eds223: Winter Storm Uri in TX

Megan Hessel

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Impacts of Winter Storm Uri in Houston, Texas

Investigating blackout data from Winter Storm Uri and comparing to Median Income Census Track data.

Downloading libraries and data

```
# Import libraries
library(terra) # raster handling
library(tidyverse)
library(tmap) # map making
library(kableExtra) # table formatting
library(geodata) # spatial data
library(stars)
library(raster)
```

```
# Download Data

# Night lights data (VNP46A1)
# with read_stars()... sf
light_1 <- read_stars(here::here("data", "VNP46A1", "VNP46A1.A2021038.h08v05.001.20210390643
light_2 <- read_stars(here::here("data", "VNP46A1", "VNP46A1.A2021038.h08v06.001.20210390643
light_3 <- read_stars(here::here("data", "VNP46A1", "VNP46A1.A2021047.h08v05.001.20210480911
light_4 <- read_stars(here::here("data", "VNP46A1", "VNP46A1.A2021047.h08v06.001.20210480911

# With rast()... terra
#l1 <- rast("data/VNP46A1/VNP46A1.A2021038.h08v05.001.2021039064328.tif")
#l2 <- rast("data/VNP46A1/VNP46A1.A2021038.h08v06.001.2021039064329.tif")
```

```r
#l3 <- rast("data/VNP46A1/VNP46A1.A2021047.h08v05.001.2021048091106.tif")
#l4 <- rast("data/VNP46A1/VNP46A1.A2021047.h08v06.001.2021048091105.tif")


# Road Data - just 'moterways'
roads <- st_read(here::here("data", "gis_osm_roads_free_1.gpkg"), query = "SELECT * FROM gis_

# House 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')
  ")


# Texas Data

# Looking at the various layeres
st_layers(here::here("data", "ACS_2019_5YR_TRACT_48_TEXAS.gdb"))

# Pulling out the geometry and income layers
geom_texas <- st_read(here::here("data/ACS_2019_5YR_TRACT_48_TEXAS.gdb"), layer = "ACS_2019_5
income_texas <- st_read(here::here("data/ACS_2019_5YR_TRACT_48_TEXAS.gdb"), layer = "X19_INCO
```

Coordinate Reference Systems

Checking CRS

```r
st_crs(light_1) # WGS 84
st_crs(light_2) # WGS 84
st_crs(light_3) # WGS 84
st_crs(light_4) # WGS 84

st_crs(roads) # WGS 84
st_crs(houses) # WGS 84
st_crs(geom_texas) # NAD83 *** NEEDS TO MATCH THE OTHERS **
```

```r
# Create print message function to check crs
crs_check <- function(crs1, crs2) {
  if (st_crs(crs1) == st_crs(crs2)) {
    print("its a match")
  } else {
    print("Its NOT a match")
  }
}


# Check crs between roads, houses, and TX' geom
crs_check(roads, houses)
```

```
[1] "its a match"
```

```r
crs_check(roads, geom_texas)
```

```
[1] "Its NOT a match"
```

```r
crs_check(houses, geom_texas)
```

```
[1] "Its NOT a match"
```

```r
# Check crs between all the light dfs
crs_check(light_1, light_2)
```

```
[1] "its a match"
```

```r
crs_check(light_1, light_3)
```

```
[1] "its a match"
```

```r
crs_check(light_1, light_4)
```

```
[1] "its a match"
```

```
crs_check(light_2, light_3)
```

```
[1] "its a match"
```

```
crs_check(light_2, light_4)
```

```
[1] "its a match"
```

```
crs_check(light_3, light_4)
```

```
[1] "its a match"
```

```
# Need to change geom_texas to match the others
```

Transforming CRS

```
# Change geom_texas crs to match roads' crs with st_transform()
geom_texas <- st_transform(geom_texas, st_crs(roads))
```

Final CRS Check

```
# Check crs between roads, and TX' geom
crs_check(roads, geom_texas)
```

```
[1] "its a match"
```

Create Blackout Mask

- 2021-02-07: light_1 and light_2
- 2021-02-16: light_3 and light_4

Create a raster object for each day:

Combine the 2 light tiles by date - Feb 7 and 16

```
# Combine light data based on y
feb7sf <- st_mosaic(light_1, light_2)
feb16sf <- st_mosaic(light_3, light_4)

# Check if extents match
print(st_bbox(feb7sf))
```

```
xmin ymin xmax ymax
-100   20  -90   40
```

```
print(st_bbox(feb16sf))
```

```
xmin ymin xmax ymax
-100   20  -90   40
```

```
# Remove the light objects
rm(list = c('light_1', 'light_2', 'light_3', 'light_4'))
```

Find where there were blackouts (with a power difference that's greater than 200 nW $cm^{-2}sr^{-1}$)

```
# Difference of the two days that are greater than 200 = blackouts
# Creating a list of boolean operators
difference <- (feb7sf - feb16sf) > 200
  # returns TRUES for more than 200; FALSE for less than 200
```

