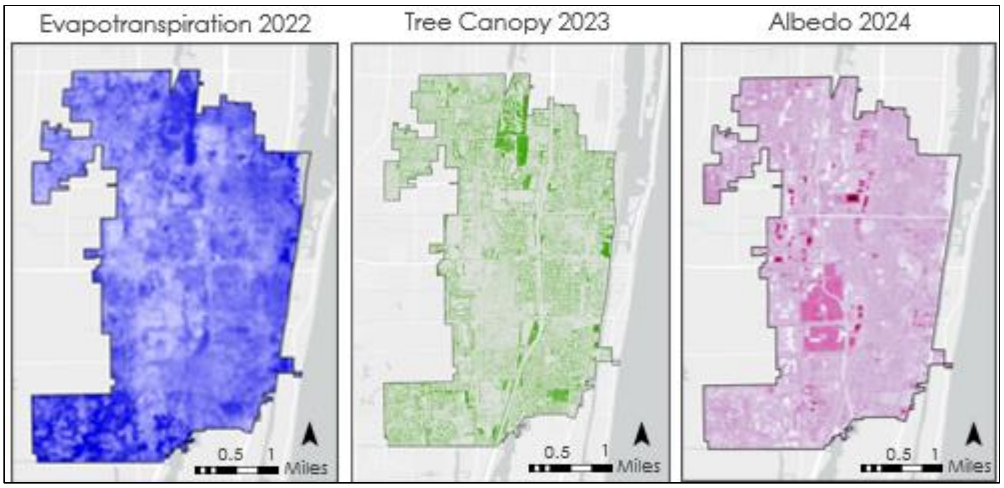
3. To create a median composite map over the specified period, navigate to the **Analysis** tab. Under analysis, click on **Tools.** In the **Find tools** search bar, search for the **Cell Statistics** geoprocessing tool. Ensure that you select the **Spatial Analyst** tool version.

4. Select each desired year under **Input Rasters.** For our project we compiled data from 2021 and 2022. Name the output raster **MedianCompositeEvapotranspiration**. Select **Median** for the overlay statistic and click run.

5. The resulting map will produce the median composite of all desired years of data for evapotranspiration.

2.7 Heat Hot Spot Analysis

1. Place calculated albedo, evapotranspiration, and tree canopy composite data from their most recent year into a single map.



Basemaps credits: NASA–ESRI EULA

2. Resample the data to create a common coordinate system amongst the indices.

3. Using the project raster data management geoprocessing tool, begin by setting parameters.
    a. **Input**: dataset that needs to be converted.
    b. **Output**: dataset that serves as desired coordinate system (e.g., albedo in this project)
    c. **Geo transform**: accept
    d. **Resampling**: bilinear interpolation
    e. **Output cell size**: same dataset as output (e.g., albedo in this project)
    f. **XY**: accept

4. Navigate to the **Environments** tab in the **Geoprocessing** tool
    a. **Snap raster**: choose the output layer (e.g., albedo in this project)

5. To normalize, open the **Raster Calculator** tool in the **Geoprocessing** pane.

6. Use the following equation to normalize albedo, evapotranspiration, and tree canopy data.

$$x = \frac{(x - x_{min})}{(x_{max} - x_{min})}$$

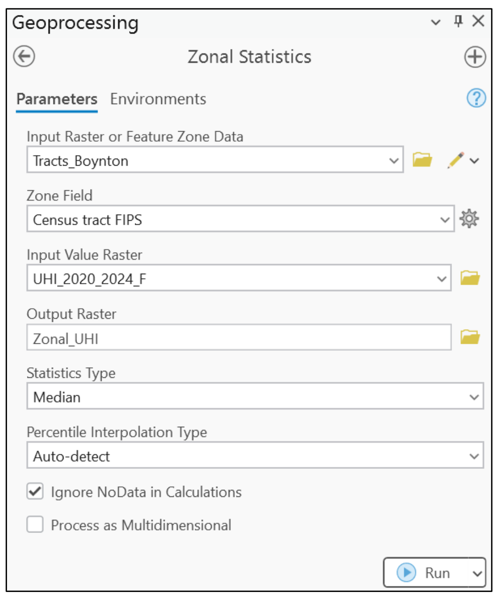
7. After normalizing each dataset, combine each of them using the **Cell Statistics** tool. Select each normalized dataset and select median for the overlay statistic. This will create a heat hotspot map with values between 0 and 1.

