Identifying Impacts of Extreme Weather: Texas Blackouts

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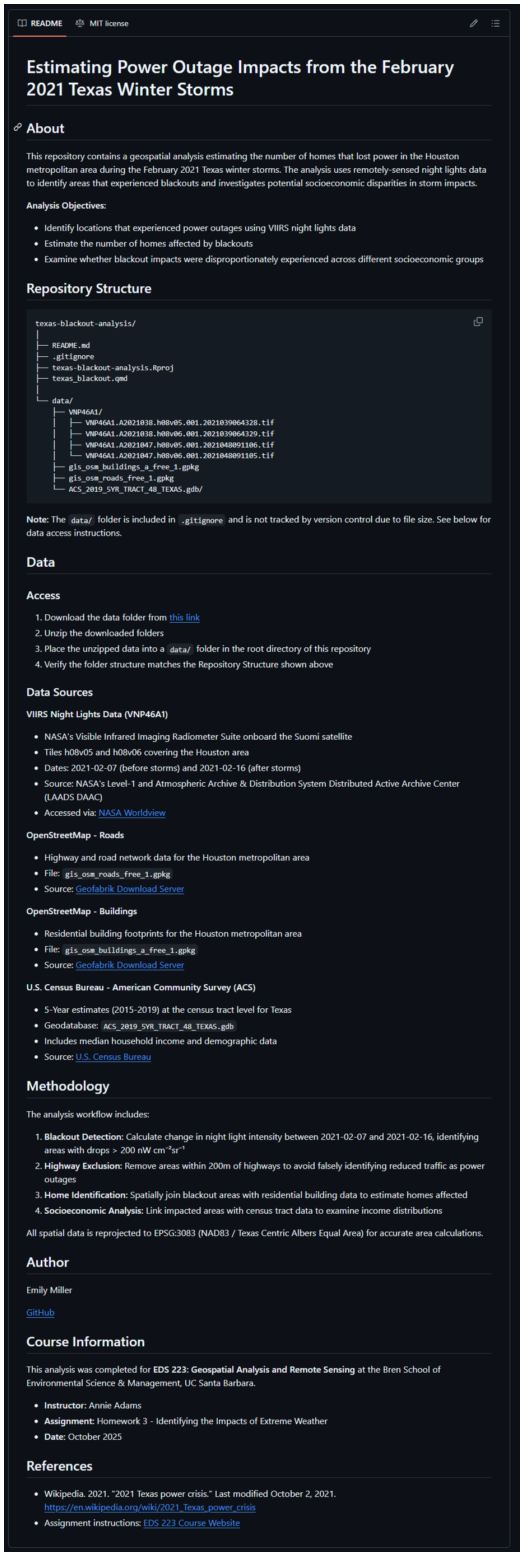
README.md Screenshot



README MIT license

Estimating Power Outage Impacts from the February 2021 Texas Winter Storms

About

This repository contains a geospatial analysis estimating the number of homes that lost power in the Houston metropolitan area during the February 2021 Texas winter storms. The analysis uses remotely-sensed night lights data to identify areas that experienced blackouts and investigates potential socioeconomic disparities in storm impacts.

Analysis Objectives:

- Identify locations that experienced power outages using VIIRS night lights data
- Estimate the number of homes affected by blackouts
- Examine whether blackout impacts were disproportionately experienced across different socioeconomic groups

Repository Structure

```
texas-blackout-analysis/
│
├── README.md
├── .gitignore
├── texas-blackout-analysis.Rproj
├── texas_blackout.qmd
│
└── data/
    ├── VNP46A1/
    │   ├── VNP46A1.A2021038.h08v05.001.2021039064328.tif
    │   ├── VNP46A1.A2021038.h08v06.001.2021039064329.tif
    │   ├── VNP46A1.A2021047.h08v05.001.2021048091106.tif
    │   └── VNP46A1.A2021047.h08v06.001.2021048091105.tif
    ├── gis_osm_buildings_a_free_1.gpkg
    ├── gis_osm_roads_free_1.gpkg
    └── ACS_2019_5YR_TRACT_48_TEXAS.gdb/
```

Note: The `data/` folder is included in `.gitignore` and is not tracked by version control due to file size. See below for data access instructions.

Data

Access

1. Download the data folder from this link
2. Unzip the downloaded folders
3. Place the unzipped data into a `data/` folder in the root directory of this repository
4. Verify the folder structure matches the Repository Structure shown above

Data Sources

VIIRS Night Lights Data (VNP46A1)

- NASA's Visible Infrared Imaging Radiometer Suite onboard the Suomi satellite
- Tiles h08v05 and h08v06 covering the Houston area
- Dates: 2021-02-07 (before storms) and 2021-02-16 (after storms)
- Source: NASA's Level-1 and Atmospheric Archive & Distribution System Distributed Active Archive Center (LAADS DAAC)
- Accessed via: NASA Worldview

OpenStreetMap - Roads

- Highway and road network data for the Houston metropolitan area
- File: `gis_osm_roads_free_1.gpkg`
- Source: Geofabrik Download Server

OpenStreetMap - Buildings

- Residential building footprints for the Houston metropolitan area
- File: `gis_osm_buildings_a_free_1.gpkg`
- Source: Geofabrik Download Server

U.S. Census Bureau - American Community Survey (ACS)

- 5-Year estimates (2015-2019) at the census tract level for Texas
- Geodatabase: `ACS_2019_5YR_TRACT_48_TEXAS.gdb`
- Includes median household income and demographic data
- Source: U.S. Census Bureau

Methodology

The analysis workflow includes:

1. **Blackout Detection:** Calculate change in night light intensity between 2021-02-07 and 2021-02-16, identifying areas with drops > 200 nW $cm^{-2}sr^{-1}$
2. **Highway Exclusion:** Remove areas within 200m of highways to avoid falsely identifying reduced traffic as power outages
3. **Home Identification:** Spatially join blackout areas with residential building data to estimate homes affected
4. **Socioeconomic Analysis:** Link impacted areas with census tract data to examine income distributions

All spatial data is reprojected to EPSG:3083 (NAD83 / Texas Centric Albers Equal Area) for accurate area calculations.

