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Georgia Disasters
Evaluating the Impacts of Hurricane Irma on Georgia Heirs Property Owners Using NASA Earth Observations

DEVELOP Technical Report
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1. Abstract

In September 2017, Hurricane Irma made landfall in southern Georgia, causing severe flooding and widespread destruction. Disaster recovery programs were inaccessible for heirs property owners due to title difficulties. The NASA DEVELOP team worked in partnership with The Georgia Heirs Property Law Center (The Center) to identify potential heirs properties impacted by Hurricane Irma. We created flood extent maps, a socioeconomic overlay, and identified potential areas of structural damage. We utilized surface reflectance data from Landsat 7 Enhanced Thematic Mapper Plus (ETM+), Landsat 8 Operational Land Imager (OLI) and Sentinel-2 MultiSpectral Instrument (MSI) and backscatter data from Sentinel-1 C-band Synthetic Aperture Radar (C-SAR). We produced flood extent maps by consolidating these Earth observations in NASA SERVIR's Hydrologic Remote Sensing Analysis for Floods (HYDRAFloods) tool in Google Earth Engine (GEE). To produce one socioeconomic overlay, we used Computer Assisted Mass Appraisal (CAMA) data to identify areas of heirs properties likelihood. To identify potential structural damage, we used optical imagery data from PlanetScope and RapidEye. Our flood extent map results found that backscatter data was more reliable than surface reflectance, resulting in mainly coastal flooding. With these maps, we created one socioeconomic overlay for Camden County. Lastly, we found only nine potential instances of structural damage in Albany, Dougherty County. These end products will allow The Center to make informed decisions about the allocation of funds for heirs property disaster assistance.

Key Terms

Hurricane Irma, HYDRAFloods, flood extent, heirs property, CAMA

2. Introduction

2.1 Background Information

Georgia is located in the southeastern region of the United States, has a humid subtropical climate, and commonly experiences extreme weather events, such as hurricanes, tornadoes, flooding etc. Coastal areas are more vulnerable to flooding than inland areas. Natural disasters affect the political, social, and economic situation of a place (Bossak et al., 2014). A government's mitigation plan post-disaster has a major influence on the public.

Making impact the morning of September 12th, 2017, Hurricane Irma moved into southern Georgia as a tropical storm (Cangialosi et al., 2018). The tropical storm brought with it wind gusts of up to 62 miles per hour, heavy rainfall, and a storm surge that caused 3-5 ft of flooding along coastal Georgia (Federal Emergency Management Agency, n.d.). Irma caused a total of $50.5 billion dollars of property damage, making it the 6th costliest hurricane in United States history (NOAA NCEI, 2018a). As the prevalence of severe weather events is expected to rise, the need for flood maps to aid in disaster planning and mitigation is more important than ever (Otto, 2016).

Hurricane Irma devastated properties across the Eastern United States, and it highly impacted heirs property owners. Heirs property is a type of property ownership that occurs when an owner dies without the necessary legal paperwork to confer ownership. After the owner's death, the ownership of the property is transferred to all legal heirs of the land, which includes the spouse and all blood relatives of the original owner. This type of fractional ownership results in an "tangled title", a title shared amongst multiple family members. Due to the nebulous legal nature of these properties, they are often denied FEMA (Federal Emergency Management Agency) funds, Small Business Administration (SBA) loans, along with other state and local relief. This issue first became prominent after Hurricane Katrina and has since become a known problem throughout the South (Gaither et al., 2019).

This project focused on 15 counties of southern Georgia: Berrien, Camden, Charlton, Chatham, Coffee, Cook, Crisp, Dougherty, Glynn, Liberty, McIntosh, Thomas, Turner, Wilcox, and Worth counties (Figure 1). Our partners, the Georgia Heirs Property Law Center, decided the study area based on the 15 counties that were designated for Federal Emergency Management Agency (FEMA) Public Assistance and Individual

Assistance (Georgia Department of Community Affairs, 2020). Regarding the flood extent and structural damage, our studied time period was from January 2012 – September 2017. To overlay the socio-economic data onto the flood extent maps, we used CAMA data for one county, Camden County.

This project used two types of satellite data: optical and SAR. Optical imagery uses multispectral sensors that measure reflected light in multiple bands from the visible to shortwave infrared spectrum. Synthetic Aperture Radar (SAR) is an active remote sensing technique that calculates the amount of texture and structure of the surface, and targets backscatter returned to the sensor. SAR functions in the microwave region, and this wavelength allows the sensor to penetrate cloud cover and record targets on Earth's surface in all weather conditions. This project also used NASA SERVIR's Hydrologic Remote Sensing Analysis for Floods (HYDRAFloods) tool. HYDRAFloods is an open-source Python package, which allows for near-real time mapping of surface water.

Past studies used satellite-based Earth observations to detect flooding extent. William et al.,2021 proposed a multisensory SAR based automated flood detection method using image processing techniques, which potentially outperform benchmark manual approaches. They used SAR to demonstrate for flood extent and HYDRAFloods to understand the flood risk in the Central America Disasters project. To assess the surface water extent before and after Hurricane Ita and Iota, they used the Edge Otsu thresholding algorithm. Using this information, we used similar remotely sensed data and HYDRAFloods to look at the impact of Hurricane Irma on Georgia heirs property owners.

