Milky Way Visibility Maps
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Project Information:

I, Sarah Kurelowech, am conducting research on the points around a city or town in which the Milky Way can be seen. I am conducting this research under Diane Turnshek and Stephen Quick, both of Carnegie Mellon University.

I hope to analyze light pollution maps in order to gain an understanding of the shape that the visibility boundary makes around a city. I also wish to determine if the shape is in any way influenced by the terrain surrounding the city and, if so, how it is influenced.

The research began on July 24th, 2020 and will continue through the end of the summer session. I would like to have the project continue longer than the scheduled class time, if possible.

Objectives:

1. Determine where the Milky Way can be seen at points around a city.
2. Analyze how the terrain around a city influences the visibility of the Milky Way.

Methodology:

1. Determine and define at what light pollution level the Milky Way can be seen.
2. Determine which cities to analyze.
3. Look up these cities using multiple light pollution maps.
4. Determine which colors on the map correspond to the defined light pollution level.
5. Take a screenshot of the map being sure to include the area in which the Milky Way can be seen.

6. Carefully trace the boundary line.
7. Repeat for all desired cities.
8. Analyze the results.

Internship Role:

During my time working on this project, I created maps with boundary lines indicating the point in which the Milky Way can begin to be seen around a city. In addition to these maps, I measured the distance between the city center and the boundary for each cardinal direction.

To begin my tasks, I first determined how to tell where the Milky Way was visible. On the Bortle Scale, at a value of 5, the Milky Way is barely visible and appears washed away. I decided to use 5 as the value at which I would say the Milky Way is visible. I assumed that most people's eyesight would be decent enough at this value to see even a washed away Milky Way. In my opinion, this is considered visible.

I then had to convert this to units of mag/arcsec^2 so that the values would correspond to those on the light pollution maps. 5 on the Bortle Scale was found to be 19.1-29.4 mag/arcsec^2. I used this range of values to look at the legend on the light pollution map and determine the color in which the Milky Way could be seen.

I began by using two light pollution maps[1] and compared their outputs to determine the optimal map to use for the project. In comparison, the first map source that I used appeared to

[1] Two light pollution map sources.
https://www.lightpollutionmap.info/#zoom=9.80&lat=5047007&lon=-8558398&layers=B0FFFFFTFFFFFFFFF
https://darksitefinder.com/maps/world.html#4/39.00/-98.00

have more detail about small-town light pollution. On the other hand, it seemed that the second link took the city data and then extrapolated it out to the small towns without actually taking data in the small towns. Since I am gathering images for both small towns and large cities, it is necessary that the small-town maps be as accurate as possible. The following figure shows the difference between the two sources in a small-town case.

I have been able to gather map screenshots for 23 cities so far. With these screenshots, I drew the boundaries of where the Milky Way could be seen. These images can be seen in the results section. I then used the map to determine the distance between the city center and the edge of the boundary in each of the cardinal directions. This is to give a sense of really how far out of the city a person must be to see the Milky Way. This data can also be found in the results section. After this, I took map screenshots of the terrain in each of the cities, which are also visible in the results section. I use the terrain to explain the shape of the boundary.

Results:

In the following figure are the light pollution maps for the cities that I chose along with the Milky Way boundary lines and the surrounding terrain. It is important to note that the Milky Way could possibly be visible inside of these boundaries. More research is needed to determine why this happens or to define better boundary lines.

<table>
<tr><th>Milky Way Boundary</th><th>Terrain Map</th></tr>
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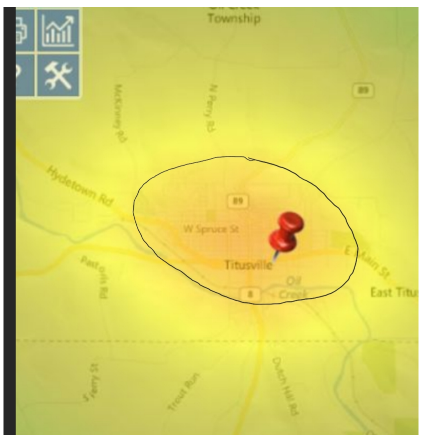

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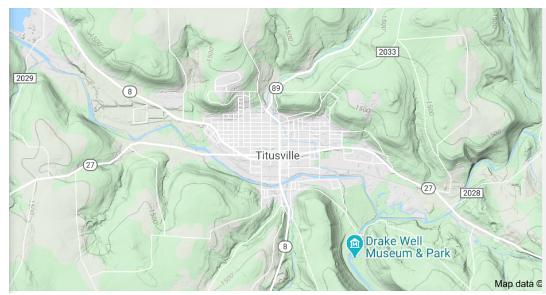

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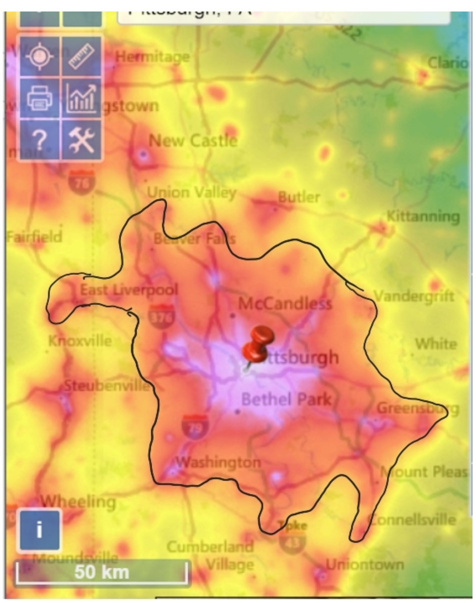

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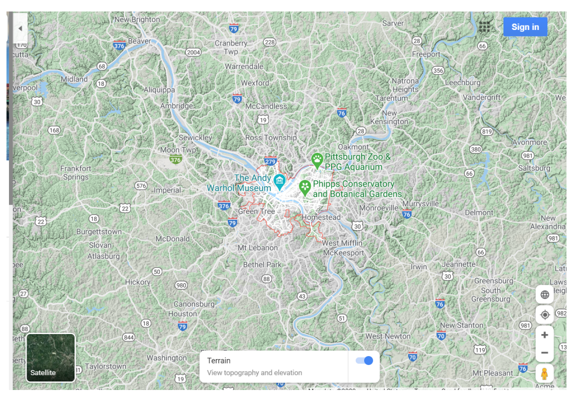