Author

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GitHub

Course Information

This analysis was completed for **EDS 223: Geospatial Analysis and Remote Sensing** at the Bren School of Environmental Science & Management, UC Santa Barbara.

- **Instructor:** Annie Adams
- **Assignment:** Homework 3 - Identifying the Impacts of Extreme Weather
- **Date:** October 2025

References

- Wikipedia. 2021. "2021 Texas power crisis." Last modified October 2, 2021. https://en.wikipedia.org/wiki/2021_Texas_power_crisis
- Assignment instructions: EDS 223 Course Website

Setup

```
# Load required packages
library(tidyverse)
library(sf)
library(here)
library(terra)
library(stars)
library(tmap)
library(kableExtra)
library(basemaps)
```

Data Loading and Preparation

```
# Read in the data

# Use rast() to read the night lights raster data tiles

VIIRS_07a <- rast(here("data/VNP46A1/VNP46A1.A2021038.h08v05.001.2021039064328.tif"))

VIIRS_07b <- rast(here("data/VNP46A1/VNP46A1.A2021038.h08v06.001.2021039064329.tif"))

VIIRS_16a <- rast(here("data/VNP46A1/VNP46A1.A2021047.h08v05.001.2021048091106.tif"))

VIIRS_16b <- rast(here("data/VNP46A1/VNP46A1.A2021047.h08v06.001.2021048091105.tif"))

# Use st_read() to read the gdb and gpkg files and query to extract only motorways and reside

highways <- st_read(here("data/gis_osm_roads_free_1.gpkg/gis_osm_roads_free_1.gpkg"),
                    query = "SELECT * FROM gis_osm_roads_free_1 WHERE fclass='motorway'", quiet

houses <- st_read(here("data/gis_osm_buildings_a_free_1.gpkg/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')", quiet = TRU

socio <- st_read(here("data/ACS_2019_5YR_TRACT_48_TEXAS.gdb/ACS_2019_5YR_TRACT_48_TEXAS.gdb/"
```

```r
# Make a data.frame containing the crs of the loaded datasets
crs_summary <- data.frame(
  Dataset = c("VIIRS tiles", "Highways", "Houses", "Socioeconomic"),
  EPSG = c(st_crs(VIIRS_07a)$epsg,
           st_crs(highways)$epsg,
           st_crs(houses)$epsg,
           st_crs(socio)$epsg))

# Display the crs
kable(crs_summary,
      caption = "Coordinate Reference Systems of Input Data") %>%
    kable_styling(bootstrap_options = c("striped", "hover"))
```

Table 1: Coordinate Reference Systems of Input Data

Dataset	EPSG
VIIRS tiles	4326
Highways	4326
Houses	4326
Socioeconomic	NA

The socioeconomic data does not have a crs in its current form so we will have to extract the geometry and combine it with the relevant attributes

```r
# Get the layers information
layers_info <- st_layers(here("data/ACS_2019_5YR_TRACT_48_TEXAS.gdb/ACS_2019_5YR_TRACT_48_TE

# Display as scrollable table with kableExtra
kable(data.frame(
  Layer_Number = 1:length(layers_info$name),
  Layer_Name = layers_info$name,
  Geometry_Type = unlist(layers_info$geomtype)
),
      caption = "Available Layers in ACS Geodatabase") %>%
  kable_styling(bootstrap_options = c("striped", "hover", "condensed"),
                fixed_thead = TRUE) %>%
  scroll_box(height = "300px")
```

Table 2: Available Layers in ACS Geodatabase

Layer_Number	Layer_Name	Geometry_Type
1	X01_AGE_AND_SEX	NA
2	X02_RACE	NA
3	X03_HISPANIC_OR_LATINO_ORIGIN	NA
4	X04_ANCESTRY	NA
5	X05_FOREIGN_BORN_CITIZENSHIP	NA
6	X06_PLACE_OF_BIRTH	NA
7	X07_MIGRATION	NA
8	X08_COMMUTING	NA
9	X09_CHILDREN_HOUSEHOLD_RELATIONSHIP	NA
10	X10_GRANDPARENTS_GRANDCHILDREN	NA
11	X11_HOUSEHOLD_FAMILY_SUBFAMILIES	NA
12	X12_MARITAL_STATUS_AND_HISTORY	NA
13	X13_FERTILITY	NA
14	X14_SCHOOL_ENROLLMENT	NA
15	X15_EDUCATIONAL_ATTAINMENT	NA
16	X16_LANGUAGE_SPOKEN_AT_HOME	NA
17	X17_POVERTY	NA
18	X18_DISABILITY	NA
19	X19_INCOME	NA
20	X20_EARNINGS	NA
21	X21_VETERAN_STATUS	NA
22	X22_FOOD_STAMPS	NA
23	X23_EMPLOYMENT_STATUS	NA
24	X25_HOUSING_CHARACTERISTICS	NA
25	X27_HEALTH_INSURANCE	NA
26	X28_COMPUTER_AND_INTERNET_USE	NA
27	X29_VOTING_AGE_POPULATION	NA
28	X99_IMPUTATION	NA
29	X24_INDUSTRY_OCCUPATION	NA
30	X26_GROUP_QUARTERS	NA
31	TRACT_METADATA_2019	NA
32	ACS_2019_5YR_TRACT_48_TEXAS	Multi Polygon

```
# Extract the geometry layer
socio_geom <- st_read(here("data/ACS_2019_5YR_TRACT_48_TEXAS.gdb/ACS_2019_5YR_TRACT_48_TEXAS
                      layer = "ACS_2019_5YR_TRACT_48_TEXAS", quiet = TRUE)
```

```r
# Extract the income layer
socio_income <- st_read(here("data/ACS_2019_5YR_TRACT_48_TEXAS.gdb/ACS_2019_5YR_TRACT_48_TEXA
                        layer = "X19_INCOME", quiet = TRUE)

# Rename the socio_income GEOID column to match the one in socio_geom
socio_income <- socio_income %>%
  rename("GEOID_Data" = "GEOID")

# Join the income with the geometry by the GEOID_Data column
socio <- socio_geom %>% left_join(socio_income, by = "GEOID_Data") %>%
  st_transform(st_crs(houses))

# Verify successful join
if(!("B19013e1" %in% names(socio))) {
  stop("Median household income (Estimate) column not found after join")
}
```