Create Mask & Subset for Blackout Regions that are greater than 200

```
# Create raster mask of the same resolution and extent
diff_mask <- difference

# Assign NA to all locations that experienced a drop of less than 200 nW cm-2sr-1 change ("FA
diff_mask[diff_mask == "FALSE" ] <- NA

# Remove the difference object
rm(difference)
```

Vectorize the Blackout Mask

```r
# Convert from a raster to a vector with st_as_sf
diff_mask_vec <- st_as_sf(diff_mask)

# Invalid geometries
which(!st_is_valid(diff_mask_vec)) # Tell us which specific ones are invalid

# Fixing invalid geometries
diff_mask_vec <- st_make_valid(diff_mask_vec)
```

Crop (spatially subset) the blackout mask to the Houston area

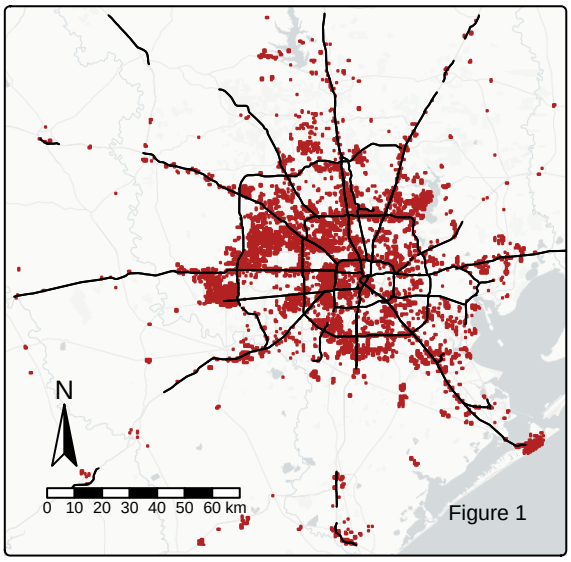
```r
# Create the Houston bounding box
bound_box <- st_bbox(c(xmin =-96.5, xmax = -94.5, ymax = 30.5, ymin = 29), crs = st_crs(diff_

# Crop difference vector with the bounding box
diff_crop <- st_crop(diff_mask_vec, bound_box)
  # ANOTHER WAY: diff_crop <- difference_mask[bound_box, op = st_intersects]
```

Re-project the cropped blackout dataset to EPSG:3083

```r
# Changing the crs to NAD83 / Texas Centric Albers Equal Area
diff_crop_epsg <- st_transform(diff_crop, crs = 'EPSG:3083')
```

Plot!

```r
# Want to Map Houston's light difference data (with the road data for clarity)

# Unionize / Aggregating road data to make it more manageable
road_union <- st_union(roads)

# Plot it!
tm_shape(diff_crop_epsg) +
  tm_polygons(col = "firebrick") +
  tm_shape(road_union) +
  tm_lines() +
  tm_basemap("CartoDB.PositronNoLabels") +
  tm_title(text = "All Blackouts in Houston, TX During Winter Storm Uri") +
  tm_compass(position = c("left", "bottom")) +
  tm_scalebar(position = c("left", "bottom")) +
  tm_credits("Figure 1", position = c("right", "bottom"))
```