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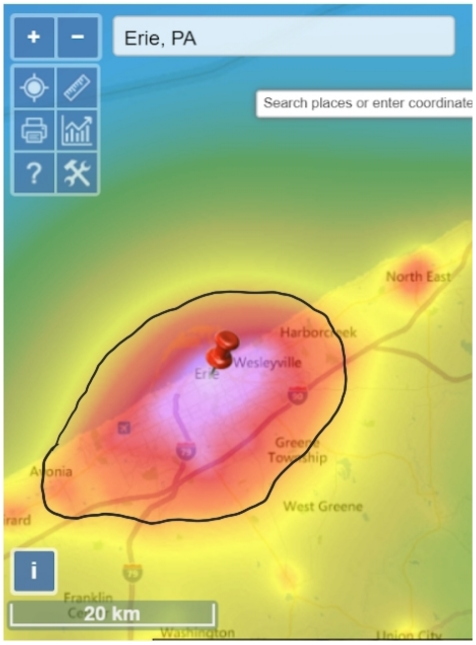
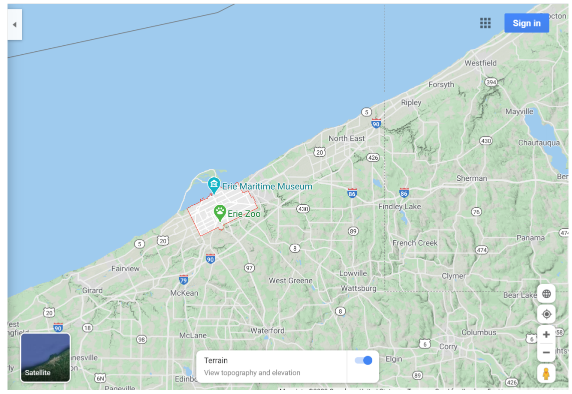
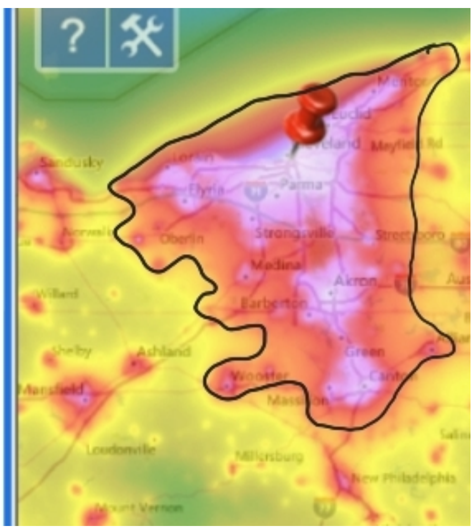
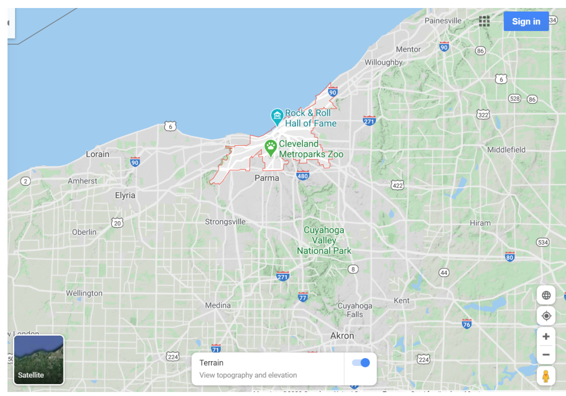
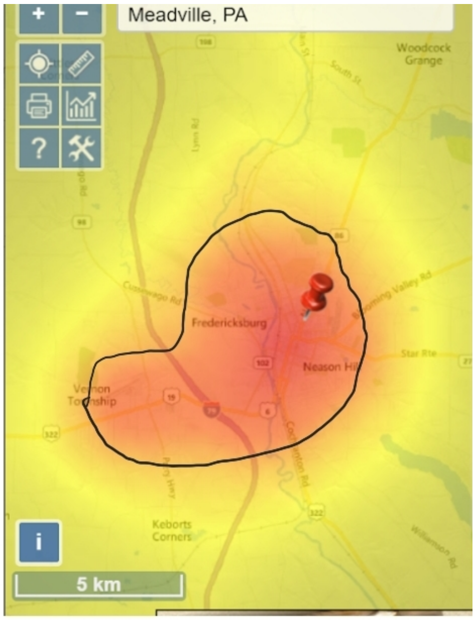
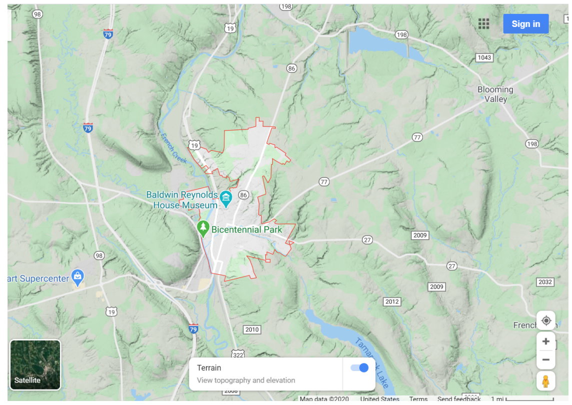

Erie, PA
Search places or enter coordinate
North East
Harborcreek
Wesleyville
Erie
Greene Township
West Greene
20 km

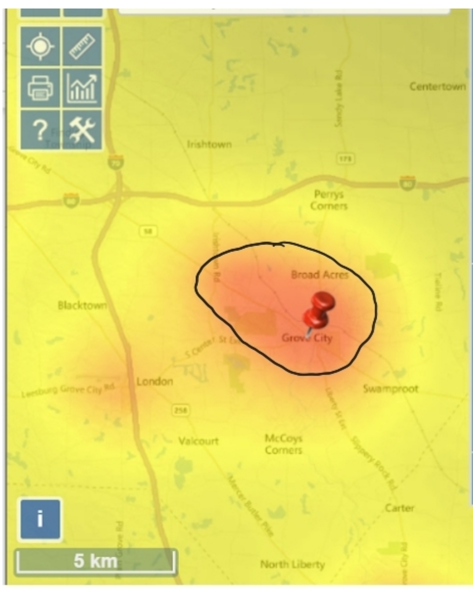

Sign in
Westfield
Ripley
North East
Erie Maritime Museum
Erie Zoo
Fairview
McKean
West Greene
Waterford
Terrain
View topography and elevation
Satellite

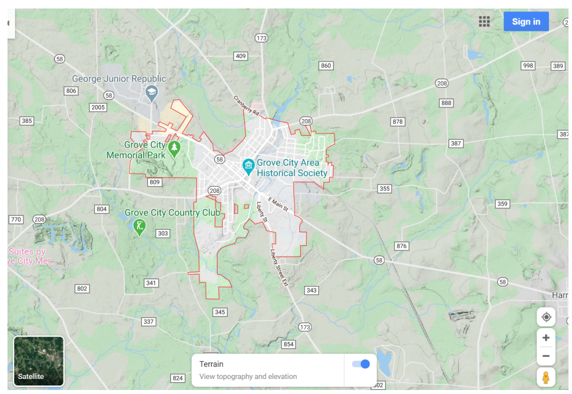

Sandusky
Lorain
Elyria
Parma
Oberlin
Strongsville
Medina
Akron
Barberton
Ashland
Wooster
Mansfield
Massillon