Analysis

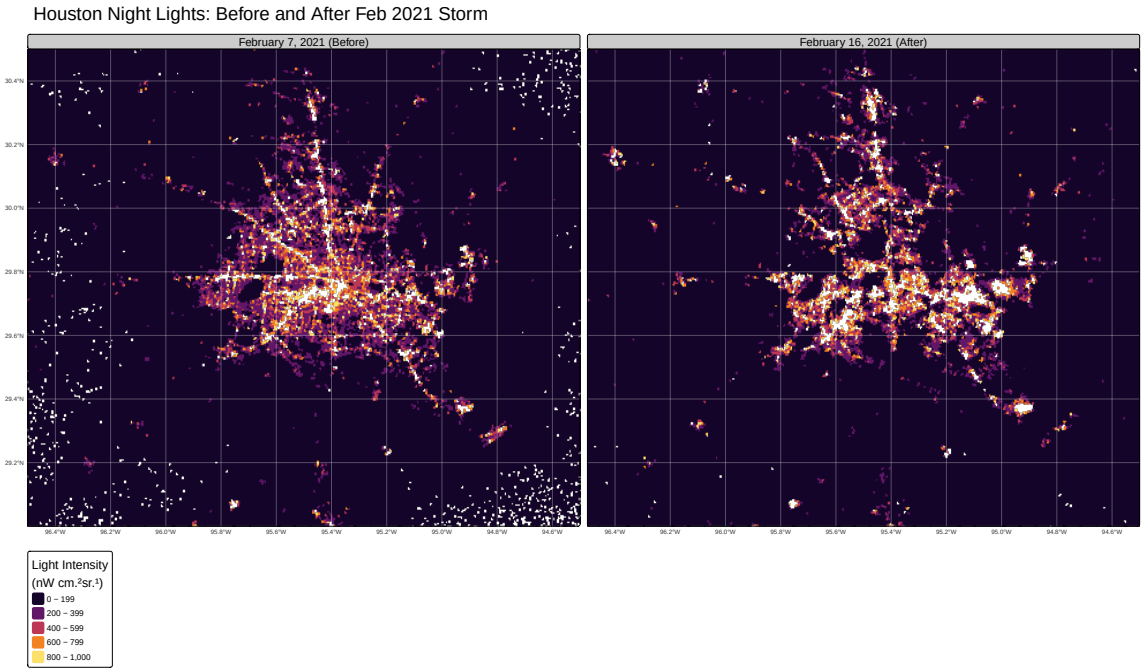
Visualize Before and After

Map the difference in night light before and after the storms

```r
# Merge the tiles for each date
VIIRS_07 <- merge(VIIRS_07a, VIIRS_07b)   # February 7, 2021
VIIRS_16 <- merge(VIIRS_16a, VIIRS_16b)   # February 16, 2021


# Crop, mask, and combine for plotting purposes
# 1. Define a Houston bounding box using the provided coordinates
HOUSTON_BBOX <- st_bbox(c(xmin = -96.5, ymin = 29,
                          xmax = -94.5, ymax = 30.5),
                        crs = st_crs(VIIRS_07))

# 2. Crop rasters using Houston bbox
crop_07 <- crop(VIIRS_07, HOUSTON_BBOX)
crop_16 <- crop(VIIRS_16, HOUSTON_BBOX)

# 3. Mask non-positive values and values above 1000
masked_07 <- crop_07
masked_07[(masked_07 > 1000) | (masked_07 <= 0)] <- NA
```

```r
masked_16 <- crop_16
masked_16[(masked_16 > 1000)  | (masked_16 <= 0)] <- NA

# 4. Combine cropped and masked rasters
combined_crop <- c(masked_07, masked_16)

# Name the layers
names(combined_crop) <- c("February 7, 2021 (Before)", "February 16, 2021 (After)")
```

```r
# Plot the before and after
tm_shape(combined_crop) +
  tm_raster(col.scale = tm_scale(values = "inferno"),
            col.legend = tm_legend(title = "Light Intensity\n(nW cm ⁻²sr ⁻¹)",
                                   title.size = 1,
                                   text.size = 0.7)) +
  tm_facets(ncol = 2, free.scales = FALSE) +
  tm_title("Houston Night Lights: Before and After Feb 2021 Storm",
           size = 1.5) +  # Bigger title
  tm_layout(legend.outside = TRUE,
            legend.outside.position = "right",
            legend.outside.size = 0.15,  # Control legend size
            panel.labels = c("February 7, 2021 (Before)",
                             "February 16, 2021 (After)")) +
  tm_graticules(lwd = 0.2, col = "white", alpha = 0.3, labels.size = 0.5)
```