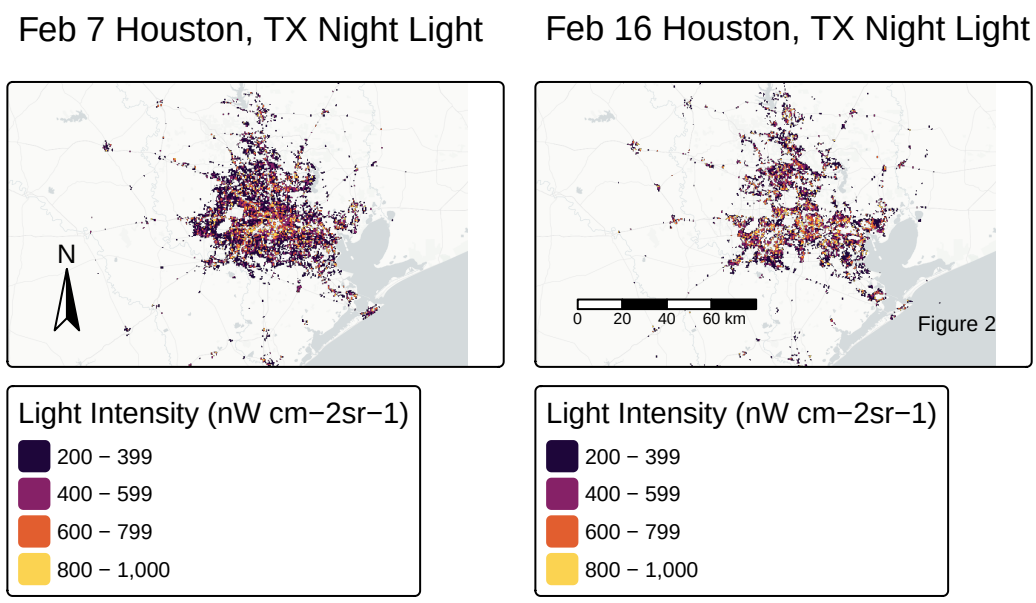
Before and After plots

A set of maps comparing night light intensities before and after the first two storms

```
# Crop to Houston Texas bounding box
feb7sf_houston <- st_crop(feb7sf, bound_box)
feb16sf_houston <- st_crop(feb16sf, bound_box)

# Mask to get rid of extremes
feb7sf_houston[feb7sf_houston < 200 | feb7sf_houston > 1000] <- NA
feb16sf_houston[feb16sf_houston < 200 | feb16sf_houston > 1000] <- NA

# Map feb 7 and feb 16
feb7map <- tm_shape(feb7sf_houston) +
  tm_raster(col.scale = tm_scale(values = "inferno"),
            col.legend = tm_legend(title = "Light Intensity (nW cm-2sr-1)")) +
            #title = "Light Intensity (nW cm-2sr-1)") +
  tm_title(text = "Feb 7 Houston, TX Night Light") +
  tm_compass(position = c("left", "bottom")) +
  tm_basemap("CartoDB.PositronNoLabels")


feb16map <- tm_shape(feb16sf_houston) +
  tm_raster(col.scale = tm_scale(values = "inferno"),
```

```
            col.legend = tm_legend(title = "Light Intensity (nW cm-2sr-1)"))+
            #title = "Light Intensity (nW cm-2sr-1)" ) +
  tm_title(text = "Feb 16 Houston, TX Night Light") +
  tm_scalebar(position = c("left", "bottom")) +
  tm_credits("Figure 2") +
  tm_basemap("CartoDB.PositronNoLabels")

tmap_arrange(feb7map, feb16map, outer.margins = 0.03)
```

```
[plot mode] fit legend/component: Some legend items or map compoments do not
fit well, and are therefore rescaled.
i Set the tmap option `component.autoscale = FALSE` to disable rescaling.
[plot mode] fit legend/component: Some legend items or map compoments do not
fit well, and are therefore rescaled.
i Set the tmap option `component.autoscale = FALSE` to disable rescaling.
```

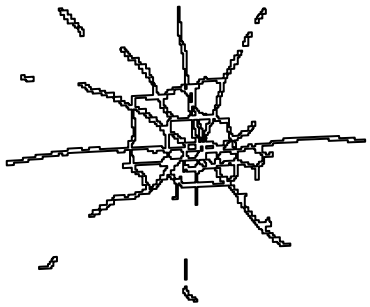



```
# Get rid of unneccary dfs
rm(list = c('feb7sf', 'feb16sf'))
```

Exclude Highways from the Mask

Identify areas within 200m of all highways with a buffer

```
# Unionize road data to make it more manageable - Aggregating road data
road_union <- st_union(roads)

# Buffer areas within 200 m of all highways
road_buffer <- st_buffer(road_union, dist = units::set_units(200, "m"))

# Look at the Road buffer
plot(road_buffer)
```

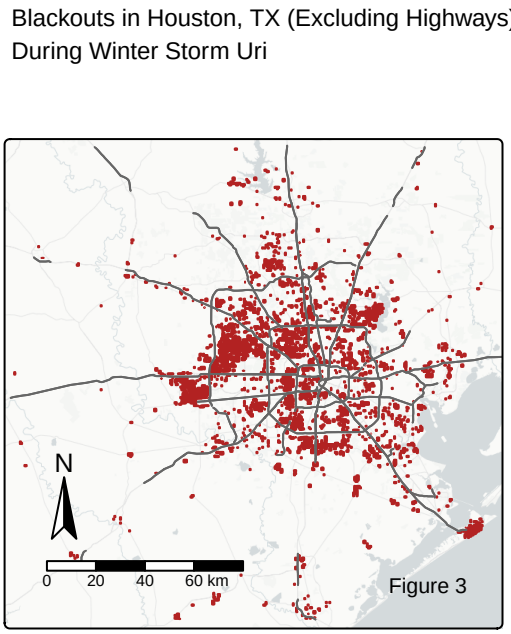


Exclude the 200m highway/road buffer from the blackout area

```
# Merge blackout areas with road buffer

# Check if CRS match
crs_check(road_buffer, diff_crop)
```

```
[1] "its a match"
```

```r
# Locating all blackouts NOT within the 200m highway buffer
blackouts_200m_highway <- st_difference(diff_crop , road_buffer)

# Plot it
tm_shape(blackouts_200m_highway) +
  tm_polygons(col = "firebrick") +
  tm_shape(road_union)+
  tm_lines(col = "grey40") +
  tm_basemap("CartoDB.PositronNoLabels") +
  tm_title(text = "Blackouts in Houston, TX (Excluding Highways)\nDuring Winter Storm Uri") +
  tm_compass(position = c("left", "bottom")) +
  tm_scalebar(position = c("left", "bottom")) +
  tm_credits("Figure 3")
```



