# Identifying the impacts of extreme weather

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## Table of contents

# Screenshot of GitHub README.md

## Identifying the impacts of extreme weather

This repository contains the details of the assignment 2 for the course EDS 223: Geospatial Analysis & Remote Sensing for the Master of Environmental Data Science (MEDS) program.

The assignment focuses on identifying the impacts of a series of extreme winter storms in the Houston metropolitan area, Texas.

### Background

Climate change is increasing the frequency and severity of extreme weather events, leading to devastating impacts. In February 2021, Texas experienced a major power crisis caused by three severe winter storms that swept across the United States on February 10–11, 13–17, and 15–20.

This assignment aims to identify the impacts of these extreme winter storms by estimating the number of homes in the Houston metropolitan area that lost power and examining whether these impacts were disproportionately distributed. The analysis is based on remotely sensed night light data.

All analysis were done on R version 4.5.1 using the following libraries tidyverse, sf, here and tmap.

### Objective of the assignment

- Create a set of maps comparing night light intensities before and after the first two storms
- Create a map of the homes in Houston that lost power
- Estimate of the number of homes in Houston that lost power
- Create a map of the census tracts in Houston that lost power
- Create a plot that compares the distributions of median household income between census tracts that did and did not experience blackouts
- Summarize the results and discuss any limitations of this study in 100 words.

### Contents

This repository contains the following files 1. .gitignore 2. impacts-of-extreme-weather.Rproj 3. .qmd 4. figs: visual representation that is derived from the raw data 5. README.md

**File Structure**

```
impacts-of-extreme-weather
└──figs/
    └── before-after-storm.jpeg
└──.gitignore
    └──data
        └──gis_osm_buildings_a_free_1.gpkg
        └──gis_osm_roads_free_1.gpkg
        └──ACS_2019_5YR_TRACT_48_TEXAS.gdb
            └──census tract gdb files
        └──VNP46A1
            └──VIIRS data files
└──impacts-of-extreme-weather.Rproj
└──README.md
└──texas_blackout.html
└──texas_blackout.pdf
└──texas_blackout.qmd
```

### Data

Due to its large size, the `data` folder is included in `.gitignore` and is not tracked by version control. For this assignment, the data were pre-downloaded and provided by the team. Details of the data sources and download links are as follows:

**Data download link**

To access the data, click here

**Data Source**

**Night lights** The NASA's Worldview is explored for extracting the data around the day of the storm. There are several days with too much cloud cover to be useful, but 2021-02-07 and 2021-02-16 provides two clear, contrasting images to visualize the extent of the power outage in Texas.

VIIRS data is distributed through NASA's Level-1 and Atmospheric Archive & Distribution System Distributed Active Archive Center (LAADS DAAC). Many NASA Earth data products are distributed in 10x10 degree tiles in sinusoidal equal-area projection. Tiles are identified by their horizontal and vertical position in the grid. Houston lies on the border of tiles h08v05 and h08v06. These two tiles per date were pre-downloaded and provided by the team.

**Roads** We used Geofabrik's download sites to retrieve a shapefile of all highways in Texas and prepared a Geopackage (.gpkg file) containing just the subset of roads that intersect the Houston metropolitan area.

**Houses** The data were downloaded from Geofabrik and processed to create a GeoPackage containing only residential buildings within the Houston metropolitan area.

**Socioeconomic** The socioecoomic data were obtained from the U.S. Census Bureau's American Community Survey for census tracts in 2019.

### Course Information

- **Course Title:** EDS 222 - Geospatial Analysis & Remote Sensing
- **Term:** Fall 2025
- **Program:** UCSB Masters in Environmental Data Science.

Teaching Team:

- **Instructor:** Annie Adams
- **Teaching Assistant:** Alessandra Vidal Meza

Complete description for the homework can be found on the Assignment-3

**Author: Aakriti Poudel**

### Load required libraries

```
library(tidyverse)
library(sf)
library(tmap)
library(terra)
library(stars)
```

### Read data

```
# Read night lights data
tile05_07 <- read_stars(here::here('data', 'VNP46A1', 'VNP46A1.A2021038.h08v05.001.202103906
tile06_07 <- read_stars(here::here('data', 'VNP46A1', 'VNP46A1.A2021038.h08v06.001.202103906
tile05_16 <- read_stars(here::here('data', 'VNP46A1', 'VNP46A1.A2021047.h08v05.001.202104809
tile06_16 <- read_stars(here::here('data', 'VNP46A1', 'VNP46A1.A2021047.h08v06.001.202104809


# Read roads data
highways <- st_read(here::here('data', 'gis_osm_roads_free_1.gpkg'),
                    query = "SELECT * FROM gis_osm_roads_free_1 WHERE fclass = 'motorway'") %>%
  st_transform(crs = 'EPSG:3083')


# Read houses data
houses <- st_read(here::here('data',
                             'gis_osm_buildings_a_free_1.gpkg'),
  query = "SELECT *
    FROM gis_osm_buildings_a_free_1
    WHERE (type IS NULL AND name IS NULL)
      OR type IN ('residential', 'apartments', 'house', 'static_caravan', 'detached')") %>%
    st_transform('EPSG:3083')


# Explore the contents of the geodatabase
socioeconomic <- st_layers(here::here('data', 'ACS_2019_5YR_TRACT_48_TEXAS.gdb'))

# Extract the census tract information
census_tract <- st_read(here::here('data', 'ACS_2019_5YR_TRACT_48_TEXAS.gdb'), layer = 'ACS_
  st_transform('EPSG:3083')
```

```
# Extract the income information
income <- st_read(here::here('data', 'ACS_2019_5YR_TRACT_48_TEXAS.gdb'), layer = 'X19_INCOME
```

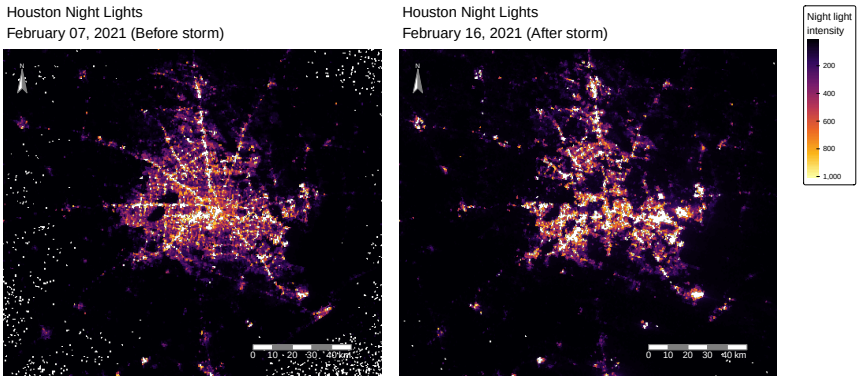
### Merge raster data and create houston bounding box

```
# Merge two raster data of February 7
nightlight_07 <- st_mosaic(tile05_07, tile06_07)

# Merge two raster data of February 16
nightlight_16 <- st_mosaic(tile05_16, tile06_16)

# Create Houston bounding box
houston_bbox <- st_bbox(c(xmin = -96.5, xmax = -94.5, ymin = 29, ymax = 30.5),
                        crs = 'EPSG:4326')

# Crop all raster data to Houston area
nightlight_07_crop <- st_crop(nightlight_07, houston_bbox)
nightlight_07_crop[(nightlight_07_crop > 1000) | (nightlight_07_crop <= 0)] <- NA

nightlight_16_crop <- st_crop(nightlight_16, houston_bbox)
nightlight_16_crop[(nightlight_16_crop > 1000) | (nightlight_16_crop <= 0)] <- NA
```