Use the blackout mask to mask, bounding box to crop crop, and st_as_stars -> st_as_sf to vectorize the raster

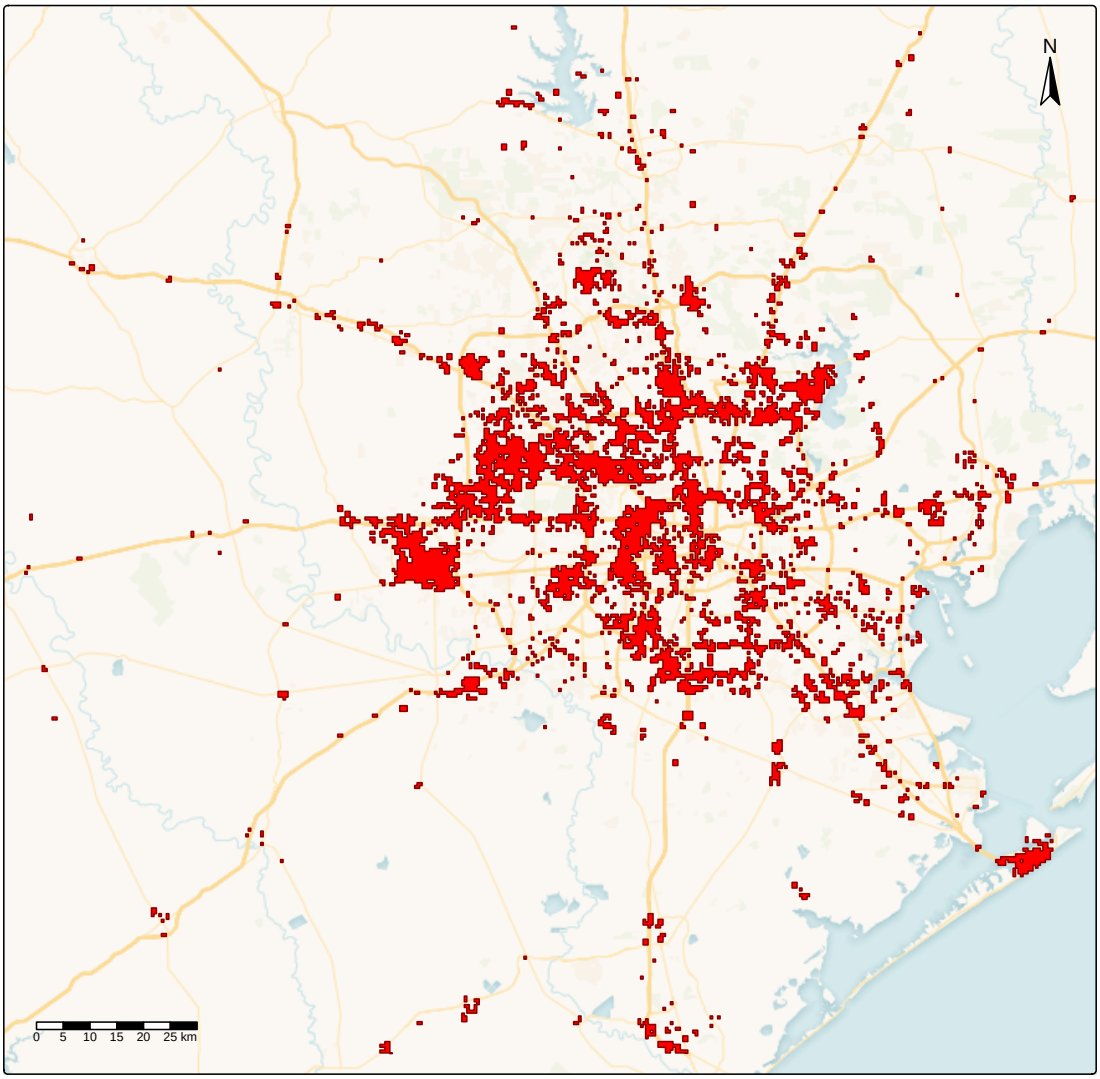
```
# Calculate the difference in light intensity between the two dates
VIIRS_houston_diff <- VIIRS_07 - VIIRS_16


# Classify areas with light intensity drops greater than 200 as blackouts
blackout_mask <- classify(VIIRS_houston_diff,
                      matrix(c(-Inf, 200, NA,  # Not a blackout
                               200, Inf, 1),   # Blackout
                             ncol = 3, byrow = TRUE))

# Vectorize the blackout mask and fix any invalid geometries
blackout_vector <- st_as_stars(blackout_mask) %>%
  st_as_sf() %>%
  st_make_valid()

# Crop the vectorized blackout mask to the Houston area
blackout_houston <- st_crop(blackout_vector, HOUSTON_BBOX)
```

```r
# Reproject to EPSG:3083 (NAD83 / Texas Centric Albers Equal Area)
blackout_houston <- st_transform(blackout_houston, crs = 3083)

# Verify cropping was successful
if(nrow(blackout_houston) == 0) {
  stop("No blackout areas remain after cropping to Houston")
}
```

Plot the resulting raster

```r
# Merge geometries for plotting
blackout_houston_union <- st_union(blackout_houston)

# Make the map
tm_basemap("CartoDB.VoyagerNoLabels") +
  tm_shape(blackout_houston_union) +
  tm_polygons(fill = "red",
              col = "darkred") +
  tm_title("Initial Blackout Areas in Houston", size = 1.2) +
  tm_layout(legend.show = FALSE) +
  tm_scalebar(position = c("left", "bottom")) +
  tm_compass(position = c("right", "top"))
```

