

A Look at Houston's Winter Storm Blackouts

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PUBLISHED

December 2, 2025

```
# Import libraries
library(tidyverse)
library(tmap)
library(terra)
library(sf)
library(ggspatial)
library(here)
```

0.0.1 README Preview

The following image shows a preview of the project's README file hosted on GitHub:

mmorenorolon / **texas-winterstorm-2021**

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texas-winterstorm-2021 (Public)

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mmorenorolon Add analysis of nightlight intensity cb74f46 · 22 minutes ago 10 Commits

.gitignore Add data/* directory to .gitignore 2 weeks ago

LICENSE Initial commit 2 weeks ago

README.html Add README 24 minutes ago

README.md Add README 24 minutes ago

texas-winterstorm-2021.Rproj Create .qmd file and load in data. 2 weeks ago

texas_winterstorm_2021.qmd Add analysis of nightlight intensity 22 minutes ago

About

This repository contains the geospatial analysis of the 2021 Texas winter storms and resulting power outages in Houston. This project aims to estimate the number of homes affected and explore socioeconomic disparities in recovery.

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Investigating the 2021 Houston Winter Storm Blackouts

EDS 223: Geospatial Analysis & Remote Sensing UCSB Masters of Environmental Data Science

Purpose

This repository contains the workflow, data, and outputs for Homework 3 of EDS 223, completed by Melannie Moreno Rolón. The project analyzes the February 2021 winter storms in Houston, Texas, which caused widespread power outages. Using NASA VIIRS night-light data, OpenStreetMap building and road data, and U.S. Census socioeconomic data, the analysis estimates the spatial extent of blackouts, identifies affected residential areas, and examines the socioeconomic context of power loss. The workflow was conducted entirely in R and documented in a Quarto report integrating geospatial data analysis, raster operations, and vector-based overlay techniques.

Description of Repository

This repository contains spatial and statistical analyses exploring the impact of the February 2021 winter storms on power distribution and socioeconomic inequality in Houston, Texas. By comparing satellite imagery before and after the storms, the study identifies blackout areas, filters out non-residential and highway-adjacent regions, and estimates the number of homes likely affected. Census and income data are then used to evaluate whether blackout exposure varied across different income levels. The results are presented as a series of maps and a boxplot visualizing median household income distributions for tracts that did and did not experience blackouts.

Repository Structure

```
C:.
|   .gitignore
|   LICENSE
|   README.html
|   README.md
```

```
texas-winterstorm-2021.Rproj
texas_winterstorm_2021.qmd

data
|   gis_osm_buildings_a_free_1.gpkg
|
|   ACS_2019_5YR_TRACT_48_TEXAS.gdb
|       ACS_2019_5YR_TRACT_48_TEXAS.gdb
|           census tract gdb files
|
|   gis_osm_roads_free_1.gpkg
|
|   VNP46A1
|       VIIRS data files
```

Data Access

- **NASA VIIRS Nighttime Lights (VNP46A1):** Daily radiance data downloaded from NASA's Black Marble product suite. These data were used to measure changes in light intensity before and after the blackout (February 7 and February 16, 2021).
- **OpenStreetMap Roads and Buildings:** Extracted from the OpenStreetMap (OSM) Geofabrik Texas dataset. Roads were filtered for fclass = 'motorway' to represent major highways, while buildings were filtered for residential types (e.g., house, apartments, detached).
- **U.S. Census ACS 2019 (5-Year Estimates):** Geodatabase sourced from the U.S. Census Bureau containing tract-level demographic and income information for the state of Texas. Median household income (variable B19013e1) was used to analyze socioeconomic differences in blackout exposure.

To reproduce the analysis, ensure that the following R packages are installed: `sf`, `terra`, `tmap`, `tidyverse`, `here`, and `ggspatial`.

Acknowledgements

This project was made possible through the use of open-source spatial data and R-based geospatial analysis tools.

- NASA Black Marble VIIRS data were obtained from the NASA Earth Observations platform.
- OpenStreetMap data were accessed via Geofabrik's open data repository.
- ACS 2019 Census Data were downloaded from the U.S. Census Bureau and accessed through the TIGER/Line shapefiles and geodatabase products.

Special thanks to the developers of the R packages used in this analysis, including `{sf}`, `{terra}`, `{tmap}`, `{ggspatial}`, and `{tidyverse}`, which enabled geospatial data processing, raster manipulation, and visualization in Quarto.