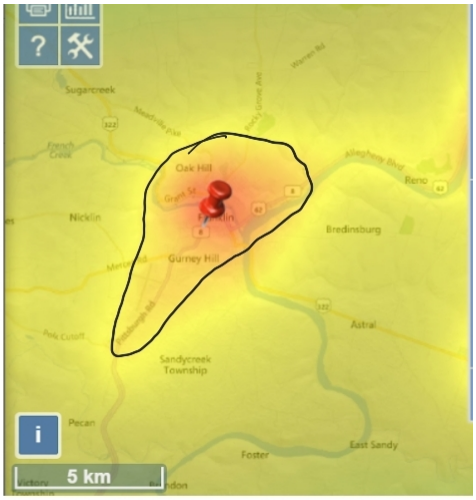

Sign in
Painesville
Mentor
Willoughby
Rock & Roll Hall of Fame
Cleveland Metroparks Zoo
Lorain
Elyria
Parma
Strongsville
Cuyahoga Valley National Park
Medina
Akron
Kent
Terrain
View topography and elevation
Satellite


Meadville, PA
Woodcock Grange
Fredericksburg
Vernon Township
Keborts Corners
5 km

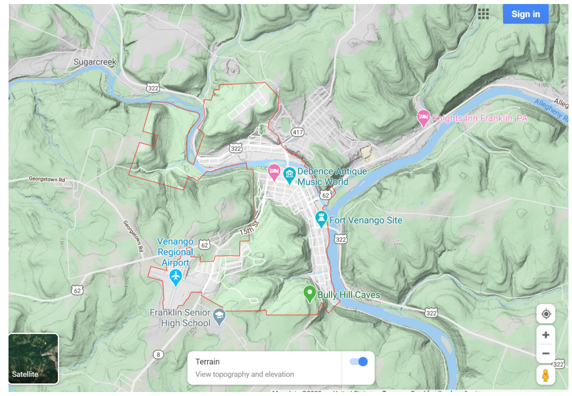

Sign in
Blooming Valley
Baldwin Reynolds House Museum
Bicentennial Park
Terrain
View topography and elevation
Satellite


Centertown
Irishtown
Perrys Corners
Broad Acres
Grove City
Blacktown
London
Swamproot
Valcourt
McCoys Corners
Carter
North Liberty
5 km

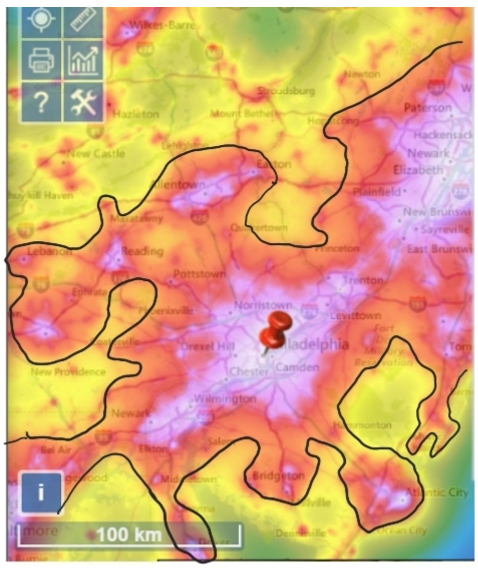

Sign in
George Junior Republic
Grove City Memorial Park
Grove City Area Historical Society
Grove City Country Club
Terrain
View topography and elevation
Satellite



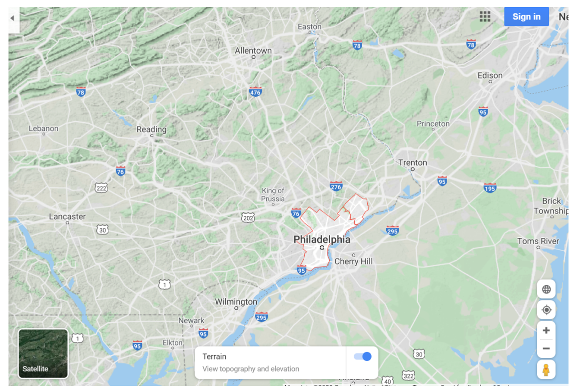
Sugarcreek
Oak Hill
Nickl!n
Bredinsburg
Gurney Hill
Astral
Sandycreek Township
Pecan
Foster
East Sandy
5 km



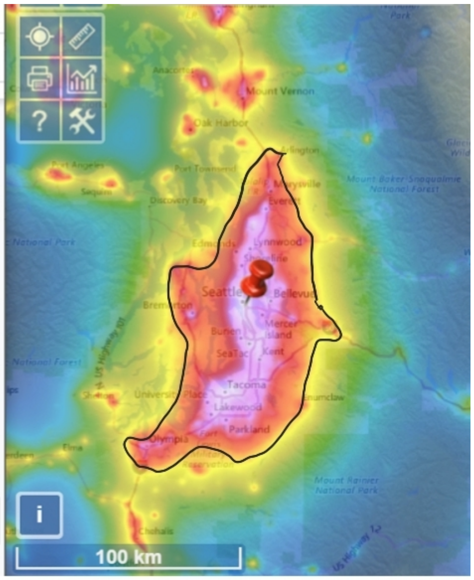
Sign in
Sugarcreek
Debence Antique Music World
Fort Venango Site
Venango Regional Airport
Bully Hill Caves
Franklin Senior High School
Satellite
Terrain
View topography and elevation

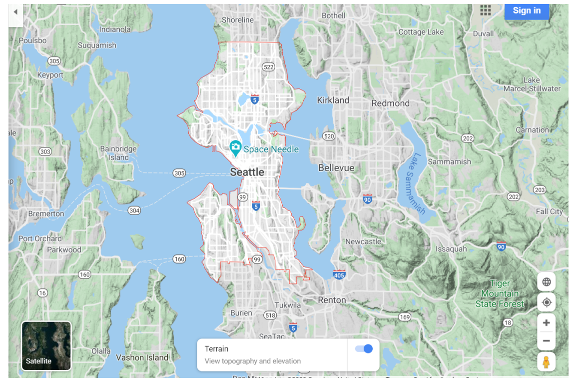


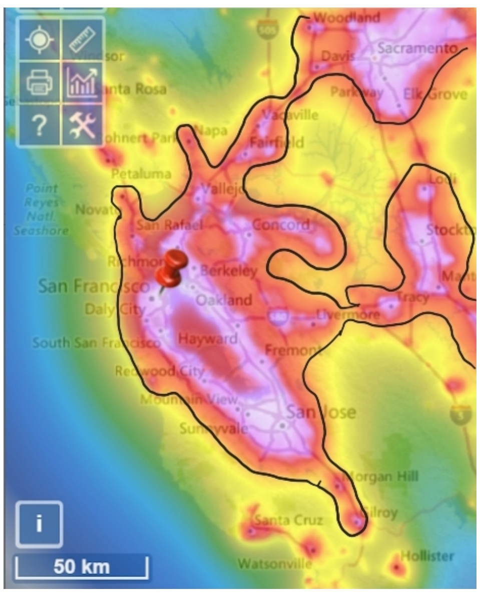
Wilkes-Barre
Hazleton
Stroudsburg
Paterson
Newark
Elizabeth
Allentown
Easton
Reading
Pottstown
Norristown
Trenton
Levittown
Camden
Chester
Wilmington
Newark
Bridgeton
Atlantic City
100 km