Initial Blackout Areas in Houston



Exclude highways from the cropped blackout mask

Highways may show reduced light intensity due to decreased traffic rather than power outages. Exclude areas within 200m of highways.

```
# Reproject highways to match blackout data (EPSG:3083)
highways <- st_transform(highways, crs = 3083)
```

```r
# Join all the highway geometries into one and then buffer by 200m
highway_buffer <- highways %>%
  st_union() %>%
  st_buffer(dist = 200)

# Remove highway buffer zones from blackout areas
blackout_final <- st_difference(blackout_houston, highway_buffer)

# Verify data remains after highway exclusion
if(nrow(blackout_final) == 0) {
  warning("No blackout areas remain after excluding highways")
}
```

Identify the number of homes impacted by blackouts

```r
# Reproject houses to match blackout crs (EPSG:3083) before intersecting
houses <- st_transform(houses, crs = 3083)

# Extract homes that intersect blackout areas
blackout_homes <- st_intersection(houses, blackout_final)

# Count number of impacted homes
n_blackout_homes <- length(unique(blackout_homes$osm_id))

n_total_homes <- nrow(houses)

# Calculate percent impacted
pct_impacted <- round((n_blackout_homes / n_total_homes) * 100, 1)
```

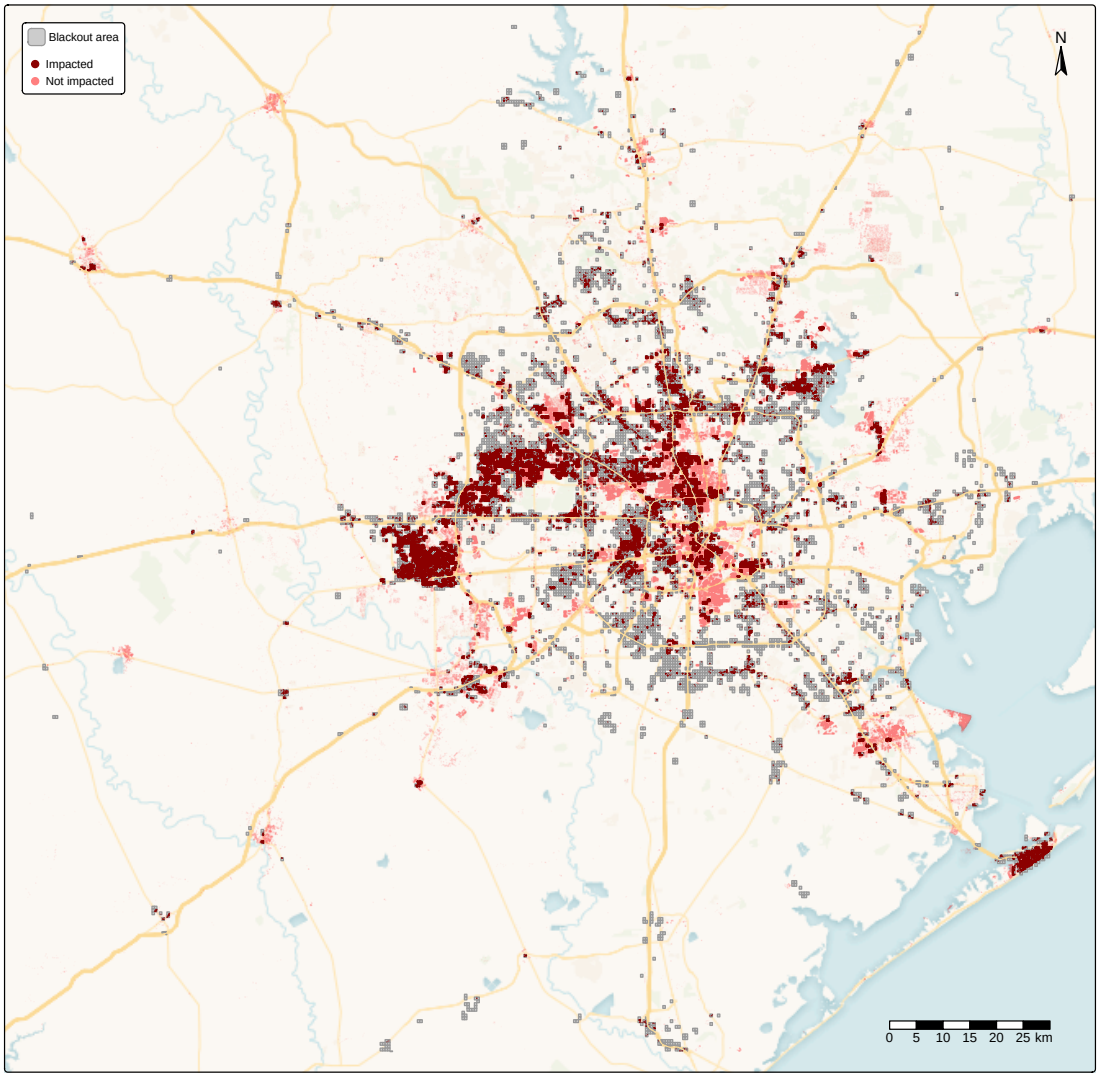
Results: Approximately **157,410** homes (33.1% of residential buildings in the dataset) experienced blackouts during the February 2021 storms.