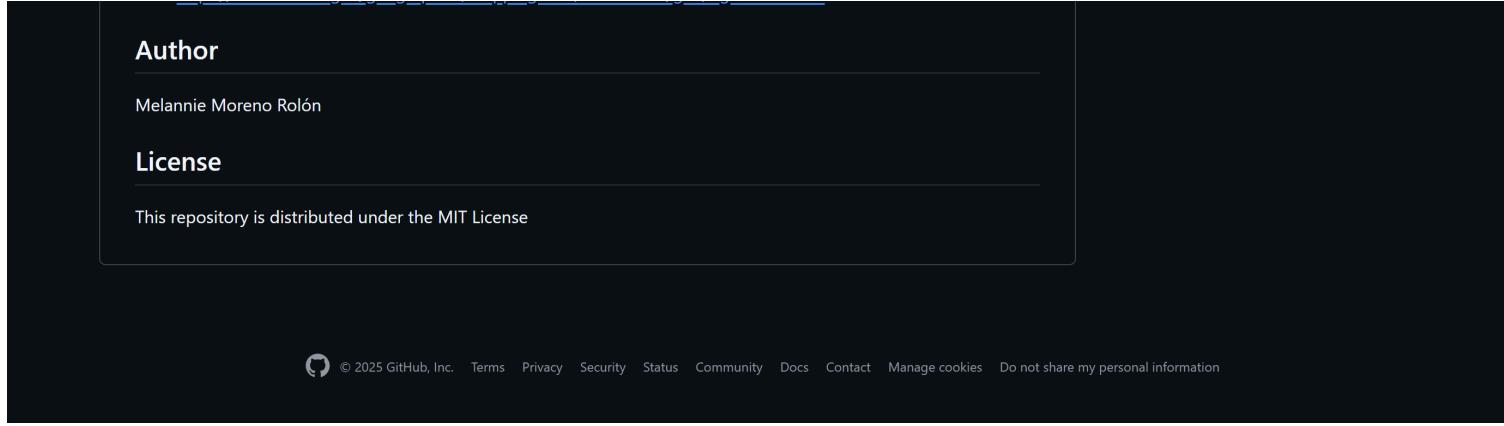
This work was completed as part of EDS 223: Geospatial Analysis & Remote Sensing at the University of California, Santa Barbara, under the guidance of course instructor Annie Adams and TA Alessandra Vidal Meza, whose feedback and teaching supported the completion of this project.

Citations

NASA Earth Science Division. (n.d.). Black Marble VIIRS Nighttime Lights (VNP46A1). Retrieved November 10, 2025, from <https://blackmarble.gsfc.nasa.gov/>

OpenStreetMap contributors. (n.d.). Texas OSM Roads and Buildings Data (Geofabrik). Retrieved November 10, 2025, from <https://download.geofabrik.de/north-america/us/texas.html>

U.S. Census Bureau. (2019). American Community Survey (ACS) 5-Year Estimates, 2019. Retrieved November 10, 2025, from <https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-data.html>



Preview of the project README showing project purpose, data sources, and acknowledgements.

0.1 Introduction

Rapid changes in climate are leading to higher intensity and more frequent extreme weather events in recent years. If we look at the United States, there are many examples. One particular event that highlights this increasing pattern in weather events are the February 2021 winter storms in Houston, Texas. For the first time in years, Houston experienced a power outage of massive scale. A combination of extreme weather, grid isolation, and lack of winterization became the perfect storm that exposed Houston's underlying systemic issues.

This analysis aims to estimate the number of households in the Houston metropolitan area that resulted in loss of electricity service due to the extreme winter storms experienced in February 2021.

1 Methods

Key steps of this analysis include:

1. Find locations that experienced a blackout
2. Exclude highways from analysis
3. Identify homes that experienced blackouts by combining the locations of homes and blackouts
4. Identify the census tracts likely impacted by blackout

2 Data Analysis

2.0.1 Import Socioeconomic Data

```
#|echo: false
#|label: census-data
# Load 2019 socioeconomic census tract data
census_tracts <- st_read(here::here("data", "ACS_2019_5YR_TRACT_48_TEXAS.gdb"),
                         layer = "ACS_2019_5YR_TRACT_48_TEXAS", quiet = T)

# Load household income data
income <- st_read(here::here("data", "ACS_2019_5YR_TRACT_48_TEXAS.gdb"),
                   layer = "X19_INCOME", quiet = T)
```

2.0.2 Import Roads and Homes Data

```
#|label: rds-bldgs-data
# Load roads data
roads <- st_read(here::here("data", "gis_osm_roads_free_1.gpkg"),
                  query = "SELECT * FROM gis_osm_roads_free_1 WHERE fclass='motorway'", quiet = T)

# Load houses data
buildings <- 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 ('res
```



2.0.3 Import Satellite Images

```
#|label: raster-data
# February 7 tiles
tile_0701 <- rast(here::here("data", "VNP46A1",
                             "VNP46A1.A2021038.h08v05.001.2021039064328.tif"))

tile_0702 <- rast(here::here("data", "VNP46A1",
```

```

    "VNP46A1.A2021038.h08v06.001.2021039064329.tif"))

# February 16 tiles
tile_1601 <- rast(here::here("data", "VNP46A1", "VNP46A1.A2021047.h08v05.001.2021048091106.tif"))

tile_1602 <- rast(here::here("data", "VNP46A1",
                             "VNP46A1.A2021047.h08v06.001.2021048091105.tif"))