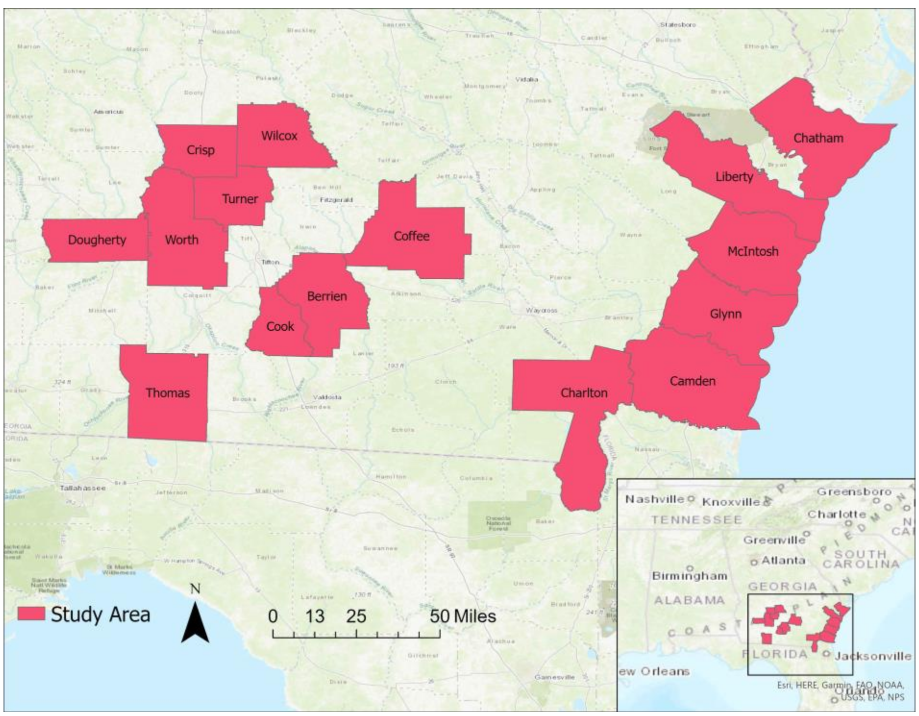

Figure 1. A map showing the counties in the study area.

2.2 Project Partners & Objectives

The Georgia Heirs Property Law Center specializes in clearing and consolidating heirs property titles through estate planning, asset education, and outreach. The Center works with heirs property owners to not only obtain necessary relief, but to help facilitate the management of property. Recently, the Center received a grant to partner with the Georgia Department of Community Affairs to provide legal services to heirs property owners recovering from Hurricane Irma. This grant also funds disaster mitigation planning efforts to ensure heirs property owners are considered in future disaster relief and outreach to inform potential vulnerable communities.

Using remotely sensed data and HYDRAFloods, our project's objective was to look at the impact of Hurricane Irma on Georgia heirs property owners to improve disaster responses and aid in consequent policy making. We generated flood extent maps for the study area, using optical and SAR imagery and produced socioeconomic overlays for one of the 15 counties. We conducted a preliminary investigation for structural damage and blue tarps using Planetscope optical imagery, and overlayed the results for Albany, Dougherty onto the SAR and optical flood extent maps.

3. Methodology

3.1 Data Acquisition

We acquired data from Earth observation sources and governmental entities. NASA and the US Geological Survey (USGS) sourced imagery for Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat 8 Operational Land Imager (OLI) Surface Reflectance. The European Space Agency (ESA) sourced imagery for Sentinel-1 C-band Synthetic Aperture Radar (C-SAR) Backscatter and Sentinel-2 MultiSpectral Instrument (MSI) Surface Reflectance. The satellite data for Landsat 7, Landsat 8, and Sentinel-1 were acquired through Google Earth Engine's (GEE) data catalog with the Python API's HYDRAFloods package on Google Collaboratory. Sentinel-2's satellite data was acquired from the Sentinel Hub Earth Observation Browser. The optical imagery used to identify structural damage was acquired from the PlanetScope satellite constellation. Property information used to identify heirs properties likelihood was acquired from Computer-Assisted Mass Appraisal (CAMA) datasets, provided by the University of Georgia's Carl Vinson Institute of Government. This project used various years of data: observed permanent water from 2012-2017, CAMA data for Camden County from 2014, and the impact of Hurricane Irma on Georgia from September 2017. Therefore, the time period for this project was from January 2012 - September 2017.

Table 1. Earth observation satellites and sensors, parameters, and image capture dates

Platform / Sensor	**Parameters**	**Processing Level**	**Image Capture Dates**
Landsat 7 ETM+	Surface reflectance	Level 2 Collection 2 Tier 1	9/10/21 – 9/20/17
Landsat 8 OLI	Surface reflectance	Level 2 Collection 2 Tier 1	9/10/21 – 9/20/17
Sentinel-2 MSI	Surface reflectance	Level-2A	9/19/2017
Sentinel-1 C-SAR	Backscatter	Level-2A	9/11/17 – 9/20/17
PlanetScope	Surface reflectance		8/11/17, 9/07/17, 10/17/17, 10/13/17

3.2 Data Processing

This project had different processing methods for 5 data types: 1) Landsat 7 ETM+ and Landsat 8 OLI, 2) Sentinel-2 MSI, 3) Sentinel-1 C-SAR, 4) PlanetScope, and 5) CAMA data. The overall methodology is depicted in Figure 2. The purple boxes indicate software/coding programs, the blue boxes indicate data, orange boxes indicate data types, the grey boxes indicate processing methods, and the pink boxes indicate end products. GEE's Python API was used to create flood extent maps with Landsat 7 ETM, Landsat 8 OLI, and Sentinel-1 C-SAR. ArcGIS Pro was used to create a flood extent map with Sentinel-2 MSI. GEE's JavaScript API was used to make a structural damage map with PlanetScope. Microsoft Excel was used to filter heirs property likelihood with CAMA data. ArcGIS Pro was also used to mosaic the 15 counties into one shapefile.

