Kentucky & Texas Disasters

Utilizing NASA Earth Observations to Monitor the Duration and Extent of Power Outages Due to Severe Weather Events in Kentucky and Texas

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Abstract: Severe disasters like tornadoes and derechos cause power outages and infrastructure damage, decreasing resilience, and safety in urban areas. This project utilized NASA Earth observations to monitor the duration and extent of power outages due to severe weather events in Kentucky and Texas. The team visualized changes in nighttime light (NTL) intensity and assessed the duration of power outages by county within each study area. The distribution of vegetation loss in the area was analyzed by computing the Normalized Difference Vegetation Index (NDVI) with optical imagery from Landsat 8 Operational Land Imager and Sentinel-2 Multi-Spectral Instrument. In Kentucky, the team observed changes in NTL values between a pre-event image and a post-event image in counties along the tornado track. The team also created time series graphs for each county in Kentucky to visualize changes in NTL and track power recovery. In Texas, the team observed increases and decreases in NTL across the study area of southeastern Texas. The team compared Harris County and Liberty County to assess NTL change differences in urban versus rural areas. The team created NTL time series graphs for all Texas counties as well. The team utilized NDVI to visualize and quantify vegetation damage across Kentucky. This methodology can be used to better establish disaster management plans, assess damage rapidly in future disasters, and identify severely damaged areas. This study will help project partners holistically assess damage and narrow the scope of their fieldwork, which will reduce work costs and increase working efficiency.

Key Terms: disasters, tornado, derecho, Western Kentucky, Houston, remote sensing, Texas Division of Emergency Management (TDEM), National Weather Service (NWS)

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1. Introduction

The United States suffers from a variety of severe weather impacts and is frequently subject to damage from Mesoscale Convective Systems (MCS). MCS events occur most frequently in the eastern and central portions of the United States, where as many as 500 to 700 events take place every year (Schumacher & Rasmussen, 2020). The average duration of MCS events has increased by 4% per decade and the total rainfall they produce has increased, particularly for the most extreme events (Schumacher & Rasmussen, 2020). While every MCS event is unique, these events spawn both tornadoes and derechos. Each of these storms are defined by their high wind speeds, be they rotational and narrow as in a tornado (Markowski & Richardson, 2014), or broad-reaching and straight in the case of a derecho (Liebl, 2004). These high wind speeds produce a variety of damages through the direct and tangible destruction of infrastructure, crops, and the electric grid. However, these costs also extend past the realm of the tangible and interrupt emergency communications, disrupt the flow of commerce, and unsettle the security and well-being of the communities they impact (Doktycz & Abkowitz, 2019).

Several professional organizations at the federal and state levels exist to address the damage produced by MCS events in the prominent central and eastern regions of the United States. At the federal level, the National Weather Service (NWS) informs the public on severe weather through the generation of high-quality and accurate forecasts. Not only does the NWS generate forecasts, but they also deploy post-disaster surveyors to examine damage from severe weather. The NWS Forecast Office located in Paducah, Kentucky forecasts for 58 counties across the Lower Ohio and Mid-Mississippi Valleys, 22 of those counties being in western Kentucky (NWS, n.d.)

The responsibility of emergency management is also taken on at the state level. The Texas Division of Emergency Management (TDEM) seeks to improve severe weather response and recovery. To achieve this goal, TDEM implements programs to increase public threat and hazard awareness, coordinates emergency planning, and provides specialized disaster training (The Texas A&M University System, n.d.). TDEM divides their efforts among many distinct regions. TDEM region 4 is on the southeastern border of Texas near the Gulf of America, which suffers from powerful MCS events which can become derecho events.

The NWS forecasting office and TDEM both seek to understand power loss and vegetation destruction resulting from severe MCS events like tornados and derechos; however, to examine these types of damage, they typically deploy ground observations. Due to the vast spatial extent of storms of this type, deploying ground observations alone can create an incomplete and fragmented image of power outages and vegetation destruction. In addition, the presence of artificial light and vegetation is not equally distributed across rural and urban settings. For example, a heavily urbanized area will likely have more lights and less vegetation than a rural area, which creates the necessity for the two areas to be studied differently. In these cases, Earth observations can be used to visualize the spatial extent of power outages and vegetation damage from severe weather events. NWS and TDEM have varying levels of experience using Earth observations. The Paducah NWS Forecast Office has never used nighttime lights (NTL) or normalized difference vegetation index (NDVI) analysis post-disaster to study an event. TDEM has partnered with NASA's Disaster Response Coordination System to study Hurricane Beryl using NTL imagery to detect power outages. Both organizations expressed an interest in increasing their use of Earth observations to better inform their post-disaster response that align with their organizational goals.

Earth observations from satellites cover a wider area than a surveyor could encounter on foot, providing the ability to capture extents of damage on larger scales. The same Earth observations can also be tailored to rural and urban areas using the NDVI and NTL imagery respectively. In rural regions, the application of NDVI is most common. NDVI change analysis, the practice of mapping the change in NDVI before and after storm damage, has been used to search for rural tornado tracks (Yuan et al., 2002) and to identify agricultural vegetation damage after thunderstorms (Bentley et al., 2002). Damage to electric grids can be traced through similar change analyses of NTL imagery before and after the passage of a damaging storm through an illuminated urban area. This practice has been applied to monitor power outages caused by Winter Storm Uri (Xu et al., 2023) and Hurricane Maria (Román et al., 2019).

Within this project, the team established a primary goal to demonstrate if Earth observations are informative for post-disaster analysis in rural and urban areas. This led to two objectives of identifying the spatial extent of disasters in urban areas through power outages and the spatial extent of disasters in rural areas through vegetation damage. To achieve the objectives, the team analyzed NTL data for power outage and restoration in heavily populated, urban areas. For more rural and vegetated areas, the team conducted an NDVI analysis for vegetation damage.

The team examined the feasibility of applying NDVI and NTL change analysis to two case studies, the 2021 Western Kentucky tornado (hereafter Kentucky tornado) and the 2024 Houston derecho (hereafter Houston derecho). The Kentucky tornado tore across northwest Tennessee and western Kentucky on December 10, 2021 (NWS, 2024; Figure 1). This tornado spawned from a large storm system that produced multiple tornadoes and caused damage across the Southern United States earlier that day. At 8:49 pm Central Standard Time, the tornado touched down in Obion County, Tennessee and continued its track across eleven counties in western Kentucky before ending at 11:45 pm. The Kentucky tornado was one of the longest-tracked tornadoes in history, covering 165.7 miles (NWS, 2024; Marshall et al., 2022).

