**Maya Forest Water Resources**

*Using NASA Earth Observations to Map Forested Inundation in the Maya Forest*

**Project Team**

***Project Team:***

Madelyn Savan (Project Lead)

Kathryn Tafoya

Lara O’Brien

Stephanie Jiménez

Tamara Rudic

***Advisors & Mentors:***

Benjamin Holt (NASA Jet Propulsion Laboratory, California Institute of Technology)

Dr. Bruce Chapman (NASA Jet Propulsion Laboratory, California Institute of Technology)

Dr. Emil Cherrington (NASA SERVIR, NASA Marshall Space Flight Center)

***Team POC:*** Madelyn Savan, madelynsavan@gmail.com

***Partner POC:*** Dr. Anabel Ford, anabel.ford@ucsb.edu

**Project Overview**

***Project Synopsis:***

As extreme weather events increase in frequency and severity due to climate change, tropical wetlands and the essential ecosystem services they provide are increasingly at risk. To monitor the extent of seasonal flooding within the tri-national Maya Forest, the DEVELOP team created a series of inundation maps during 2008, the year that Tropical Depression 16 brought extreme flooding to Central America. Land management agencies will use these maps to improve monitoring of inundation dynamics and inform forest management, sustainable agricultural practices, and community safety.

***Abstract:***

 As climate change increases the severity and frequency of extreme weather events in the tropics, it is vital for the safety of local communities and the health of ecosystems to monitor seasonal inundation. Forested inundation affects the ability of forested wetlands to provide ecosystem services, such as flood mitigation, water filtration, carbon storage, and erosion mitigation. While ground-based monitoring has traditionally been used to map inundation extent, those methods are costly and time-intensive. The NASA DEVELOP team focused on seasonal inundation throughout 2008 in the Maya Forest, when changes in inundation were drastic. To monitor seasonal inundation, our team used in situ field data and Earth observations from Landsat 7 Enhanced Thematic Mapper (ETM+), Advanced Land Observing Satellite (ALOS) Phased Array type L-band Synthetic Aperture Radar (PALSAR) 1, Shuttle Radar Topography Mission (SRTM), and products from the Ice, Cloud, and Land Elevation Satellite (ICESat). The team applied a Random Forest algorithm to Landsat 7 imagery, generating an object-level land cover classification with an overall accuracy of 72.1% and forest class with 100% recall and 78% precision. The team applied L-band backscatter thresholds from existing literature to forest-masked ALOS imagery and refined the thresholds in an iterative process using field data and hydrology models to delineate seasonal inundation extent. These publicly available data products help end users from Belize’s Land Information Center (LIC) and Forest Department, Guatemala’s Center for Monitoring and Evaluation (CEMEC), and Mexico’s El Colegio de la Frontera Sur (ECOSUR) to inform land management and protect community infrastructure.

***Key Terms:***

ALOS PALSAR, L-band, Landsat 7, Random Forest, seasonal flooding, Tropical Depression 16

***National Application Area Addressed:*** Water Resources

***Study Location:*** Maya Forest – Belize, Guatemala, & Mexico

***Study Period:*** May – October 2008

***Community Concerns:***

* The Maya Forest is the largest remaining tropical rainforest in North and Central America and contains forested wetlands that provide essential ecosystem services to nearby communities, such as flood mitigation, water filtration, carbon storage, and erosion reduction.
* The Maya Forest ecosystem is highly vulnerable to land-use change, including deforestation and extreme weather events, that are increasing in severity and frequency.
* It is vital to understand the extent of forested inundation by monitoring flood-prone areas so community members and environmental departments can make more informed management decisions regarding forests, agriculture, and development.
* Archaeological research in the Maya Forest region seeks to combine remote sensing, geographic information systems (GIS), and Indigenous knowledge of past inundation management to help mitigate future flooding events.

***Project Objectives:***

* Identify the best methods for combining L-band SAR, LiDAR, and optical satellite imagery for mapping inundation below the forest canopy
* Write preliminary scripts in Google Earth Engine to be refined by the next term of the project
* Present inundation thresholds and map observed seasonal inundation throughout 2008 as an exemplary case study

**Partner Overview**

***Partner Organizations:***

|  |  |  |  |
| --- | --- | --- | --- |
| **Organization** | **POC (Name, Position/Title)** | **Partner Type** | **Boundary Org?** |
| **Ministry of Forestry, Fisheries, Environment & Sustainable Development, Forest Department (Belize)** | Edgar Correa, Forest Officer | End User | No |
| **Ministry of Natural Resources, Land Information Center (Belize)** | Alfred Cal, GIS Analyst | End User | No |
| **National Council of Protected Areas, Center for Monitoring and Evaluation (Guatemala)**  | Victor Hugo Ramos, Adjunct Director, CEMEC | End User | No |
| **El Colegio de la Frontera Sur (Mexico)** | Dr. Jorge Mendoza-Vega, Victor Ku, Department of Agriculture, Society, and Environment  | Collaborator | No |
| **NASA Goddard Space Flight Center** | Sean McCartney, Senior Scientific Analyst | Collaborator | No |
| **University of California Santa Barbara, MesoAmerican Research Center**  | Dr. Anabel Ford, Director; Thomas Crimmel, GIS Manager; Sherman Horn, Research Affiliate | Collaborator | No |
| **Boles Environmental Consulting** | Dr. Ed Boles, Ecologist | Collaborator | No |
| **NASA SERVIR Science Coordination Office** | Dr. Emil Cherrington, West Africa Regional Science Coordination Lead | Collaborator | No |

