**NASA DEVELOP National Program**

**2020 Spring Project Proposal**

**Virginia – Langley**

**Toa Baja Disasters**

*Mapping Tropical Storm Susceptibility in Puerto Rico’s ‘Underwater City’ Using NASA Earth Observations to Assist the Municipality’s Intervention Efforts*

**Project Overview**

***Project Synopsis*:** The city of Toa Baja on the northern coast of Puerto Rico is extremely flood prone due to its unique geography and the island’s location in “hurricane alley.” The high concentration of informal settlements in this area results in a cycle of destruction and loss of life in Toa Baja. In partnership with Municipio Autonómo de Toa Baja, ResilientSEE, and the Massachusetts Institute of Technology (MIT) Urban Risk Lab, this project aims to use Sentinel-1 C-SAR, Landsat 8 OLI, and Sentinel-2 MSI to map historical flood events. These maps will be integrated with data from GPM and additional datasets such as elevation, land use, and population to generate a flood susceptibility map and risk maps for Toa Baja. The ability to dynamically visualize flood events in the context of the area will allow city planners to prioritize regions in need of additional infrastructure to cope with the effects of tropical storms and will aide future development decisions.

***Community Concern:*** Toa Baja, located just outside of San Juan in northern Puerto Rico, is known as *“La Ciudad Bajo Aguas”* or “the underwater city” due to its propensity to flood. During tropical storm events, the city is inundated by flood water from storm surge at the northern coast and flooding of Rio de la Plata, which runs through the city. Following the 2017 hurricane season, over 14,000 homes were flooded, and damages in the city amounted to over $1.3 billion, which limits the capacity to develop projects and provide services for residents of the municipality. In addition to these concerns, Toa Baja has the highest proportion of unmet housing needs in Puerto Rico. In June 2019, new FEMA flood maps designated 63% of the municipality’s total area in a flood plain, up from 48% in previous assessments.

***Source of Project Idea:*** This project arose from conversations between the LaRC Fellow and Yanel de Angel at ResilientSEE, who was introduced through Janice Barnes at Climate Adaptation Partners. Initial conversations recognized the benefit of involving MIT’s Urban Risk Lab and the municipal government in Toa Baja. During planning stages, Puerto Rico was impacted by Hurricane Dorian, highlighting the pressing need for a more comprehensive understanding of local flood risk and vulnerability. The potential partners submitted a compelling letter of support for this project.

***National Application Areas Addressed:*** Disasters, Water Resources, Urban Development

***Study Location:*** Toa Baja, Puerto Rico

***Study Period:*** January2000 – January 2020

***Advisors:*** Dr. Kenton Ross (NASA Langley Research Center), Dr. Venkataraman Lakshmi (University of Virginia)

**Partner Overview**

***Partner Organizations:***

|  |  |  |  |
| --- | --- | --- | --- |
| **Organization** | **POC (Name, Position/Title)** | **Partner Type** | **Boundary Org?** |
| **Municipio Autonómo de Toa Baja** | Desiree Pearlman, Executive Assistant, Division of Economic Development and Tourism; Edgar Gomez, Community Outreach Director | End User | Yes |
| **ResilientSEE** | Yanel de Angel, Project Manager and Principal at Perkins & Will | End User | Yes |
| **Massachusetts Institute of Technology, Urban Risk Lab** | Larisa Ovalles, Research Associate: Latin America, Prototyping, Design, and Urbanism | Collaborator | No |

***End User Overview***

***End User’s Current Decision-Making Process:***Decisions for future infrastructure and emergency planning in the municipality are made by the Mayor, who is provided with an analysis of scenarios based on available data from a team of professionals and associated resources. These resources include two city planners, an economic development official, the legal office, public works personnel, a civil engineer, emergency management personnel, a GIS expert, and the Mitigation Plan of the municipality. Due to resource limitations, remote sensing data and analyses are not integrated into their current decision making process.

***End User’s Capacity to Use NASA Earth Observations:***

*Municipio Autonómo de Toa Baja* – Officials from the city of Toa Baja have experience using Landsat data and are familiar with remote sensing methodologies, including image classification and analysis. This project will help the city understand how they can incorporate data from many different Earth observations to monitor flooding and strategically plan relief efforts and future infrastructure. The municipality is experienced in a range of Esri ArcGIS products and would benefit from an ArcGIS integrated solution. City officials have limited capability with coding and are comfortable working with some Python, Javascript, Arcade, and SQL.

