**NASA DEVELOP National Program**

**Georgia – Athens**

*Project Summary – Summer 2018*

**Puerto Rico Disasters**

*Assessing Changes in Cloud Dynamics in the Luquillo Tropical Montane Cloud Forest Using NASA Earth Observations and In Situ Measurements Following Defoliation from Hurricane Maria*

**VPS Title:** Seeing Through the Clouds: Cloud Dynamics in the El Yunque National Forest

**Project Team**

***Project Team*:**

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**Project Overview**

***Project Synopsis*:** Puerto Rico’s Luquillo Tropical Montane Cloud Forest, situated in the El Yunque National Forest, experienced catastrophic defoliation during Hurricane Maria in September 2017. Using NASA Earth observations and *in situ* measurements from around the Luquillo Mountains, this project aims to describe the impact of Hurricane Maria on cloud base heights (CBH) and cloud spatial coverage due to changes in evapotranspiration (ET) rates and land cover. The results of our work will help the US Forest Service International Institute for Tropical Forestry (IITF) to develop management strategies to deal with the impacts on the highly specialized ecosystems during the reforestation process.

***Abstract*:**

The Luquillo Mountains in the El Yunque National Forest is the most biologically diverse forest in the United States. It is a cloud forest rich in endemic species and streams that bring clean water to the people of Puerto Rico. This unique environment was exposed in the aftermath of Hurricane Maria, which devastated Puerto Rico during its landfall on September 20th, 2017. One of the numerous effects hurricane Maria had on the landscape was substantial defoliation of the forest within the Luquillo Mountains. Large scale defoliation events have been linked to changes in the physical environment as well as cloud formations potentially related to a decrease in evapotranspiration (ET) rates from vegetation. This project will investigate how hurricane Maria impacted cloud dynamics in the Luquillo Mountains. It is known that relatively small changes in cloud base height (CBH) can have a drastic impact on the flora and fauna of the area that have evolved to live in near constant cloud immersion. The team utilized Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) data to determine CBH over the study area and calibrated it against the theoretical CBH from the radiosonde data. We also used Terra Moderate Resolution Imaging Spectroradiometer (MODIS) cloud mask data to analyze changes in cloud coverage pre- and post- Maria. This work will provide the US Forest Service International Institute for Tropical Forestry (IITF) with an estimated change in CBH and cloud distribution before and after Maria that can be incorporated to IITF’s management plans.

**Keywords:**

Cloud base height, evapotranspiration, Terra MODIS, CALIPSO, Luquillo Mountains, Hurricane Maria

***National Application Area Addressed:*** Disasters

***Study Location:*** El Yunque National Forest, PR, USA

***Study Period:*** June2006 – March 2018

***Community Concern:***

* Tropical Montane Cloud Forests (TMCF) are essential habitats for many endemic and threatened plant and animal species.
* In addition to critical habitat, the Luquillo Mountains also provide many social and environmental services. Clean water is an important service provided by El Yunque National Forest in the Luquillo Mountains. According to the U.S. Department of Agriculture (USDA), over half of all water flowing from the forest on a typical day is extracted for municipal use and human consumption. The IITF administered area is also an important living research laboratory and recreation/tourist site.
* Following hurricane Maria’s landfall in September 2017, the Luquillo Mountains experienced defoliation and downed trees. Due to this damage, it is hypothesized that CBH have risen as a result of land-cover and ET changes. As a consequence, flora and fauna dependent on the moisture provided by the cloud-immersed rainforest could experience recolonization difficulties following hurricane Maria. In addition to vertical shifts in CBH, overall cloud coverage is also expected to diminish due to defoliation and subsequent changes in ET. In an area where up to 60% of the moisture input to TMCFs is derived from cloud water interception from low clouds, any diminishment of cloud coverage could negatively impact the local water budget.
* Understanding how defoliation has affected CBH and cloud spatial coverage will be an important consideration for organizations working to manage the reforestation process in the Luquillo Mountains.

***Project Objectives:***

* Determine changes in CBH pre- and post-hurricane Maria using CALIPSO
* Compare CALIPSO derived CBH change with mixed-layer lifted condensation level (MLLCL) calculated with radiosonde data from San Juan, Puerto Rico
* Analyze cloud spatial coverage change pre- and post-hurricane Maria using Landsat8 surface reflectance
* Correlate changes in CBH with changes in NDVI pre- and post-Hurricane Maria by using MODIS data, if CBH has experienced change as hypothesized.
* Provide the partners with end-products to better estimate changes in CBH and cloud coverage pre- and post-Maria

**Partner Overview**

***Partner Organizations:***

|  |  |  |  |
| --- | --- | --- | --- |
| **Organization** | **POC (Name, Position/Title)** | **Partner Type** | **Boundary Org?** |
| **USDA, US Forest Service, International Institute of Tropical Forestry** | Dr. Grizelle Gonzalez, Research scientist | End User | No |
| **USGS National Research Program** | Martha Scholl, Research hydrologist | Collaborator | No |

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

Recently, El Yunque National Forest revised its Land and Resource Management Plan in accordance with the 2012 forest Planning Rule for the National Forest System. The 2012 Planning Rule seeks to maintain and restore National Forest System land and water ecosystems while also providing ecosystem services. The revised El Yunque Forest Management Plan explicitly intends to adapt planning and site specific activities to the conditions of the cloud layer as well as to better understand climatic conditions and cloud elevation shifts.