### Visualize before and after night light intensities

```
# Map for February 7 (before storm)
beforestorm <- tm_shape(nightlight_07_crop) +
  tm_raster(col.scale = tm_scale_continuous(values = 'inferno'),
            col.legend = tm_legend(title = 'Night light\nintensity',
                                   position = tm_pos_out('right'))) +
  tm_title('Houston Night Lights\nFebruary 07, 2021 (Before storm)',
           size = 1.3) +
  tm_compass(position = c('left', 'top'),
             type = 'arrow',
             size = 3,
             text.size = 0.6,
             color.dark = 'grey50',
             text.color = 'white') +
  tm_scalebar(position = c('right', 'bottom'),
```

```
              text.size = 0.8,
              color.dark = 'grey50',
              text.color = 'white') +
  tm_layout(bg.color = 'white',
            outer.bg.color = 'white',
            frame = FALSE,
            legend.show = FALSE)


# Map for February 16 (after storm)
afterstorm <- tm_shape(nightlight_16_crop) +
  tm_raster(col.scale = tm_scale_continuous(values = 'inferno'),
            col.legend = tm_legend(title = 'Night light\nintensity',
                                   position = tm_pos_out('right'))) +
  tm_title('Houston Night Lights\nFebruary 16, 2021 (After storm)',
           size = 1.3) +
  tm_compass(position = c('left', 'top'),
             type = 'arrow',
             size = 3,
             text.size = 0.6,
             color.dark = 'grey50',
             text.color = 'white') +
  tm_scalebar(position = c('right', 'bottom'),
              text.size = 0.8,
              color.dark = 'grey50',
              text.color = 'white') +
  tm_layout(frame = FALSE,
            legend.show = FALSE)

legend_map <- tm_shape(nightlight_16_crop) +
  tm_raster(col.scale = tm_scale_continuous(values = 'inferno'),
            col.legend = tm_legend(title = 'Night light\nintensity',
                                   position = tm_pos_out('right'))) +
  tm_layout(legend.only = TRUE, legend.outside = TRUE, legend.position = c("right", "center")

tmap_arrange(beforestorm, afterstorm, legend_map, ncol = 3)
```

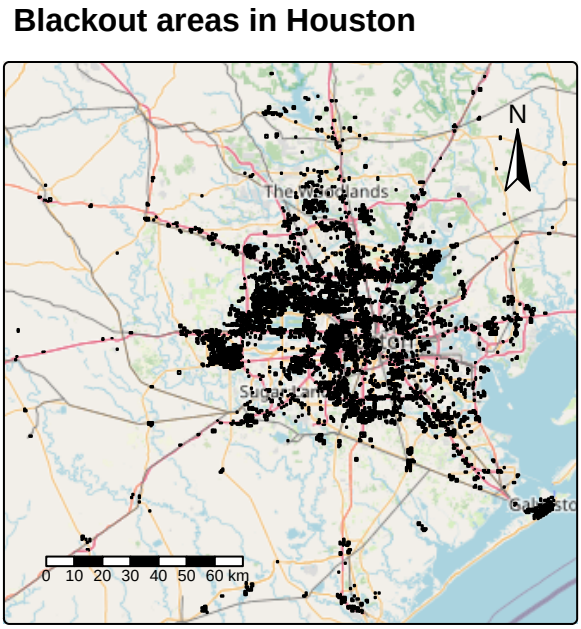



## Create blackout mask

```
# Calculate the difference in light intensity
nightlight_diff <- nightlight_07 - nightlight_16

# Crop and reclassify the raster data
mask <- st_crop(nightlight_diff, houston_bbox)
mask[mask < 200] <- NA

# Vectorize the blackout mask
blackout <- st_as_sf(mask,
                     as_points = FALSE,
                     merge = TRUE) %>%
  st_make_valid() %>%
  st_transform(crs = 'EPSG:3083')
```

```
# Combine all highway geometries into one
highways_union <- st_union(highways)

# Create 200m buffer around all highways
highways_buffer <- st_buffer(highways_union, dist = 200)

# Find areas that experienced blackouts further than 200m from highways
blackout_far <- st_difference(blackout, highways_buffer)

# Visualize the blackout in Houston
tm_basemap('OpenStreetMap') +
  tm_shape(blackout_far) +
    tm_polygons(fill = 'ivory', fill_alpha = 0.8, col = 'black') +
```

```
    tm_title('Blackout areas in Houston', fontface = 'bold', size = 1) +
    tm_layout(legend.show = TRUE) +
    tm_scalebar(position = c('left', 'bottom')) +
    tm_compass(position = c('right', 'top'))
```




### Estimate of the number of homes in Houston that lost power

Approximately **157,970** homes in Houston lost power in February 2021 due to the severe winter storms and resulting major power crisis.

Note: I used `st_intersects`. `st_intersects` returns a boolean value indicating whether two geometries share any features or if they have any point in common. `TRUE (or 1)` if the geometries intersect, `FALSE (or 0)` if they are completely separate.