2.8 Heat Vulnerability Index

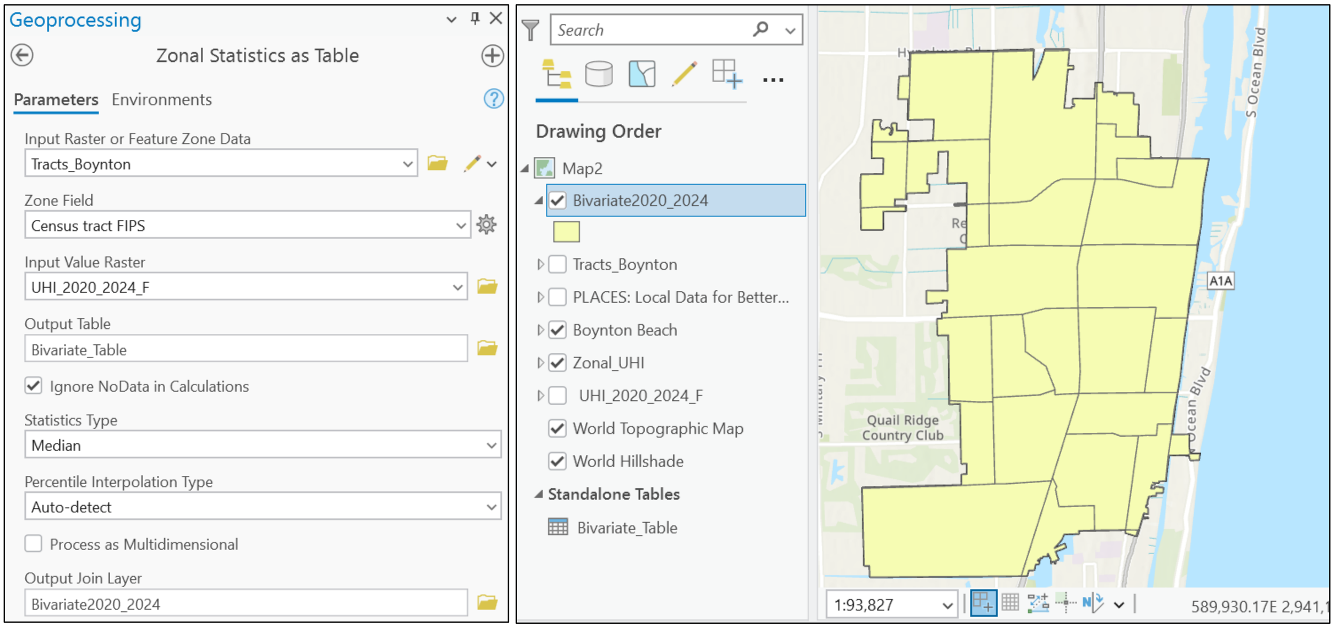
A bivariate map was created to generate the heat vulnerability index. For this analysis, our study compared crude asthma prevalence data with data from our composite daytime UHI analysis. Ensure that the health data are imported into ArcGIS Pro (1.8 Acquiring CDC Health Data from the ArcGIS Online Portal).

1. In the **View** tab, open the **Geoprocessing** pane and open the **Zonal Statistics** tool.

2. In **Input Raster or Feature Zone Data**, select **Tracts**. In **Zone Field**, select **Census tract FIPS**. In **Input Value Raster**, select the composite image of your UHI effect. In **Output Raster**, name this new layer. Finally, change **Statistics Type** from **Mean** to **Median**. This will calculate the median of the UHI data for each tract to ensure that it can later be combined with the health metric.