```

2.0.4 Blackout Detection

Find locations that experienced a blackout.

```

#|label: merge-rasters
# Set the extent to Houston to later plot radiance before and after winter storms
houston_ext <- terra::ext(c(-96.5, -94.5, 29, 30.5))

# Merge raster objects
r_before <- terra::mosaic(tile_0701, tile_0702, fun = "mean") %>%
  crop(houston_ext)
r_after <- terra::mosaic(tile_1601, tile_1602, fun = "mean") %>%
  crop(houston_ext)

#Apply log transformation (log1p) to reduce skew from bright outliers
# and enhance contrast in low-light areas
r_before_log <- log1p(r_before)
r_after_log <- log1p(r_after)

```

```

#|label: light-diff
# Compute the change in light intensity
r_change <- r_before - r_after

```

```

# Create a re-classification matrix
reclass_matrix <- matrix(c(-Inf, 200, NA,      # values below 200 → NA
                           200, Inf, 1),     # values above 200 → 1
                           ncol = 3,

```

```

byrow = TRUE)

# Reclassify the raster
masked_difference <- classify(r_change, reclass_matrix)

# Convert raster mask to polygons (vectorized blackout)
blackout_vector <- st_as_sf(as.polygons(masked_difference))
blackout_vector <- st_make_valid(blackout_vector)

#|label: polygon-check
# Check that `blackout_vector` is a polygon
sum(!st_is_valid(blackout_vector))

```

[1] 0

```

# Define the bounding box coordinates for Houston, Texas
houston_bbox <- st_as_sfc(st_bbox(c(xmin = -96.5, xmax = -94.5,
                                         ymin = 29, ymax = 30.5),
                                         crs = st_crs(blackout_vector)))
                                         )

# Crop the vectorized blackout polygons with the Houston bounding box
cropped_blackout <- st_crop(blackout_vector, houston_bbox) %>% st_make_valid()

# Reproject the cropped blackout vector to EPSG:3083 (Texas Centric Albers Equal Area)
cropped_blackout <- st_transform(cropped_blackout, 3083)

```

2.0.5 Spatial Filtering

Exclude highways from the cropped blackout mask.

```

# Check CRS match between highways and blackout polygons
if (st_crs(roads) != st_crs(cropped_blackout)) {
  message("Transforming highways to match cropped_blackout CRS...")
  roads <- st_transform(roads, st_crs(cropped_blackout))
}

```

```
if (st_crs(roads) == st_crs(cropped_blackout)) {  
  message("CRS matches.")  
} else {  
  message("CRS still doesn't match.")  
}
```

```
# Create a buffer of 200 meters  
buffered_highways <- st_buffer(roads, dist = 200)  
  
# Combine geometries  
highways_200m <- st_union(buffered_highways)  
  
# Erase overlapping areas to remove highways  
blackout_not_highway <- st_difference(cropped_blackout, highways_200m)  
  
# Fix invalid geometries if necessary  
if (sum(!st_is_valid(blackout_not_highway)) > 0) {  
  blackout_not_highway <- st_make_valid(blackout_not_highway)  
}
```

2.0.6 Socioeconomic Context

Identify the number of homes likely impacted by blackouts.

```
if (st_crs(buildings) != st_crs(blackout_not_highway)) {  
  message("Transforming buildings to match blackout CRS...")  
  buildings <- st_transform(buildings, st_crs(blackout_not_highway))  
}  
  
if (st_crs(buildings) == st_crs(blackout_not_highway)) {  
  message("CRS matches!")  
} else {  
  message("CRS still doesn't match. ")  
}
```

```

# Find the intersection of homes within Houston that experienced a blackout
buildings_affected <- st_intersection(buildings, blackout_not_highway)

if (sum(!st_is_valid(buildings_affected)) > 0) {
  buildings_affected <- st_make_valid(buildings_affected)
}

##|label: num-affected
# Find the number of homes affected by the blackout
num_affected <- nrow(buildings_affected)

```

The number of homes likely impacted by the winter storms in February 2021 are approximately 157411.

2.0.7 Compare the distributions of household income that experienced and did not experience a blackout

```

# Clean the income dataset
income_clean <- income %>%
  # Remove geometries (there is not but just in case)
  st_drop_geometry() %>%
  # Remove last 10 characters so that they match with
  #the census tract's GEOFID value format
  mutate(GEOID = substr(GEOID, nchar(GEOID) - 10, nchar(GEOID))) %>%
  select(GEOID, MEDIAN_HH_INC = B19013e1)

# Join income and census tract data
census_income <- left_join(census_tracts, income_clean, by = "GEOID")

# Check CRS match
if (st_crs(blackout_not_highway) != st_crs(census_income)) {
  warning("CRS does not match")
  message("Transforming CRS to match...")
  census_income <- st_transform(census_income, st_crs(blackout_not_highway))
}

```

```

# Identify which census tracts intersect blackout areas
census_blackout <- census_income[st_intersects(census_income, blackout_not_highway, sparse = FALSE), ]

# Add blackout status column
census_income <- census_income %>%
  # Add a new column 'blackout' to indicate whether each census tract's
  # GEOID appears in the list of tracts that intersect blackout areas
  # (Yes = experienced blackout, No = did not)
  mutate(blackout = ifelse(GEOID %in% census_blackout$GEOID, "Yes", "No"))