Homes Impacted by Blackouts

Homes that overlap with areas that experienced blackouts

```r
# Check crs
if(st_crs(houses) == st_crs(diff_crop)){ # Check if match
  print("CRS match!")
```

```
  } else {
  warning("Updating CRS to match")

  # Transform to match
  diff_crop <- st_transform(diff_crop, st_crs(houses))
  }
```

```
[1] "CRS match!"
```

```
# Invalid geometries
#which(!st_is_valid(houses))
#which(!st_is_valid(diff_crop))

# Fixing invalid geometries
houses <- st_make_valid(houses)
diff_crop <- st_make_valid(diff_crop)

# Homes that experienced  blackouts
home_blackout <- st_filter(diff_crop, houses, .predicate = st_intersects)
```

Estimate of the number of homes in Houston that lost power

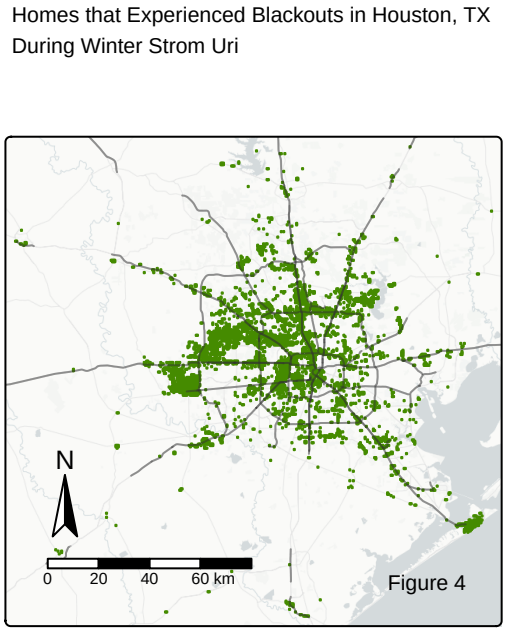
```
# Number of observations in the home_blackout raster
est <- ncell(home_blackout)

print(paste("About", est, "of Houston homes lost power"))
```

```
[1] "About 9390 of Houston homes lost power"
```

```
# Remove estimate object
rm(est)
```

Mapping Homes that experienced blackouts

```r
# Map it!
tm_shape(home_blackout) +
  tm_polygons(col = "chartreuse4") +
  tm_basemap("CartoDB.PositronNoLabels") +
  tm_shape(road_union)+
  tm_lines(col = "grey20",
           alpha = 0.3) +
  tm_title(text = "Homes that Experienced Blackouts in Houston, TX\nDuring Winter Strom Uri")
  tm_compass(position = c("left", "bottom")) +
  tm_scalebar(position = c("left", "bottom")) +
  tm_credits("Figure 4")
```



Comparing Blackouts with Census Track Data

Data frames that are needed for this task:

- Texas income data = "income_texas"
- Texas geometries = "geom_texas"

Important income columns:

- 19013e1: median household income in the past 12 months

- 19052e1: wage or salary income in the past 12 months for households

Join Texas geometries and income data layers

=> a data frame of all Texas income and geometry data = "texas_df"

```
# Looking at dataframes
print(dim(geom_texas))
print(dim(income_texas))

# Join Texas geom and incomes
texas_df <- cbind(geom_texas, income_texas)
# Know dfs will line up b/c they are different layers of the same data
# ANOTHER WAY: LEFT JOIN: texas_df <- left_join(geom_texas, income_texas)

# Print new df's dimensions - see if the joined worked
print(dim(texas_df))

# Remove un-joined dfs
rm(list = c('geom_texas', 'income_texas'))
```

Merge Texas data (containing income + geom) with house blackout data

(1) Data frame with homes that DID experienced a blackout and their income = "income_bo_homes"

(2) Data frame with homes that did NOT experienced a blackout and their income = "income_NO_bo_homes"

```
# Checking crs

if(st_crs(texas_df) == st_crs(home_blackout)){ # Check if match
  print("CRS match!")
  } else {
  warning("Updating CRS to match")
  # Transform to match
  texas_df <- st_transform(texas_df, crs = st_crs(home_blackout))
  }
```

```
[1] "CRS match!"
```

Filter for homes that did AND did not experience blackouts (BOs) in census data

(1) Homes that DID experience blackouts

```r
# (1) st_filter for homes experiencing BOs
income_bo_homes <- st_filter(texas_df, home_blackout, .predicate = st_intersects) %>%
  mutate(blackout = "TRUE") # Adding a column pertaining to experiencing a BO
```