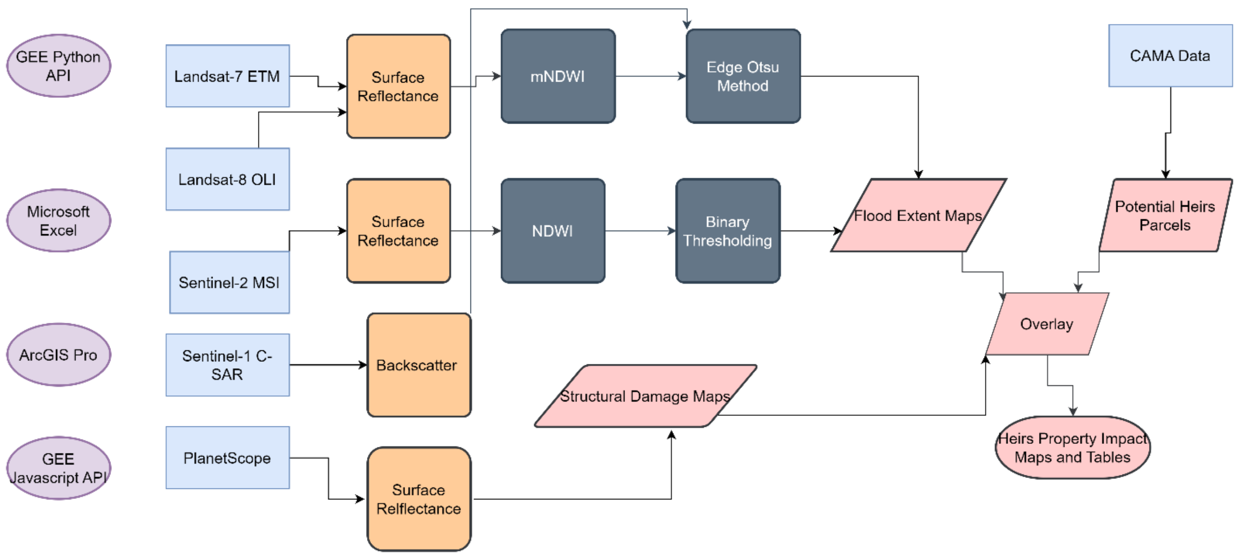

Figure 2. A flowchart that depicts the methodology of the project.

3.2.1 Flood Extent – HYDRAFloods Tool

HYDRAFloods is an open-source, cloud-based Python package that allows easy access to satellite data and creation of near real-time flood extent maps. HYDRAFloods can be implemented using Google Earth Engine's (GEE) Python API and Google Cloud Platform (GCP). With HYDRAFloods, we acquired satellite data for Landsat 7 ETM+, Landsat 8 OLI, and Sentinel-1 C-SAR with applied calibration/georegistration and atmospheric correction.

3.2.2 Flood Extent – Landsat 7 ETM+ and Landsat 8 OLI

HYDRAFloods was used to acquire data within the shapefile of the area of interest and the desired time period. To include data from before and after the hurricane, the flood extent map time period was from September 10th, 2017 – September 21st, 2017. With these parameters, HYDRAFloods obtained two images from Landsat 7 ETM+ and four images from Landsat 8 OLI. We calculated the Modified Normalized Difference Water Index (mNDWI), a ratio of the green and shortwave infrared bands used to emphasize areas of water, during the time period for each satellite and sensor (Zhou et al., 2017). To identify the data as classes of water and non-water, we also used the thresholding algorithm "Edge Otsu" (Markert et al., 2020). This was then compared to the permanent water to distinguish flood from permanent water sources with the Joint Research Centre (JRC) Yearly Water Classification History from 2012-2017.

$$mNDWI = \frac{GREEN - SWIR}{GREEN + SWIR} \tag{1}$$

3.2.3 Flood Extent – Sentinel-2 MSI

The Sentinel-2 MSI imagery for the relevant time period was not available to call in from the GEE's data catalog. Due to this, it was processed differently than the imagery from Landsat 7 ETM+ and Landsat 8 OLI satellites. Instead, relevant imagery was found on the Sentinel Hub EO Browser, an open-source database with contributions from the European Space Agency. Pertaining to our time period, we found one available image from September 19, 2017. We downloaded a raster of raw bands from the EO Browser and loaded it into ArcGIS Pro. We utilized the Raster Calculator tool to calculate the Normalized Difference Water Index (NDWI), a ratio of the green and near-infrared bands (Gao, 1996). After, we used the Binary Thresholding tool to separate the NDWI raster into two separate projected water and non-water classifications with a value of -0.38.

$$NDWI = \frac{GREEN - NIR}{GREEN + NIR} \tag{2}$$

3.2.4 Flood Extent – Sentinel-1 C-SAR

For Sentinel-1 C-SAR analysis, we used the HYDRAFloods tool through the GEE's Python API to calibrate and analyze Sentinel-1 C-SAR imagery for the study area. We chose a nine-day window, September 11th, 2017 – September 20st, 2017, for when Hurricane Irma inundation could be observed. This produced nine Sentinel-1 C-SAR images with VV polarization. SAR imagery is often affected by an interference of signals reflected from the ground that create speckle, so a speckle filter was applied to reduce this granular noise. Using the Global Hydrography Digital Elevation Model from MERIT Hydro (Yamazaki), elevation information was inputted to mask areas 20 meters above the nearest drainage point. A pseudo-terrain correction was then applied to correct shadowing from hills and three-story buildings that used elevation information the USGS 3D Elevation Program (3DEP). Similarly, to Landsat 7 and 8, we used the "Edge Otsu" thresholding algorithm to identify classes of water and compared this information to permanent water data received from the JRC Yearly Water Classification History.

3.2.5 Socioeconomic Processing - CAMA

We used CAMA data to identify potential heirs property affected by flooding from Hurricane Irma. The CAMA data was selected for Camden County from 2014. To finalize the heirs properties, we looked at three variables in the CAMA data: (1) properties owned by natural peoples (i.e. no business, governmental organizations, religious institutions etc.), (2) a transfer date older than 30 years, and (3) no preferential tax status. We used three tables: PE_Owners, PE_Acessory, PE_Saleinfo, to filter out properties that were unlikely to be heirs properties. Several keywords were used to identify and filter out these properties, seen in Table 3.

To combine these three tables, we used the PE_ RealProperty table. Using Microsoft Excel's power query function, we joined the PE_Owners, PE_Accessory, and PE-Saleinfo table, into the PE_RealProperty table. The PE_Owners table was joined first via the OWNKEY, an identifier unique to the owners table, then the PE_Accessory and PE_Saleinfo tables were joined via the REALKEY, which is common among several tables.