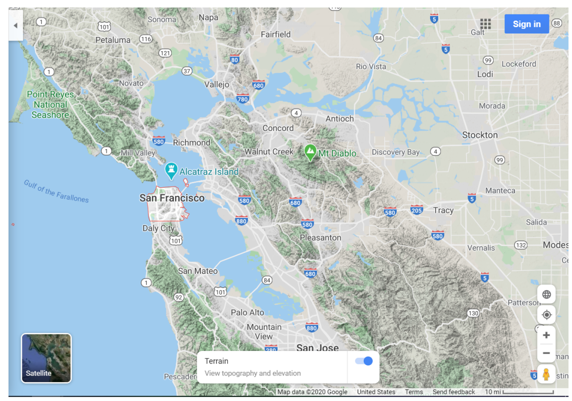


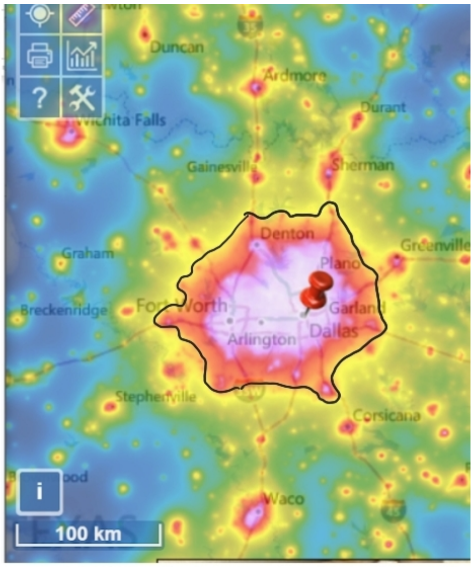
Sign in
Easton
Allentown
Edison
Lebanon
Reading
Princeton
Trenton
King of Prussia
Lancaster
Philadelphia
Cherry Hill
Toms River
Wilmington
Newark
Satellite
Terrain
View topography and elevation

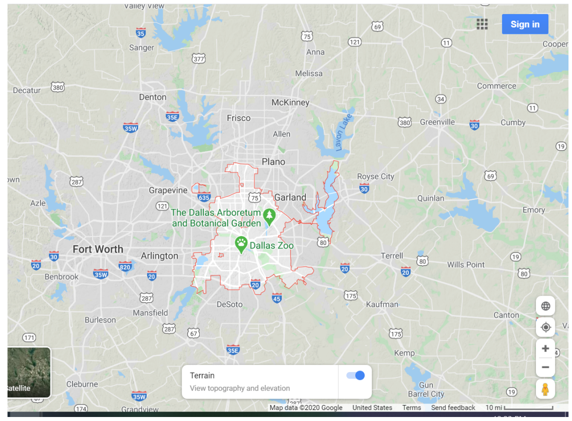

Mount Vernon
Oak Harbor
Port Angeles
Everett
Lynnwood
Seattle
Bellevue
Bremerton
Mercer Island
Burien
SeaTac
Kent
Tacoma
Lakewood
Parkland
Olympia
100 km

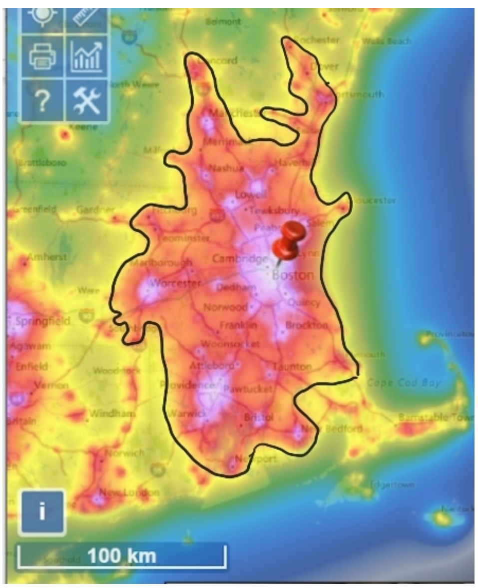

Sign in
Shoreline
Bothell
Kirkland
Redmond
Space Needle
Seattle
Bellevue
Bainbridge Island
Bremerton
Port Orchard
Newcastle
Issaquah
Renton
Burien
Tukwila
Vashon Island
Satellite
Terrain
View topography and elevation

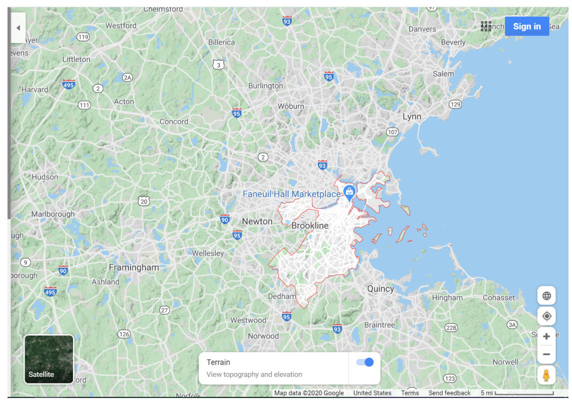

Woodland
Davis
Sacramento
Elk Grove
Vacaville
Fairfield
Napa
Petaluma
Vallejo
San Rafael
Concord
Berkeley
Oakland
San Francisco
Daly City
Hayward
Livermore
Fremont
Redwood City
Mountain View
San Jose
Sunnyvale
Morgan Hill
Santa Cruz
Watsonville
Hollister
50 km