(2) Homes that did NOT experience blackouts

```r
# (a) Look for areas of intersections
idx_intersect <- st_intersects(texas_df, home_blackout, sparse = FALSE)
# Build a logical matrix (sparse = false) of boolean operators (TRUE and FALSES) that explai


# (b) Looking for areas NOT included in the intersection data
income_NO_bo_homes <- texas_df[!apply(idx_intersect, 1, any), ] %>%
  mutate(blackout = "FALSE") # Adding a column pertaining to NOT experiencing a BO
  # Loops over all rows to see if there is a any "TRUE" or "FALSE" values in every row
  # ! keeps only rows with no intersection


# PROBLEMS: DID NOT WORK (happened to a lot of people)
# st_disjoint(texas_df, home_blackout)
# st_filter(texas_df, home_blackout, .predicate = st_disjoint)
  # Because "disjoint" is saying: Keep all features in texas_df that are disjoint (do not tou


# Look at shapes - See if filtering worked... it did!
print(dim(texas_df))
```

```
[1] 5265 3061
```

```r
print(dim(home_blackout))
```

```
[1] 4695    2
```

```r
print(dim(income_bo_homes))
```

```
[1]  856 3062
```

```r
print(dim(income_NO_bo_homes))
```

```
[1] 4409 3062
```

```
# Remove intermediate 'idx_intersect' df
rm(idx_intersect)
```

Visualizing income and blackouts spatially

Visually checking to see if filtering homes worked

```
# Create my color palette
my_palette = c('#488f30', '#a9bb5a', '#ffe896', '#ffad76', '#fc7082')


# Map of mean (of median) income with no blackouts
no_blackout_income_map <- tm_shape(income_NO_bo_homes) +
  tm_polygons(fill = "B19013e1",
              fill.legend = tm_legend(title = "Median Income"),
              fill.scale = tm_scale(breaks = c(0, 50000, 100000, 150000, 200000, 300000),
                                    values = my_palette)) +
    tm_shape(diff_crop, is.main = TRUE) +
  tm_title(text = "Medium Income Cenus Track for Homes with Power") +
  tm_compass(position = c('right', 'bottom')) +
  tm_basemap("Esri.WorldTopoMap")


# Map of mean (of median) incomes of home that experienced blackouts
blackout_income_map <- tm_shape(income_bo_homes) +
  tm_polygons(fill = "B19013e1",
              fill.legend = tm_legend(title = "Median Income"),
               fill.scale = tm_scale(breaks = c(0, 50000, 100000, 150000, 200000, 300000),
                                     values = my_palette)) +
  tm_shape(diff_crop, is.main = TRUE) +
  tm_title(text = "Medium Income Cenus Track for Homes without Power") +
  tm_scalebar(position = c('left', 'bottom')) +
  tm_credits(text = "Figure 5", position = c(0.7, -0.05)) +
  tm_basemap("Esri.WorldTopoMap")

# Look at both together
tmap_arrange(no_blackout_income_map, blackout_income_map)
```