Table 3. A list of terms used to filter out non-natural peoples

Classification	**Filtered Terms**
General Corporations/Commercial	Limited, Company, Co, LLC, LLP, LLLP, Ltd, Inc, Enterprises, Properties
Food and Grocery	Taco, Chick, McDonalds, Burger, Pizza, Seafood, Market, Restaurant, Chicken, Pies, Foods, Firehouse, Subway, Café, Buffet, Grocery, Walmart, Publix, Kroger
Religious	Church, Baptist, Presbyterian, Lutheran, Assembly, Chapel, Methodist
Government	USA, Army, Georgia, Camden, Brunswick, Kingsland, Bureau, National, Park, Water, Utilities, School, Federal, Secretary, City of
Places of Business	Wine, Liquor, Spirits, Hotel, Shops, Cinema, Bank, Landscaping, Suites, Funeral, Builders, Insurance, Plumbing, Spa, Jewelers, Center, Department, Club, Store, Broadcasting, Auto

Medical	Clinic, Dental, Medical, Therapy, Spine, Rehabilitation, Medicine, PC (Primary Care), OB/GYN, Hospital, Pharmacy
Miscellaneous	Family Trust, Admin, Homeowners, Pineapple, Patch, Plus, Humanity, Union, Developers, Land, Surveyors

3.2.6 Structural Damage Maps - PlanetScope

To assess structural damage, we used 3-meter high-spatial resolution optical imagery from PlanetScope. This PlanetScope imagery was selected by considering dates that had the most imagery in the study area and the least cloud cover. Some images only covered portions of the study area. We explored the PlanetScope imagery in GEE and visually inspected it to find blue tarps and structural damage for three areas, listed in Table 2, within the 15 counties. To decide where to look in the imagery, we considered several factors, such as where documented FEMA applications were located, the path of the hurricane, and where precipitation and wind speeds were the highest.

Table 2. A list of dates and county/city we looked at Planetscope imagery

City/County	**Image Capture Dates**
City of Albany, Dougherty	9/07/17; 9/17/17
City of Douglas, Coffee	8/11/17
Dougherty County	9/08/17; 10/13/17

3.3 Data Analysis

3.3.1 Visualization

To visualize the flood extent from Landsat 7 ETM+, Landsat 8 OLI, and Sentinel-1 C-SAR, we exported GeoTiffs of the flood extent and permanent water. However, GEE's Python API exports the imagery without visualizations in the GEE Map. These Python GeoTiffs were imported into GEE's JavaScript API, added visualization parameters, and then exported again. ArcGIS Pro was then used to compile these different layers into the different flood extent maps.

3.3.2 Data Gaps – Earth Observations

Landsat 7 ETM+ had data gaps in Camden, Charlton, Chatham, Glynn, Liberty, and McIntosh within the image capture dates. Landsat 8 OLI had data gaps in Berrien, Coffee, Cook, Crisp, Dougherty, Thomas, Turner, Wilcox, and Worth. Sentinel-2 MSI had data gaps in Chatham, Camden, Glynn, and McIntosh counties. Sentinel-1 C-SAR had a data gap in Coffee County.

3.3.3 Socioeconomic Overlay – CAMA

To show and identify the effect of Hurricane Irma on heirs properties, we overlayed the socioeconomic data onto the SAR flood extent map through ArcGIS Pro. After loading the layers of flood and permanent water, we joined the filtered CAMA data with the shapefile of all the property parcels of Camden County. The centroids were extracted from the filtered parcels.

3.3.4 Structural Damage Overlay – PlanetScope and Flood Extent

We analyzed the PlanetScope images in the GEE JavaScript API. Then we extracted the longitude and latitude coordinates of those nine instances from GEE. After, we overlayed these coordinates onto the SAR (Sentinel-1) and Optical (Landsat 7 and Landsat 8) flood extent maps in ArcGIS Pro.

3.3.5 Flood Extent Comparison
In ArcGIS Pro, the flood extent measured from each satellite was found with the pixel count from those flood layers with the zonal statistics function. The pixel count from each satellite for each county was then input into Microsoft Excel. We then converted the pixel count of the flood extent with the respective spatial resolutions to the area (km^2) of flood. The area of flood in each county was then compared to the county's total area to find the percentage of flood extent. This allowed us to compare how much flood extent was measured by each satellite and how much flooding occurred in different counties and types of counties, coastal and inland.

4. Results and Discussion
For our results, we produced maps with similar layouts. Each map represents the flood extent of Hurricane Irma within the 15 counties. The inset map visualizes our study area within the state of Georgia. Blue represents permanent water, while red represents flooding.

4.1 Flood Extent Results - Landsat 7 ETM+ and Landsat 8 OLI
In Figure 3, we combined the flood extent maps created with surface reflectance data from Landsat 7 ETM+ and Landsat 8 OLI. Landsat 7 ETM+ observed more flooding in the inland counties, whereas Landsat 8 OLI observed more coastal flooding. In terms of flood extent, Landsat 7 ETM+ observed 1320.31 km^2 while Landsat 8 ETM+ observed only 249.68 km^2. Landsat 7 ETM+'s observations are depicted with some streaks, which indicates there may be some issues with what was observed. During the hurricane, there was a significant amount of cloud cover and optical imagery tends to have trouble penetrating through it. Therefore, we hypothesize that Landsat 7 ETM+ may have observed this instance as flood.

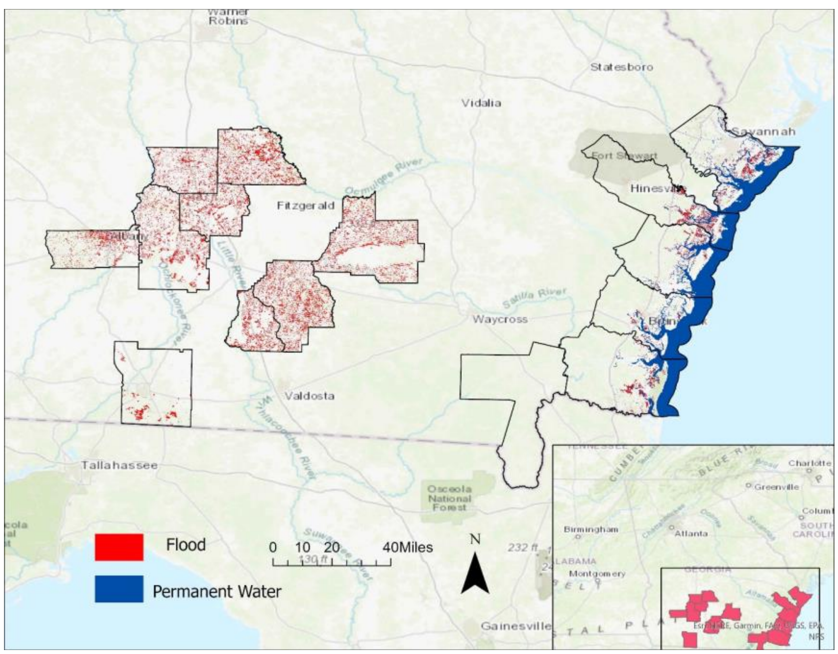

Figure 3. This is the optical flood extent map created with Landsat 7 ETM+ and Landsat 8 OLI.