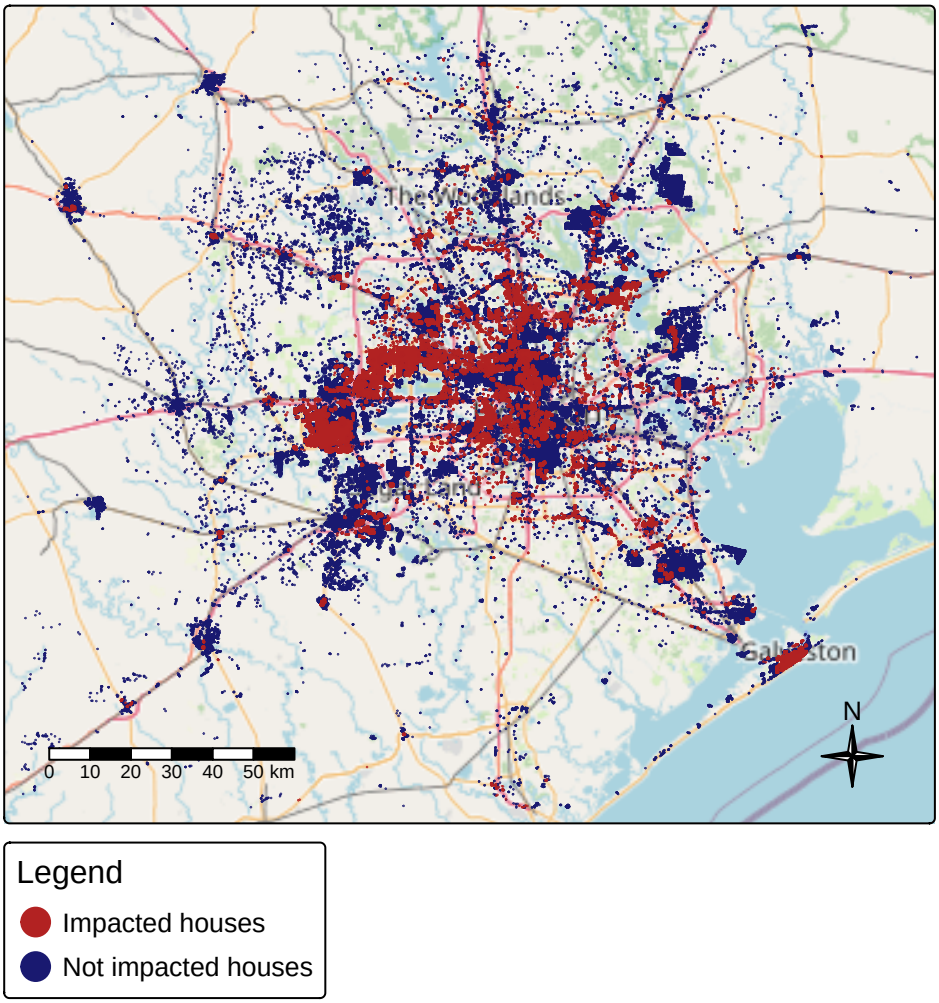
```
# Keep buildings that intersect with blackout areas
houses_blackout <- st_intersects(houses, blackout_far)

# Check if each building is in a blackout area
in_blackout <- lengths(houses_blackout) > 0

# Filter buildings in blackout areas
blackout_houses <- houses[in_blackout, ]
```

```r
# Number of impacted buildings
n_blackout_houses <- nrow(blackout_houses)

# Convert all buildings to centroids
houses_points <- houses %>%
  st_centroid()

# Houses impacted by blackouts
houses_impacted <- blackout_houses %>%
  st_centroid()

# Houses not impacted by blackouts
houses_not_impacted <- houses_points %>%
  filter(!osm_id %in% blackout_houses$osm_id)
```

**Map of the homes in Houston that lost power**

```r
# Create the map
tm_basemap('OpenStreetMap') +
  tm_shape(houses_not_impacted) +
    tm_dots(fill = 'midnightblue', size = 0.02, fill_alpha = 0.8) +
  tm_shape(houses_impacted) +
    tm_dots(fill = 'firebrick', size = 0.02, fill_alpha = 0.8) +
  tm_title('Houses in Houston that lost power',
           position = tm_pos_out('center', 'top'),
           fontface = 'bold', size = 1.2) +
  tm_layout(legend.outside = TRUE,
            legend.outside.position = 'right',
            legend.title.size = 1,
            legend.text.size = 0.8) +
  tm_add_legend(labels = c('Impacted houses', 'Not impacted houses'),
                fill = c('firebrick', 'midnightblue'),
                col = c('firebrick', 'midnightblue'),
                alpha = c(0.2, 0.7, 0.5),
                title = 'Legend') +
  tm_scalebar(position = c('left', 'bottom'),
              text.size = 0.6) +
  tm_compass(position = c('right', 'bottom'),
             type = '4star',
             size = 2)
```