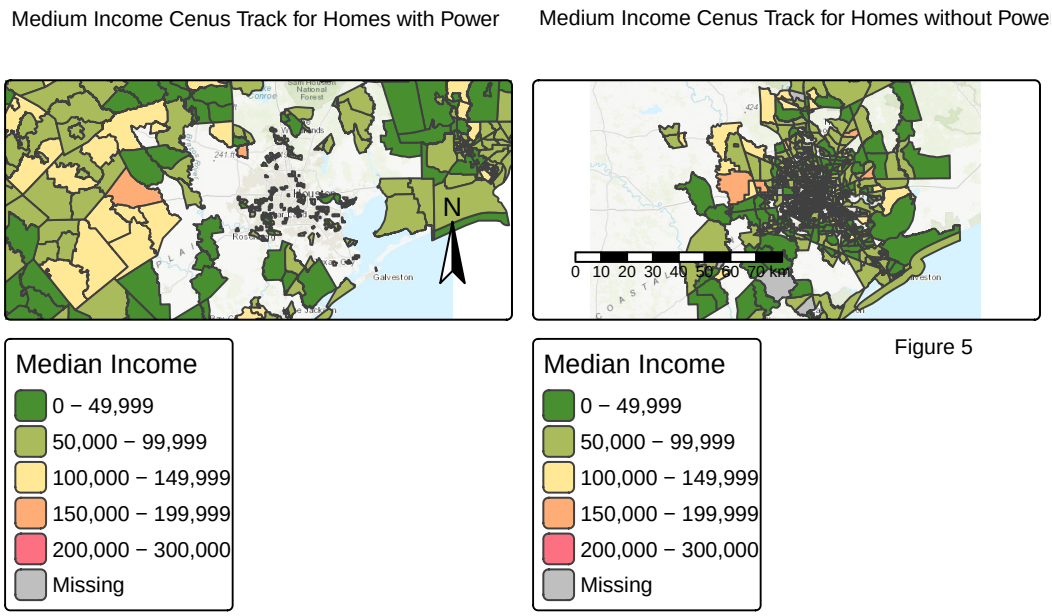
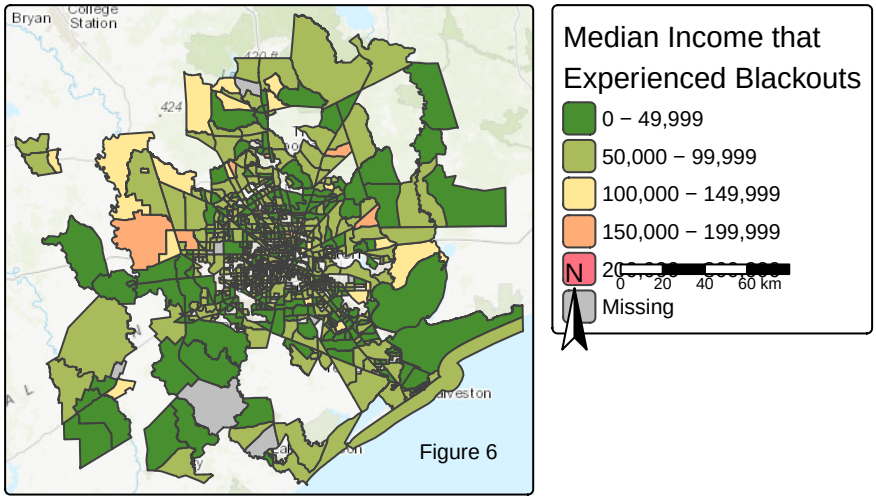


Figure 5

A map of the census tracts in Houston that lost power

```
tm_shape(income_bo_homes) +
  tm_polygons(fill = "B19013e1",
              palette = my_palette ,
              title = "Median Income that\nExperienced Blackouts",
              breaks = c(0, 50000, 100000, 150000, 200000, 300000)) +
  tm_compass(position = c(1.02, 0.5)) +
  tm_scalebar(position = c(1.14, 0.5)) +
  tm_title(text = "Median Income Census Tracts in Houston, TX that\nExperienced a Blackout Du
  tm_credits("Figure 6") +
  tm_basemap("Esri.WorldTopoMap")
```

Median Income Census Tracts in Houston, TX that
Experienced a Blackout During Winter Storm Uri



Plotting homes experiences blackouts vs not

```
# Merge mean income blackouts and no blackout dataframes
income_merge <- rbind(income_NO_bo_homes, income_bo_homes)

# Histogram
ggplot(income_merge,
       aes(x = B19013e1,
           fill = blackout)) +
  geom_histogram()+
  scale_fill_manual(labels = c("No Blackout", "Blackout"),
                    values = c("#ffaf50", "#488f30")) +
  labs(x = "Median Household Income",
       fill = "Experienced a Blackout",
       title = "Counts of Median Household Incomes\nthat did and did not Experience Blackouts
       y = 'Count',
       caption = "Figure 7") +
  theme_bw()
```