4.2 Flood Extent Results - Sentinel-2 MSI
We measured significantly less flood extent from Sentinel-2 MSI than the other satellites and sensors due to difficulties with the methodology, such as the manual thresholding from the Binary Thresholding tool. The sensor detected around 0.86 km^2 of total flood. The Sentinel-2 imagery showed only scattered instances of flood throughout the inland counties with data gaps in all counties in the study area.

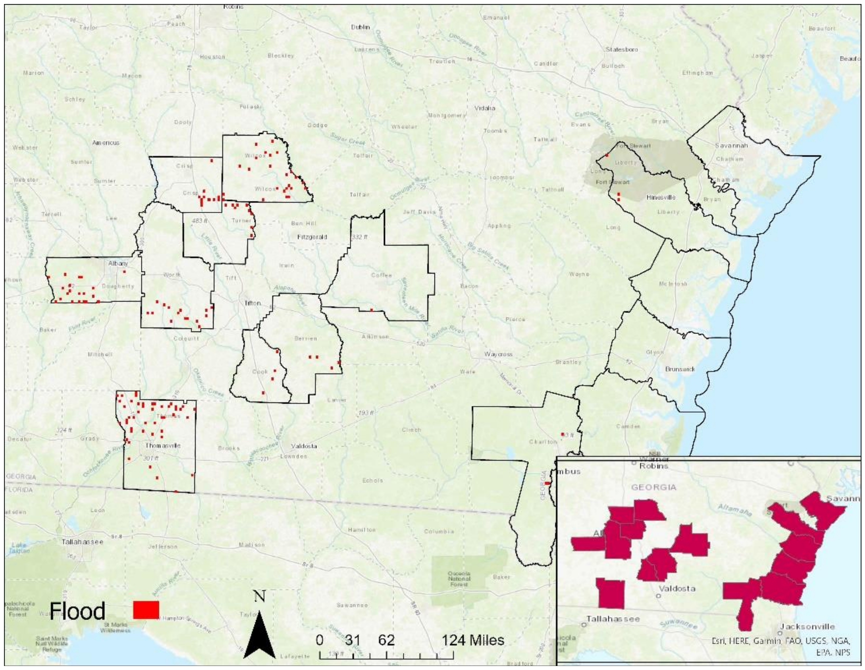

*Figure 4. F*lood extent map created with Sentinel-2 MSI.

4.3 Flood Extent Results - Sentinel-1 C-SAR

Sentinel-1 C-SAR measured 16.45 km^2 of total flood extent. SAR data is considered more reliable to measure flood extent than optical data, so the structural damage overlay created from PlanetScope imagery and the socioeconomic overlay created from CAMA data were overlayed with only the SAR flood extent map.

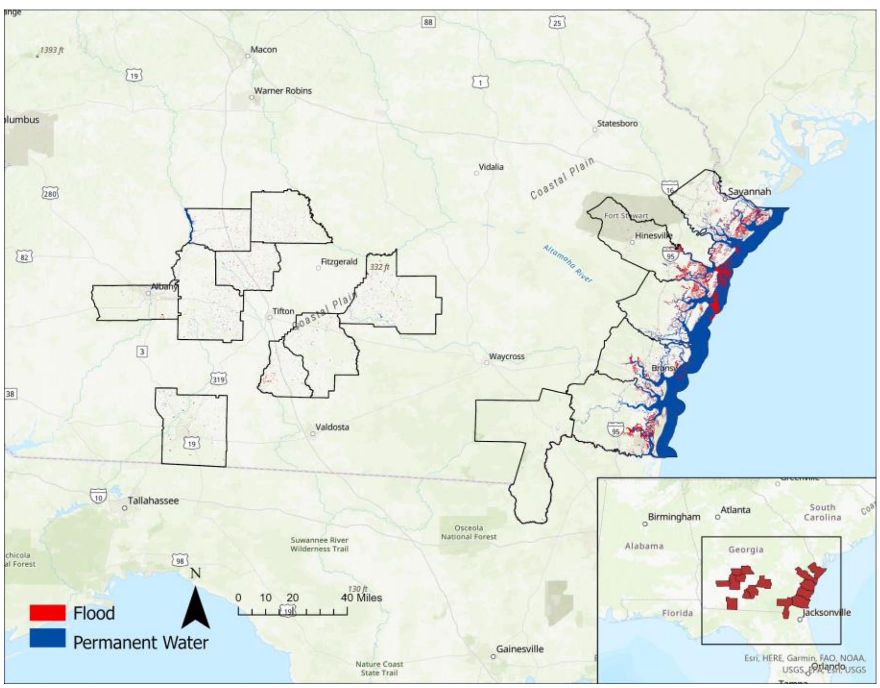

Figure 5. Flood extent map measured with Sentinel-1 C-SAR.

4.3 Socioeconomic Overlay – CAMA and Sentinel-1 C-SAR

In Figure 6, we made a socioeconomic map of potential heirs properties for one county, Camden County, and overlayed it onto the SAR flood extent map. The results of our CAMA data analysis indicate that there are 660 potential heirs properties out of 30,788 parcels within Camden County, a ratio of 2.14%. Many of these heirs properties were threatened by flooding, with the most at-risk properties concentrated around sources of permanent water, such as the East, Satilla, and St. Mary's rivers. Further analysis indicates that over 52 properties were located within 50 m of flooding.