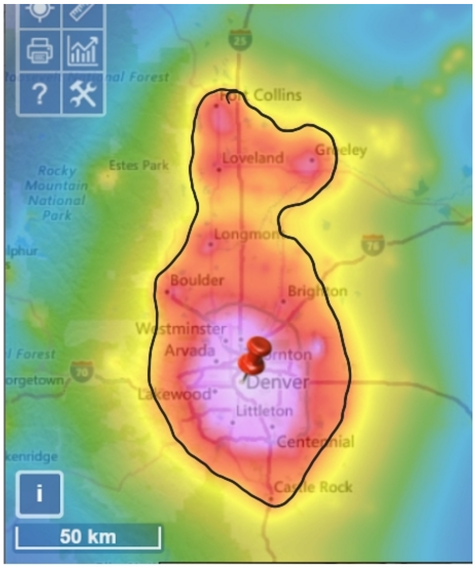
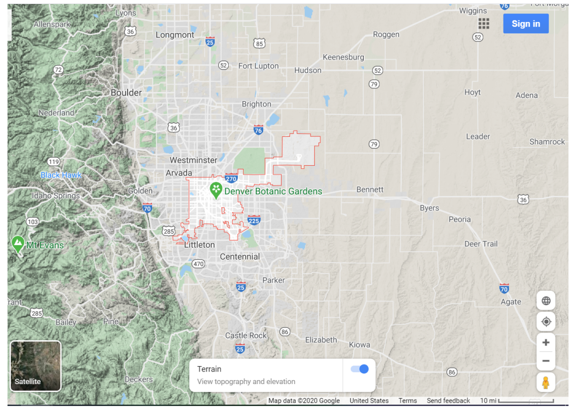
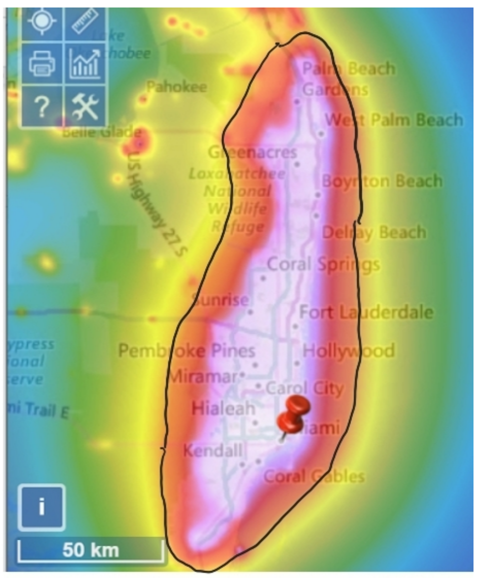
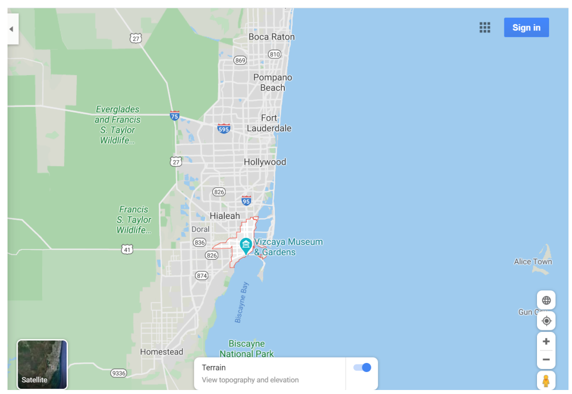

Sign in
Sonoma
Napa
Petaluma
Fairfield
Novato
Vallejo
Point Reyes National Seashore
Concord
Antioch
Richmond
Walnut Creek
Mt Diablo
Alcatraz Island
San Francisco
Daly City
Stockton
Lodi
Tracy
Pleasanton
San Mateo
Palo Alto
Mountain View
San Jose
Satellite
Terrain
View topography and elevation


Duncan
Ardmore
Durant
Wichita Falls
Gainesville
Sherman
Denton
Graham
Greenville
Plano
Breckenridge
Fort Worth
Garland
Dallas
Arlington
Stephenville
Corsicana
Waco
100 km


Sign in
Denton
McKinney
Frisco
Allen
Plano
Grapevine
Garland
The Dallas Arboretum and Botanical Garden
Dallas Zoo
Fort Worth
Arlington
DeSoto
Mansfield
Burleson
Cleburne
Terrell
Kaufman
Royse City
Greenville
Terrain
View topography and elevation


Worcester
Cambridge
Boston
Providence
100 km


Sign in
Lynn
Faneuil Hall Marketplace
Newton
Brookline
Framingham
Quincy
Dedham
Satellite
Terrain
View topography and elevation

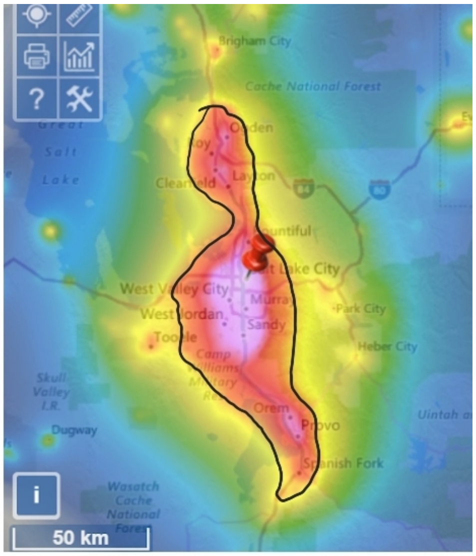
	
	

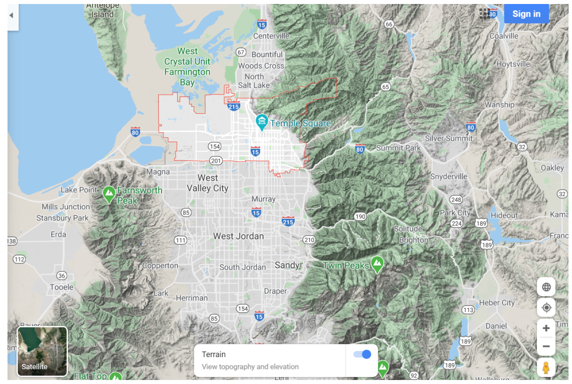
Fort Collins
Loveland
Greeley
Estes Park
Rocky Mountain National Park
Longmont
Boulder
Brighton
Westminster
Arvada
Denver
Lakewood
Littleton
Centennial
Castle Rock
50 km

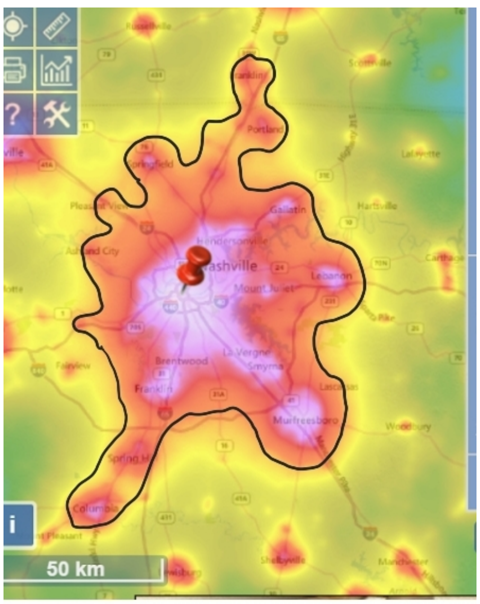
Longmont
Fort Lupton
Keenesburg
Roggen
Wiggins
Hudson
Boulder
Brighton
Hoyt
Adena
Leader
Shamrock
Westminster
Arvada
Denver Botanic Gardens
Bennett
Byers
Peoria
Deer Trail
Littleton
Centennial
Parker
Agate
Castle Rock
Elizabeth
Kiowa
Sign in
Terrain
View topography and elevation
Satellite

Palm Beach Gardens
West Palm Beach
Pahokee
Greenacres
Loxahatchee National Wildlife Refuge
US Highway 27 S
Boynton Beach
Delray Beach
Coral Springs
Sunrise
Fort Lauderdale
Pembroke Pines
Hollywood
Miramar
Carol City
Hialeah
Kendall
Coral Gables
50 km

Boca Raton
Pompano Beach
Fort Lauderdale
Everglades and Francis S. Taylor Wildlife
Hollywood
Francis S. Taylor Wildlife
Hialeah
Doral
Vizcaya Museum & Gardens
Homestead
Biscayne National Park
Sign in
Terrain
View topography and elevation
Satellite