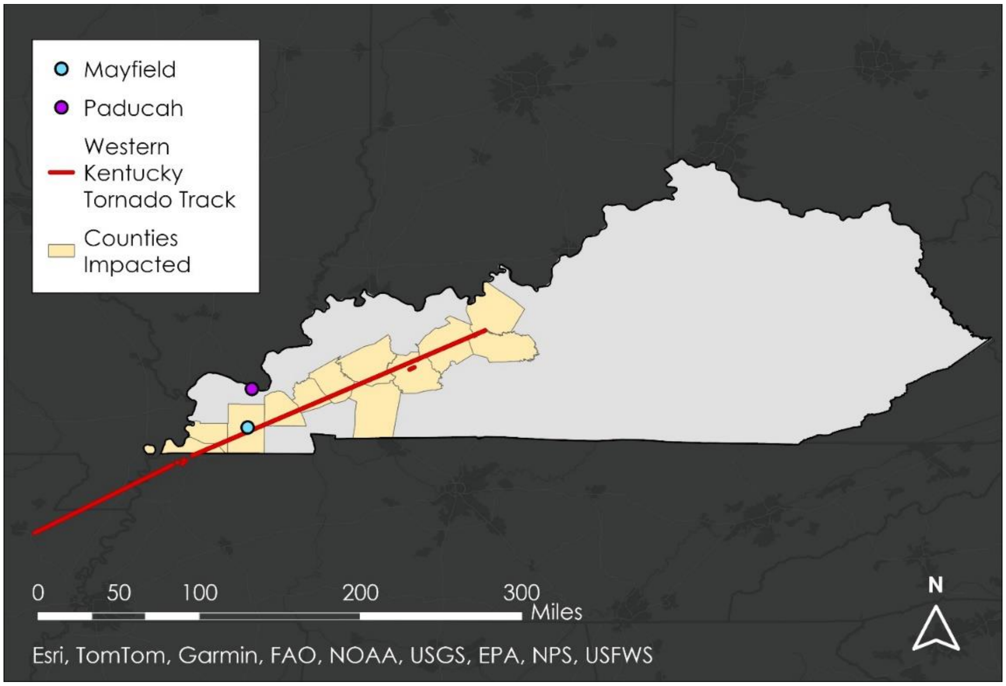


Figure 1. Study area map of the 2021 Western Kentucky Tornado track across Kentucky with cities of interest and counties impacted labeled.

The second case study, the Houston derecho, occurred on May 16th and was the result of a series of strong and long-lasting storms that formed in central Texas and continued through southeastern Texas across Louisiana (Voiland, n.d.; Hazard HQ Team, 2024; Adams & Cady, 2024; Figure 2). In contrast to normal wind and thunderstorm events, derechos are characterized by wind speeds of at least 58 mph and cause damage that spans more than 240 miles (NWS, 2015). TheHouston derecho contained wind speeds that exceeded 75 mph, with a peak wind speed of 78 mph in Houston (Henson, 2024; Hazard HQ Team, 2024; Adams & Cady, 2024). A large heat dome sitting over the Caribbean Sea and Gulf of America in May caused elevated heat and humidity in south and southeastern Texas. Dry, cold air along the northern edge of the high-pressure system clashed with the hot, humid air producing these strong storms on May 16th, 2024 (Voiland, n.d.; Wasson, 2024).

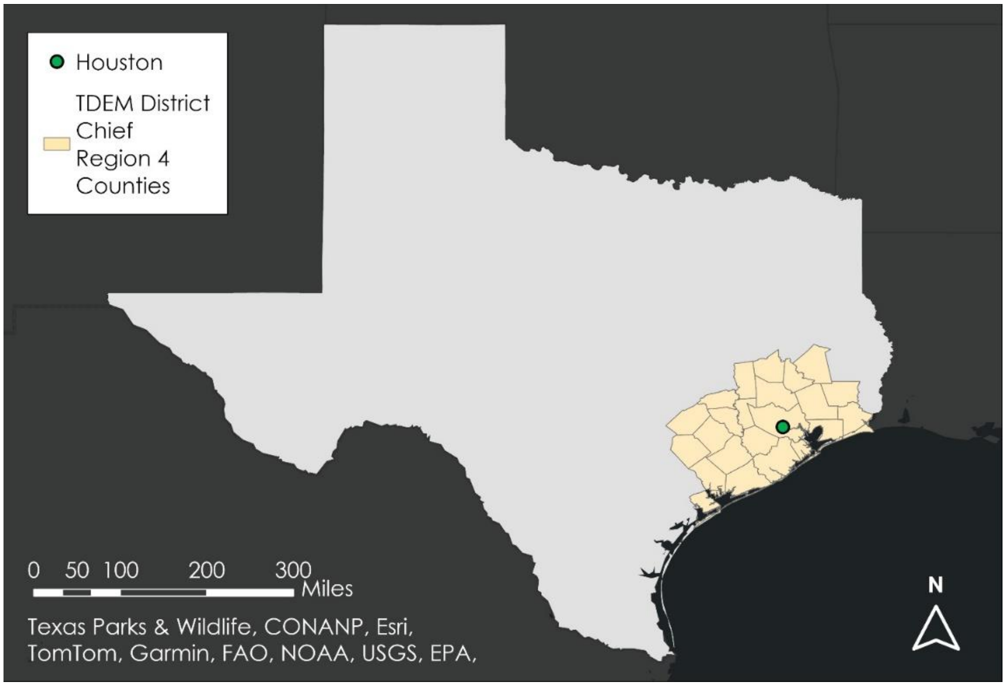


Figure 2. Study area map showing the counties of Texas impacted by the 2024 Houston Derecho with the city and counties of interest labeled.

While the basis of the Kentucky tornado and the Houston derecho was different, both led to significant damage from high wind speeds. In both cases, airborne debris damaged overhead electric cables and towers as well as ground-based equipment. The morning after the tornado in 2021, the Kentucky governor reported over 56,000 power outages across the state and this number was reported to still be over 23,000 on December 14th, 2021, 3 days after the event (Aulbach, 2021). During the Houston derecho, more than one million customers in and around Houston lost power (Hazard HQ Team, 2024). Harris County alone, which contains Houston, reported over 800,000 power outages (Marsden, 2024). Over 500,000 customers in the impacted area still did not have power 24 hours after the Houston derecho (Hazard HQ Team, 2024).

2. Methodology

2.1 Data Acquisition

2.1.1 Nighttime Light Data – NASA Suomi NPP VIIRS

To observe the damage extent caused by disasters in urban areas, the team used the NASA data product VNP46A2 - VIIRS/NPP Gap-Filled Lunar BRDF-Adjusted Nighttime Lights Daily L3 Global 500m Linear Lat Lon Grid (Román et al., 2019; Table 1). The team used Land Processes (LP) Distributed Active Archive Center (DAAC) and Level-1 and Atmosphere Archive & Distribution System (LAADS) DAAC sites to access and download NTL imagery from Suomi NPP VIIRS (Román et al, 2018). The team acquired pre-event imagery for the Kentucky tornado from November 28th, 2021, and for the Houston derecho, the team acquired imagery from April 30th, 2024. The team chose pre-event imagery with minimal cloud cover, given cloud cover can distort NTL values. For post-event imagery, the team acquired imagery for December 10th to 18th, 2021 for Kentucky, and May 16th to May 24th, 2024, for Texas (Table A1). When acquiring Suomi NPP VIIRS imagery, the team did not use a cloud filter parameter.