```

2.1 Results

2.1.1 Nightlights before and after the winterstorms

```

#|label: vis1-nightlights

# Night lights before storm
map_before <- tm_shape(r_before_log) +
  tm_raster(col.legend = tm_legend(title = "log(Radiance + 1) \n(nW/cm²/sr)",
                                    title.size = 0.8,
                                    frame = FALSE,
                                    orientation = "portrait"),
             col.scale = tm_scale_continuous(values = "magma")) +
  tm_title(size = 1, text = "Nighttime Light Intensity in Houston \nBefore the 2021 Winter Storms") +
  tm_graticules(lines = FALSE, labels.show = TRUE) +
  tmap_options(component.autoscale = FALSE)

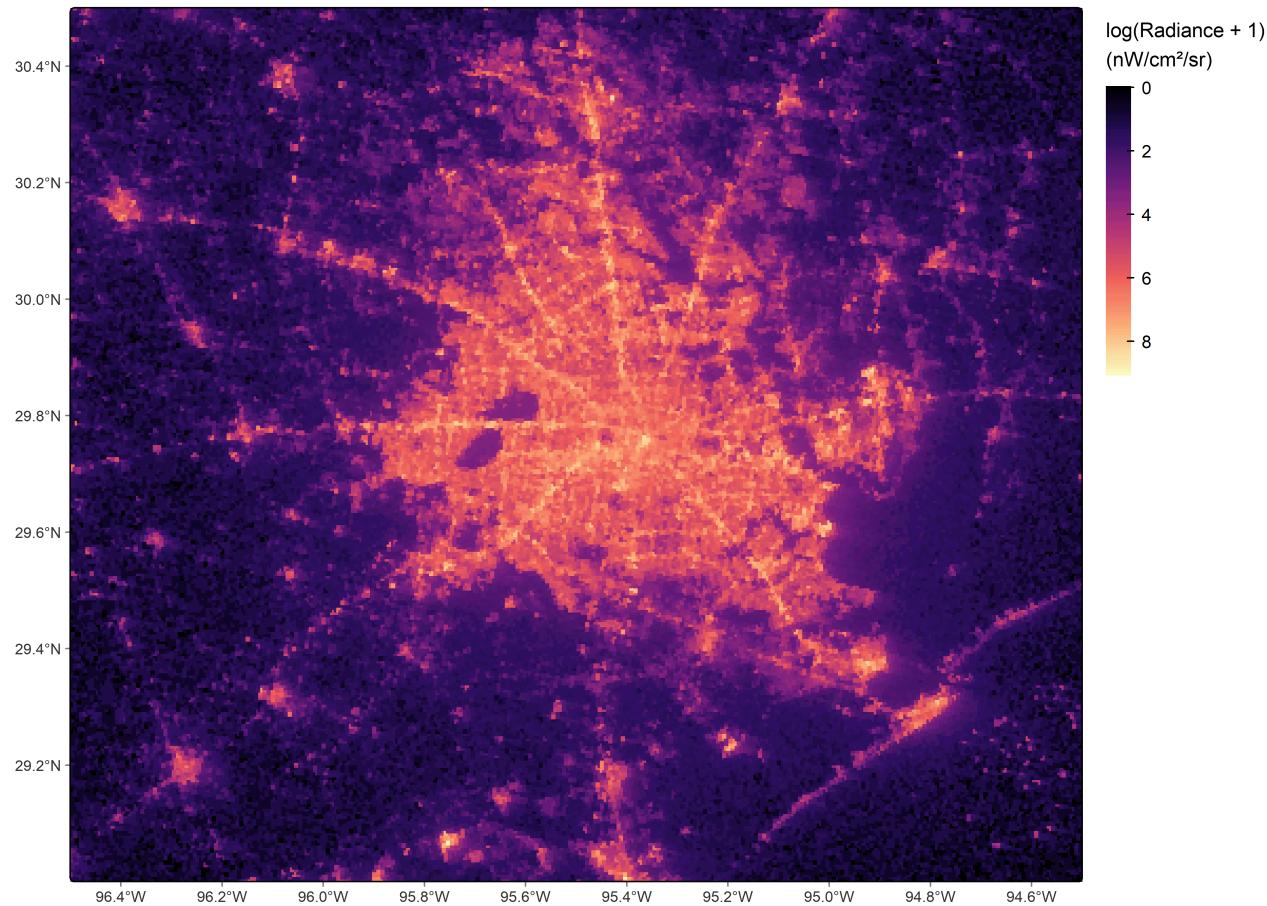
# Night lights after storm
map_after <- tm_shape(r_after_log) +
  tm_raster(col.legend = tm_legend(title = "log(Radiance + 1) \n(nW/cm²/sr)",
                                    title.size = 0.8,
                                    frame = FALSE,
                                    orientation = "portrait",
                                    title.align = TRUE),
             col.scale = tm_scale_continuous(values = "magma")) +