Map impacted homes

```r
# Create points for all homes for plotting
all_homes_points <- st_centroid(houses)

# Separate impacted and not impacted homes
```

```r
not_impacted_homes <- all_homes_points[!all_homes_points$osm_id %in% blackout_homes$osm_id, ]

# Take the center of blackout homes for plotting
impacted_homes_points <- st_centroid(blackout_homes)
```

```r
# Map with layers in order: blackout areas, not impacted, then impacted on top
tm_basemap("CartoDB.VoyagerNoLabels") +
  tm_shape(blackout_final) +
  tm_polygons(fill = "grey80", col = "grey60") +
  tm_shape(not_impacted_homes) +
  tm_dots(fill = "#FF7F7F", size = 0.005, fill_alpha = 0.05) +
  tm_shape(impacted_homes_points) +
  tm_dots(fill = "darkred", size = 0.008, fill_alpha = 0.6) +
  tm_title("Homes in Houston Impacted by Blackouts", size = 1.8) +
  tm_layout(legend.outside = FALSE,  # Put legend INSIDE
            legend.position = c("left", "top"),
            legend.bg.color = "white",
            legend.bg.alpha = 0.8,
            legend.text.size = 0.6,
            legend.title.size = 0.8) +
  tm_add_legend(type = "polygons",
                labels = "Blackout area",
                fill = "grey80", col = "grey60", size = 0.4) +
  tm_add_legend(type = "symbols",
                labels = c("Impacted", "Not impacted"),
                fill = c("darkred", "#FF7F7F"),
                shape = 19, size = 0.4) +
  tm_scalebar(position = c("right", "bottom"), text.size = 0.7) +
  tm_compass(position = c("right", "top"), size = 1.5)
```



Analyze census tracts

Investigate whether census tracts with different median household incomes experienced differential blackout impacts.

```
# Transform census data to match blackout CRS (EPSG:3083)
socio <- st_transform(socio, crs = 3083)
```

```r
# Crop to Houston
houston_tracts <- st_crop(socio, st_bbox(blackout_houston))

# Count number of impacted homes per census tract
houston_tracts$n_homes <- as.numeric(lengths(st_intersects(houston_tracts, blackout_homes)))

# Create categories for visualization
houston_tracts$impact_category <- cut(houston_tracts$n_homes,
                                      breaks = c(1, 10, 50, 150, 500, 1500, Inf),
                                      labels = c("Very Low (1-10)",
                                                 "Low (11-50)",
                                                 "Medium (51-150)",
                                                 "High (151-500)",
                                                 "Very High (501-1,500)",
                                                 "Extreme (>1,500)"))

# Create blackout indicator
houston_tracts$blackout <- factor(houston_tracts$n_homes > 0,
                                  levels = c(TRUE, FALSE),
                                  labels = c("Blackout", "No Blackout"))

# Verify data quality
if(sum(!is.na(houston_tracts$B19013e1)) == 0) {
  stop("No valid median income data found")
}
```

```r
# Summary statistics
cat("Census tract summary:\n")
```

```
Census tract summary:
```

```r
cat("Total tracts:", nrow(houston_tracts), "\n")
```

```
Total tracts: 1114
```

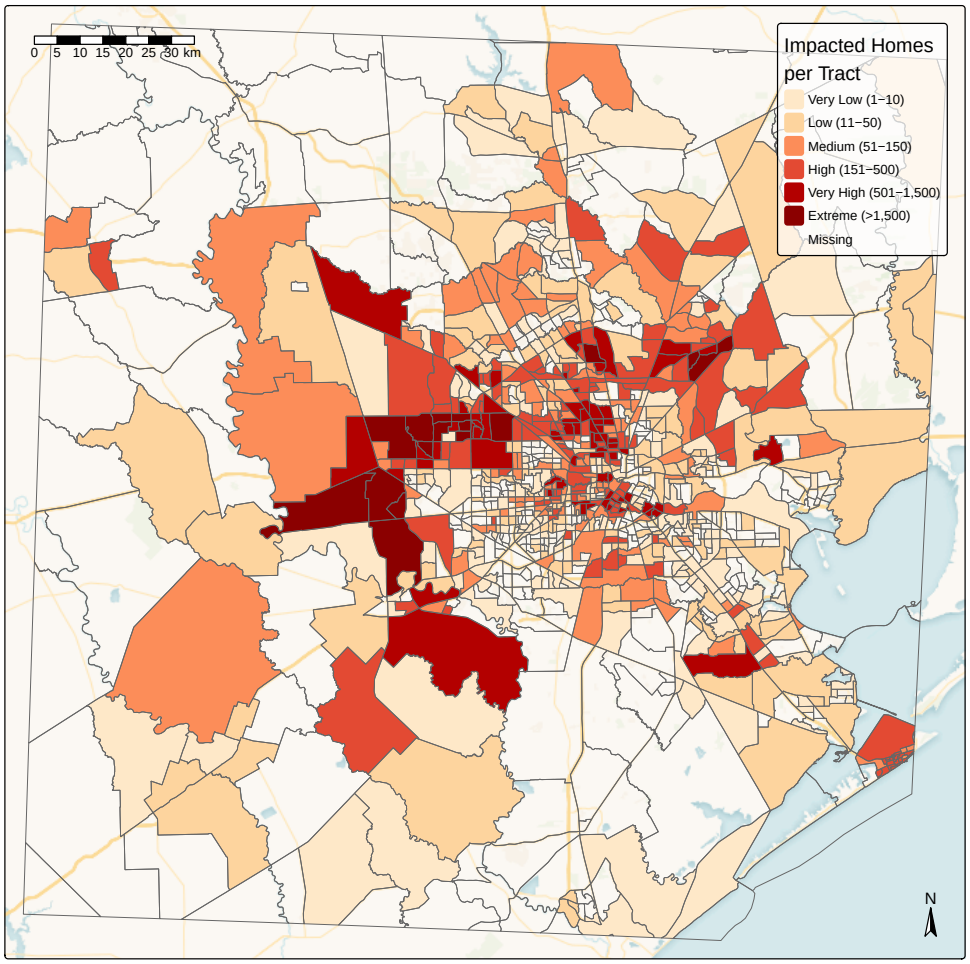
```r
cat("Tracts with blackouts:", sum(houston_tracts$n_homes > 0), "\n")
```

```
Tracts with blackouts: 753
```

```r
cat("Tracts without blackouts:", sum(houston_tracts$n_homes == 0), "\n")
```

```
Tracts without blackouts: 361
```