Table 1

NASA Suomi NPP VIIRS – VNP46A2 Bands Used

Variable	Band Name	Use
0	DNB_BRDF_Corrected_NTL	Original NTL values
5	QF_Cloud_Mask	Masks out cloud cover

2.1.2 Normalized Difference Vegetation Index Earth Observation Data

To observe the damage extent caused by disasters in rural areas, the team acquired data from Landsat 8 Operational Land Imager (OLI) Collection 2 Level-2 Surface Reflectance Science Product and Sentinel-2 Multi-Spectral Instrument (MSI) Level 2A Bottom-of-Atmosphere Reflectance – 10m Resolution (Table 2). The team also accessed and downloaded Level 2 Landsat 8 OLI imagery, with cloud coverage of 20% or less from the United States Geological Survey (USGS) EarthExplorer browser, specifically for the Texas case study (Table A2). The team downloaded Sentinel-2 MSI Level 1C imagery. All Sentinel-2 MSI imagery contained cloud coverage of 30% or less. The team acquired pre- and post- imagery for dates very close to the passage of the disaster events, for both the 2021 Western Kentucky tornado and the 2024 Houston derecho, from Sentinel-2 MSI through the Copernicus Browser (Table A3). The team selected dates close to the event to produce maps of NDVI as near to the severe weather event as possible to see how much vegetation was immediately damaged. The Western Kentucky imagery was from December 8th, 2021, two days before the tornado. The post-tornado imagery was from December 13th, 2021, three days after the tornado. The team also collected imagery from spring 2021 and spring 2022, the springs before and after the tornado, to compare vegetation during a greener season. The team collected spring images on April 12th, 2021, and April 27th, 2022. For the Houston derecho, the team acquired imagery one day before the derecho, May 15th, 2024, and four days after the derecho, May 20th, 2024. The team also collected multiple pre- and post-derecho images. Pre-event imagery was collected on April 22nd, 2024, and May 15th, 2024 whereas post-event imagery was collected on May 18th, 19th, and 20th, 2024.

Table 2

Earth Observation Data Details for Normalized Difference Vegetation Index Analysis

Satellite & Instrument	Parameter	Bands	Spatial Resolution	Temporal Resolution
Landsat 8 OLI	Surface Reflectance	Band 4: Red Band 5: Near-Infrared	30 meters	16-day
Sentinel-2 MSI	Surface Reflectance	Band 4: Red Band 8: Near-Infrared	10 meters	5 days (combined) 10 days (individual)
	Top-of-atmosphere Reflectance	Band 10: Shortwave Infrared	60 meters	

2.1.3 2021 Western Kentucky Tornado Land Cover Contextualization

The team contextualized the types of land cover within the tornado track using the European Space Agency (ESA) WorldCover 2020. To achieve this goal, the team selected an NDVI image displaying the track using a difference image from April 12th and 27th, 2022. The team acquired ESA WorldCover 2020 raster image from the ESA website, with a spatial resolution of 10 meters by 10 meters (Zanaga et al., 2020).

2.2 Data Processing

2.2.1 Nighttime Light Data Processing

The team first converted NTL data into TIFF files from Hierarchical Data Format-Earth Observing System (HDF-EOS5) files. The Suomi NPP VIIRS dataset has multiple variables, but the team used Variable 0: original NTL data, and Variable 5: quality flag (QF) cloud masking data. To determine the percent of cloud confident pixels within NTL imagery, the team used the QF band and converted the digital number values into binary data. The team converted digital number values to binary through a standard conversion method by dividing the number by 2 repeatedly and recording the remainders, which form the binary value when read in reverse order. The team then classified the pixels into cloudy or clear based on binary values at bit positions 6 and 7, then calculated the cloud cover percentage for each county. The team calculated the cloud cover percentage to establish accuracy of the NTL values for each county, given that cloud cover can distort NTL data values. Calculating the percent cloud cover across each county allowed the team to better understand the accuracy of observed changes in NTL values.

2.2.2 Normalized Difference Vegetation Index Data Processing

The team used Sentinel-2 MSI imagery to calculate NDVI (Equation 1; Tucker, 1979) for the 2021 Western Kentucky tornado and attempted to use it for the 2024 Houston derecho. Due to cloud contamination for Sentinel-2 MSI across the TDEM region 4 during the Houston derecho, the team decided to look at Landsat 8 OLI imagery, but the same contamination existed. Therefore, the team ruled out an NDVI calculation for the Houston derecho and focused on using Sentinel-2 MSI imagery to calculate NDVI for the Kentucky tornado. The team followed standard methodology to calculate NDVI using Sentinel-2 MSI imagery. The team used the near-infrared light (NIR) and visible red light (R) bands to calculate NDVI.

$$NDVI = \frac{NIR - R}{NIR + R} \tag{1}$$

To calculate cloud coverage, the team used the shortwave infrared (SWIR) band for Sentinel-2 MSI and set the image digital numbers greater than 1000, which is equivalent to 0.1 reflectance (Equation 2; European Space Agency, n.d.), as cirrus clouds The team removed those clouds because they created false NDVI values in the analysis. To identify the damage caused by the Kentucky tornado, the team calculated the difference between pre-event NDVI imagery and post-event NDVI imagery.

$$DN = 10000 \cdot REFLECTANCE \tag{2}$$

2.2.3 2021 Western Kentucky Tornado Land Cover Contextualization

After downloading the ESA WorldCover 2020 raster, the team opened the file in ArcGIS Pro 3.2.1. To identify the spatial extent of the tornado track, the team manually created a shapefile of the spatial extent of the tornado track. The team used the NDVI difference image between spring 2021 and spring 2022 to visualize and identify the tornado track. Once the NDVI difference image was visualized, the team manually created a shapefile using the Create Feature Class tool so that its spatial extent overlaid the tornado track as observed in the spring 2021 to spring 2022 NDVI difference image.

2.3 Data Analysis

2.3.1 Nighttime Light Analysis

To determine the spatial extent and duration of the power outages caused by each event, the team compared NTL imagery from a pre-event image to all post-event images. For the Kentucky tornado, the time series spanned from December 10th to December 18th, 2021, supplemented with a pre-event image from November 28th, 2021, to illustrate NTL changes from baseline conditions. For the Houston derecho, the time series spanned from May 16th to May 24th, 2024, supplemented with a pre-event image from April 30th, 2024, to illustrate NTL changes from baseline conditions. The team mapped the difference images, between

November 28th and December 11th, 2021 for the Kentucky tornado and between April 30th and May 17th for the Houston derecho to show the spatial extent of power outages caused by each event.

