Houston Texas Environmental Impacts

Winter Storm Event, Feburary 2021- Blackout

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Import Libraries

```
library(terra) # raster handling
library(tidyverse) #for boxplot
library(tmap) # map making
library(kableExtra) # table formatting
library(spData) # spatial data
library(spDataLarge) # spatial data
library(geodata) # spatial data
library(here)
library(sf)
library(raster)
library(stars)
```

Importing Data

```
texas <- st_read(here::here('data','ACS_2019_5YR_TRACT_48_TEXAS.gdb'),
                 layer ='ACS_2019_5YR_TRACT_48_TEXAS' ,
                 # Adding to not show output message
                 quiet = TRUE)
homes <- st_read(here('data','gis_osm_buildings_a_free_1.gpkg'),
                 query = "SELECT * FROM gis_osm_buildings_a_free_1 WHERE (type IS NULL AN
                # Adding to not show output message
                 quiet = TRUE)
roads <- st_read(here('data','gis_osm_roads_free_1.gpkg'),
                 query = "SELECT * FROM gis_osm_roads_free_1 WHERE fclass='motorway'",
                # Adding to not show output message
                 quiet = TRUE)
# Raster Data -
vnp_05 <- rast(here("data", "VNP46A1", "VNP46A1.A2021038.h08v05.001.2021039064328.tif"))
vnp_06 <- rast(here("data", "VNP46A1", "VNP46A1.A2021038.h08v06.001.2021039064329.tif"))
vnp_05_2 <- rast(here("data", "VNP46A1", "VNP46A1.A2021047.h08v05.001.2021048091106.tif")
vnp_06_2 <- rast(here("data", "VNP46A1", "VNP46A1.A2021047.h08v06.001.2021048091105.tif")

# Using Stars for before and after
vnp_051 <- read_stars(here("data", "VNP46A1", "VNP46A1.A2021038.h08v05.001.2021039064328.
vnp_061 <- read_stars(here("data", "VNP46A1", "VNP46A1.A2021038.h08v06.001.2021039064329.
vnp_05_21 <- read_stars(here("data", "VNP46A1", "VNP46A1.A2021047.h08v05.001.202104809110
vnp_06_21 <- read_stars(here("data", "VNP46A1", "VNP46A1.A2021047.h08v06.001.202104809110
```

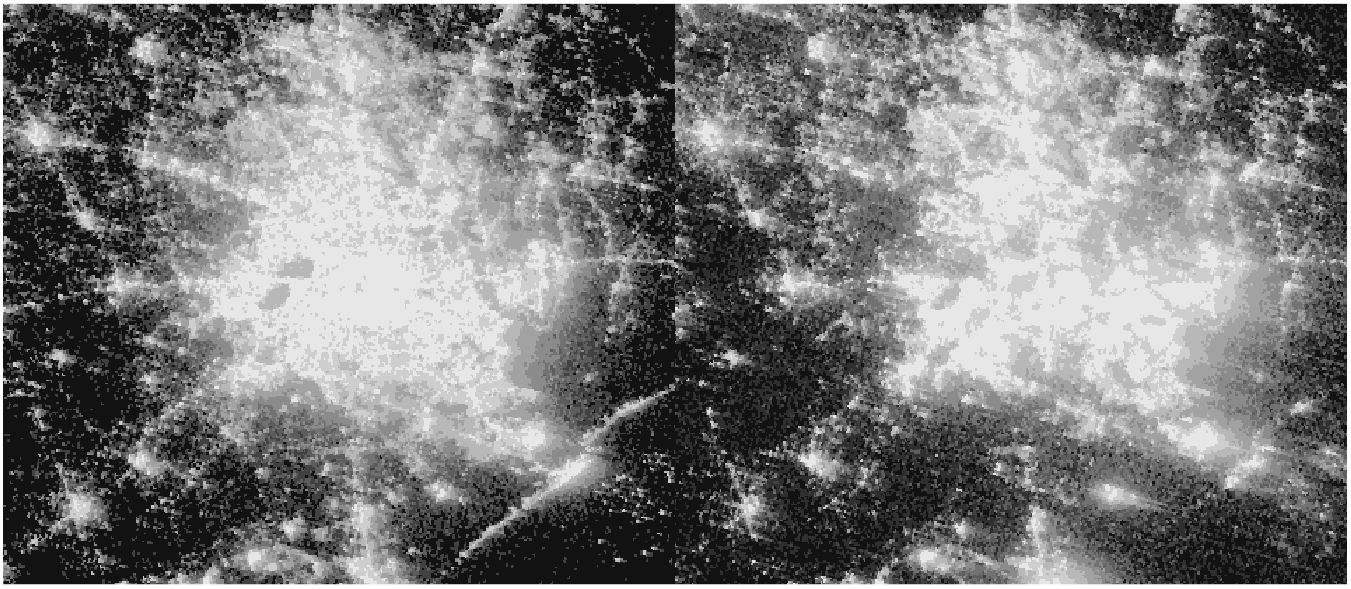
Creating Raster Objects with Stars Package

```
# Checking Extents:
if(st_crs(vnp_05) == st_crs(vnp_06)){
  print("Extents match :)")
}  else{
  warning("extents do not match :(")
}
```

```
[1] "Extents match :)"
```

```
# Stars
vnp_feb7<- st_mosaic(vnp_051,vnp_061)
vnp_feb16 <- st_mosaic(vnp_05_21, vnp_06_21)

#Cropping extent
extent <- st_bbox(c(xmin = -96.5, # xmin
                    ymin = 29, # ymin
                    xmax = -94.5, # xmax
                    ymax = 30.5),
                    crs = st_crs(vnp_feb7))
# Arranging plots- side by side
par(mfrow = c(1, 2))

#Cropped VNP
vnp_7_crop <- st_crop(vnp_feb7, extent)

vnp_16_crop <- st_crop(vnp_feb16, extent)

vnp_07 <- plot(vnp_7_crop, main = "Before Storm", key.pos = NULL)
vnp_16 <- plot(vnp_16_crop, main = "After Storm", key.pos = NULL)
```