```

```
tm_title(size = 1, text = "Nighttime Light Intensity in Houston \nAfter the 2021 Winter Storms") +  
tm_grid(lines = FALSE, labels.show = TRUE) +  
tmap_options(component.autoscale = FALSE)
```

map_before

Nighttime Light Intensity in Houston
Before the 2021 Winter Storms



map_after

Nighttime Light Intensity in Houston
After the 2021 Winter Storms

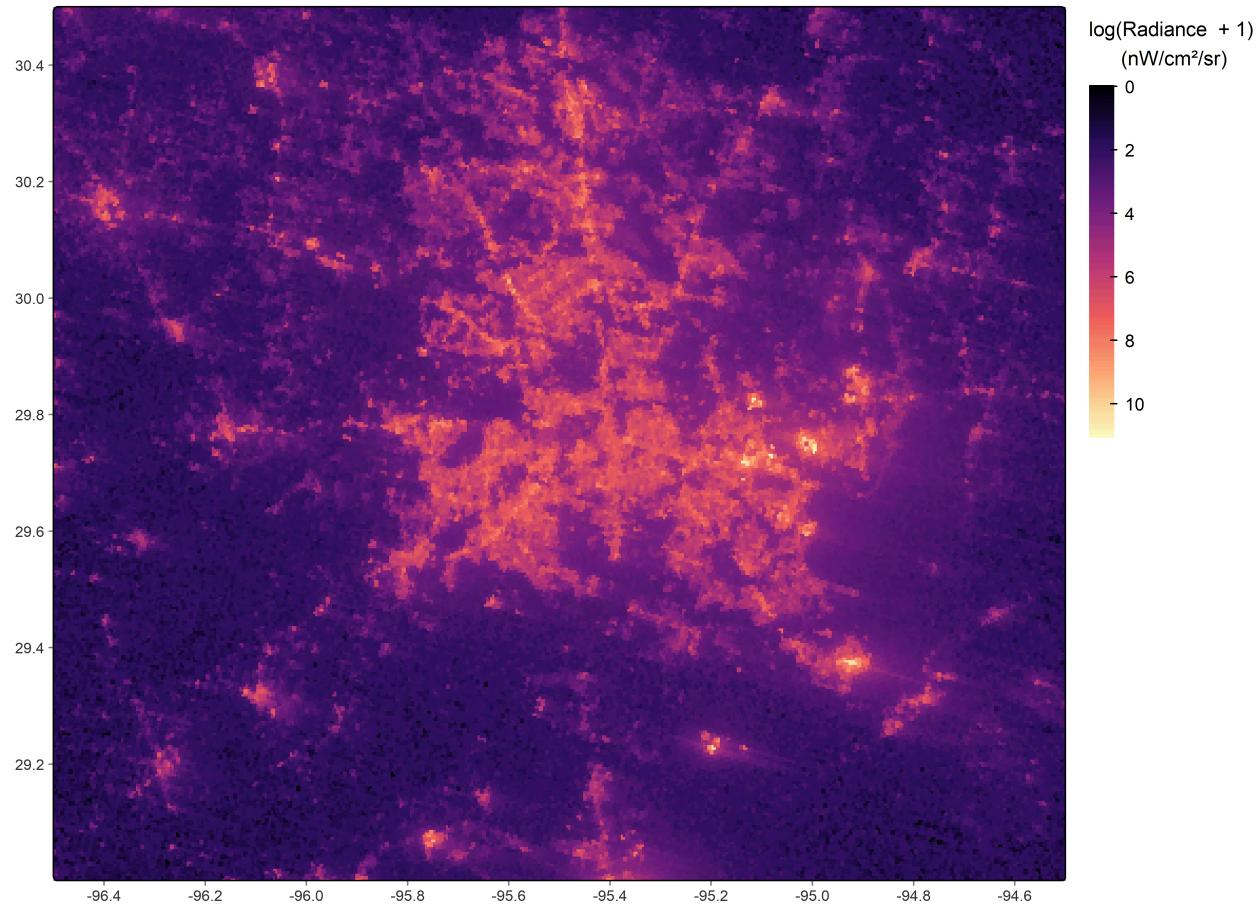


Figure 1. Comparison of nightlight intensity across Houston before (February 7, 2021) and after (February 16, 2021) the winter storm.

Lighter areas indicate higher radiance values, while darker areas represent reduced light intensity, likely due to power outages during the blackout.