Along with mapping the differences between pre-event and post-event imagery for each event, the team used NTL imagery to create time series graphs for each county within Texas and Kentucky to visualize changes in NTL values and quantify the time of power recovery overtime. The team calculated the mean and median NTL values for each day in the time series using the original and QF flagged variables of the NTL imagery. The team also used the QF masked variable to calculate the total number of pixels without cloud cover, based on the total number of pixels in the image. The team plotted mean and median NTL values as well as the percentage of pixels without cloud cover across the time series length for each county within Kentucky and Texas.

2.3.2 Normalized Difference Vegetation Index Analysis

The team mapped NDVI images from Sentinel-2 MSI imagery using ArcGIS Pro to identify areas damaged by the Kentucky tornado. To visualize areas of low, moderate, and high vegetation damage from the tornado, the team mapped NDVI difference. The team assessed the NDVI difference magnitude and sign to draw conclusions about the destructive extent of the tornado in rural regions. The team mapped NDVI difference images using classification symbology to visually identify the Kentucky tornado track.

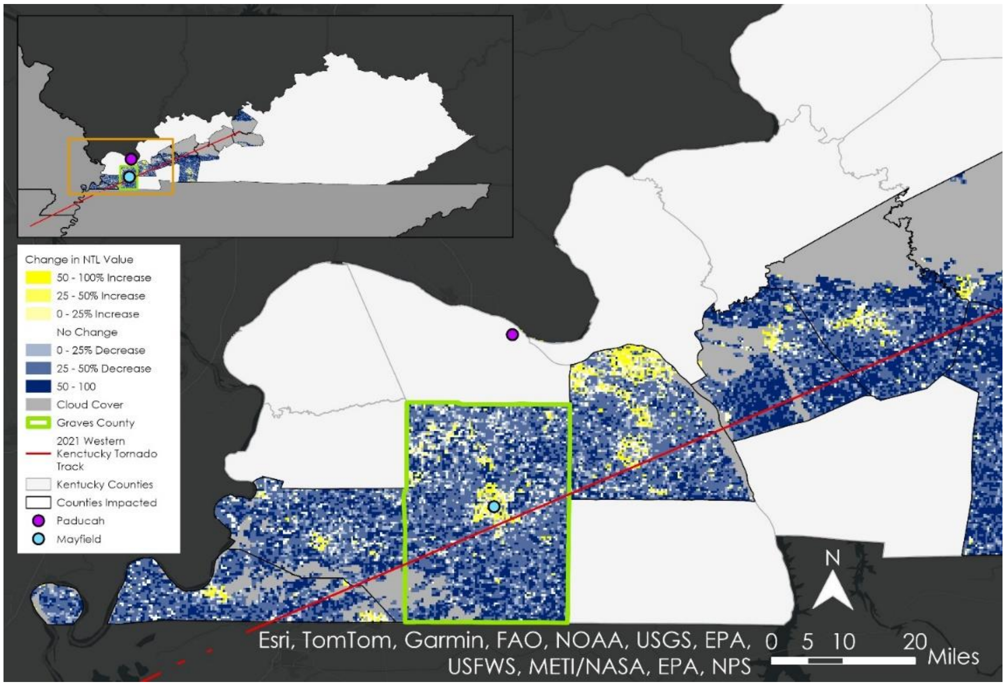
2.3.3 2021 Western Kentucky Tornado Landcover Contextualization

The team identified the type of landcover within the tornado track to distinguish the kinds of landcover damaged by the tornado (Table C2). In ArcGIS Pro, the team reclassified the ESA WorldCover raster, then created a shapefile of the tornado track based on the Spring 2021 to 2022 NDVI difference image. The team then used Raster to Polygon tool, Summery Statistics tool and ESA WorldCover attribute table to calculate the total area of each landcover type within the tornado track.

3. Results

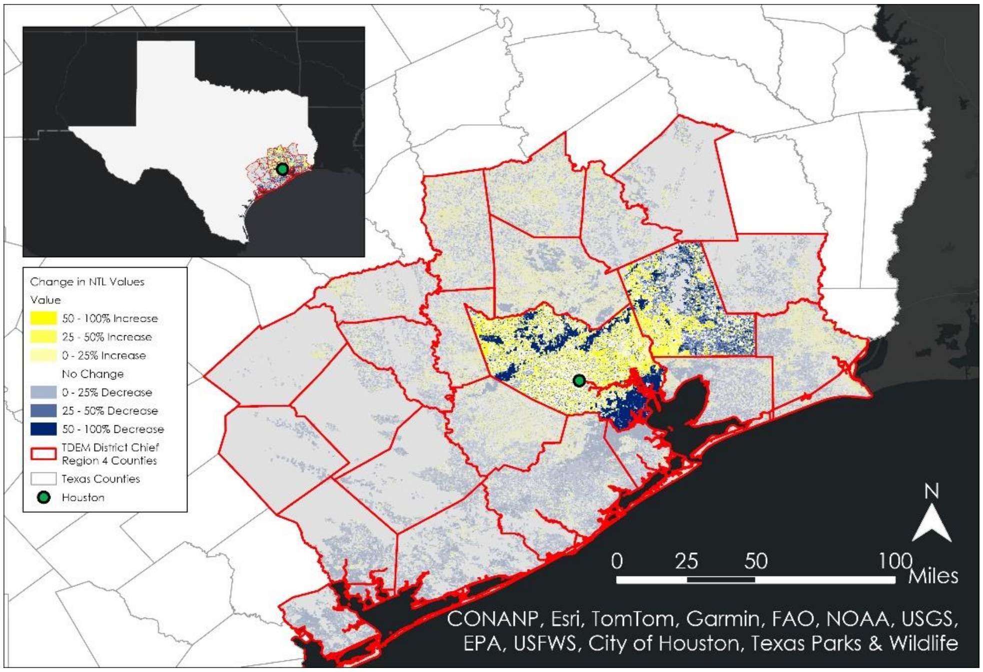
3.1.1 Nighttime Light Analysis Results

The resulting difference images for the Kentucky and Texas case studies show areas that experienced an increase, decrease, and no change between the pre-event imagery day (Figure 3) and the post-event imagery day (Figure 4). Mayfield, Kentucky, was a city of particular interest due to the damage it sustained during the tornado. The team focused on Graves County, which contains the city of Mayfield (Figure B1). For the Texas case study, the team focused on Harris County and the neighboring Liberty County due to the TDEM's interest between rural and urban areas (Figure B2). Harris County is home to the major metropolitan area of Houston, while Liberty County is less densely populated.



Esri, TomTom, Garmin, FAO, NOAA, USGS, EPA, USFWS, METI/NASA, EPA, NPS

Figure 3. Nighttime Light Difference Image for November 28th and December 11th, 2021. Western Kentucky counties impacted by the tornado are shown. Yellow indicates an increase in NTL values and blue indicates a decrease in NTL values. Areas in white observed no change, while areas shown in dark grey are areas obscured by cloud-cover. The tornado track is shown as a red line. Cities of interest are labeled. Graves County is outlined in green.