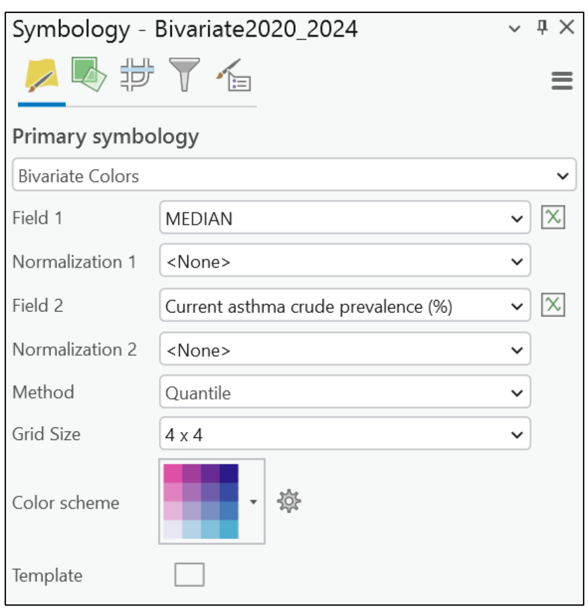
3. In the Geoprocessing pane, open the **Zonal Statistics as Table** tool. In **Input Raster or Feature Zone Data**, select the layer you created in the previous step. In **Zone Field**, select Census tract FIPS. In **Input Value Raster**, select your composite UHI data. In **Output Table**, name the attribute table that will be created. Change the **Statistics Type** from Mean to Median. Lastly, in **Output Join Layer**, name the new layer that will be created.



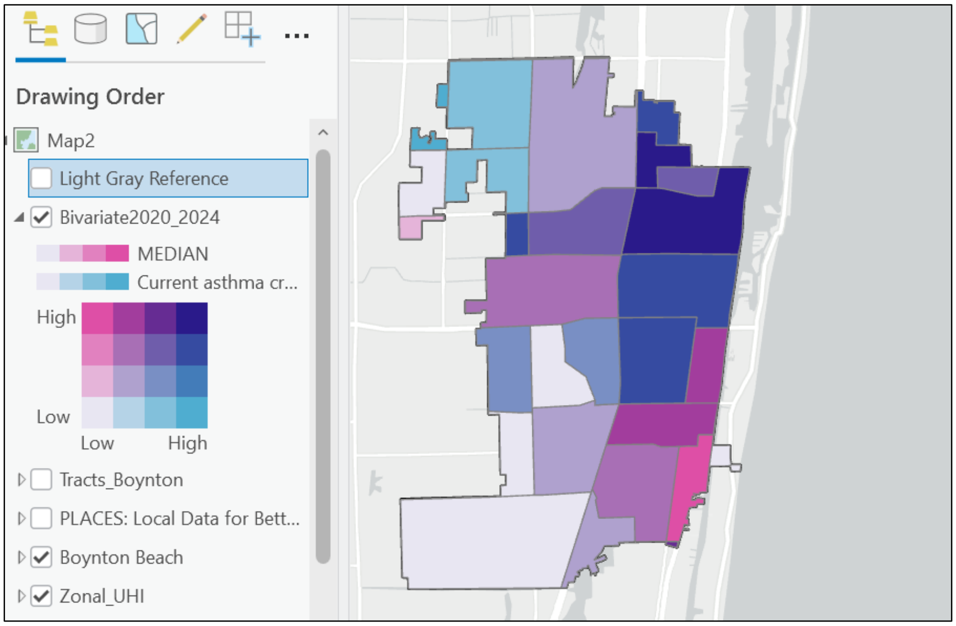
Basemaps credits: NASA–ESRI EULA

4. Select **Run**. This will create a new layer in your **Contents** pane. Right-click the layer and select **Symbology**. In the dropdown, change the **Primary Symbology** from **Single Symbol** to **Bivariate Colors**.

5. In **Field 1**, select **MEDIAN**. This was the statistics type with your heat data created in the last step. In **Field 2**, select **Current asthma crude prevalence (%)**. This is a health metric to combine the heat data with. We changed the **Grid Size** to **4x4** for our analysis.



6. This will create a bivariate map comparing crude asthma prevalence and urban heat island effect data.



Basemaps credits: NASA–ESRI EULA

2.9 Albedo and Energy Bivariate Map

The correlation between albedo and annual energy cost is quantified through creating a bivariate map.