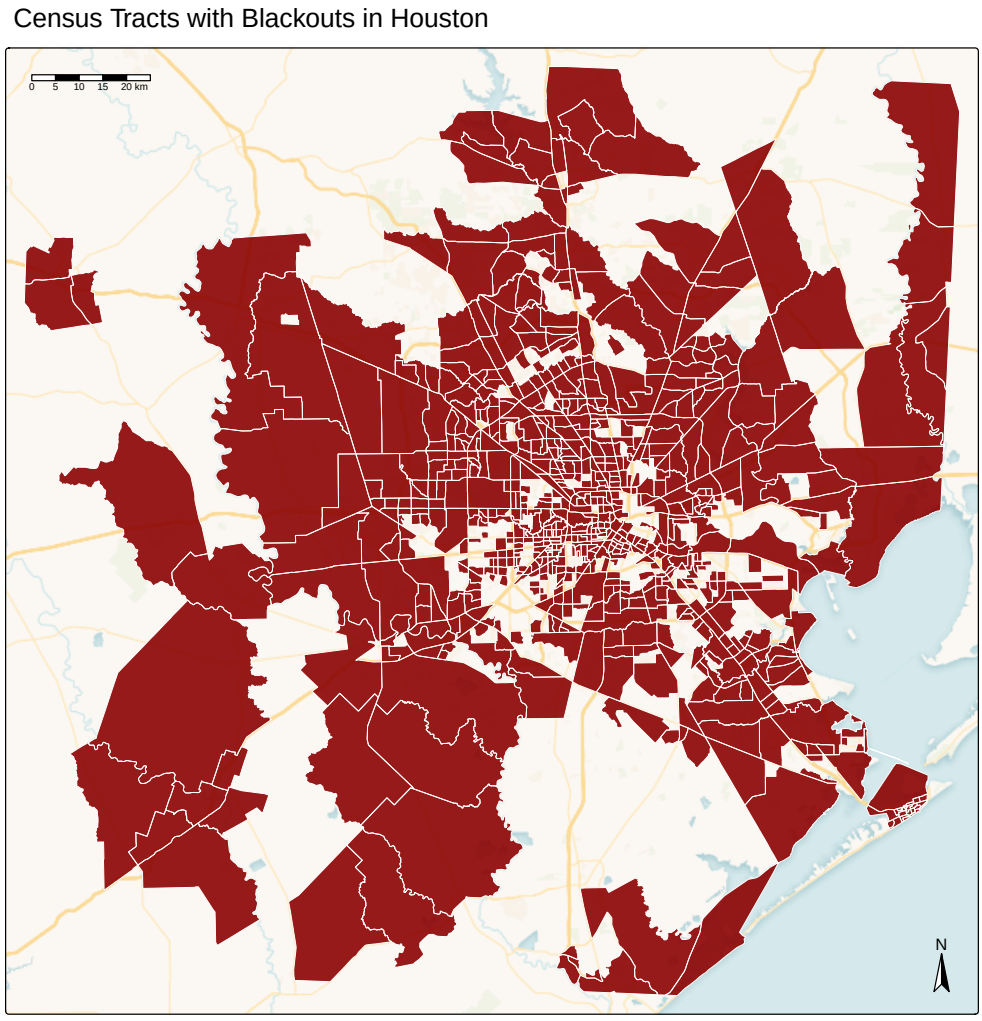
```r
# Map the census tracts that lost power
tm_basemap("CartoDB.VoyagerNoLabels") +
  tm_shape(houston_tracts) +
  tm_fill(fill = "impact_category",
          fill.scale = tm_scale(values = c("#fee8c8", "#fdd49e", "#fc8d59", "#e34a33", "#b30
                                value.na = "transparent"),
          fill.legend = tm_legend(title = "Impacted Homes\nper Tract",
                                  title.size = 1,
                                  text.size = 0.7)) +
  tm_borders(col = "grey40", lwd = 0.01) +
  tm_title("Census Tracts: Number of Homes Impacted by Blackouts", size = 1.8) +
  tm_scalebar(position = c("left", "top"), text.size = 0.7) +
  tm_compass(position = c("right", "bottom"), size = 1.5) +
  tm_layout(legend.outside = FALSE,  # Inside instead
            legend.position = c("right", "top"),
            legend.bg.color = "white",
            legend.bg.alpha = 0.7)
```