CONANP, Esri, TomTom, Garmin, FAO, NOAA, USGS, EPA, USFWS, City of Houston, Texas Parks & Wildlife

Figure 4. Nighttime Light Difference Image for April 30th and May 17th, 2024. TDEM Chief Region 4 counties in which the derecho impacted are shown. Yellow indicates an increase in NTL values and blue indicates a decrease in NTL values between April 30th and May 17th. Areas in white observed no change, while areas shown in dark grey are obscured by cloud-cover. The city of Houston is labeled.

3.1.3 Nighttime Light Time Series Results

The team conducted a time series analysis for the impacted counties in Kentucky and Texas. For each county, the team calculated the mean and median NTL, and the cloud-free percentage referred to as confident clear for each county for each day. The team identified how the NTL and cloud cover changed daily. We used county shapefiles to calculate the statistics for each day using the various tools in ArcGIS Pro. To check when the NTL intensity returned to the pre-event baseline, the team also created normalized graphs for each county for each day by calculating the percentage difference from a pre-event image and normalizing it to 100%. In Graves County, Kentucky, the team identified a drop in NTL intensity on December 10th and 11th in the NTL time-series graph, after the tornado, before NTL values increased again (Figure 5). The team also identified a dip in the normalized NTL difference on December 10th and 11th in the recovery graph, which increased afterward relative to the November 28th baseline image (Figure 6). Another key observation in this graph is the importance of selecting an appropriate pre-event image to quantify change due to the event. The normalized difference is always over 100%, suggesting NTL values post-event dates are higher than pre-event.

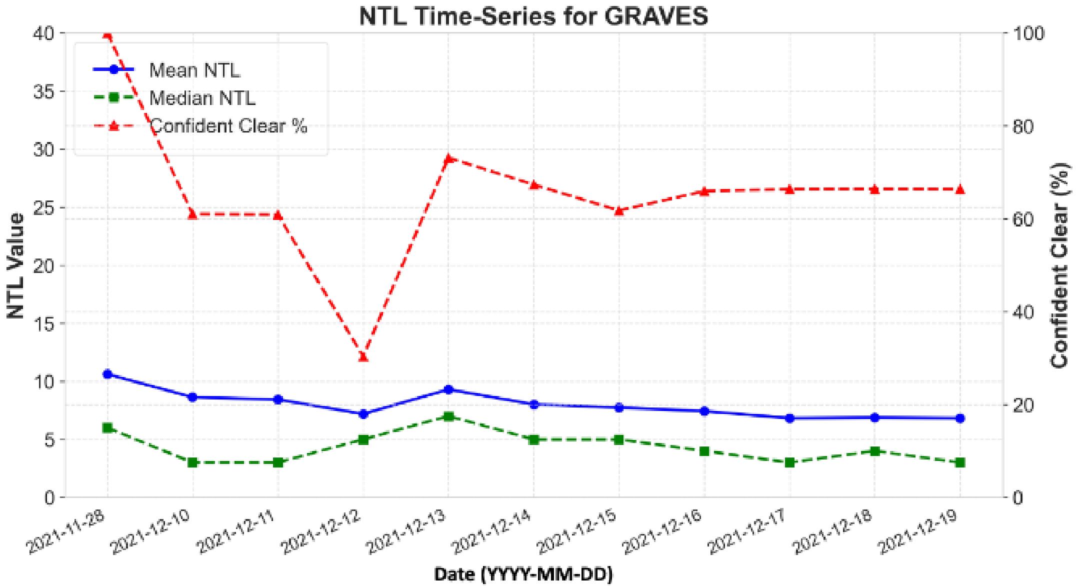


Figure 5. Time series for Graves County, KY showing daily mean NTL intensity for each day in blue, daily median county NTL intensity in green, and daily confident clear % for county in red.

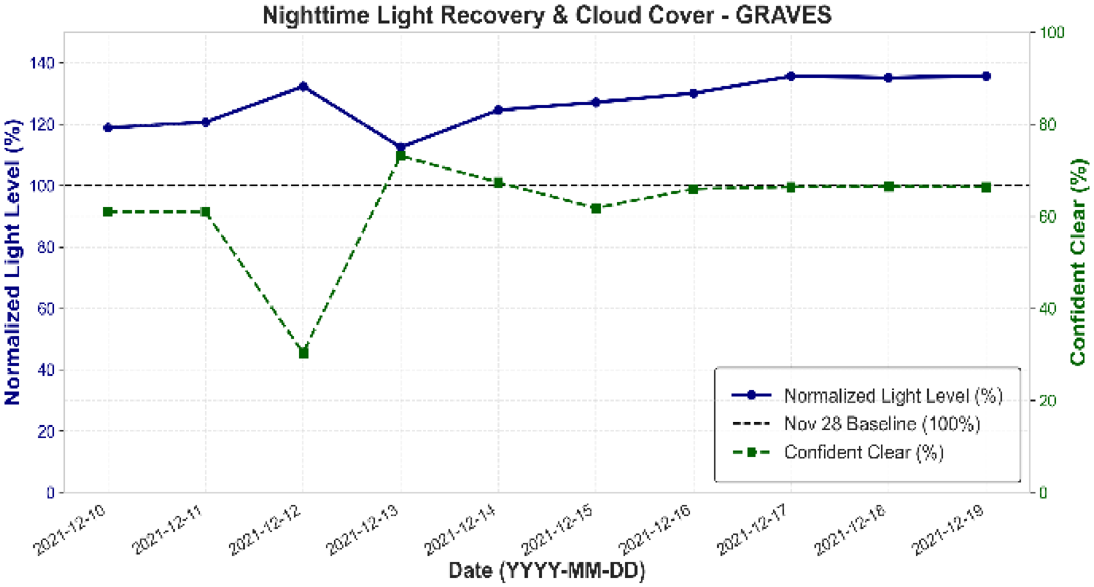


Figure 6. NTL recovery time series for Graves County, KY showing the Nov 28 baseline in grey and normalized NTL difference % in blue showing the normalized percentage difference for each day with respect to the baseline NTL intensity. Daily confident clear % is shown in the green dashed line.

3.1.4 Normalized Difference Vegetation Index Change Analysis Results

For the Kentucky tornado, the team produced two NDVI difference maps. One shows the NDVI difference on a portion of the tornado track between December 8th, 2021, and December 13th, 2021, two dates close to the tornado (Figure C1). Both figures feature the 2021 Western Kentucky tornado track from the FEMA Disaster Resilience Hub (Federal User Community, 2020). Regarding the difference map generated from the dates close to the tornado passage, it is important to note that there is an emergent linear feature above the FEMA track which primarily displays a minor increase in NDVI as opposed to a decrease, which would be expected following the passage of the damaging tornado. The range of differences for the map using the December dates is very narrow, 0.02 to -0.02, which is the only range on which the linear feature became visible.