## Houses in Houston that lost power




### Census tracts in Houston that lost power

```
# Rename the column in income dataset to match with the census tract
income_renamed <- income %>%
  rename("GEOID_Data" = "GEOID")

# Left join the two datasets by the geometry
census_income <- census_tract %>% left_join(income_renamed, by = 'GEOID_Data')
```

```r
# Check CRS of the dataset
if(st_crs(census_income) == st_crs(houston_bbox)){
print("Coordinate reference systems match!")
} else {
warning("Update coordinate reference systems to match!")
}
```

```
Warning: Update coordinate reference systems to match!
```

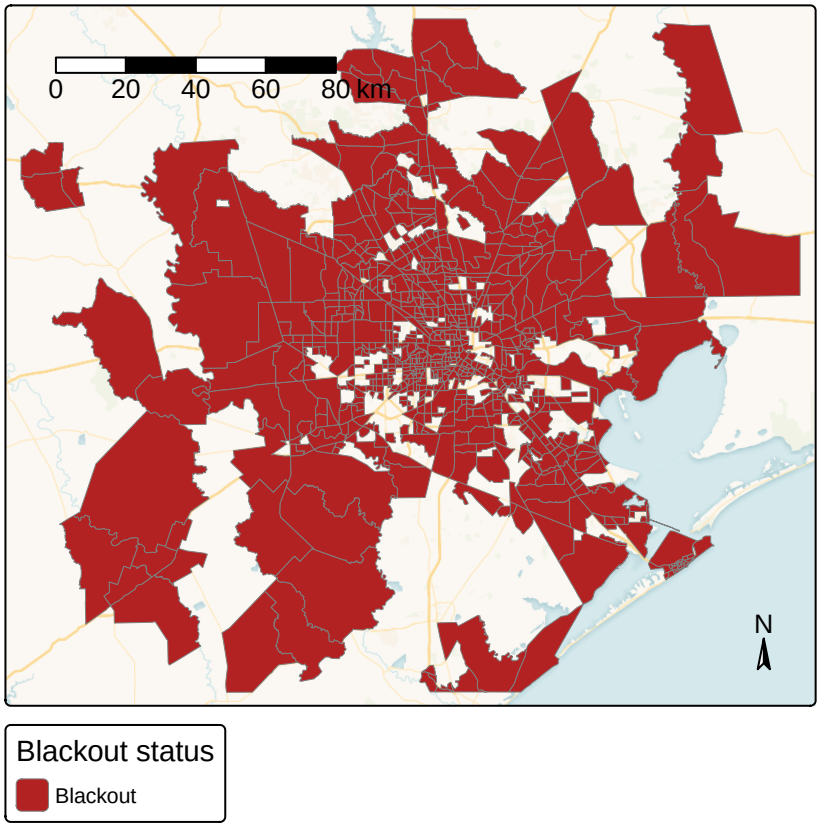
```r
# Transform the CRS and crop to houston bounding box
census_income <- st_transform(census_income, crs = 'epsg:4326')

# Crop census income to Houston
census_income_crop <- census_income %>%
  st_crop(houston_bbox)

# Transform and clean blackout houses
blackout_houses_transformed <- blackout_houses %>%
  st_transform(crs = 'epsg:4326')

# Identify the blackout areas
census_blackout <- st_intersects(census_income_crop, blackout_houses_transformed)

# Create the column
census_blackout_col <- census_income_crop %>%
  mutate(blackout = lengths(census_blackout) > 0)

# Select only the values that are true for plotting
census_blackout_col_filtered <- census_blackout_col[census_blackout_col$blackout, ]
```

**Map of the census tracts in Houston that lost power**

```r
# Map the census tracts that lost power
tm_basemap('CartoDB.VoyagerNoLabels') +
  tm_shape(census_blackout_col_filtered) +
  tm_polygons(fill = 'blackout',
              fill.scale = tm_scale_categorical(
                values = c('TRUE' = 'firebrick'),
                labels = c('TRUE' = 'Blackout')),
              fill.legend = tm_legend(title = 'Blackout status'),
```

```
            col = 'grey50',
            lwd = 0.2) +
tm_title('Census tracts in Houston that lost power',
         position = tm_pos_out('center', 'top'),
         fontface = 'bold',
         size = 1) +
tm_layout(legend.outside = TRUE,
          legend.outside.position = 'right',
          legend.bg.color = 'white',
          legend.bg.alpha = 0.8) +
tm_compass(position = c('right', 'bottom'),
           type = 'arrow',
           size = 1) +
tm_scalebar(position = c('left', 'top'),
            text.size = 0.8)
```