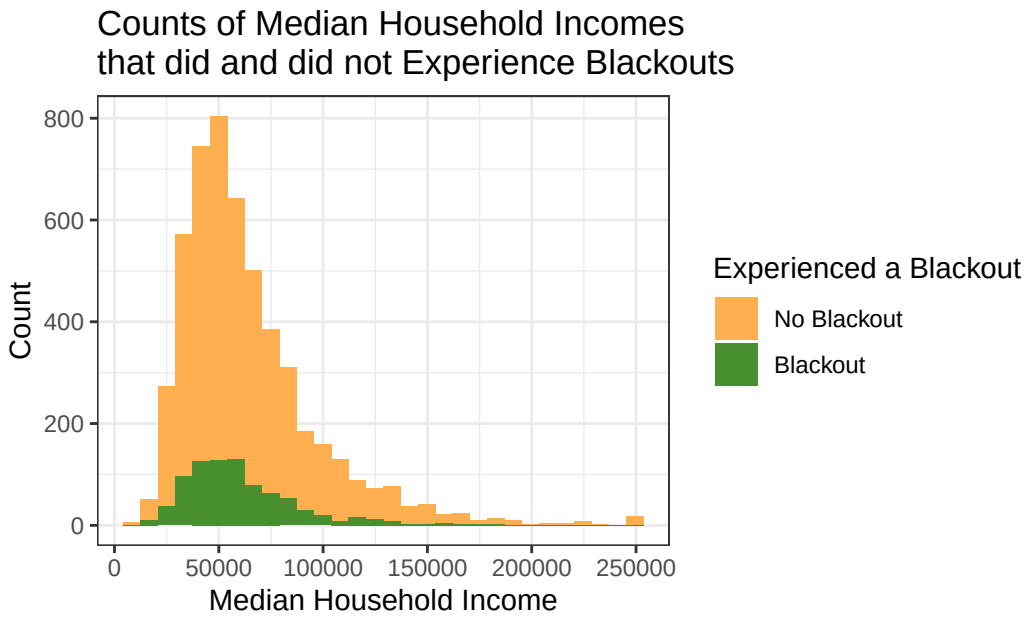


Figure 7

```
# Boxplot
ggplot(income_merge,
       aes(y = B19013e1,
           x = blackout,
           fill = blackout)) +
  geom_boxplot(outlier.size =0.2,
               outlier.color = 'grey30')+
  scale_fill_manual(labels = c("No Blackout", "Blackout"),
                    values = c("#ffaf50", "#488f30")) +
  labs(fill = "Experienced a Blackout",
       title = "Median Household Incomes that\ndid and did not Experience Blackouts",
       caption = "Figure 8",
       y = "Median Incomes",
       x = "Blackout Experience") +
  theme_bw()
```

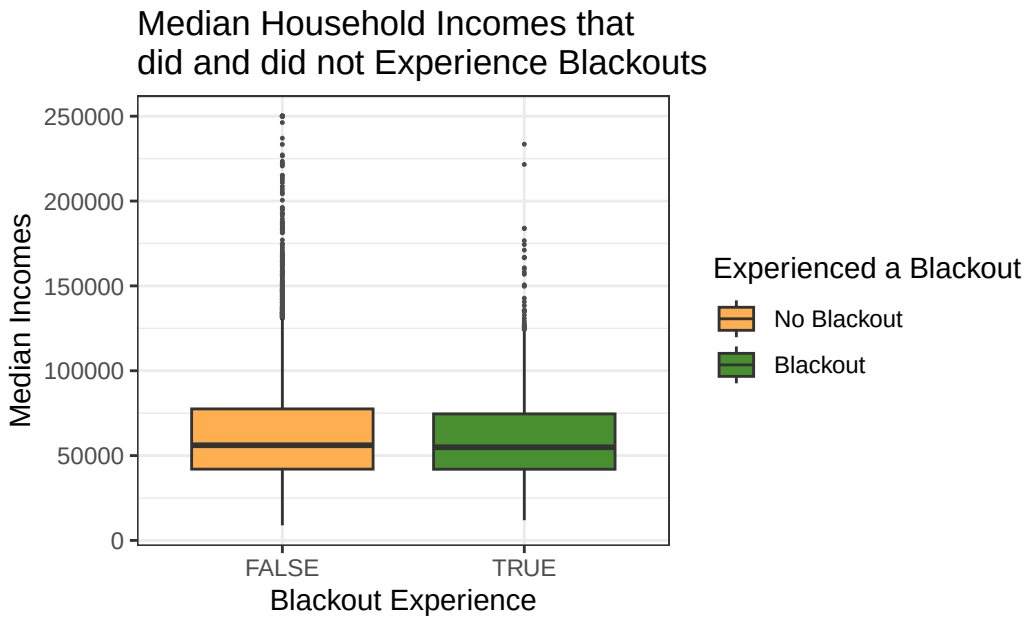


Figure 8

Income classes that did and did not experienced a blackout

Create a df with a new column specifying income CLASS

```
# Select only needs columns and drop geometry
income_class <- income_merge[, c('GEOID', 'B19013e1', 'blackout')] %>%
  st_drop_geometry()


# Add new column based on median income for INCOME CLASSES
income_class <- income_class %>%
  mutate(class = case_when(
    is.na(B19013e1) ~ NA_character_,
    B19013e1 < 40000 ~ "lower_class",
    B19013e1 < 125000 ~ "middle_class",
    TRUE ~ "upper_class" # All others are upper class
  ) )
# Made these income classes based on Fullerton, 2026

# COUNTS of homes experiencing blackouts vs not per income class
income_class_sum <- income_class %>%
  group_by(class, blackout) %>%
  summarise(count = n())
```

```
# Plot it
ggplot(income_class_sum,
       aes(x = class,
           y = count,
           fill = blackout)) +
  geom_col(position="fill",
           stat="identity",
           color = "black") +
  scale_fill_manual(labels = c("No Blackout", "Blackout"),
                    values = c("#ffad76", "#488f30")) +
  scale_x_discrete(labels = c('Lower Class', 'Middle Class', 'Upper Class', 'NAs')) +
  labs(title = "Proportion of Households that did and did not\nExperienced Blackouts in Vari
       x = "Income Classes",
       y = "Proportion",
       fill = "Experienced Blackout",
       caption = "Figure 8:\nLower income class is below $40,000.\nMiddle class is $40,000 t
  theme_bw()
```