The team also generated a springtime NDVI difference map between April 12th, 2021, and April 27th, 2022, two springtime dates, in the same region of the tornado track (Figure 7). The range of NDVI difference values in the springtime difference map is larger on this map, with a maximum NDVI difference of 0.85, and minimum NDVI difference of -1.21. The team discovered a similar emergent linear feature slightly above the expected track that matched the track-like feature in the NDVI difference map generated from the December dates. The line feature above the FEMA tornado track showed a decrease of higher magnitude than the increase observed in the original difference map. The springtime difference was performed to validate the potential track observed in the NDVI difference map from the December dates.

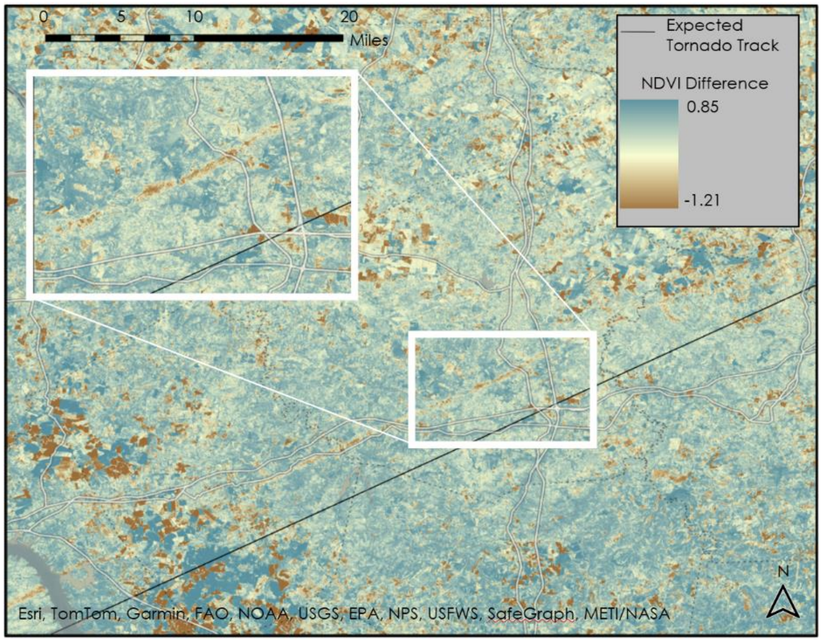


Figure 7. NDVI difference map from April 12th, 2021, a springtime date prior to the passage of the tornado, and April 27th, 2022, a springtime date after the passage of the tornado. This figure shows the tornado track from the FEMA Disaster Resilience Hub in black. The inset map highlights a portion of the FEMA tornado track and the emergent linear feature. An increase in NDVI following the tornado is indicated as a turquoise color and a decrease in NDVI following the tornado is indicated as a brown color.

3.2 Errors & Uncertainties

The team encountered limitations regarding selecting pre-event baseline data during the NTL percent difference analysis in both case studies. Many Kentucky counties exhibited higher NTL reflectance in December than was recorded in the team's initial pre-event date, November 28th, 2021. The team hypothesized this may be attributable to the seasonal presence of holiday lights or diminished cover from tree canopies as the winter season progresses. When analyzing NTL data, the selection of a pre-event date for comparison should not be made purely on the basis of data quality with respect to cloud coverage. Other seasonal fluctuations must be investigated and taken into account. With respect to the Texas derecho, cloud coverage obscured NTL values and therefore limited the accuracy of the team's results.

The team experienced limitations in the data acquisition and analysis phases of the project. Regarding the Kentucky tornado, NWS Paducah expressed interest in a documented break in the tornado track which they suspected not to be a true break. However, the team could not apply springtime NDVI to this portion due to insufficient Sentinel-2 MSI imagery and time limitations. The team found that images from mid-to-late April in the track-break region were either incomplete or did not pass cloud coverage quality standards. The team attempted a difference map for the track break region with imagery from March 3rd, 2021, and March 6th, 2022; however, these dates were likely not sufficiently green and did not show a track of any kind. In addition, the team ordered imagery from PlanetScope to analyze the track-break region a higher resolution to address the NWS partner's theory. However, the team did not receive this imagery by the end of the project's analysis phase and therefore it could not be included.

For the Houston derecho, the team struggled to acquire data from both Sentinel-2 MSI and Landsat 8 OLI due to cloud coverage in the Houston area. Since cloud coverage was a persistent complication in this case, an alternative could be to use Sentinel-1 C-Band Synthetic Aperture Radar (C-SAR). However, due to time constraints, the team could not involve another instrument. The team also discovered that applying the methodology for mapping NDVI difference in the case of a tornado and derecho cannot be applied equally. The spatial damage extent of a derecho is wider and often is not linear in nature, as in the case of a tornado.

As such, more imagery is required to search for derecho damage, which increases the chances of encountering cloud coverage, especially in the humid Houston region.

4. Conclusions

4.1 Interpretation of Results

Overall, the team found that NTL data can be used to determine the spatial extent of damage post-disaster, for both the tornado and derecho, although this type of analysis is better suited for highly populated urban areas compared to rural areas. In rural areas, the team found NDVI analysis could be used to detect areas of damage post-disaster, although the team could only acquire imagery for the tornado case study. The team also found that NDVI analysis was better suited for detecting damage for events with narrow spatial extents of damage compared to events with widespread damage extents. This project found that NASA's Black Marble dataset and Sentinel-2 MSI can be used to determine post-disaster damage analyses in rural and urban areas. In Kentucky, the team identified a drop in average NTL intensity by county on December 10th and 11th before NTL values gradually increased again. However, there was a general increase in NTL values immediately following the tornado in urban areas. For example, the team observed this increase in Mayfield, a city that experienced devastating damage from the tornado (Figure 3). The team also observed this pattern in Texas, where NTL values increased relative to the baseline on April 30th in Houston. However, NTL values generally decreased on average in the surrounding counties following the derecho (Figure 4). The team hypothesized that this pattern could be due to power restoration being prioritized in urban areas.

4.2 Feasibility & Partner Implementation

The team found the feasibility and application of this project's methodology to be dependent on the partners' capacity to work with Earth observation data and conduct geospatial analysis. TDEM showed particular interest in how the NTL analysis may be utilized to address community concerns caused by extreme weather events. TDEM currently downloads and conducts analyses using Earth observation data with several individuals who have experience working with Earth observation data and geospatial analysis. NTL analysis, including the creation of difference images, can be used to validate TDEM's current damage assessment process after a disaster. GIS data, imagery, and descriptions collected through TDEM State of Texas Assessment Tool (STAT) surveys for local jurisdictions; currently used to assess disaster damage can be validated using NTL imagery. Additionally, processed NTL imagery can be used to visualize power outages experienced in near-real-time. The ability to visualize changes in NTL and power loss can be used to support resident claims and help TDEM access FEMA recovery support more readily. Although, within the scope of this study, the team found NDVI analysis results were limited for the Houston derecho event which was located near the Gulf of America, due to the climatology of the study area and the event type. If this methodology was to be applied to an area more inland and to an event with a narrower damage extent, then the methods would be feasible.