Before Storm **After Storm**



```
# Saving Image
# filename = here("images", "median_income.png")
ggsave(filename = here("images", "vnp_07_before.png"), plot = vnp_07, width = 8, height =
ggsave(filename = here("images", "vnp_16_after.png"), plot = vnp_16, width = 8, height =
```

Using Terra Packages- Combining Rasters

- Checking boundaries, and computing difference between rasters

```
# Combining Rasters: Using xmin and xmax
vnp_feb07 <- merge(vnp_05, vnp_06)
vnp_feb16 <- merge(vnp_05_2, vnp_06_2)


# Checking if bounding box are the same
st_bbox(vnp_feb07)
```

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

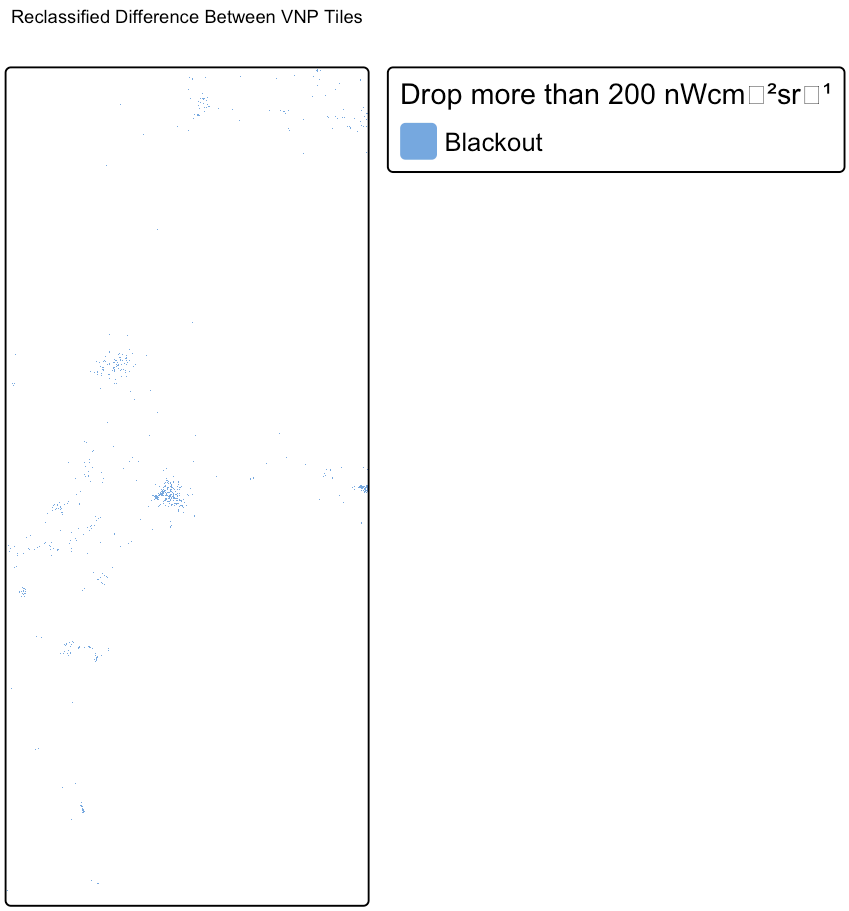
```
st_bbox(vnp_feb16)
```

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

```
# Computing the Difference
vnp_change <- (vnp_feb07) - (vnp_feb16) # Using Terra
```

Reclassify the difference raster, assuming that any location that experienced a *drop of more than 200 nW cm-2sr-1* experienced a blackout

```
# Define the reclassification matrix
rcl_vnp <- matrix(c(-Inf, 200, NA,   # values -Inf to 200 = NA
                    200, Inf, 1),    # values 200 to Inf = 1
                  ncol = 3, byrow = TRUE)

# Use classify function
reclassified <- terra::classify(vnp_change, rcl = rcl_vnp)
# Assinging map to a variable
reclassified_map <- tm_shape(reclassified) +
  tm_raster(
    title = "Drop more than 200 nWcm⁻²sr⁻¹",
    labels = c("Blackout")) +
  tm_layout(
    main.title = "Reclassified Difference Between VNP Tiles",
    main.title.size = 1,
    legend.title.size = 0.9,
    legend.text.size = 0.8)

# Viewing map
reclassified_map
```




```
# Saving Map
tmap_save(reclassified_map,filename = here("images", "reclassified_map.png"),width = 1200
```