Currently, the IITF relies upon a mix of anecdotal observations and *in situ* ceilometer measurements to determine cloud base patterns within the Luquillo Mountains. Several scientific papers have made observations regarding CBH dating back to 1968, however more recent articles have been published to better determine a contemporary CBH baseline for the Luquillo Mountains. There have not been any attempts to compare CBH measurements or changes in the spatial distribution of cloud cover before and after Hurricane Maria.

***Project Benefit to End User***:

CBH measurements will contribute to establishing baseline CBH information for future restoration of the TMCF and potentially serve as a basis for prediction of future impacts from similar hurricanes. In addition to highlighting areas that are potentially impacted by a rise in CBH, a spatial understanding of any change in cloud cover could further inform forest managers, researchers, and decision makers as to where post-disaster forest management practices should be implemented. Information gleaned from our research concerning cloud elevation shifts, following hurricane Maria, directly concerns the objectives of the revised forest management plan and can serve in its current implementation phase as well as inform the future plan.

**Earth Observations & End Products Overview**

***Earth Observations:***

|  |  |  |
| --- | --- | --- |
| **Platform & Sensor** | **Parameters** | **Use** |
| **Terra MODIS** | Cloud mask, NDVI, ET | The cloud mask product derived from Terra MODIS was used to monitor changes pre- and post-Maria in the spatial coverage of clouds in the study area. MODIS data will also be used to assess degree of defoliation pre- and post-Maria using NDVI, as well as changes to evapotranspiration (ET) from the forest. |
| **LANDSAT 8** | Surface Reflectance | Surface reflectance values form Landsat 8 were used to monitor changes in cloud coverage before and after Hurrican Maria in the El Yunque Forest |
| **CALIPSO CALIOP** | Cloud height, Cloud thickness | Cloud heights and thicknesses were calibrated against radiosonde observations to determine the change in CBH pre- and post-Maria. |

***Ancillary Datasets:***

National Centers for Environmental Information (NCEI) Integrated Radiosonde Archive (IGRA) - Calculate

theoretical cloud base height using the mixed layer lifted condensation level (MLLCL) from temperature and moisture trajectories measured by weather balloons from San Juan, Puerto Rico

IITF Vaisala CL31 Ceilometer - *In situ* laser measurements of CBH to cross validate CALIPSO and MLLCL

calculations

USGS cloud monitoring camera – *In situ* images of cloud immersion at multiple altitudes in the Luquillo

Mountains to help validate the MLLCL

USGS precipitation records – 25-yr record of rainfall in the Luquillo Mountains which will be compared to

pre- and post-Maria CBH to analyze changes in rainfall

USGS National Elevation Dataset (NED) – Topographic data to visualize areas that will experience regular

cloud-immersion loss following hurricane Maria

***Software & Scripting:***

Python 3.6.4 – Processes radiosonde observations using SHARPpy module

Esri ArcGIS 10.5 – Visualize areas that lost/retained cloud-immersion and had changes in CBH; process MODIS NDVI and NED

JMP – Conduct statistical comparisons of ceilometer, CALIPSO, and MLLCLs

Google Earth Engine – Processes our large time series analysis of cloud spatial coverage

***End Products:***

|  |  |  |  |
| --- | --- | --- | --- |
| **End Products** | **Earth Observations Used** | **Partner Benefit & Use** | **Software Release Category** |
| **Cloud Base Height and Cloud Cover Heat Map** | CALIPSO  Terra MODIS  Landsat 8 | This end product will allow IITF to more accurately develop its forest management strategies in the wake of Maria, specifically, which areas of the Luquillo Mountains are susceptible to species migration in the absence of cloud immersion and changes in CBH. | I |
| **Statistical CBH Diagnostic Tool** | CALIPSO | This tool will allow IITF to use the MLLCL from the San Juan, PR, radiosonde and adjust it to determine the most likely post-Maria CBH in the forest. | III |

**Project Handoff Package**

**Transition Plan:**

The summer 2018 DEVELOP team will formally present the finalized deliverables to the project partners by video conference at the end of the summer term. The final CBH and Cloud Cover maps will be handed off virtually. Furthermore, there is potential for an in person presentation of the findings at the winter meeting of the Long Term Ecological Research (LTER) Forest Group in January 2019.

*Software Release Plan*: In order to aid the comprehension and utility of the Statistical CBH Diagnostic Tool, the team will prepare a white paper to explain to the partners how the tool is used. Additionally, a README file will be given to the end users to explain the Google Earth Engine tool.

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**Handoff Package:**

* Cloud cover map
* Cloud base height map
* White paper describing the statistical adjustment tool for future CBH prediction
* A README file will be given to the end users to explain the Google Earth Engine tool.

**References:**

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