Brigham City
Cache National Forest
Ogden
Layton
Clearfield
Bountiful
Salt Lake City
West Valley City
West Jordan
Murray
Sandy
Tooele
Park City
Heber City
Orem
Provo
Spanish Fork
Dugway
50 km


Temple Square
West Valley City
West Jordan
Sandy
Terrain
Satellite
Sign in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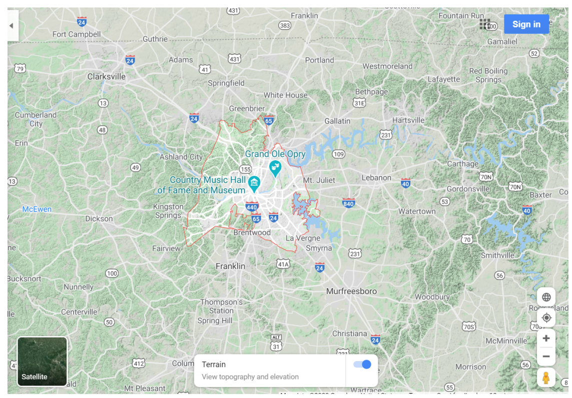
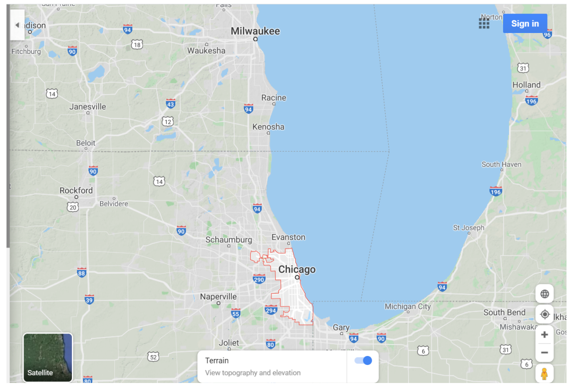
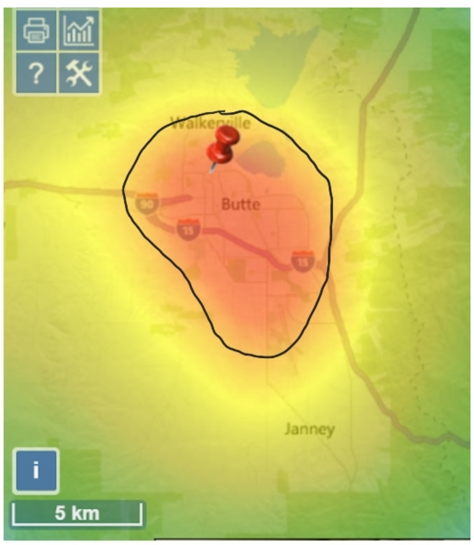
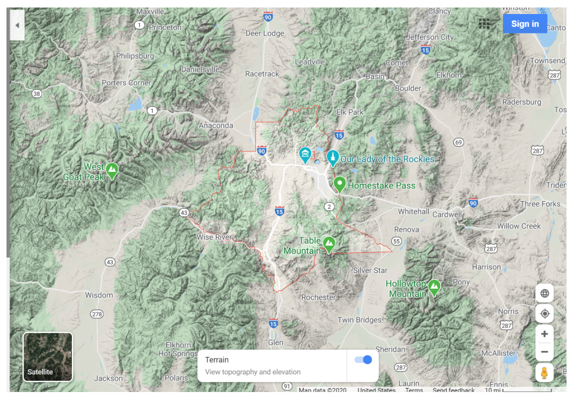
50 km

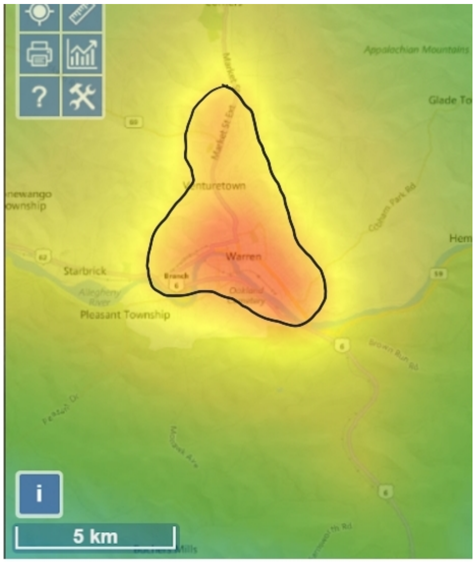

Grand Ole Opry
Country Music Hall of Fame and Museum
Murfreesboro
Clarksville
Lebanon
Franklin
Terrain
Satellite
Sign in

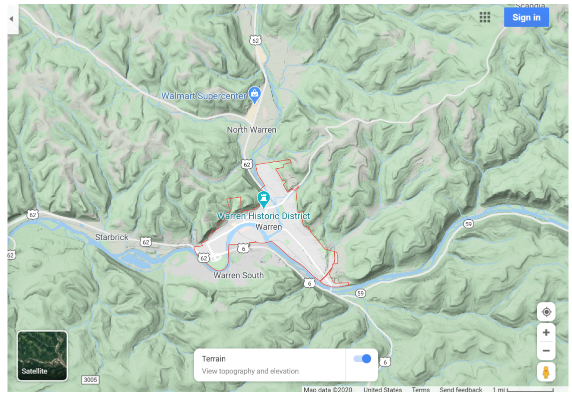

Fond du Lac
Sheboygan
Lake
Michigan
Madison
Milwaukee
Janesville
Kenosha
Freeport
Rockford
Waukegan
Chicago
Dixon
Sea of
Evanescence
Joliet
Gary
Valparaiso
Ottawa
Kankakee
Peoria
Pontiac
Bloomington
100 km

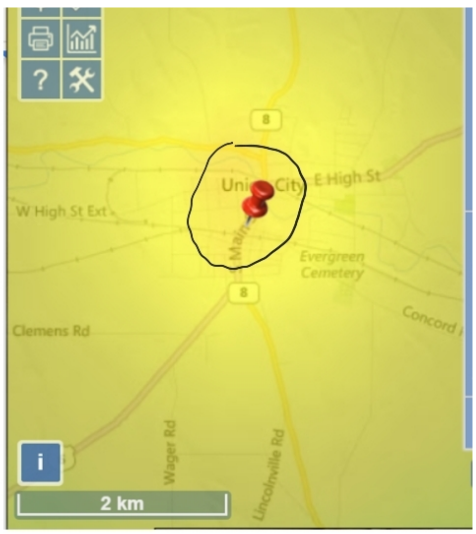

Milwaukee
Sign in
Waukesha
Holland
Janesville
Racine
Kenosha
Beloit
South Haven
Rockford
Belvidere
Schaumburg
Evanston
St Joseph
Chicago
Naperville
Michigan City
South Bend
Gary
Joliet
Satellite
Terrain
View topography and elevation