Vectorize the blackout mask

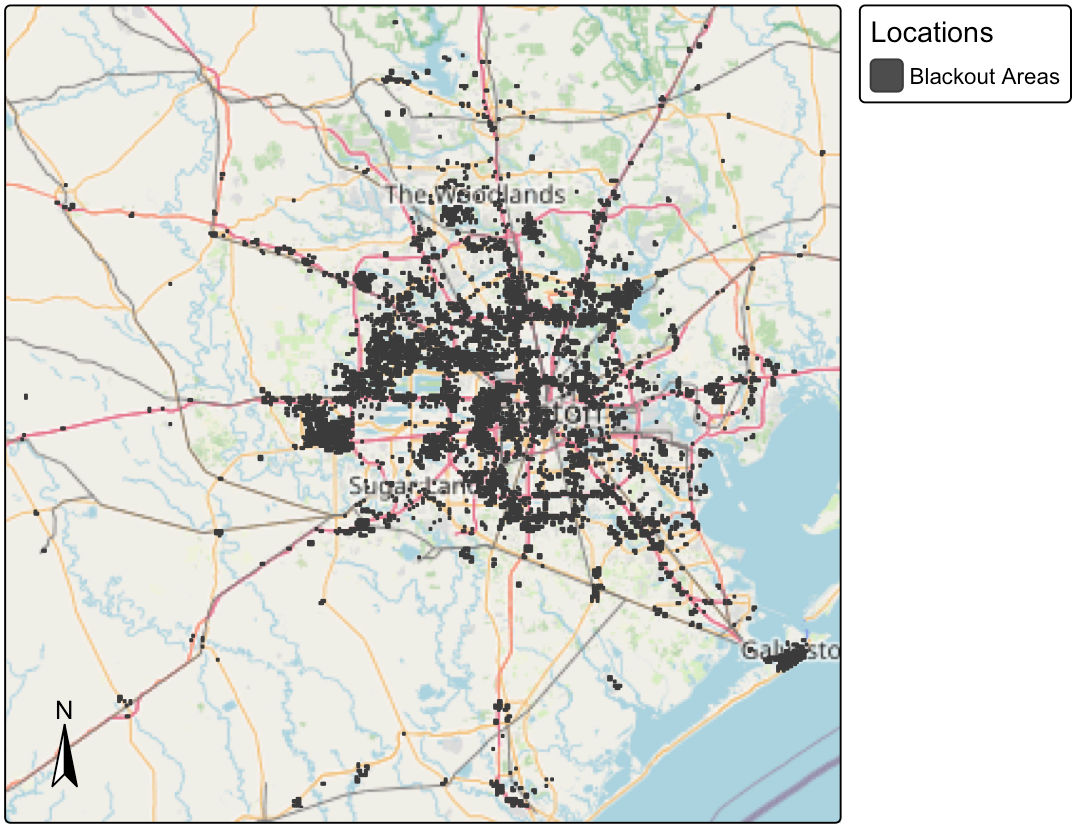
```
blackout_vector <- st_as_stars(reclassified)%>%
  st_as_sf() %>%
  st_make_valid()
```

Crop(spatially subset) the blackout mask to the Houston area as defined by the following coordinates:

(-96.5, 29), (-96.5, 30.5), (-94.5, 30.5), (-94.5, 29)

```
# Define bounding box coordinates
blackout_houston_bounds <- c(xmin = -96.5, xmax = -94.5,
                             ymin = 29, ymax = 30.5)

# Creating bbox and assign CRS
houston_bbox <- st_bbox(blackout_houston_bounds, crs = st_crs(vnp_feb07))

# Convert bbox to an sf polygon
```

```r
houston_bbox_sf <- st_as_sfc(houston_bbox)

# Crop the vectorized blackout map to Houston area
blackout_houston <- st_intersection(blackout_vector, houston_bbox_sf)

# Re-project the cropped blackout dataset to *EPSG:3083* (NAD83 / Texas Centric Albers Eq
blackout_houston_proj <- st_transform(blackout_houston, crs = 3083)

# Checking CRS
#st_crs(blackout_houston_proj)

blackout_houston_map <- tm_shape(blackout_houston_proj) +
    # Add OpenStreetMap as the basemap
  tm_basemap(server = "OpenStreetMap") +
  tm_polygons()+
  tm_layout(main.title = "Blackout Map of Houston, Texas",
            main.title.size = 1.5)+
  tm_add_legend(
    type = "fill",
    labels = "Blackout Areas",
    col = "gray30",
    title = "Locations")+
    tm_compass(north = 0, position = c("left", "bottom"))


# Viewing
blackout_houston_map
```




```
# Saving Map
tmap_save(blackout_houston_map,filename = here("images", "blackout_houston_map.png"),widt
```

Exclude highways from the cropped blackout mask and Identify areas within 200m of all highways - hint: you may need to use st_union

```
# Checking Extents:
if(st_crs(blackout_houston_proj) == st_crs(roads)){
  print("Extents match :)")
}  else{
  warning("extents do not match :(")
}
```

```
Warning: extents do not match :(
```

```
#Checking Units
st_crs(roads, parameters = TRUE)$units_gdal # Degrees
```

```
[1] "degree"
```

```
# Transform
highway <- st_transform(roads, st_crs(blackout_houston_proj))

#Checking Units
st_crs(highway, parameters = TRUE)$units_gdal # Metres
```

```
[1] "metre"
```

```
# Confirming Extents:
if(st_crs(blackout_houston_proj) == st_crs(highway)){
  print("Extents match :)")
}  else{
  warning("extents do not match :(")
}
```