1. See section 1.9 to download energy data and import it into ArcGIS Pro.

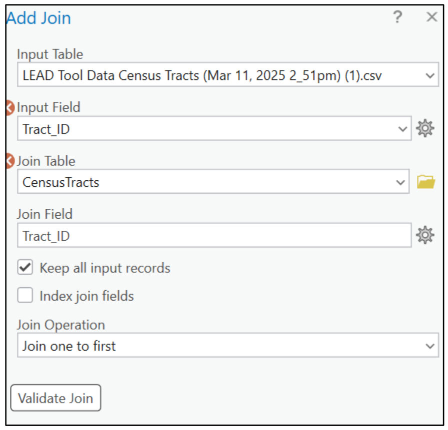
Field: Add Calculate Selection: Select By Attributes Zoom To Switch Clear Delete Copy Rows: Insert

	Geography ID	Avg. Annual Energy Cos...	Avg. Annual Energy Cos...	Avg. Annual Energy Cos...	Avg. Annual Energy Cos...	Black/ African American...	American Indian/
1	12099005000	1611	1564	47	0	21	4
2	12099005101	1746	1711	27	8	20	2
3	12099005102	2017	1913	102	2	26	0
4	12099005202	1547	1513	31	3	19	0
5	12099005203	1274	1255	19	0	10	8
6	12099005204	1621	1567	53	1	9	1
7	12099005300	1511	1468	43	0	6	0
8	12099005411	1723	1661	59	3	0	0
9	12099005412	1345	1336	8	1	1	0
10	12099005413	1253	1237	16	0	0	0
11	12099005501	1504	1445	59	0	39	0
12	12099005502	2140	2101	38	1	29	0
13	12099006203	2215	2199	15	1	47	1
14	12099006203	1344	1336	8	0	0	0
15	12099005702	1833	1821	10	2	67	0

2. After importing the above data table, search for census tract data from the desired area of focus.

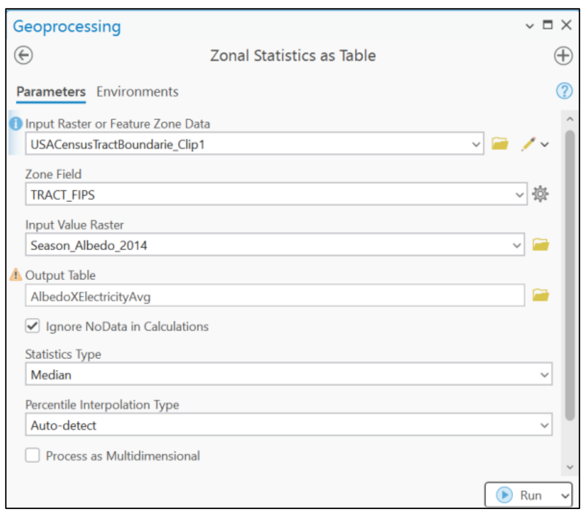
3. **Download** the **census tract data** for the desired area and import into ArcGIS.
4. Right click on the LEAD Tool Data Census Tracts chart and navigate to **joins and relates**. Click **add join**.

5. In the add join tool, make your input table the data table with the annual energy cost data from LEAD. **Input Tract_ID**. Make the **join table** your **Census Tract table**. Make the **join field Tract_ID** again to make this the common factor between the two tables. Click okay.



6. Name this table TractXEnergy Cost and delete all extra fields except Tract ID and average annual energy cost.

7. To bring in albedo data, locate the **Zonal Statistic as Table** geoprocessing tool. Input your census tracts as the input raster. Make the zone field TRACT_FIPS. Your input raster value should be your albedo data. Finally, name your output value albedoXelectricityaverage.