2.1.2 Homes in Houston that lost power

```
# Convert polygons to points for clearer display
buildings_points <- st_centroid(buildings_affected) %>%
  select(geometry = geom)

# Plot the homes that experienced a blackout
tm_shape(buildings_points) +

  tm_dots(col = NA,                      # no borders
          fill = "red",                  # buildings affected point color
          size = 0.1,
          fill_alpha = 0.3,
          fill.legend = tm_legend(title = "Homes affected")) +

  tm_basemap("Esri.WorldGrayCanvas") +

  tm_add_legend(type = "symbols",# Add a point symbol in the legend
                fill = "red",
                title = "Homes affected") +
  tm_layout(frame = FALSE,
            legend.outside = TRUE) +
  tm_title(text = "Homes in Houston that Lost Power") +
  tm_compass(type = "arrow", position = tm_pos_in("right", "top")) +
  tm_scalebar(position = tm_pos_in("left", "bottom"))
```

Homes in Houston that Lost Power

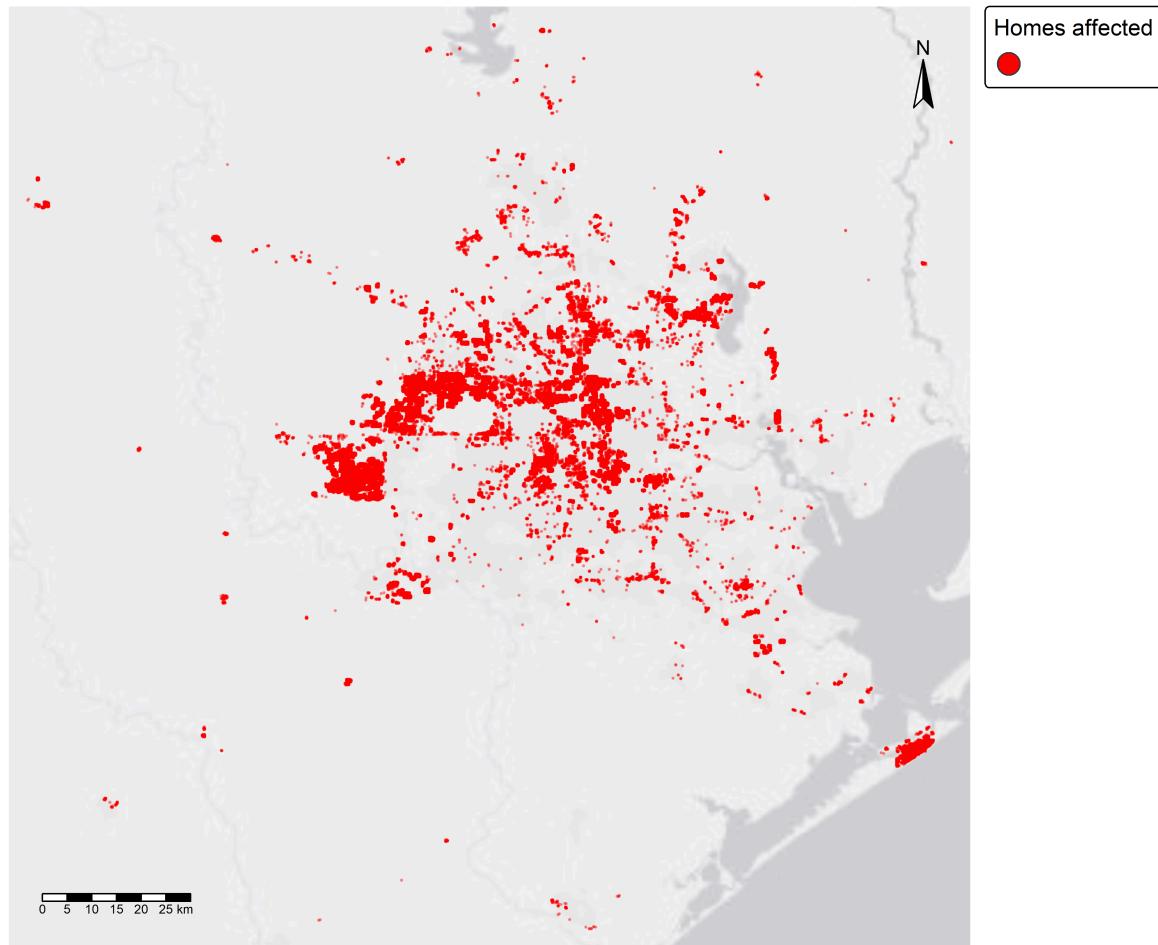


Figure 2. Residential structures within Houston that likely lost power during the February 2021 blackout. Grey areas represent detected blackout zones (excluding highways) and red points indicate the locations of affected residential buildings.