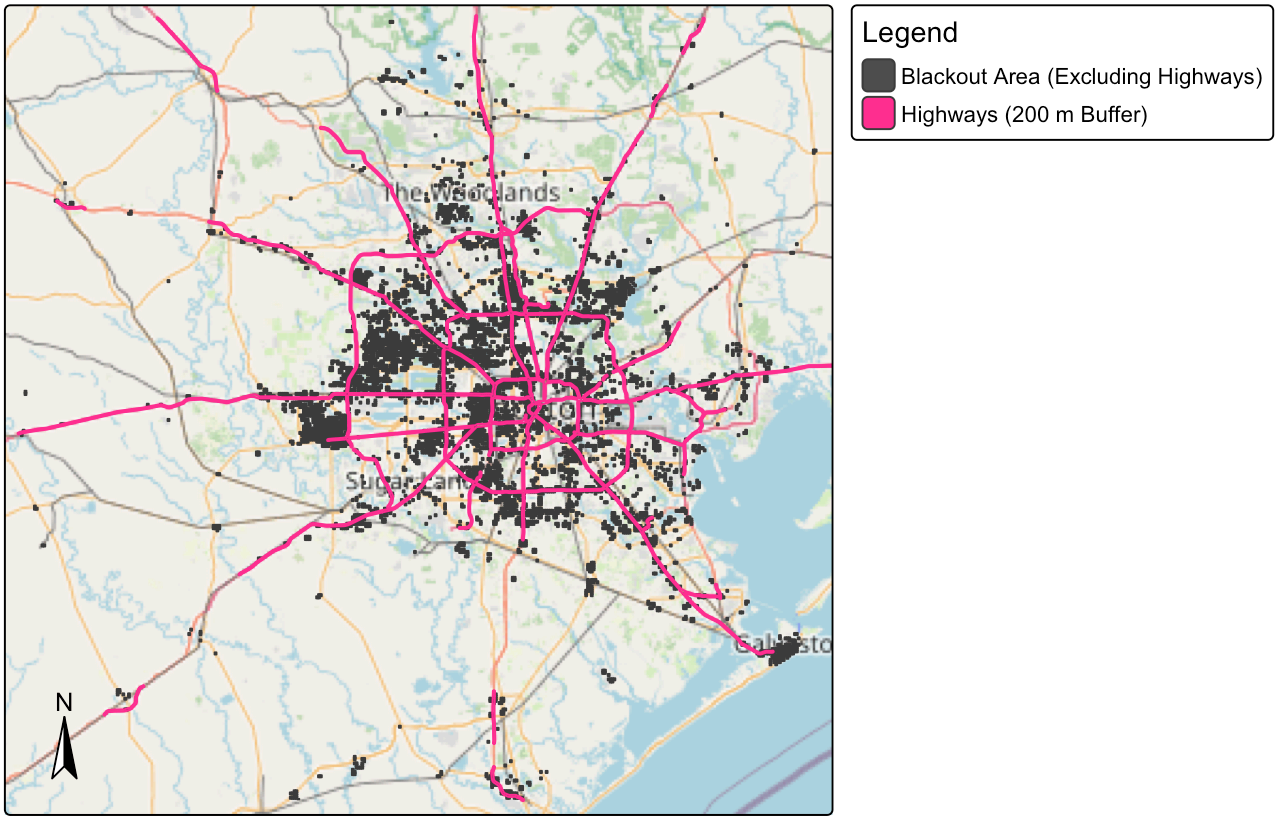
```
[1] "Extents match :)"
```

```
# Creating buffer
highway_200 <- st_buffer(highway, dist = 200) %>%
  st_union()

# Difference in blackout houston project and highway buffer 200 m
highway_blackouts <- st_difference(blackout_houston_proj, highway_200)
```

```
Warning: attribute variables are assumed to be spatially constant throughout
all geometries
```

```
# MAP
highway200_buff <- tm_basemap("OpenStreetMap") +
  tm_shape(highway_blackouts) +
  tm_polygons(col = "gray30", border.col = NA, alpha = 0.6) +
  tm_shape(highway_200) +
  tm_borders(col = "deeppink", lwd = 1) +
  tm_layout(main.title = "Houston Blackouts Highways(Buffer of 200m)",
            main.title.size = 1.5)+
  tm_add_legend(
    type = "fill",
    labels = c("Blackout Area (Excluding Highways)", "Highways (200 m Buffer)"),
    col = c("gray30", "deeppink"),
    title = "Legend")+
    tm_compass(north = 0, position = c("left", "bottom"))

# Viewing
highway200_buff
```

Houston Blackouts Highways(Buffer of 200m)




```
# Saving Map
tmap_save(highway200_buff,filename = here("images", "highway200_buff.png"),width = 1200,
```