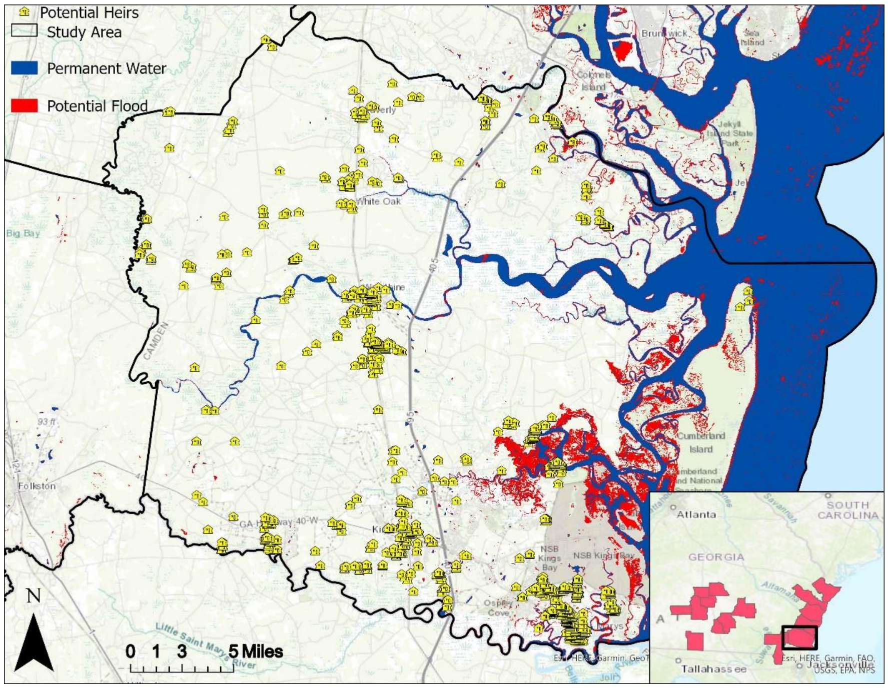

Figure 6. A map overlaying potential heirs properties on SAR flood extent map

4.4 Structural Damage Maps Results – PlanetScope

Upon analyzing the PlanetScope images, we only found nine blue tarps in the city of Albany, Dougherty, depicted in Figure 7. In the left map, Landsat 7 ETM+ and Landsat 8 OLI seems to have registered more flooding around the areas of the blue tarps. However, in the right map, Sentinel 1 C-SAR depicted less areas of flooding in this region overall.

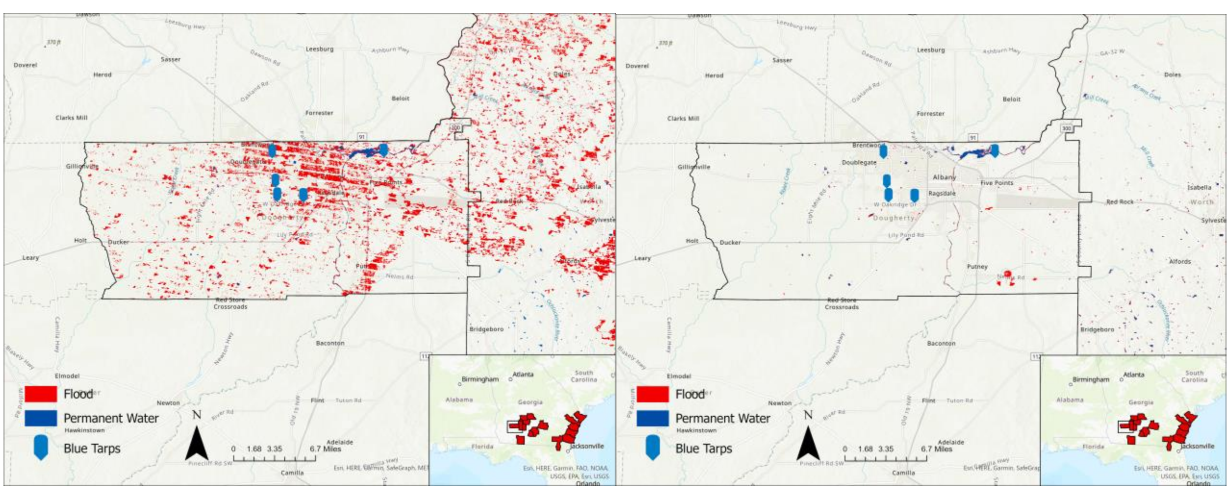

Figure 7. Overlays of the potential structural damage found in Albany, GA onto flood extent maps.

The left map displays the overlay onto 7 ETM+ and Landsat 8 OLI flood extent maps. The right map displays the overlay onto the Sentinel-1 C-SAR flood extent map.

4.5 Flood Extent Comparison - Sentinel 1 C-SAR, Landsat 7 ETM+, Landsat 8 OLI, and Sentinel 2 MSI

The total percentage of flood extent measured by each sensor was compared in Figure 8. We also compared what percentage of flood extent was measured in coastal counties and inland counties from these satellites. This comparison substantiates that Sentinel 1 C-SAR measured coastal and inland flood, Landsat 7 ETM+ measured inland flood, Landsat 8 OLI measured coastal flood, and Sentinel-2 MSI measured nearly no flood.

Figure 9 breaks down Sentinel 1's flood area percentage for each county in the study area, distinguishing them between coastal and inland. From these results, we verified that more coastal flooding occurred, with Chatham and Liberty having the highest flood area percentage of around 7.2%.

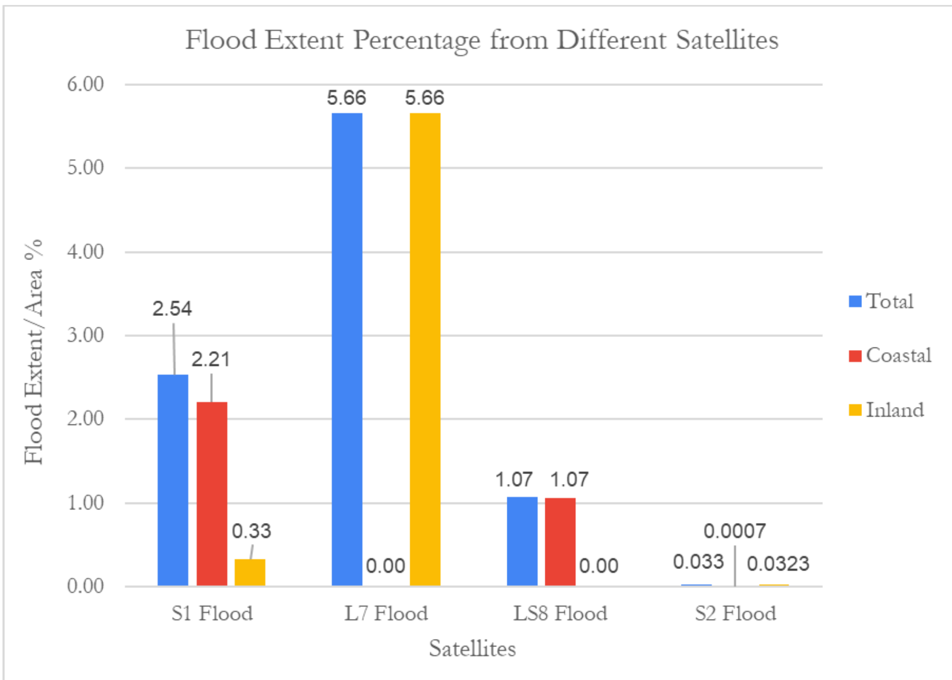

Figure 8. Comparison of the total flood extent percentage from the different satellites used: Sentinel-1 (S1), Landsat 7 (L7), Landsat 8 (L8), and Sentinel-2 (S2). In red, the coastal flood percentage measured. In yellow, the inland flood percentage measured.