2.2 Census tracts that lost power after the storms

```
# Match CRS
blackout_not_highway <- st_transform(blackout_not_highway, st_crs(census_tracts))

if (st_crs(blackout_not_highway) == st_crs(census_income)) {
  message("CRS matches!")
} else {
  message("CRS still doesn't match." )
}

# Define the Houston bounding box (same extent you used before)
houston_bbox <- st_as_sfc(st_bbox(c(xmin = -96.5, xmax = -94.5,
                                         ymin = 29, ymax = 30.5),
                                         crs = 4326)) %>%
  st_transform(st_crs(census_tracts))

# Crop the census tracts to the Houston area
census_houston <- st_crop(census_tracts, houston_bbox)

# Identify census tracts in Houston that intersect blackout areas
houston_blackout <- census_houston[st_intersects(census_houston, blackout_not_highway, sparse = FALSE), ]

# Add "blackout" column and mark tracts as Yes/No based on intersection
census_houston <- census_houston %>%
  mutate(blackout = ifelse(GEOID %in%
                           houston_blackout$GEOID, "Yes", "No"))

# Map census tracts in Houston that experienced blackouts
tm_shape(census_houston) +
  tm_borders(col = "gray", lwd = 0.8) +
  tm_shape(houston_blackout) +
  tm_polygons(col = "tomato", fill = "#98F5F9", lwd = 0.8) +
  tm_compass(type = "arrow", position = c("right", "top"), size = 0.8) +
  tm_scalebar(position = c("left", "bottom")) +
```

```
tm_title(text = "Census Tracts in Houston that Experienced Blackouts",
         position = tm_pos_out("center", "top"),
         size = 1.2,
         frame = FALSE) +
tm_map_options(component.autoscale = FALSE)
```

Census Tracts in Houston that Experienced Blackouts

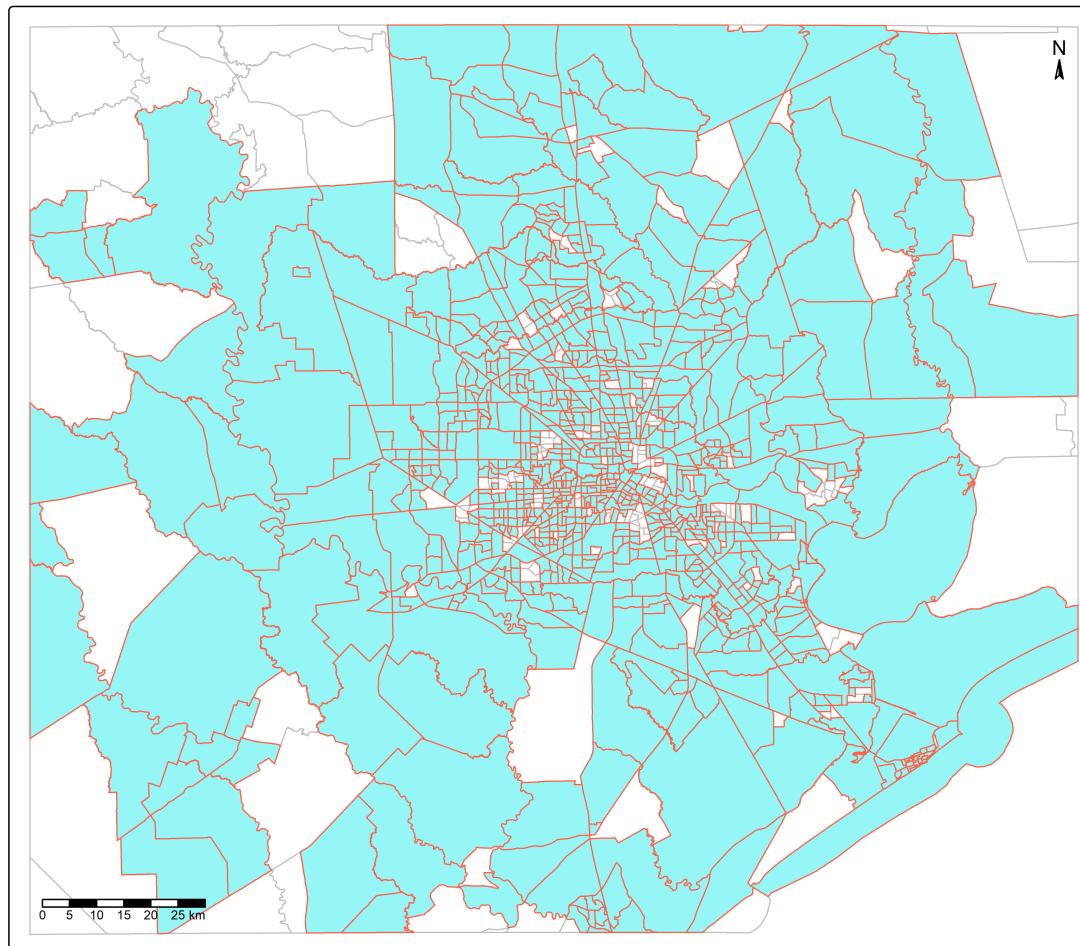


Figure 3. Census tracts within the Houston metropolitan area that experienced blackouts following the winter storm. Turquoise tracts denote areas that overlapped with the detected blackout mask, while lighter tracts did not show evidence of power loss.