Because Western Kentucky is largely rural, the team's NWS Paducah partner expressed interest in the NDVI analysis to determine the spatial extent of tornado damage to vegetated areas. NDVI analysis, which could provide the spatial extent of severe weather events, would validate ground-based damage observations. Similarly, NTL analysis can be used to validate the spatial extent of power outages caused by severe weather events. By establishing the spatial extent and severity of power outages and vegetation damage, NWS could use this methodology to better understand the characteristics of future extreme weather events as well. NWS Paducah has had minimal experience working with geospatial and remote sensed data, so the feasibility of our methods to be applied within their existing damage assessment workflow depends on their personnel and time capacity. Overall, this project demonstrated that Earth observations could be used to detect post-disaster damage using NTL and NDVI.

5. Acknowledgements

Project Partners:

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6. Glossary

Binary Data – Data stored in 0's and 1's, used to represent presence and absence
Change Analysis – The process of examining a quantity before and after the passage of a severe weather event
Classification Symbology – Visual Representation of categorized data using specific colors on a map
Cloud Contamination – Occurs when clouds in an image collected by satellites produce a false measurement because they are obscuring the earth's surface
DNB – Day/Night Band
Derecho – A large family of downburst clusters which produce rapid, straight-line winds at the ground level and produce a wide area of less concentrated damage
Digital Number Values – Raw pixel values recorded by satellite sensors
FEMA – Federal Emergency Management Agency
HDF-EOF5 – Hierarchical Data Format-Earth Observing System
LP DAAC – Land Processing Distributed Active Archive Center
MCS – Mesoscale Convective Systems, an organized groupings of thunderstorms in the tropics and mid-latitudes that span thousands of square kilometers.
MSI – Multispectral Imager
NIR – Near-Infrared Light
NDVI – Normalized Difference Vegetation Index, a quantitative measurement of vegetation health and density collected by satellites and derived from the reflection of near infrared light and visible red light at the surface of the planet.
NPP VIIRS – National Polar Orbiting Partnership Visible Infrared Imaging Radiometer Suite
NTL – Nighttime Lights
NWS – National Weather Service
OLI – Operational Land Imager
QF Flagged – "Quality Flagged", data which is labeled with a symbol or number to indicate that it's poor quality in comparison to the rest of the data set.
Reflectance – The proportion of light reflected by a surface compared to the light it receives
Sentinel-1 C-SAR – The Sentinel-1 satellite's C-band Synthetic Aperture Radar sensor
Surveyors – Meteorologists deployed on foot to examine damage exacted after a severe weather event who are trained to know what kinds of winds and other hazards produce distinct types of damage.
TDEM – Texas Division of Emergency Management
TIFF Files – A geospatial image format used for storing data like satellite imagery
Tornado – Narrow, rotating column of air within a larger thunderstorm which features high windspeeds that produce a narrow swath of concentrated damage.
Tornado Track – The path of damage left after the passage of a strong tornado.
Track-Break Region – A region along the damage path of a tornado that exhibits no damage

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8. Appendices

Appendix A: *Data Acquisition Tables*

Table A1

Suomi NPP VIIRS Imagery Details

Study Area	**Date of Event**	**Pre-Event Imagery Date**	**Post-Event Imagery Date**
Kentucky	12/10/2021	November 28, 2021	December 11, 2021
Texas	05/16/2024	April 30, 2024	May 17, 2024

Table A2

Landsat 8 OLI Imagery Details

Study Area	**Date of Event**	**Pre-Event Imagery Date**	**Post-Event Imagery Date**
Texas	5/16/2024	Apr. 22, 2024 May 15, 2024	May 18, 2024 May 19, 2024 May 20, 2024

Table A3

Sentinel-2 MSI Imagery Details

Study Area	**Date of Event**	**Pre-Event Imagery Date**	**Post-Event Imagery Date**
Kentucky	12/10/2021	April 12, 2021 Dec. 8, 2021	April 27, 2022 Dec. 13, 2021
Texas	05/16/2024	May 15, 2024	May 20, 2024

Appendix B: *Zoomed in NTL Maps*

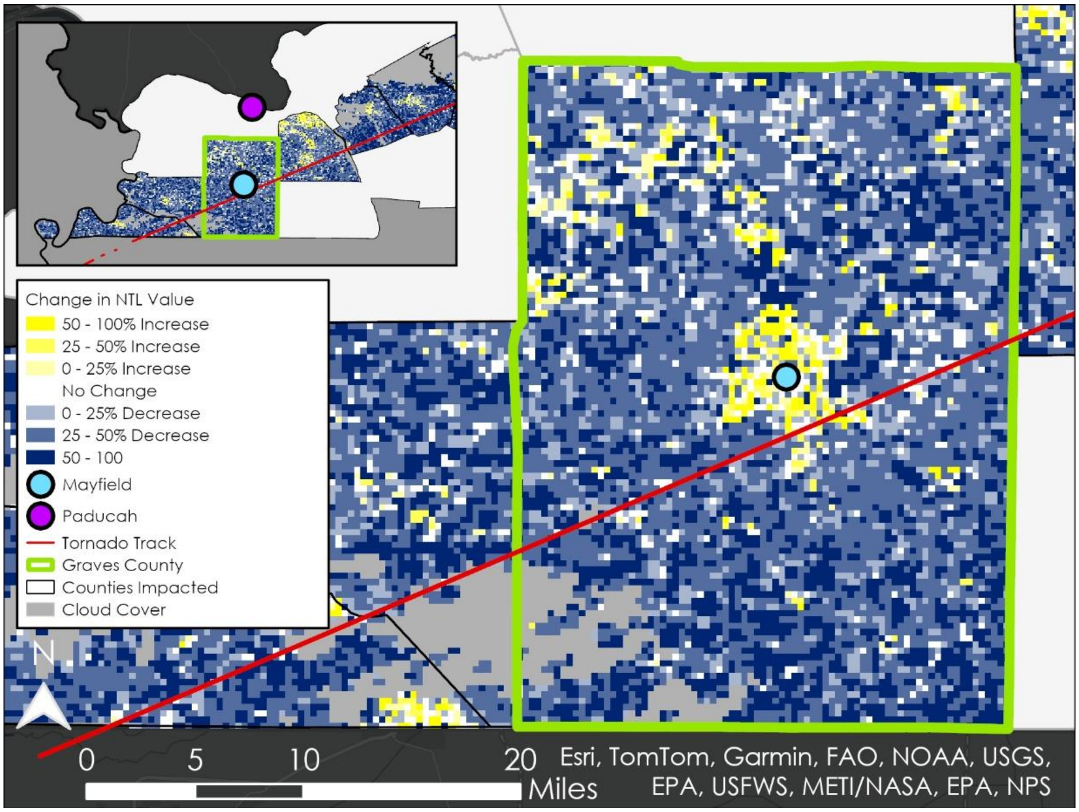

Figure B1. Nighttime Light Difference Image for November 28th and December 11th, 2021. Western Kentucky counties impacted by the tornado are shown. Yellow indicates an increase in NTL values and blue indicates a decrease in NTL values. Areas in white observed no change, while areas shown in dark grey are areas obscured by cloud-cover. The tornado track is shown as a red line. Cities of interest are labeled. Graves County is outlined in green.