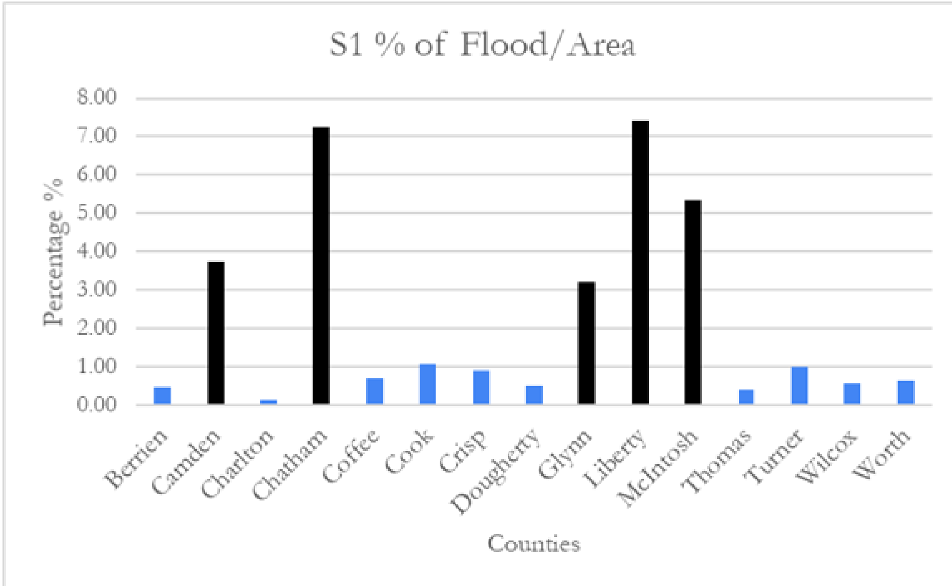

Figure 9. This is the flood percentage of each county measured by Sentinel-1 C-SAR with coastal counties shown in black and inland counties shown in blue.

4.2 Limitations

4.2.1 Landsat 7 ETM+ and Landsat 8 OLI Limitations

Optical satellites had inherent trouble penetrating cloud cover during the hurricane, because it only uses surface reflectance data. While cloud masking functions can be applied to the appropriate imagery, the amount of cloud cover may render the resulting data useless. Therefore, the Landsat 7 ETM+ and Landsat 8 OLI flood extent maps were limited. Seen in Figure 7, Landsat 7 ETM+ also had scan-line corrector failure, which results in streaky images and data gaps.

4.2.2 Sentinel-2 MSI Limitations

A significant limitation encountered with Sentinel-2 MSI was the lack of available imagery from the Sentinel 2-MSI surface reflection collection and lack of access in GEE's data catalog. This lack of data resulted in the inability to complete the analysis that was done in HYDRAFloods, such as comparing to the permanent water and applying the Edge Otsu method. We attempted to circumvent this limitation by analyzing the imagery within ArcGIS Pro, however the lack of a cloud mask and the manual thresholding made it difficult to separate water and non-water classes and resulted in low-quality and unclear data.

4.2.3 Sentinel-1 C-SAR Flood Extent Limitations

Urban areas and tree-filled areas have complicated geometry that can cause double-bounce scattering and can make the flooding be misidentified as non-water by SAR sensors. This could also mean that instances of flood appear on the flood extent map with a smaller area than the real area. Errant smooth surfaces, such as pavement or airports, may have similar backscatter characteristics as water, which introduces uncertainty to the processed imagery. Furthermore, the presence of flooded vegetation may introduce a rougher geometry, which would then be harder to identify as flood (Grimaldi et. al, 2020). Another limitation is the C-SAR sensor uses the C-band microwave wavelength, which cannot penetrate through dense canopies.

4.2.4 CAMA Limitations

The largest limitation with regards to the CAMA data was its sheer volume. Since the data represents all properties within a county, the process of filtering it requires extreme care and specificity. Many properties have specific names that do not fall within the parameters. For example, the filter "Cinema" may filter out several properties, but may not filter out a property named "AMC". Thus, several properties may have fallen between the cracks of the general parameters. Furthermore, CAMA data was standardized among 147 of

Georgia's counties in the WinGAP format, but was non-standard among the other 12 counties. This may pose an issue when attempting to identify how to join separate tables from non-standard formats.

4.2.5 Structural Damage Limitations

Due to the abrupt and intense nature of storm-caused inundation, temporal resolution becomes a key factor in obtaining accurate data. The temporal resolution of the sensors we used ranged from 10 days to 16 days, but flooding from storm surge and heavy rainfall may only last a few days. This may result in an inundation event being missed by the available imagery. We were also not able to define or identify any visual instances of property structural damage in all three areas due to difficulty identifying what was being observed, such as pools instead of blue tarps. Due to cloud obscuration and high areas of agricultural land, we did not see any blue tarps in the city of Douglas, Coffee County or in Dougherty County. Lastly, since PlanetScope imagery cannot be used in an end product due to its proprietary nature, only unconfirmed points of potential structural damage could be used.

4.3 Future Work

4.3.1 Landsat 7 ETM+ and Landsat 8 OLI Flood Extent Maps

To refine the optical flood extent maps, the Quality Assessment function in HYDRAFloods, use_QA, should be applied, because this is the cloud and cloud shadow masking algorithm (Foga). The thresholding used from Edge Otsu was likely incorrect due to clouds not being masked out. A refined version of the optical flood extent maps would be more accurate to the flood extent. Future work should also include investigating why some of the flooding is not masked out in the areas of permanent water.