2.3 Compare the distributions of median household income for census tracts that did and did not experience blackouts

```
#|label: vis4-hh-income
# Plot boxplot of median household income distribution by blackout experience
ggplot(data = census_income %>% filter(!is.na(MEDIAN_HH_INC)),
       aes(x = blackout, y = MEDIAN_HH_INC, fill = blackout)) +
  geom_boxplot(alpha = 0.8, outlier.color = "black") +
  scale_fill_manual(values = c("grey80", "firebrick4")) +
  # Add labels to x- and y-axis
  labs(title = "Median Household Income by Blackout Experience",
       x = "Blackout Experienced",
       y = "Median Household Income (USD)") +
  theme_classic(base_size = 14) +
  theme(legend.position = "none",
        plot.title = element_text(hjust = 0.5, face = "bold"))
```

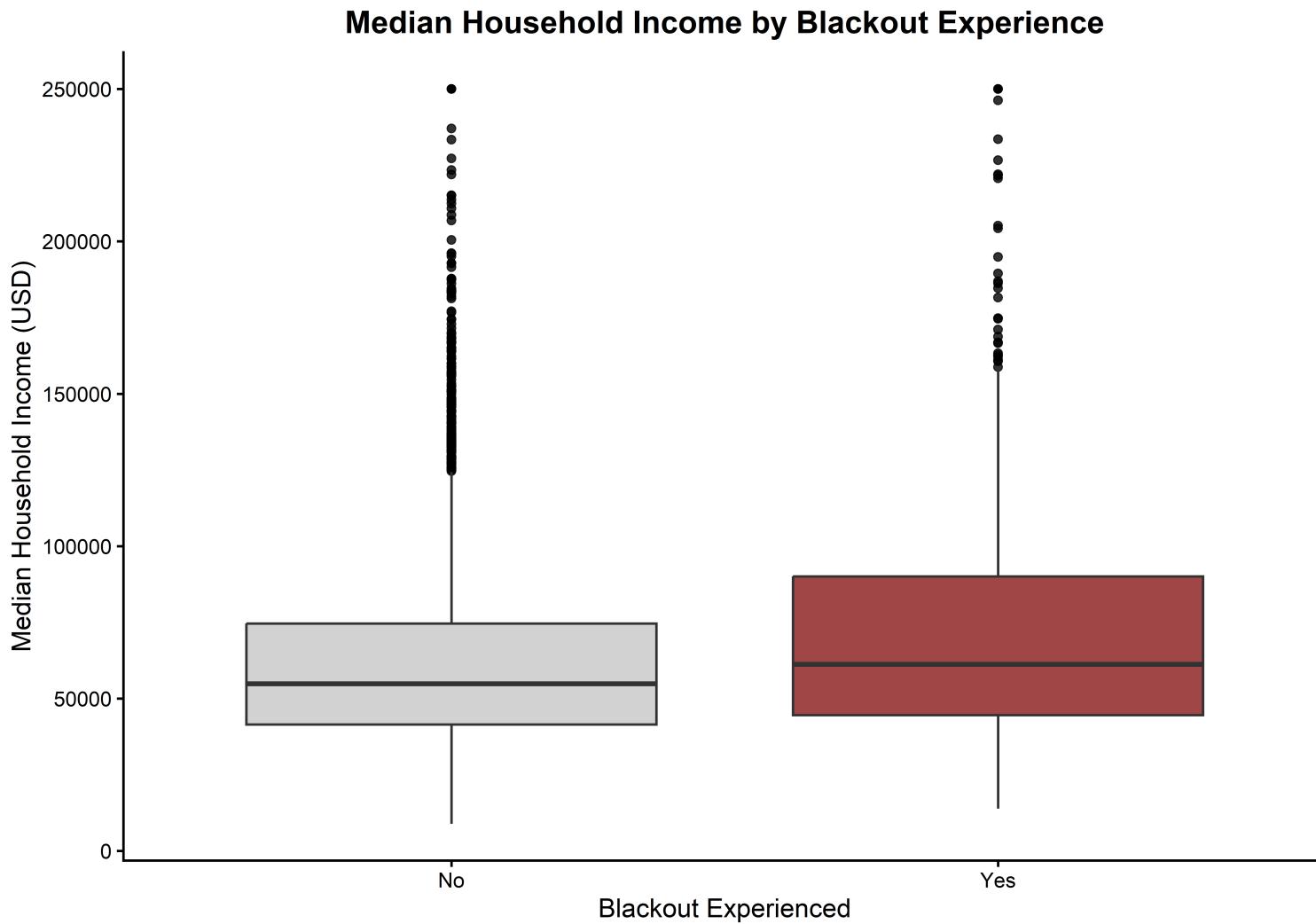


Figure 4. Distribution of median household income for census tracts that did and did not experience blackouts. While blackout-affected tracts occurred across all income levels, slightly higher variability is observed in higher-income tracts. Further analysis is recommended to determine if this difference is significant.

3 Discussion

This analysis estimated the spatial extent of Houston's February 2021 winter storm blackouts by combining satellite night-light data, road networks, and census information. The results suggest that thousands of residential structures

across diverse neighborhoods lost power, with outages distributed across both lower- and middle-income census tracts. While the data reveal clear spatial clustering of blackouts, several limitations remain. The night-light data provide an indirect proxy for outages and may underestimate impacts in densely developed or industrial areas. Additionally, variations in data resolution, cloud cover, and temporal mismatches between datasets introduce uncertainty in the estimated extent of power loss.