***Decision-Making Practices & Policies:***

The Maya Forest intersects governing management end-user agencies in Belize and Guatemala and collaborating researchers in Mexico. In Belize, the Forest Department currently uses NASA Earth observations, including Fire Information for Resource Management System (FIRMS) and Landsat imagery, to regulate national forest extraction activities and manage terrestrial protected areas, including forested wetland Ramsar sites. The Land Information Center (LIC) uses Earth observation data and focuses on incorporating Light Detection and Ranging (LiDAR) data to assess elevation and gradients for flooding analysis. In Guatemala, the National Council of Protected Areas Center for Monitoring and Evaluation (CEMEC) uses NASA Earth observations to monitor forest cover and fire activity. CEMEC additionally uses on-the-ground methods for wetland monitoring and surface water mapping and aims to transition to remote sensing methods. Mexico’s El Colegio de la Frontera Sur (ECOSUR) seeks to contribute to the sustainable development of the southern border of Mexico, Central America, and the Caribbean through research emphasizing the conservation of the region’s cultural systems, natural resources, and biological wealth.

**Earth Observations & End Products Overview**

***Earth Observations:***

|  |  |  |
| --- | --- | --- |
| **Platform & Sensor** | **Parameter(s)** | **Use** |
| **Advanced Land Observing Satellite (ALOS) Phased Array type L-band Synthetic Aperture Radar (PALSAR) 1** | RTC level L-band SAR, backscatter, HH and HV polarization  | Backscatter values used to map inundation and water body extent, specifically under the forest canopy. |
| **Landsat 7 Enhanced Thematic Mapper Plus (ETM+)** | Collection 2, tier 1 surface reflectance  | Surface reflectance data used to create a land cover map over the study region. |
| **Ice, Cloud, and Land Elevation Satellite (ICESat) Geoscience Laser Altimeter System (GLAS)** | Global Forest Canopy Height Model (CHM), 1-km spatial resolution | This Canopy Height Model, derived from 2005 ICESat (Simard et al., 2011), was incorporated into the land cover classification methods and digital terrain model derivation. |

***Ancillary Datasets:***

* NASA’s Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) – Used to create a digital terrain model (DTM) to conduct flood models for study area.
* MesoAmerican Research Center Regional Hydrological, Archaeological, Geology, and Soil shapefiles – Provided context for the study area and were used within the inundation identification iterative process.
* Instituto Nacional de Estadística y Geografía (INEGI): Wetlands Cartographic Model (2014) – Shapefile of potential wetlands in Mexico used to identity and refine inundation thresholds.
* Flood Model generated by the team in ArcGIS Pro using the derived DTM – General flood model for the region used during the iterative process for identifying inundation.

***Software & Scripting:***

* Google Earth Engine – Write scripts for land cover and inundation analyses
* Esri ArcGIS Pro 2.6.2 – Create a flood model and final cartographic outputs
* Google Earth Pro – Collect land cover training points to train a random forest classifier

***End Products:***

|  |  |  |
| --- | --- | --- |
| **End Product** | **Earth Observations Used**  | **Partner Benefit & Use** |
| **Land Cover Classification Map** | Landsat 7, ICESat (Global Forest CHM) | Partners may use land cover classes (forest, grassland, cropland, settlement, open water, other land) and extents to better understand land use, inform forest management, and flood risk mitigation. |
| **Inundation****Maps** | ICESat (Global Forest CHM), ALOS PALSAR-1, SRTM | These maps identify inundation under the Maya Forest canopy and can be used to plan for flood mitigation and better understand seasonal inundation dynamics. |

***Product Benefit to End User:***

Belize’s LIC will use these end products to identify areas prone to highly variable inundation levels and develop flood zone areas in anticipation of future events. The Forest Department will use the end products to monitor current and potential wetlands in Belize’s national protected areas system and practice sustainable forest management strategies. Guatemala’s CEMEC plans to use the end products to help reduce the cost associated with the ground-based monitoring methods currently employed. Future research at ECOSUR will integrate our methodology for mapping below-canopy inundation and utilize potential wetland flood extents to inform development planning.

***Project Continuation Plan:***

The first term of this project focused on determining the feasibility of various datasets and methods for mapping inundation under the dense Maya Forest canopy. This study created a foundation for comprehensive and reproducible methodology demonstrated by initial land cover and inundation maps generated during a year of significant flooding. The second term will apply these methods to create an expanded time series of flooding and drought events throughout the Maya Forest region, including agricultural areas and urban settlements. Next term will also incorporate additional field data from partners collected to train, validate, and refine the land cover classifications and inundation extents and will finalize the reproducible script for software release.

**References**

Lang, M. and McCarty, G. (2009). Lidar intensity for improved detection of inundation below the forest canopy. *Wetlands, 29*(4), 1166-1178. <http://dx.doi.org/10.1672/08-197.1>

Simard, M., Pinto, N., Fisher, J., and Baccini, A. (2011). Mapping forest canopy height globally with spaceborne lidar. *Journal of Geophysical Research, 116*: G04021. [doi:10.1029/2011JG001708](https://doi.org/10.1029/2011JG001708)

Simmons and Associates, Ltd. (2014). A national climate change policy, strategy and action plan to address climate change in Belize. Prepared for the Caribbean Community Climate Change Centre and Government of Belize.