Identify the number of homes likely impacted by blackouts

- identify homes that overlap with areas that experienced blackouts

```
# Transform homes to match CRS
buildings <- st_transform(homes, st_crs(highway_blackouts))

# Verify
if (st_crs(highway_blackouts) == st_crs(buildings)) {
  print("CRS match :)")
} else {
  warning("CRS do not match :(")
}
```

```
[1] "CRS match :)"
```

```
# homes that overlap with blackout areas
building_overlaps <- st_intersects(buildings, highway_blackouts)
```

```r
if (st_crs(highway_blackouts) == st_crs(buildings)) {
  print("CRS match :)")
} else {
  warning("CRS do not match :(")
}
```

```
[1] "CRS match :)"
```

```r
# Boolean TRUE/FALSE for homes impacted
buildings$impacted <- lengths(building_overlaps) > 0

# Subset homes that were affected
blackout_buildings <- buildings[buildings$impacted, ]

# How many homes are impacted
impacted_count <- sum(buildings$impacted)
print(paste("Number of homes likely impacted by blackouts:", impacted_count))
```

```
[1] "Number of homes likely impacted by blackouts: 134702"
```

```r
# Switching polygons to points
building_points <- st_centroid(buildings)
```

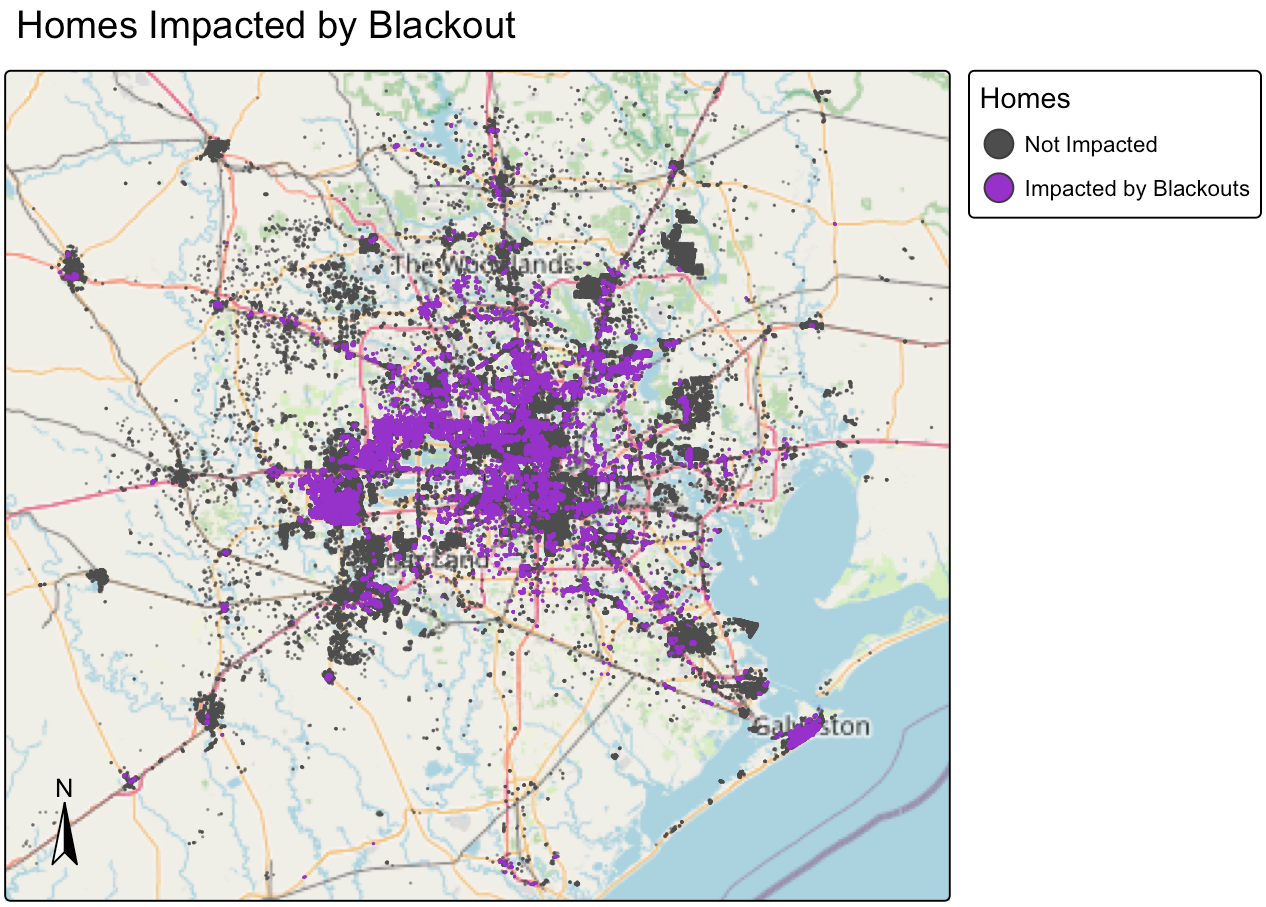
```
Warning: st_centroid assumes attributes are constant over geometries
```

```r
# Switching polygons to points
blackout_buildings_points <- st_centroid(blackout_buildings)
```

```
Warning: st_centroid assumes attributes are constant over geometries
```

```r
# MAP
building_impacted <- tm_shape(building_points) +
  # Add OpenStreetMap as the basemap
  tm_basemap(server = "OpenStreetMap") +
  tm_dots(col = "grey30", size = 0.05, alpha = 0.5,
          title = "Homes (Not Impacted)") +
tm_shape(blackout_buildings_points) +
  tm_dots(col = "darkorchid", size = 0.05, alpha = 0.8,
          title = "Homes Impacted by Blackouts") +
  tm_layout(main.title = "Homes Impacted by Blackout",
            main.title.size = 1.2)+
tm_add_legend(type = "symbol",
              labels = c("Not Impacted", "Impacted by Blackouts"),
              col = c("grey30", "darkorchid"),
              title = "Homes")+
    tm_compass(north = 0, position = c("left", "bottom"))
```

```
# Viewing
building_impacted
```