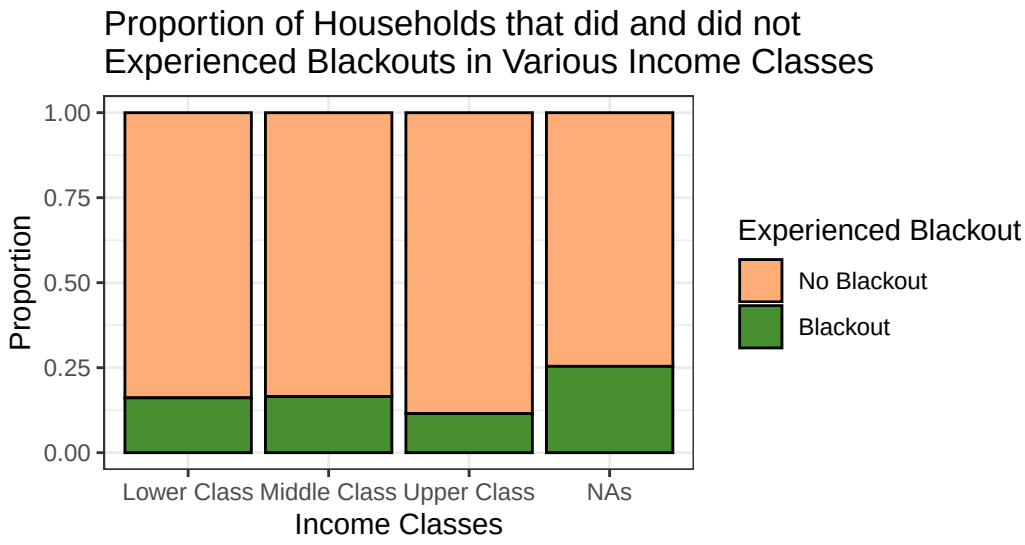


Figure 8:
Lower income class is below $40,000.
Middle class is $40,000 to $125,000.
Upper class is greater than $125,000.

Proportion of Income Classes that Experienced a Blackout

```
# Filters for home counts that experiences a blackout
class_count_blackout <- income_class_sum %>%
```

```
  filter(blackout == 'TRUE')

# Total of homes per each income class
class_count_total <- income_class_sum %>%
  group_by(class) %>%
  summarise(total = sum(count))

# Combine dataframes
class_count <- left_join(class_count_blackout, class_count_total, by ='class')

# Proportions of homes that experiences a blackout per Income Class
class_count <- class_count %>%
  group_by(class) %>%
  mutate(prop = 100*(count/total))

# Creating a kable table
knitr::kable(class_count[, c('class', 'prop')],
                      col.names = c("Income Class", "Percentage"),
                      digits = 2,
                      align = 'c',
                      caption = "Percentage of each Income Class that Experienced a Blackout
```

Table 1: Percentage of each Income Class that Experienced a Blackout

Income Class	Percentage
lower_class	16.14
middle_class	16.52
upper_class	11.51
NA	25.40

```
# Remove unnecessary dfs
rm(list = c('class_count_blackout', 'class_count_total'))
```

Conclusion

On February 11-20, 2021, Winter Storm Uri hit Texas (NOAA, 2023). Uri bright record-breaking cold and precipitation, leading to the longest stretch of freezing temperatures in Texas history (NOAA, 2023). As temperatures plummeted, power went out across the South, pipes burst, roads iced over, and countless accidents followed (NOAA, 2023 and Watson P, 2021).

Millions of people (more than 2 out of 3 people) were left in the dark and cold with no access to power or a heater at some point (Watson P, 2021).

In Houston, Texas, the power outage centered around the downtown area which is seen in Figures 1 - 5. Figures 6 - 8 investigate the power outages in comparison with income census blocks. The medium income distributions of people who experienced blackouts vs did not experience blackouts are very similar and consistent with the overall medium income distribution in Houston. As shown in Figure 7 and the table, the proportion of residents experiencing blackouts is relatively consistent across income classes, ranging from about 12% to 16%. Accordingly, there is insufficient evidence to suggest that the power outages during Winter Storm Uri were biased or unjustly distributed.

Limitations to the study: The light data was from NASA's Level-1 and Atmosphere Archive and Distribution System Distributed Active Archive Center (LAADS DAAC) which uses Visible Infrared Imaging Radiometer Suite (VIIRS). When using satellite imagery, course spatial resolution and atmospheric interference can impact the study. Furthermore, the road and house data is acquired by Open Street Map which can have data completeness and accuracy issues.

Personal Statement

I am from Houston, Texas! I was present during Winter Storm Uri. My father and I were powerless in our home while my mom (Dr. Hessel) was stuck on-call in the hospital for a couple of days. It was a crazy week with no power, pipes bursting, being locked inside, and no school.