*ResilientSEE* – ResilientSEE has not used NASA Earth observations before, but is familiar with remote sensing data products and has produced island-wide maps of various environmental parameters in collaboration with the MIT Urban Risk Lab. This project will help them integrate data from a diverse array of Earth observations in their future work in Toa Baja and will allow them to act as empowered stewards for the methodologies created in this project across changes in municipal leadership.

***Collaborator & Boundary Organization Overview***

***Collaborator Support:***

*Massachusetts Institute of Technology, Urban Risk Lab* – The MIT Urban Risk Lab partners with ResilientSEE under the shared goal of creating “a comprehensive and resilient planning and design strategy for Puerto Rico.” With this goal in mind, the lab has previously explored how temporary housing can increase resilience in Puerto Rico as an integrated component of a permanent housing solution. The Urban Risk Lab will provide support through regional expertise and first-hand knowledge of resilience efforts in Toa Baja.

***Dissemination by Boundary Organizations*:**

*Municipio Autonómo de Toa Baja* – The city of Toa Baja has very responsive leadership and has worked closely with ResilientSEE and the MIT Urban Risk Lab on prior projects. The municipality has expressed an interest in sharing their findings and resilience planning efforts with other municipalities throughout Puerto Rico and will also be responsible for disseminating the results of this project throughout the community.

*ResilientSEE* – ResilientSEE will act as the long-term custodian for the data and methodology of this project. The organization intends to continue studying resiliency in the region and will be able to share their findings with future leadership within Toa Baja. ResilientSEE may also share the results of this collaboration on their website and at future planning meetings in Puerto Rico.

***Project Communication & Transition Overview***

***In-Term Communication Plan*:** The team will have biweekly teleconferences with partners to provide updates on project methodologies and analyses throughout the term and will communicate their progress weekly via email. The team will appoint one individual to be the primary point of contact for in-term communications with project partners.

***Transition Plan*:** A handoff will be conducted at the end of the term using Webex. End users will receive a package with access to the final products through NASA Large File Transfer (LFT). The team will present their results and conclusions, lead a demonstration of the techniques generated in this project, and answer any questions the end users have during this handoff event. Any products that incorporate code will be sent to the partners by the LaRC Fellow following the software release process.

***Letters of Support*:** Yanel de Angel,Principal, Perkins & Will. Bernardo “Betito” Márquez, Mayor, Autonomous Municipality of Toa Baja. Ricardo Alvarez-Diaz, Co-Founder and Principal, Alvarez-Diaz & Villalon Architecture. Miho Mazereeuw, Associate Professor in Architecture and Urbanism, Director, MIT Urban Risk Lab. Larisa Ovalles, Researcher, MIT Urban Risk Lab. Gautam Sundaram, Associate Principal, Perkins & Will. John Haymaker, Director of Research, AREA Research.

**Earth Observations Overview**

***Earth Observations:***

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| --- | --- | --- |
| **Platform & Sensor** | **Parameter** | **Use** |
| **Landsat 8 OLI** | Reflectance | Landsat 8 imagery will be used to map historical flood extent in the study area from 2013 – January 2020 at 30 m resolution. Landsat 8 imagery will also be ingested in the flood mapping tool and processed using a flood extent algorithm to map more recent flood events. |
| **Sentinel-2 MSI** | Reflectance | Sentinel-2 imagery will be used to map historical flood extent in the study area from 2015 – January 2020 at 10 m resolution. Sentinel-2 imagery will also be ingested in the flood mapping tool and processed using a flood extent algorithm to map more recent flood events. |
| **Sentinel-1 C-SAR** | Land cover | SAR data will be used to map historical flood extent in the study area from 2015 – January 2020. SAR imagery will also be ingested in the flood mapping tool and processed using a flood extent algorithm to map more recent flood events. |
| **GPM IMERG** | Precipitation | Precipitation measurements from GPM from 2015 – 2020 will be incorporated in the static flood susceptibility map to identify flood-prone areas. |
| **TRMM TMPA** | Precipitation | Precipitation measurements from TRMM from 2000 – 2015 will be incorporated in the static flood susceptibility map to identify flood-prone areas. |

***Ancillary Datasets:***

* USGS National Land Cover Dataset (NLCD) – Integration with static susceptibility map
* USGS LiDAR DEM (2016-2017): Puerto Rico – Integration with static susceptibility map
* OpenStreetMap: Road Vectors – Incorporated in static susceptibility map as road density
* Socioeconomic Data and Applications Center (SEDAC) – Gridded Population of the World, Version 4.11 – Population and demographic spatial estimates for risk analysis
* Municipio Autonómo de Toa Baja Informal Housing Settlement Blueprints – Provide the location of informal housing settlements in risk mapping
* NOAA NWS historic precipitation data – Used for validation of GPM IMERG and TRMM TMPA data