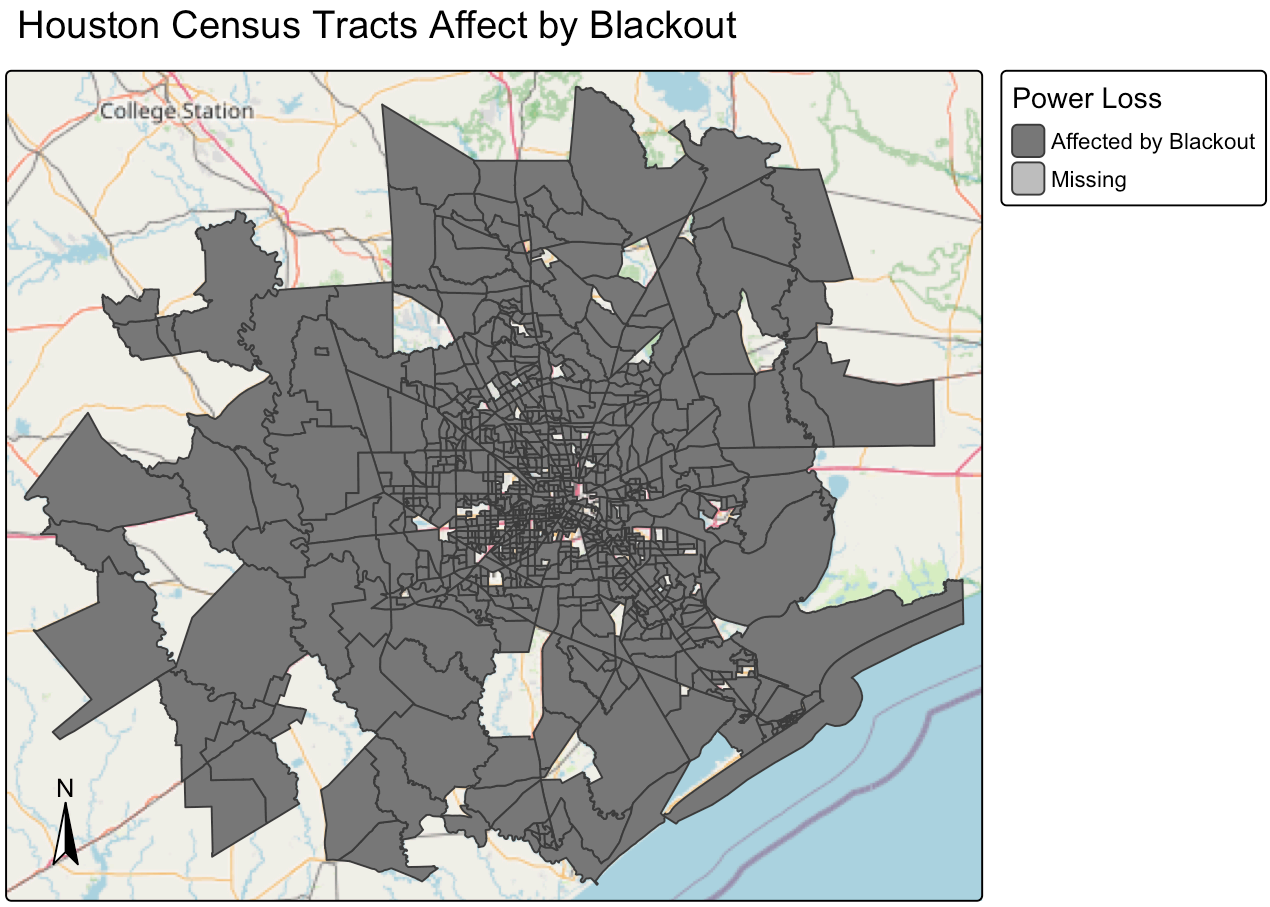

```
# Saving Map
tmap_save(building_impacted,filename = here("images", "building_impacted.png"),width = 12
```

Socioeconomic Houston Texas

Houston Census Tracts Affect by Blackout

```
houston_census_blackout <- tm_basemap("OpenStreetMap") +
  tm_shape(affected_tracts) +
    tm_polygons(
      col = "blackout_status",
      palette = "grey48",
      title = "Power Loss",
      labels = "Affected by Blackout") +
  # Title
  tm_layout(main.title = "Houston Census Tracts Affect by Blackout",
            main.title.size = 1.2)+
  tm_compass(north = 0, position = c("left", "bottom"))
```

```
# View map
houston_census_blackout
```