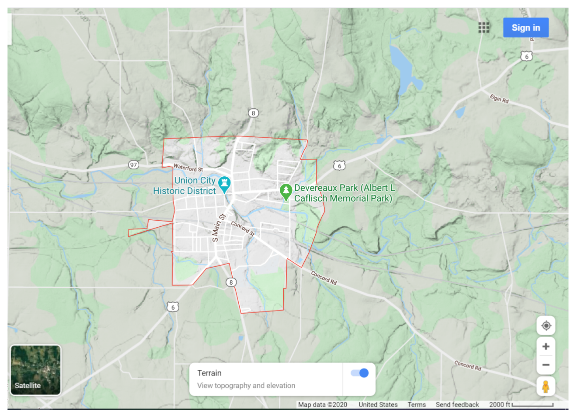

Walkerville
Butte
Janney
5 km

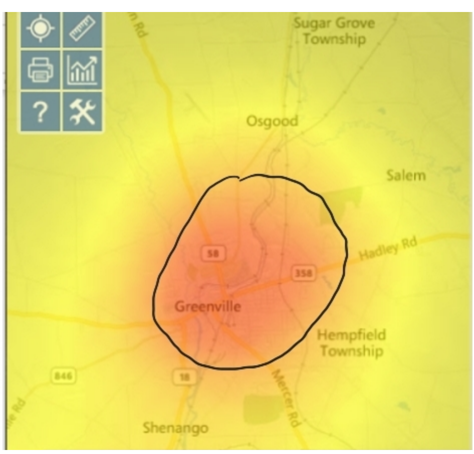

Sign in
Deer Lodge
Jefferson City
Philipsburg
Racetrack
Boulder
Anaconda
Elk Park
Our Lady of the Rockies
Homestake Pass
Whitehall
Renova
Three Forks
Willow Creek
Table Mountain
Silver Star
Wisdom
Rochester
Twin Bridges
Harrison
Glen
Sheridan
Satellite
Terrain
View topography and elevation

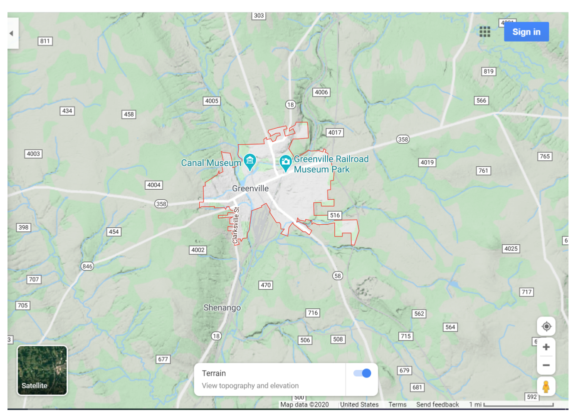

Appalachian Mountains
Venturetown
Warren
Starbrick
Pleasant Township
5 km


Sign in
Walmart Supercenter
North Warren
Warren Historic District
Warren
Starbrick
Warren South
Terrain
View topography and elevation
Satellite


8
E High St
W High St Ext
Evergreen Cemetery
Clemens Rd
Concord
Wager Rd
Lincolnville Rd
2 km


Sign in
Union City Historic District
Devereaux Park (Albert L Caflisch Memorial Park)
Terrain
View topography and elevation
Satellite


Sugar Grove Township
Osgood
Salem
Hadley Rd
Greenville
Hempfield Township
Shenango
Mercer Rd


Sign in
Canal Museum
Greenville Railroad Museum Park
Greenville
Shenango
Terrain
View topography and elevation
Satellite

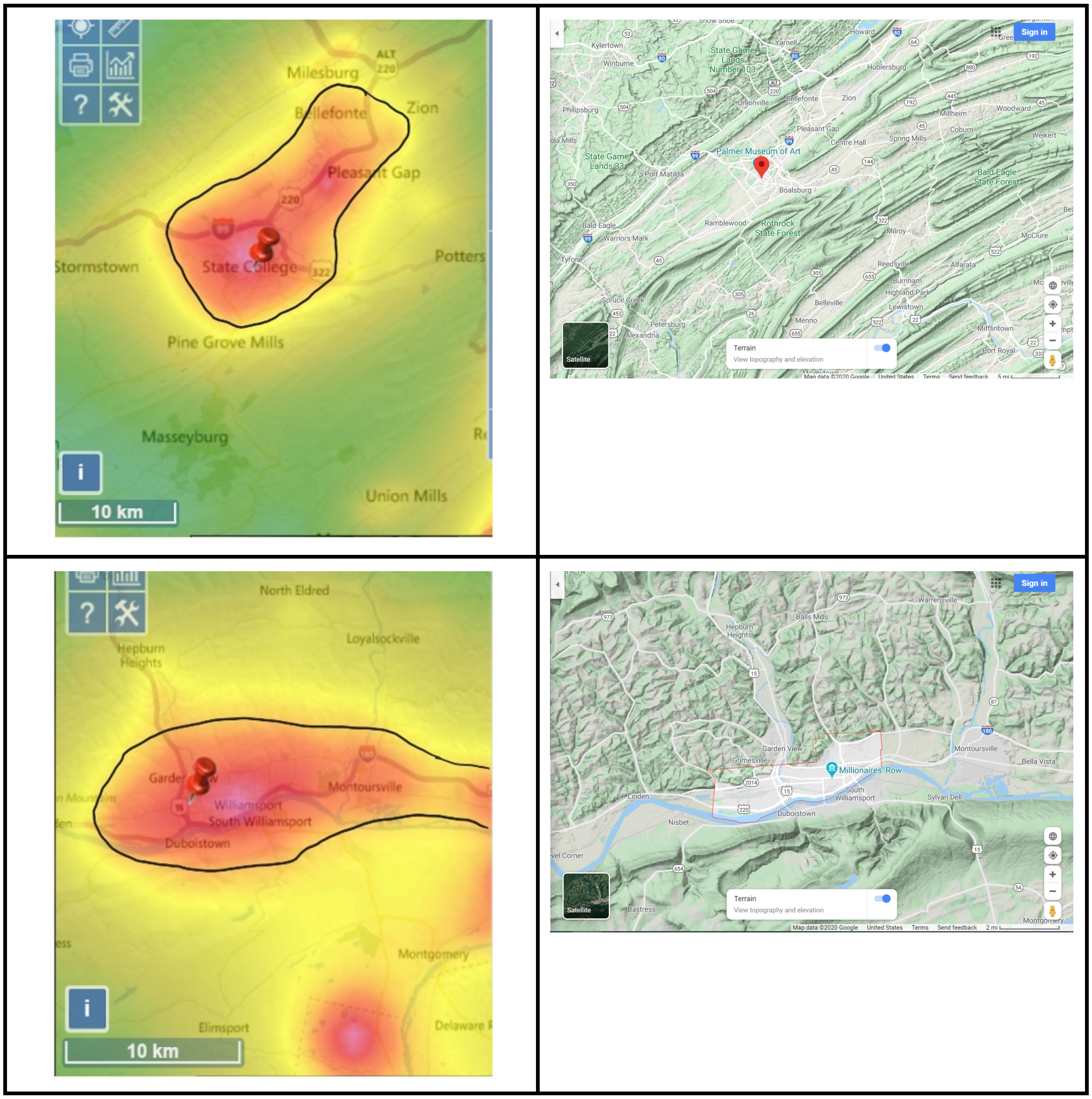


Table 1: Boundary and Terrain Maps

I then put the distance data into an Excel spreadsheet and plotted the distances I measured using the light pollution map tools. The table defines each city number and the plot shows the distance from the city center in each cardinal direction.