***Software & Scripting:***

* Python – Initial data processing and analysis
* Esri ArcGIS Pro – Generate static susceptibility map, risk maps, historical flood maps, and flood mapping tool, using Spatial Analyst Toolbox and Image Analyst extensions
* Sentinel Application Platform (SNAP) – Initial processing of Sentinel-1 imagery

**Decision Support Tool & End Product Overview**

***End Products:***

|  |  |  |  |
| --- | --- | --- | --- |
| **End Product** | **Partner Use** | **Datasets & Analyses** | **Software Release Category** |
| **ArcGIS Flood Mapping Tool** | This tool will allow the partners to map flood extent following flood events to identify impacted areas that may be in need of intervention. | This tool will ingest and process data from Sentinel-1 C-SAR, Landsat 8 OLI, and Sentinel-2 MSI and apply a unique flood mapping algorithm to map flood extent following tropical storm or hurricane events. | IV |
| **Historical Flood Maps** | These maps will indicate areas that are routinely subjected to flooding, which may be prioritized in future infrastructure planning. Point information from these maps will be incorporated in the static flood susceptibility map. | Data from Sentinel-1 C-SAR, Landsat 8 OLI, and Sentinel-2 MSI will be processed and a flood extent algorithm will be applied. | N/A |
| **Static Flood Susceptibility and Risk Maps** | The static susceptibility map will be used to identify areas that may be in need of additional infrastructure or aid in flooding events. The risk maps will incorporate additional parameters, including population and the location of informal settlements, to derive flood risk for the region. | The susceptibility map will combine flood factors in ArcGIS Model Builder, including slope and elevation, rainfall data, road density, drainage density, and land cover. This susceptibility map will be combined with information about population and the location of informal settlements to map flood risk. | N/A |
| **Flood Mapping Tutorial** | This tutorial will clearly outline the methodology and resources used in generating the flood maps so these methods can be reproduced by partners in the future. | N/A | N/A |

***End User Benefit*:** The static flood susceptibility map will help city planners in Toa Baja prioritize regions for future intervention. Historical flood maps will indicate to city planners what areas are at the greatest risk for future flooding events so that steps can be taken to alleviate flooding in those areas or evacuate inhabitants prior to heavy rainfall events or tropical storms. The flood mapping tool will allow the end user to continue to monitor flooding in Toa Baja. In conjunction with the risk maps, this tool can highlight flood prone areas with vulnerable populations, and end users will be able to monitor flood extent remotely as events occur.

**Project Timeline & Previous Related Work**

***Project Timeline:*** 1 Term: 2020 Spring

***Related DEVELOP Work:***

2018 Summer (AL) – New Orleans Urban Development: Utilizing Earth Observations to Assist Groundwork New Orleans in Reducing Flood Vulnerability in New Orleans, Louisiana, Metropolitan Area

2018 Summer (JPL) – Southern California Coast Disasters: Improving Flood Extent Mapping Using the Coastal Storm Modeling System (CoSMoS) Tool with NASA Earth Observations and UAVSAR within Southern California

2019 Spring (LaRC) – Providence & Elizabeth Urban Development: Utilizing NASA Earth Observations to Explore Heat and Flood-Related Vulnerabilities in Urban Settings

2019 Summer (LaRC) – Dominican Republic Disasters: Mapping Landslide Susceptibility and Exposure in the Dominican Republic Using NASA Earth Observations

2019 Summer (MSFC) – Central America Transportation & Infrastructure: Employing NASA Earth Observation to Map Historic Flooding in Guatemala and El Salvador

**Notes & References:**

***Notes*:** The team may explore different flood susceptibility modeling options in ArcGIS; although initially, the LaRC Fellow and Lead Science Advisor suggest the methodology outlined in the paper “GIS-based Flood Susceptibility and Risk Mapping Trinidad Using Weight Factor Modeling” by Roopnarine et al. (2019) as this methodology seems plausible with our available data sources. The team may also calculate the height above the nearest drainage, which could be incorporated into the flood susceptibility model builder in ArcGIS. Finally, the team may consider incorporating data from other SAR sensors, such as PALSAR or RADARSAT, although this data may prove difficult to acquire and integrate. There are multiple LiDAR scans of Puerto Rico available through NOAA’s Coastal LiDAR data viewer (<https://coast.noaa.gov/dataviewer/#/lidar/search/-7388403.154045135,2067927.363227158,-7331534.005000964,2105534.3811434647>) that the team can explore beyond the USGS scan listed in the ancillary data section.

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