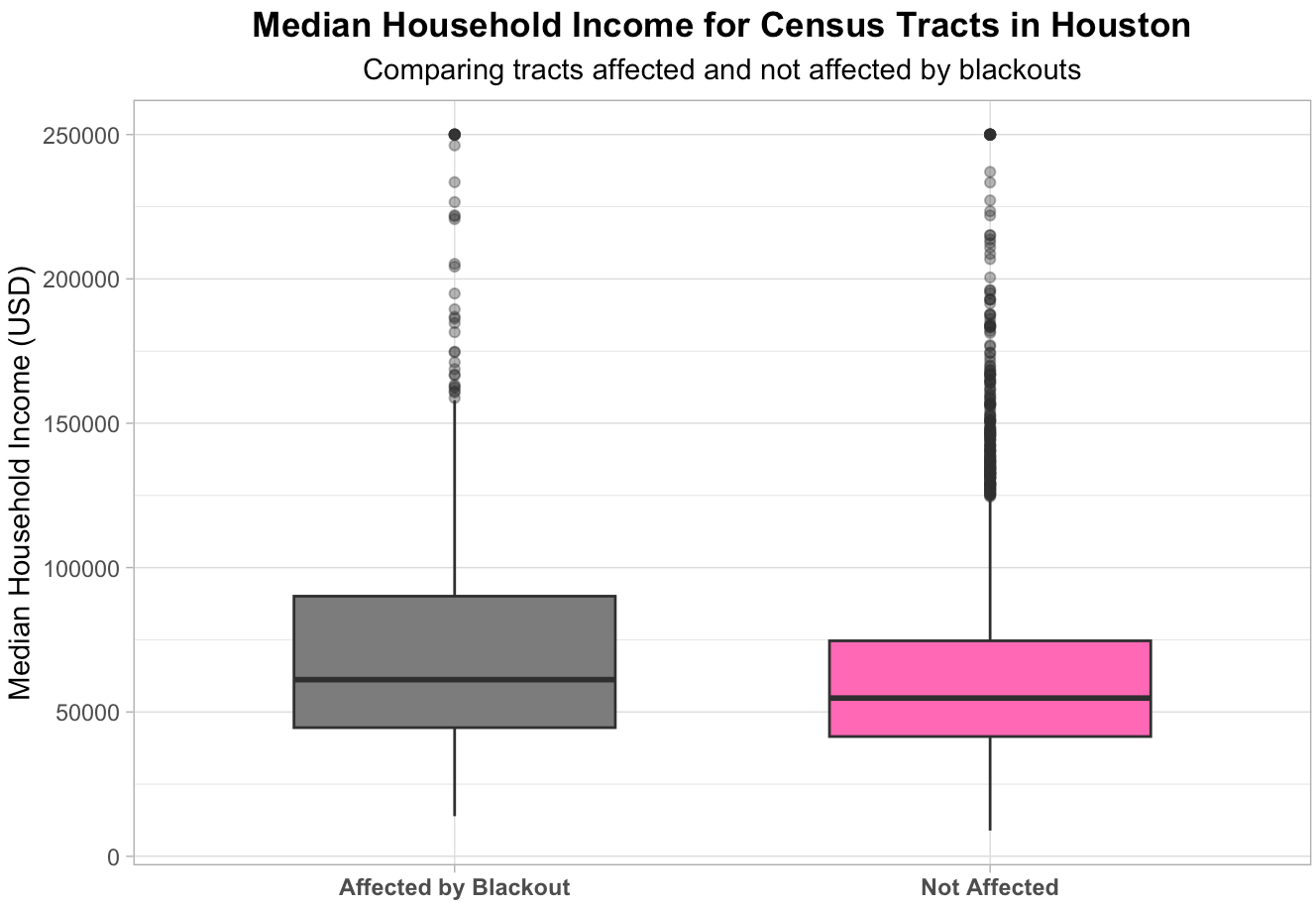



```
# Save map
tmap_save(houston_census_blackout,filename = here("images", "houston_census_blackout.png"
```

Visual of sociaeconomic median

```
# Boxplot comparing income distributions ---
median_income <- ggplot(socioeconomic_proj, aes(x = blackout_status, y = B19013e1, fill =
  geom_boxplot(width = 0.6, outlier.alpha = 0.4) +
  scale_fill_manual(values = c("Affected" = "grey30",
                               "Not Affected" = "hotpink")) +
  labs(
    title = "Median Household Income for Census Tracts in Houston",
    subtitle = "Comparing tracts affected and not affected by blackouts",
    x = "",
    y = "Median Household Income (USD)") +
  theme_light() +
  theme(
    plot.title = element_text(face = "bold", hjust = 0.5),
    plot.subtitle = element_text(hjust = 0.5),
    axis.text.x = element_text(face = "bold"),
```

```
    # Removes legend
    legend.position = "none")

# Viewing
median_income
```




```
# Saving Map
ggsave(filename = here("images", "median_income.png"), plot =median_income , width = 8, h
```

Income Summary Table

```
income_summary <- socioeconomic_proj %>%
  # Drop geometry for speed
  st_drop_geometry() %>%
  # Group by blackout
  group_by(blackout) %>%
  # Grab median incomes- using metadata
  summarize(
    mean_income = mean(as.numeric(B19013e1), na.rm = TRUE),
    median_income = median(as.numeric(B19013e1), na.rm = TRUE),
    sd_income = sd(as.numeric(B19013e1), na.rm = TRUE),
    n_tracts = n()
  ) %>%
```

```r
  # Creating new column
  mutate(blackout = ifelse(blackout, "Blackout", "No Blackout"))

# Kable Extra
income_summary %>%
  kbl(
    caption = "Summary Statistics: Median Household Income by Blackout Status",
    col.names = c("Blackout Status", "Mean Income ($)", "Median Income ($)", "SD", "Numbe
    digits = 0
  ) %>%
  kable_styling(full_width = FALSE, bootstrap_options = c("striped", "hover", "condensed"
  column_spec(2:4, width = "3cm") %>%
  add_header_above(c(" " = 1, "Income Summary" = 3, " " = 1))
```