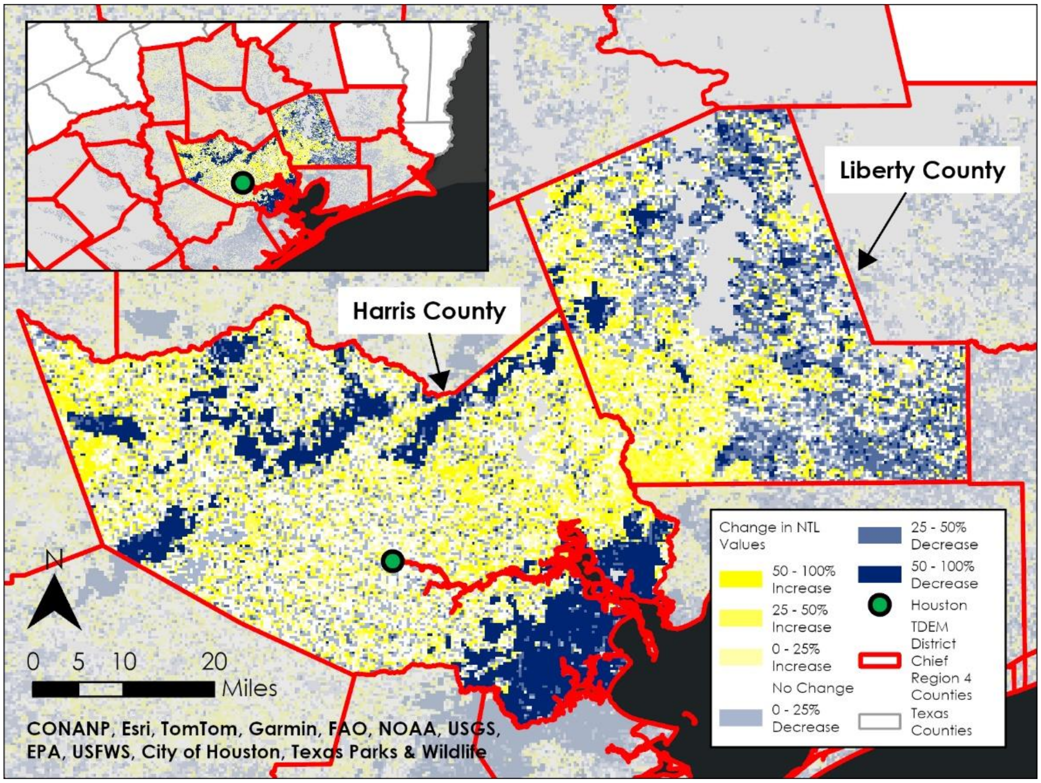

Figure B2. Nighttime Light Difference Image for April 30th and May 17th, 2024, of Harris and Liberty County. Yellow indicates an increase in NTL values and blue indicates a decrease in NTL values between April 30th and May 17th. Areas in white observed no change, while areas shown in dark grey are obscured by cloud-cover. The city of Houston is labeled. All other TDEM counties have a semi-transparent layer over them.

Appendix C: *December NDVI Difference Map and Landcover Table*

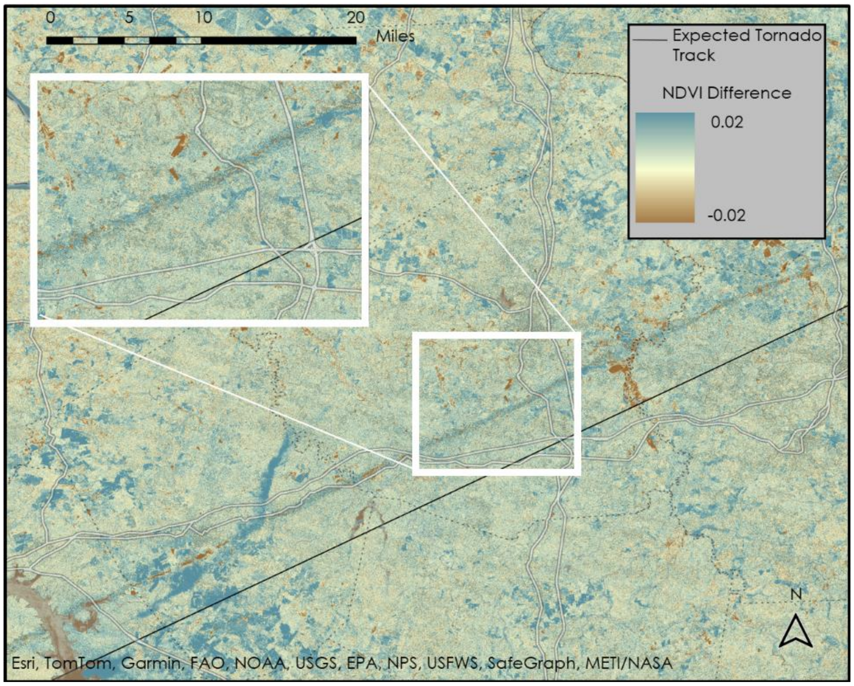

Figure C1. NDVI difference map between the pre-event date December 8th, 2021, and the post-event date December 13th, 2021. This figure shows the tornado track from the FEMA Disaster Resilience Hub in black. The inset map highlights a portion of the FEMA tornado track and the emergent linear feature. An increase in NDVI following the tornado is indicated as a turquoise color and a decrease in NDVI following the tornado is indicated as a brown color.

Table C2

Output table of Landcover Zonal Statistics within the Tornado Track of 2021 Western Kentucky Tornado

Landcover	Percentage	Area km²
Tree Cover	64.46 %	35.90
Grassland	15.21 %	8.46
Cropland	12.99 %	7.24
Built-up (Urban Areas)	0.93 %	0.52
Bare/Sparse Vegetation	0.47 %	0.27
Permanent Water Bodies	5.01 %	2.80
Herbaceous Wetland	0.93 %	0.52
Total	**100%**	**55.71**