**Census tracts in Houston that lost power**




**Plot comparing the distributions of median household income**

```
ggplot(census_blackout_col %>% filter(!is.na(B19013e1)), # Remove NA values
                                    aes( x = blackout, y = B19013e1, fill = blackout)) +
  geom_boxplot(alpha = 0.8) +
  scale_x_discrete(labels = c('TRUE' = 'Blackout',
                              'FALSE' = 'No blackout')) +
  scale_fill_manual(values = c('TRUE' = 'firebrick',
                               'FALSE' = 'midnightblue'),
                    labels = c('Blackout', 'No blackout')) +
  labs(title = 'Median household income for census tracts',
       subtitle = 'Blackout status in Houston census tracts',
       x = 'Blackout status',
```

```
      y = 'Median household income in $',
      fill = 'Status') +
scale_y_continuous(labels = scales::dollar_format()) +
theme_minimal() +
theme(plot.title = element_text(face = 'bold', size = 16),
      plot.subtitle = element_text(size = 14),
      legend.position = 'bottom')
```

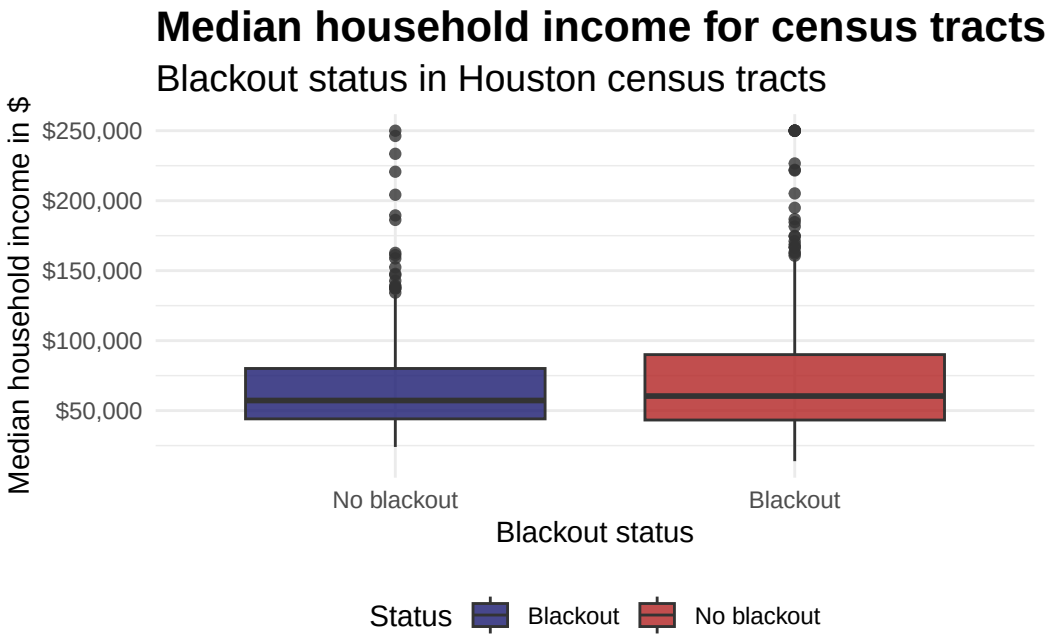



Figure 1: This plot compares the distributions of median household income between census tracts that experienced blackouts and those that did not during the severe winter storms of February 2021 in Houston, Texas.

## Brief reflection

**A brief reflection (approx. 100 words) summarizing your results and discussing any limitations to this study**

**Answer** This analysis used satellite data to compare median household incomes between areas affected and unaffected by the blackout. Interestingly, higher-income census tracts were more affected, as their median income was slightly higher than that of non-blackout areas. This result may reflect several limitations such as wealthier neighborhoods often have more outdoor lighting, census tract–level data may overlook neighborhood differences, and blackout areas

could be misclassified due to highway lighting or cloud cover. The analysis may also have assumed all structures were residential, while vegetation near power lines and the 200-meter buffer used could further limit accuracy of true lighting.