Summary Statistics: Median Household Income by Blackout Status

	Income Summary			
Blackout Status	**Mean Income ($)**	**Median Income ($)**	**SD**	**Number of Tracts**
No Blackout	62403	54816	31704	4330
Blackout	72095	61188	39605	935

Results and Limitations:

Blackout-affected census tracts in the Houston area had a somewhat higher mean ($72,095) and median ($61,188) family income than unaffected census tracts (mean $62,403; median $54,816), according to the boxplot and summary statistics. Areas losing power may have not simply been the lowest-income neighbourhoods. Also infrastructure or land-use factors (ex. industrial zones near highways) might rather explain the blackout pattern. A limitation is the omission of building use either residential or commercial and deeper socioeconomic controls such as poverty rate, income distribution, etc. Without these, we cannot be certain that socioeconomic vulnerability is the only factor contributing to unequal impact or recovery.

Houston Texas Extreme Weather Impacts

- Author: Marie Tolteca, Student at Bren School of Environmental Science and Management, Masters in Environmental Data Science

- Date 11/10/2025

This project examines the impacts of the February 2021 Texas winter storms that caused widespread power outages across the state. Using VIIRS night light data (VNP46A1), the analysis identifies areas in the Houston metropolitan region that experienced blackouts by comparing light intensity before and after the storm. These areas are then spatially joined with OpenStreetMap building data to estimate the number of affected homes and with U.S. Census data to explore potential socioeconomic disparities in the blackout's impacts.

#.....Learning Outcomes.....

Key geospatial analysis concepts:

- Raster analysis (detecting changes in satellite imagery)
- Vector operations (buffering, intersections, spatial joins)
- Loading and managing vector/raster data
- Performing raster calculations (differences in nightlight intensity)
- Conducting spatial joins and intersections
- Linking spatial data with census information

#.....Data Access.....

- All project data (above) can be accessed via this Google Drive link.| Google Drive Download | **Nightlight Data (VNP46A1)**
- VIIRS Day/Night Band imagery (before and after the storm) used to detect blackout regions. NASA LAADS DAAC | **Roads and Buildings**
- OpenStreetMap vector data for Texas; used to identify homes and major highways in Houston. Geofabrik Download Server | **Socioeconomic Data**
- 2019 ACS 5-Year Estimates for Texas census tracts, including median household income.| U.S. Census Bureau

#.....Reprository Structure.....

When uploading data into RStudio, before pushing changes into Github,make sure to update the `.gitignore` to include `data` folder. My Data Reprository Structure:

#.....Workflow Outline.....

Library Package Usage: In this project, the following packages will be used. If the library needs to be installed use `install.packages()` to install libraries. Terra, tidyyverse, tmap, kableExtra, spData, spDataLarge, geodata, here, sf, raster, and stars. #### Identify blackout regions: - **Combine VIIRS raster tiles for dates before and after the storm. - Compute the difference in nightlight intensity. - Reclassify areas with a drop greater than 200 nW/cm²/sr as blackout zones.** #### Locate affected homes - **Load Houston's OSM building data. - Perform a spatial intersection with blackout polygons. - Estimate total homes impacted.** #### Socioeconomic - **Spatially join census tracts with blackout regions. - Compare median household incomes between affected and unaffected tracts using boxplots and summary statistics.**

#.....Outputs.....

In the images folder, a before and after rasters for VNPs, reclassified map, blackout houston map, a highway buffer on the houston map,buildings impacted, and a barplot for the median income

#.....Acknowledgements.....

This repository was produced as part of teaching material for EDS 223:Identifying the impacts of extreme weather, taught by Annie Abrams. Author of Homework Assignment 3, author Ruth Oliver. - **NASA Earth Observations (VIIRS Nighttime Lights)** - **U.S. Census Bureau, American Community Survey (ACS 2019 5-Year Estimates)**
- **OpenStreetMap and Geofabrik for base vector data**

```
#.....................Reproducibility.......................
```

All analysis was conducted in RStudio using the packages listed above. Code is contained in the `Identifying_impacts_extreme_weather.qmd` file, and outputs are saved in the images/ directory.

```
My Data Reprository Structure:
├── data
│   ├── ACS_2019_5YR_TRACT_48_TEXAS.gdb
│   │   ├── census tract gdb files
│   ├── gis_osm_buildings_a_free_1.gpkg
│   ├── gis_osm_roads_free_1.gpkg
│   └── 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
├── Identifying_impacts_extreme_weather_files
├── Identifying_impacts_extreme_weather.html
├── Identifying_impacts_extreme_weather.qmd
├── Identifying_impacts_extreme_weather.Rproj
├── images
│   ├── blackout_houston_map.png
│   ├── building_impacted.png
│   ├── highway200_buff.png
│   ├── median_income.png
│   ├── reclassified_map.png
│   ├── vnp_07_before.png
│   └── vnp_16_after.png
└── README.md
└── .gitignore
```