4.3.3 Sentinel-2 MSI Flood Extent Map

The original intent of the project was consolidating many optical Earth observations to account for the data gaps implicit in using optical imagery to observe flooding from a hurricane. Sentinel-2 MSI imagery was supposed to have the same methodology as Landsat 7 ETM+ and Landsat 8 OLI, however this was not the case. If it is possible to figure out a way to upload the bands onto the GEE Python API, the next team can use the methodology with HYDRAFloods.

4.3.2 Sentinel-1 C-SAR Flood Extent Map

A buffer can be added to the flood extent map to account for flood area that is not measured due to the limitation of the geometry. This means that only areas where flood was detected but showing a small amount of area could look more accurate. The JRC Yearly Water Classification also has a class that allows the permanent water to incorporate the seasonality of the study area that could be explored. HYDRAFloods also has a Floodwater Depth Estimation Tool that could be used to see where the flooding was the most severe (Cohen). A time series of the flood could also be looked at to see how much flooding occurred as the days progressed and what areas had flood recede first or had flood occurred later.

4.3.4 Structural Damage

While working with PlanetScope imagery we found that it has limitations, which obscure this imagery to find the structural damage and blue tarps of property. Next term can avoid working on PlanetScope imagery and focus on other methods to recognize the property damage in the study area.

4.3.5 Socioeconomic Data

In this term, we were able to overlay the socioeconomic data to a flood extent map for Camden County with CAMA data. However, there are more likelihood parameters that can be observed to find potential heirs properties, such as a county's racial demographics, median incomes, education levels, etc. This data is available from the 2017 U.S. Census Bureau American Community Survey (ACS). Combining information from the CAMA and ACS datasets will make the socioeconomic layers more refined and more likely to be correct. Future work will include overlaying this socioeconomic information for all fifteen counties to better understand the impact of Hurricane Irma on Georgia heirs property owners.

4.3.6 FEMA Denials
Additionally, we could possibly explore more processing methods to create highly detailed and informative flood extent maps. The next term should look into incorporating FEMA denial data pre-processed by the Washington Post to analyze potential inequalities of disaster relief funding (Dreier). Our partners mentioned that they were interested at looking into property damage from Hurricane Michael, which was preceded Hurricane Irma. They also mentioned the possibility finding tornado tracks on PlanetScope to help identify areas of potential heirs properties.

5. Conclusions

In conclusion, we found various amounts of flooding throughout all 15 counties. In the total flood area percentage in relation to our study area, Sentinel 1 depicts about 2.54% and Landsat 8 OLI depicts about 1.07% flooding, whereas, Landsat 7 ETM+ depicts about 5.66% flooding for our study area. Though Landsat 7 ETM+ was able to identify more flooding in inland counties, the difference between this and Landsat 8 OLI suggests that it may not be entirely accurate. And Sentinel 1 showed mainly coastal flooding due to the issues it has reading flood extent in areas with complicated geometry. The majority of the flooding occurred within the 5 coastal counties (Camden, Chatham, Glynn, Mcintosh, Liberty), with SAR observing a 7x increase of flood extent compared to inland counties.

Our CAMA analysis of Camden County resulted in the identification of 660 potentials heirs properties out 30,788 parcels, an incidence rate of 2.14%. In the initial analysis of flood risk, 52 properties (about 7.8% of the total) were found to be at a high-risk within 50 meters of identified flood. This demonstrated a specific instance in which heirs properties were threatened by flooding.

Using the products we provided, our partners at the Georgia Heirs Property Law Center will be able to create a case study demonstrating how heirs properties owners were impacted by Hurricane Irma. Furthermore, by seeing where the highest concentration of heirs properties are in relation to the flooding, they will be able to further focus their efforts in clearing and consolidating heirs property titles to impacted communities. Thus, they will work towards ensuring that the most vulnerable will be able to preserve their homes, properties, and way of life.

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7. Glossary

Earth observations – Satellites and sensors that collect information about the Earth's physical, chemical, and biological systems over space and time
FEMA - Federal Emergency Management Agency
GCP – Google Cloud Platform
GEE – Google Earth Engine
GHPLC – Georgia Heirs Property Law Center
Heirs property- A type of property ownership that occurs when a property owner dies without the necessary legal paperwork to confer ownership, the title of the property becomes "tangled"
Natural peoples - No business, governmental organizations, religious institutions etc.

HYDRAFloods - Hydrologic Remote Sensing Analysis for Floods – A program used to process satellite imagery to produce flood map
Specular reflection – the reflected ray travels in one outgoing direction after hitting a smooth surface
NOAA – National Oceanic and Atmospheric Administration
CAMA – Computer Assisted Mass Appraisal
NDWI- Normalized Difference Water Index
MNDWI- Modified Normalized Difference Water Index
ETM+- Enhanced Thematic Mapper plus
OLI- Operational Land Imager
MSI- Multispectral Instrument
SAR – Synthetic Aperture Radar – Active remote sensor that creates to-dimensional images of landscapes

8. Glossary References

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9. Appendices

Table 4. Comparison of the percentage of flood extent over the area of the county from each satellite.

County	**Sentinel 1 C-SAR Flood/Area %**	**Landsat 7 ETM+ Flood/Area %**	**Landsat 8 OLI Flood/Area %**	**Sentinel 2 MSI Flood/Area %**
Berrien	0.47	18.24	0.00	0.058
Camden	3.75	0.00	2.10	0.000
Charlton	0.12	0.00	0.00	0.046
Chatham	7.24	0.00	3.57	0.000
Coffee	0.68	11.52	0.00	0.057
Cook	1.08	15.64	0.00	0.057
Crisp	0.90	11.98	0.00	0.057

Dougherty	0.50	9.16	0.08	0.058
Glynn	3.22	0.00	1.38	0.000
Liberty	7.42	0.00	3.31	0.009
McIntosh	5.35	0.00	2.53	0.000
Thomas	0.40	2.49	0.02	0.057
Turner	1.00	14.28	0.00	0.058
Wilcox	0.57	18.26	0.00	0.058
Worth	0.64	9.46	0.00	0.057
Total	2.54	5.66	1.07	0.033