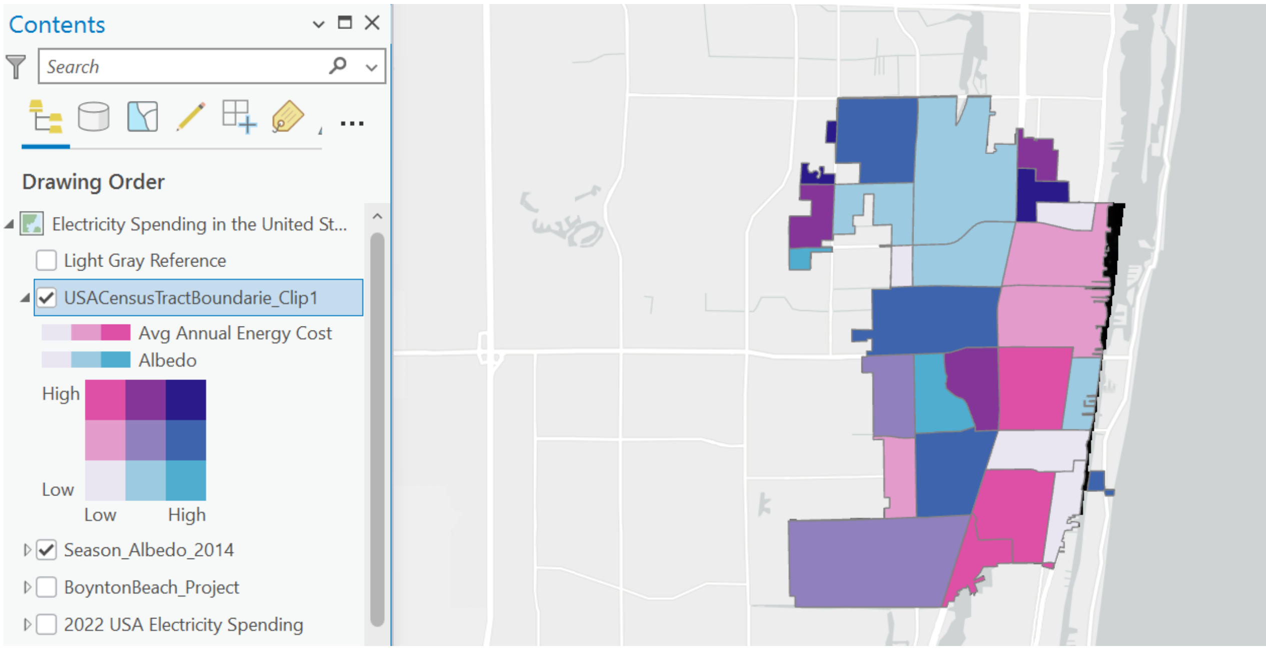


8. After creating this table, **create a join** between your **tract raster layer** and **albedoXelectricityavg** table using the same methods as step 7. This should create a raster layer containing tract, energy cost, and albedo.

9. Navigate to the **symbology** of the **tract raster layer**.

10. Select **Bivariate Colors** as your primary symbology. In **Field 1**, specify **annual energy cost.** In **Field 2**, select your **albedo data** (pictured in the image below as MEDIAN). Choose **Quantile** as your method.

11. The resulting map should look like the one below.



Basemaps credits: NASA–ESRI EULA

Conclusion

This tutorial outlined the process for creating and analyzing LST, albedo, evapotranspiration, tree canopy, and vegetation health in order to gain a comprehensive overview of the many factors contributing to urban heat. In the future, partners can reference this tutorial when using Earth observation data to create similar maps. Having maps to visualize these environmental and infrastructural factors makes this data more digestible to a general audience and policy makers. Expanding public understanding of the heat challenges facing Boynton Beach is essential for collective change. This information and data will help the city when making informed decisions about areas in need of more tree canopy and vegetation, alternative cooling methods, and other heat mitigating resources.
The process of making bivariate maps was also outlined throughout this tutorial. This information provides the City of Boynton Beach with data to make informed decisions on potential locations for community cooling centers. Moreover, it provides information on identifying areas where heat mitigation efforts may be directed. Overall, this step-by-step guide provides the partners with an in-depth tutorial on map recreation to continue assessing urban heat and its causative factors in Boynton Beach in the future, allowing them to effectively utilize Earth observations for future city planning efforts.

Acknowledgements

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Aeronautics and Space Administration.

This material is based upon work supported by NASA through contract 80LARC23FA024.

Citations

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Licensing

We used the Advanced ArcGIS Pro license and the 3D analyst, geostatistical analyst, and spatial analyst extensions.