Map of census tracts impacted by blackouts

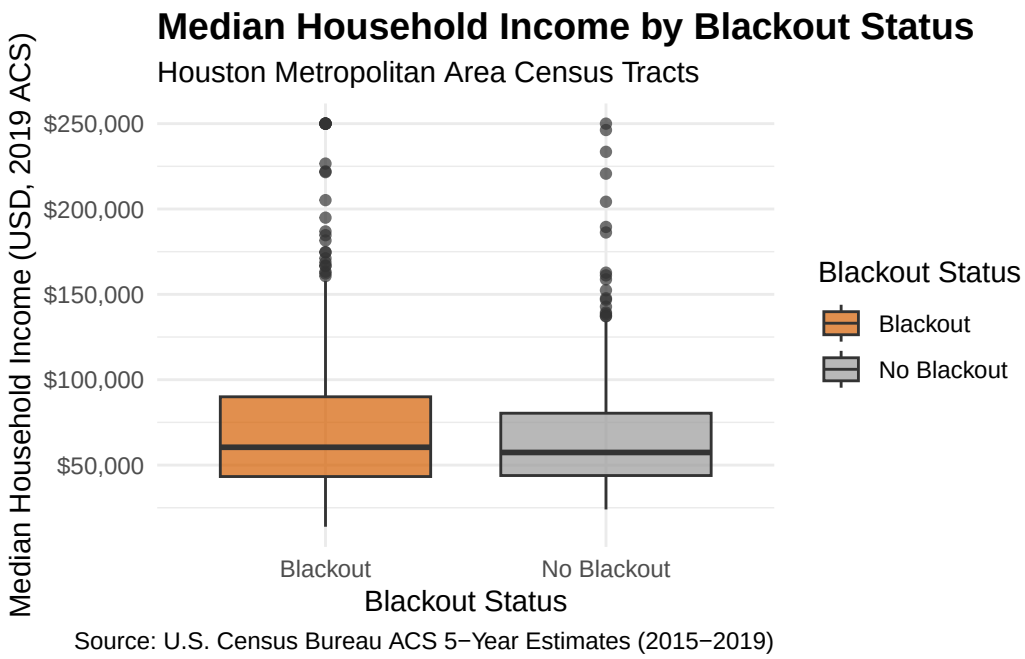
```
# Filter to only tracts with blackouts
blackout_tracts_only <- houston_tracts %>%
  filter(blackout == "Blackout")

# Plot tracts with blackouts
tm_basemap("CartoDB.VoyagerNoLabels") +
tm_shape(blackout_tracts_only) +
  tm_fill(fill = "darkred",
```

```
        fill_alpha = 0.9) +
tm_borders(col = "white", lwd = 0.2) +
tm_title("Census Tracts with Blackouts in Houston") +
tm_scalebar(position = c("left", "top")) +
tm_compass(position = c("right", "bottom")) +
tm_layout(legend.show = FALSE)
```



Compare income distributions

```
# Remove NA from income values
houston_tracts_no_na <- houston_tracts %>% filter(!is.na(B19013e1))

# Create comparison plot
ggplot(houston_tracts_no_na, aes(x = blackout, y = B19013e1, fill = blackout)) +
  geom_boxplot(alpha = 0.7) +
  scale_fill_manual(name = "Blackout Status",
                    values = c("Blackout" = "#D55E00",
                               "No Blackout" = "#999999")) +
  scale_y_continuous(labels = scales::dollar_format()) +
  labs(title = "Median Household Income by Blackout Status",
       subtitle = "Houston Metropolitan Area Census Tracts",
       x = "Blackout Status",
       y = "Median Household Income (USD, 2019 ACS)",
       caption = "Source: U.S. Census Bureau ACS 5-Year Estimates (2015-2019)") +
  theme_minimal() +
  theme(legend.position = "right",
        plot.title = element_text(size = 14, face = "bold"),
        axis.title = element_text(size = 11))
```



Summary statistics

```
income_stats <- houston_tracts %>%
  st_drop_geometry() %>%
  filter(!is.na(B19013e1)) %>%
  group_by(blackout) %>%
  summarise(
    `Number of Tracts` = n(),
    `Median Income` = median(B19013e1),
    `Mean Income` = mean(B19013e1),
    `SD Income` = sd(B19013e1)
  )

kable(income_stats,
      caption = "Income Statistics by Blackout Status",
      digits = 0,
      format.args = list(big.mark = ",")) %>%
  kable_styling(bootstrap_options = c("striped", "hover"))
```

Table 3: Income Statistics by Blackout Status

blackout	Number of Tracts	Median Income	Mean Income	SD Income
Blackout	749	60,435	71,262	39,649
No Blackout	355	57,385	67,353	35,901

Reflection

Results: This analysis identified approximately **157,410** homes in the Houston metropolitan area that likely experienced power outages during the February 2021 winter storms. The income analysis reveals that census tracts experiencing blackouts had a median household income of **60,435**, compared to **57,385** for tracts without blackouts. Areas that experienced blackouts had slightly higher median incomes, though the difference is not very significant (approximately $3,000 or 5%). The boxplot comparison shows that both groups have similar income distributions. This pattern suggests that the February 2021 blackouts affected Houston communities relatively uniformly across income levels (likely due to the severity and scale of the the storms).

Potential limitations: This analysis relies on only two temporal snapshots and a 200 nW cm ^{2}sr ^{1} threshold that may miss some outages. OpenStreetMap building data may be incomplete, and the 200m highway buffer may exclude legitimate residential blackouts. Census tract-level income masks within-tract variation in household experiences.

Data Sources

VIIRS Night Lights Data (VNP46A1) - NASA's Visible Infrared Imaging Radiometer Suite onboard the Suomi satellite - Tiles h08v05 and h08v06 covering the Houston area - Dates: 2021-02-07 (before storms) and 2021-02-16 (after storms) - Source: NASA's Level-1 and Atmospheric Archive & Distribution System Distributed Active Archive Center (LAADS DAAC) - Accessed via: NASA Worldview

OpenStreetMap - Roads - Highway and road network data for the Houston metropolitan area - File: `gis_osm_roads_free_1.gpkg` - Source: Geofabrik Download Server

OpenStreetMap - Buildings - Residential building footprints for the Houston metropolitan area - File: `gis_osm_buildings_a_free_1.gpkg` - Source: Geofabrik Download Server

U.S. Census Bureau - American Community Survey (ACS) - 5-Year estimates (2015-2019) at the census tract level for Texas - Geodatabase: `ACS_2019_5YR_TRACT_48_TEXAS.gdb` - Includes median household income and demographic data - Source: U.S. Census Bureau