City Name	City Number
Titusville	1
Pittsburgh	2
Erie	3
Cleveland	4
Meadville	5
Grove City	6
Franklin	7
Philadelphia	8
Seattle	9
San Francisco	10
Dallas	11
Boston	12
Denver	13
Miami	14
Salt Lake City	15
Nashville	16
Chicago	17
Warren	22

Union City	23
Greenville	24
State College	25
Williamsport	26

Table 2: City Numbers

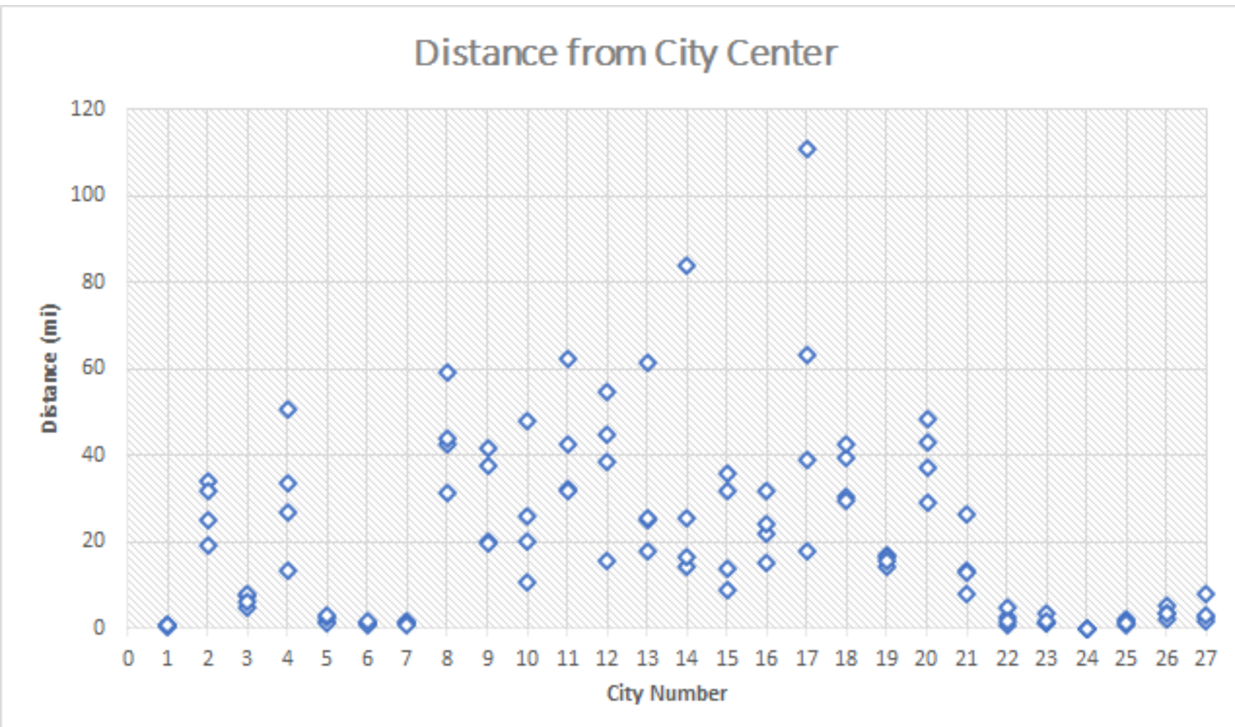


Figure 1: Plot of Distances

As we can see, there is a trend where the bigger cities have their boundaries further out than small towns. It was also found that there was a direct correlation between the terrain and the shape of the boundary line. Typically, the boundary line follows the shape of the terrain. These findings are documented in the Excel spreadsheet entitled Dark_Sky_Research in the Data

Sheet tab. Only initial comments were made regarding the boundary lines' connection to the surrounding terrain as the project had a time crunch.

Further Research:

There is much more research to be done here. I highlight the things that the next researcher should do to continue this project below.

1. Use the Python program *edge_detect* to get more accurate boundary lines. This program was written by Ela Gulsen. Any questions regarding the program, please contact egulsen@andrew.cmu.edu. I have included the image that the program outputted for the city of Pittsburgh. As we can see, the boundary line is much cleaner and more well defined than in the hand-drawn version shown earlier in the report.

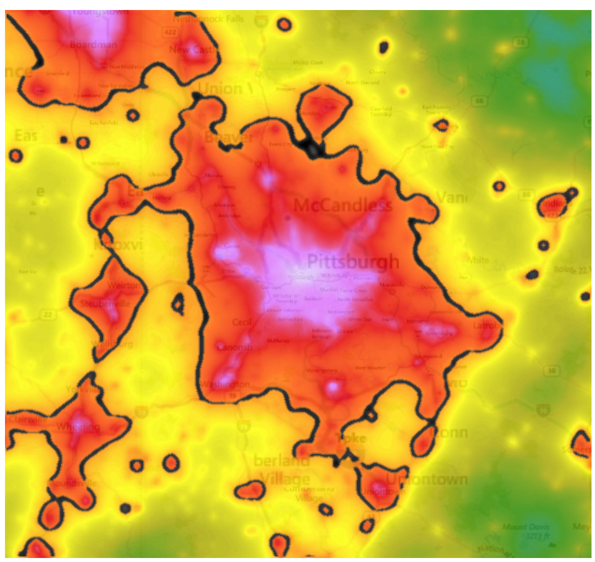


Figure 2: Python Generated Boundary

2. Determine a mathematical correlation between different terrain features and boundary lines. For example, how much does a water feature dampen Milky Way visibility in comparison to a mountain range?

3. Overlay the light pollution maps and boundaries on the terrain maps. This would be a great visual tool to see just how much the terrain defines the boundaries.
4. Determine if the size of the city is proportional to the size of the boundary.
5. Collect data on more cities. This will allow for a more comprehensive understanding of the subject.

Knowledge Gained:

By completing this project, I was able to learn more about the way research is conducted. I have never had the opportunity to conduct research here at CMU because I was never really interested in it, but after this course, I think I have more of an understanding and appreciation of research.

Additionally, I was able to connect with more people at Carnegie Mellon from various departments. Networking is a large part of professional development, and professional development is very important for a career. For example, I have had the chance to work with Ela Gulsen, a math major at CMU. She has been able to write a Python program to draw the boundary lines with more detail and precision. This program will be used in the next stages of this project.

Resources:

Dark_Sky_Research Excel Spreadsheet: 

Python edge_detect: