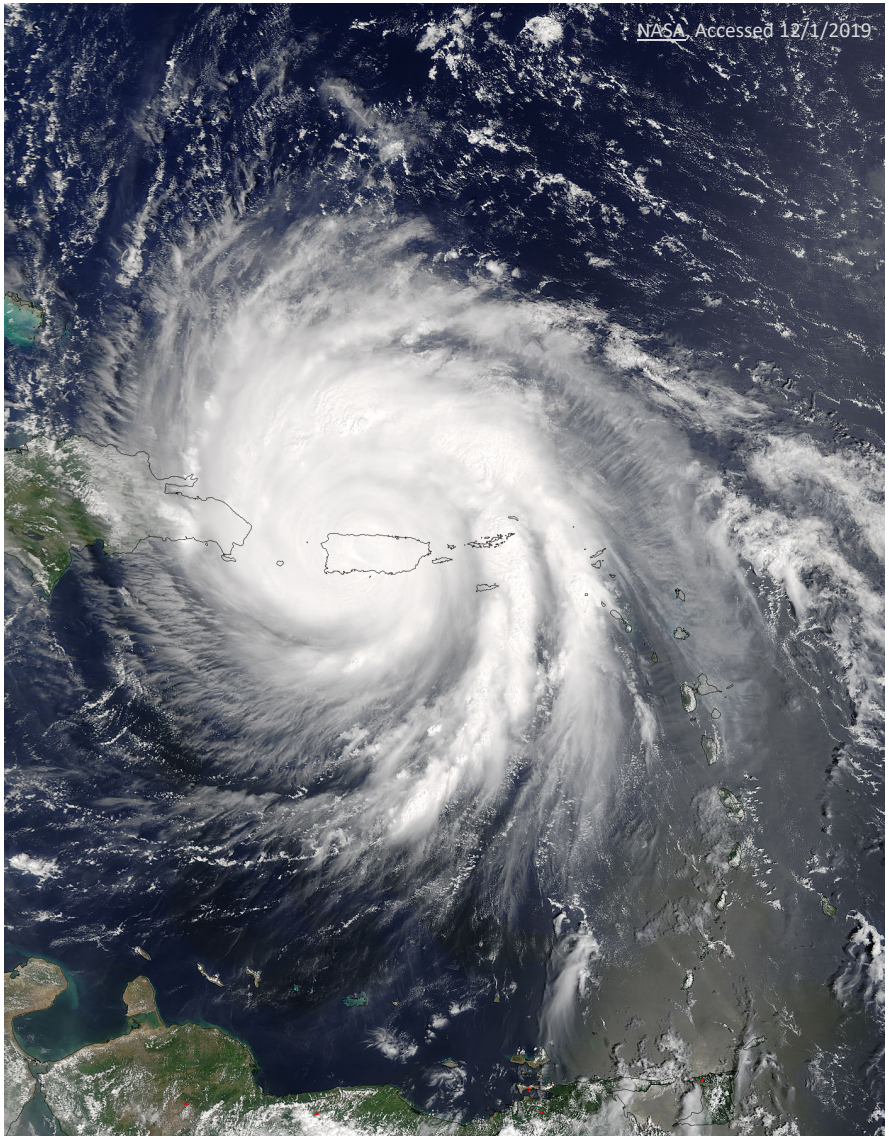
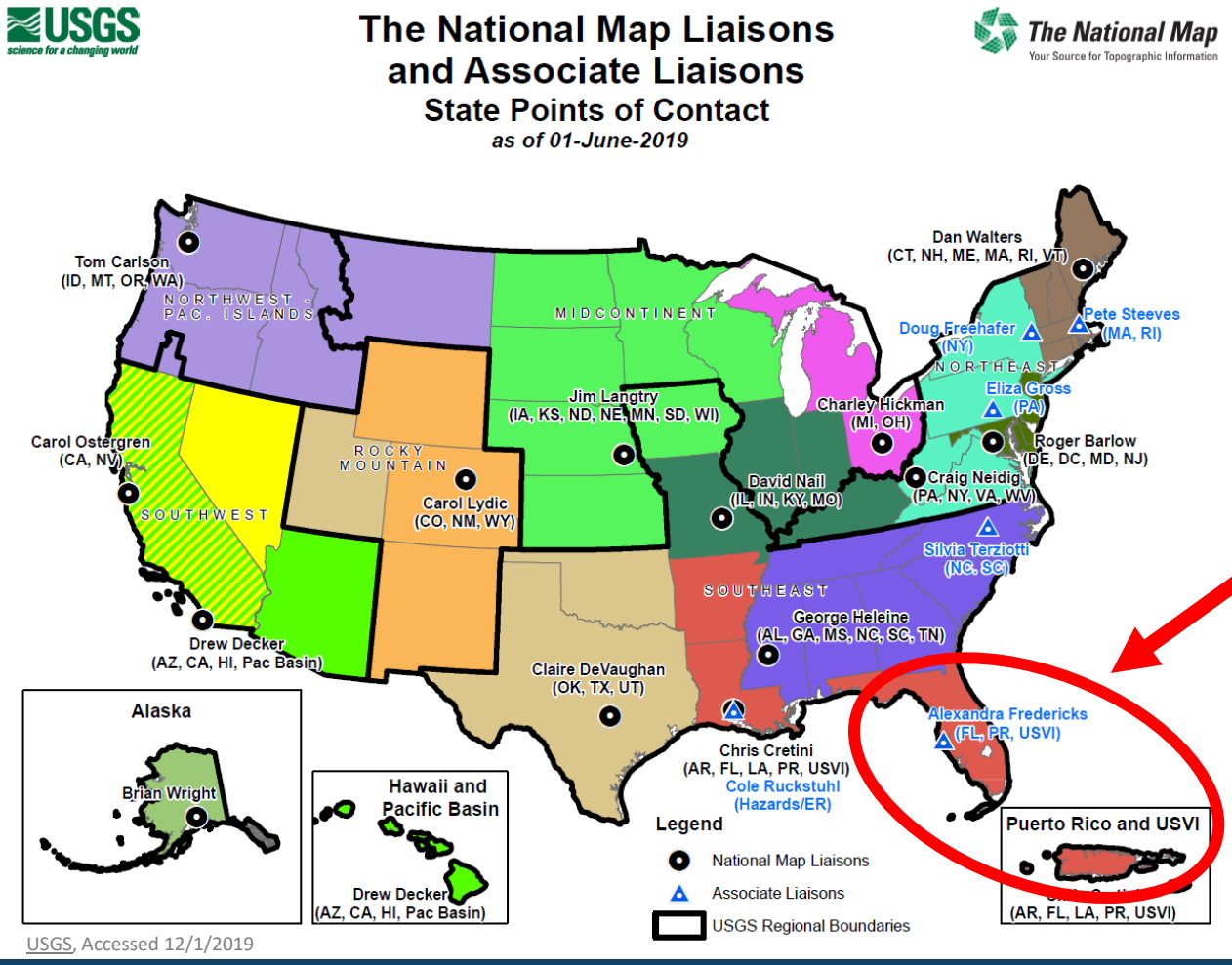
# Lidar-Derived Pre- and Post-Hurricane Maria Volumetric Change Detection for Puerto Rico




XAN FREDERICKS, GISP
CAPSTONE PROPOSAL
PSU GEOG 596A
13 DECEMBER 2019
ADVISOR: KAREN SCHUCKMAN

# Professional Background

US Geological Survey:
National Geospatial Program &
Coastal and Marine Hazards and Resources Program
Active Member: ASPRS and URISA




USGS, Accessed 12/1/2019

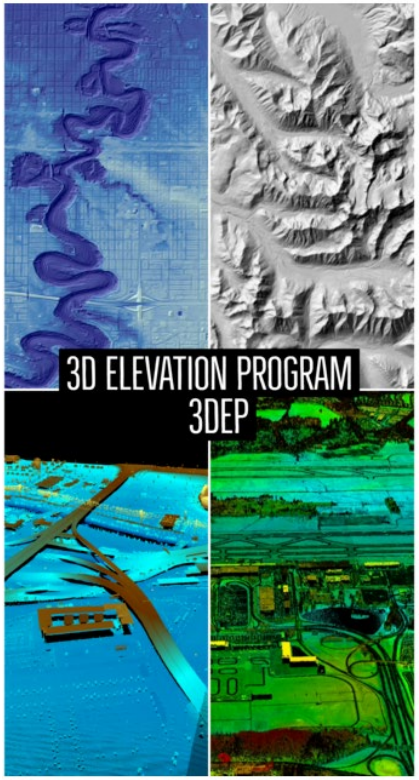
NASA, Accessed 12/1/2019

# Background

## What is 3DEP?

The 3D Elevation Program is managed by the U.S. Geological Survey National Geospatial Program to respond to growing needs for high-quality topographic data and for a wide range of other three-dimensional (3D) representations of the Nation's natural and constructed features.

USGS, Accessed 12/1/2019




Four Images created with 3DEP-quality lidar and IfSAR technology. Left to right, Clockwise: Digital Elevation Model of the Red River near Fargo, ND; IfSAR Digital Surface Model; Lidar point cloud image of Dulles Airport, VA; Lidar point cloud image of the transportation network in Denver, CO.

## Enhanced Elevation Data Support Critical Applications, such as:


Flood Risk Management


Infrastructure Management


Natural Resources Conservation


Agriculture & Precision Farming


Water Supply and Quality


Wildfire Management


Geologic Resource Assessment


Forest Resources Management


Stream Resource Management


Aviation Safety

USGS, Accessed 12/1/2019

# Background

NASA, Accessed 12/1/2019

USGS
science for a changing world

## The 3D Elevation Program—Summary for Puerto Rico

### Introduction

Elevation data are essential to a broad range of applications, including forest resources management, wildlife and habitat management, scientific research, national security, recreation, and many others. For the Commonwealth of Puerto Rico, elevation data are critical for flood risk management, landslide mitigation, natural resources conservation, sea level rise and subsidence, coastal zone management, infrastructure and construction management, and other business uses. Today, high-density light detection and ranging (lidar) data are the primary sources for deriving elevation models and other datasets. Federal, State, Tribal, U.S. territorial, and local agencies work in partnership to (1) replace data that are older and of lower quality and (2) provide coverage where publicly accessible data do not exist. A joint goal of State and Federal partners is to acquire consistent, state-


**Figure 1.** Map of the Commonwealth of Puerto Rico showing existing and planned-with-funding publicly available lidar data. Approximately 95 percent of the quality level 2 data is in the planned-with-funding category. Information source is the United States Interagency Elevation Inventory, fall 2015 (http://coast.noaa.gov/inventory/), which is updated annually. Quality level 2 or better lidar data meet 3DEP requirements. See table 1 for quality level information.

### 3D Elevation Program Benefits for Puerto Rico

### 3D Elevation Program

3DEP is a national program managed by the USGS to acquire high-resolution elevation data. The initiative is backed by a comprehensive assessment of requirements (Dewberry, 2011) and is in the early stages of implementation. 3DEP will improve data accuracy and provide more current data than is available in the National Elevation Dataset (NED). The goal of this high-priority cooperative program is to have complete coverage of the United States by the end of 2022, depending on funding and partnerships. 3DEP can conservatively provide new benefits of $1.2 billion/year and has the potential to generate $13 billion/year in new benefits through improved government services, reductions in crop and homeowner losses resulting from

### Benefits of a Funded National Program

- Economy of scale—Acquisition of data covering larger areas reduces costs by 25 percent.
- A systematic plan—Acquisition of data at a higher quality level reduces the cost of "buying up" to the highest levels needed by State, Tribal, U.S. territorial, and local governments.
- Higher quality data and national coverage—Ensure consistency for applications that span State, Tribal, U.S. territorial, and watershed boundaries and meet more needs, which results in increased benefits to citizens.
- Increase in Federal agency contributions—Reduces State, Tribal, U.S. territorial, and local partner contributions.
- Acquisition assistance—Provided through readily available contracts and published acquisition specifications.

USGS, Accessed 12/1/2019

Fact Sheet 2015–3088
February 2016


# Background

According to the National Enhanced Elevation Assessment, the top reported business uses & annual benefits for Puerto Rico are:

| Rank | Business use | Annual benefits (thousands) |
|---|---|---|
| 1 | Flood risk management | $163.78 |
| 2 | Natural resources conservation | 130.34 |
| 3 | Sea level rise and subsidence | 84.38 |
| 4 | Coastal zone management | 74.26 |
| 5 | Infrastructure and construction management | 42.85 |
| 6 | Oil and gas resources | 9.38 |
| 7 | Land navigation and safety | 8.40 |
| 8 | Aviation navigation and safety | 8.20 |
| 9 | Geologic resource assessment and hazard mitigation | 7.12 |
| 10 | Forest resources management | 4.72 |
| | Other | 3.41 |
| | Total | 536.84 |

USGS, Accessed 12/1/2019

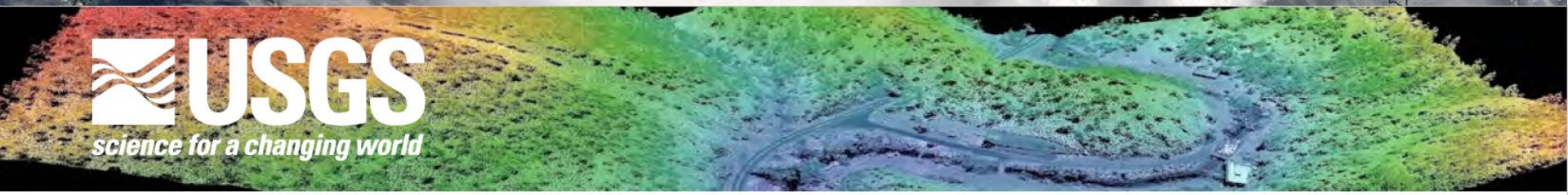
## Next Steps for Implementing 3DEP

Accomplishing the 3DEP initiative's goal of national coverage in 8 years depends on the following factors:

- Increased partnerships among Federal, State, Tribal, U.S. territorial, and local governments.
- Partnerships that acquire elevation data to the program's specifications across larger project areas.
- Increased communication about and awareness of the program's benefits and goals.
- Support for the program from government and other stakeholders.

# Background

NASA, Accessed 12/1/2019




## The 3D Elevation Program—Summary for Puerto Rico


**Figure 1.** Map of the Commonwealth of Puerto Rico showing existing and planned-with-funding publicly available lidar data. Approximately 95 percent of the quality level 2 data is in the planned-with-funding category. Information source is the United States Interagency Elevation Inventory, fall 2015 (http://coast.noaa.gov/inventory/), which is updated annually. Quality level 2 or better lidar data meet 3DEP requirements.

USGS, Accessed 12/1/2019

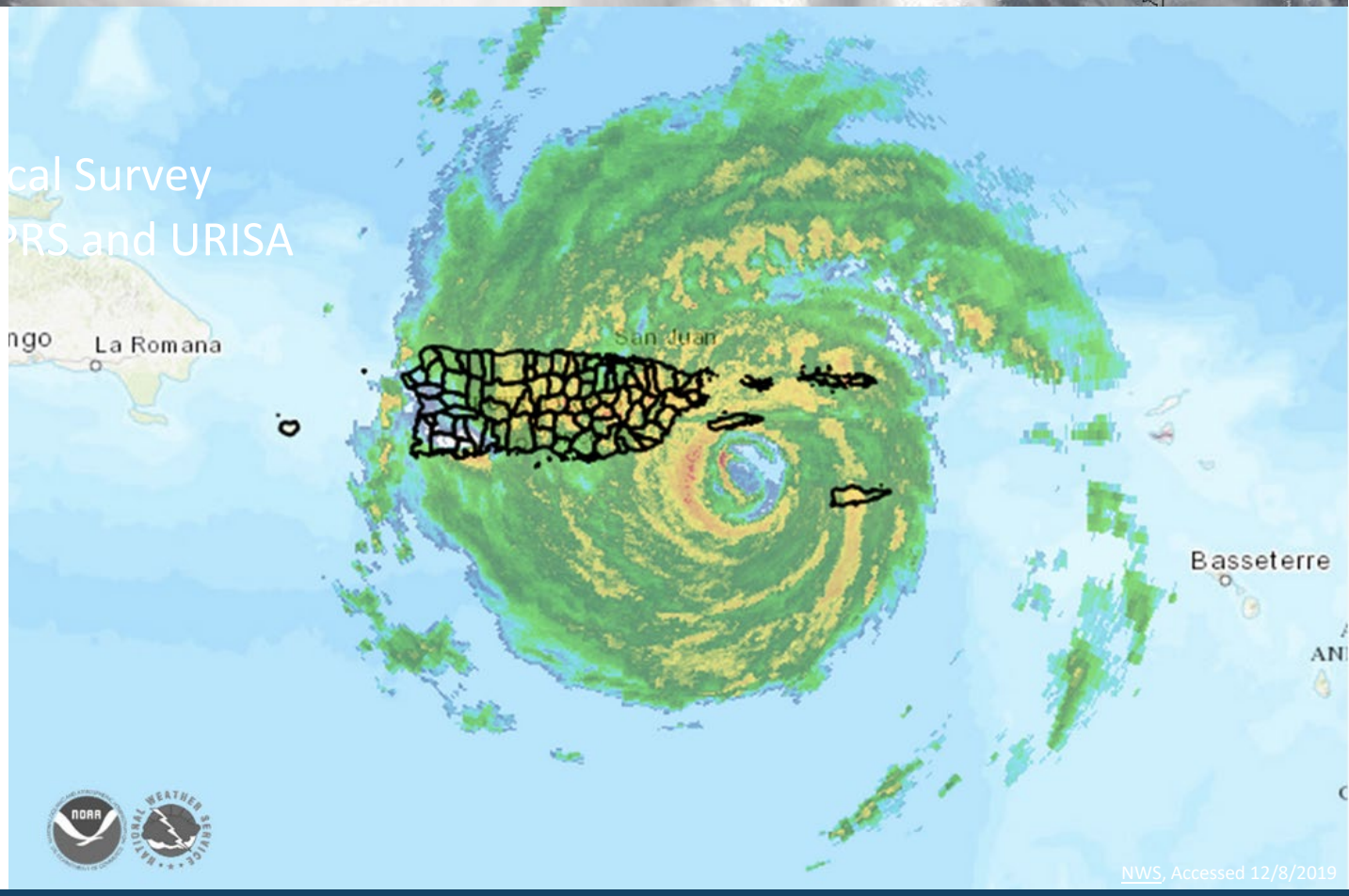
# Background

NASA, Accessed 12/1/2019

Hurricane Maria Landfall:

September 20, 2017

"At approximately 615 AM AST (1015 UTC), Maria made landfall in Yabucoa, Puerto Rico as a strong category 4 hurricane with maximum sustained winds of 155 mph. As the center of the storm moved west-northwestward over southeastern PR into the interior and northwestern PR, widespread hurricane force winds spread all over mainland PR along with extremely heavy rainfall that produced major to catastrophic flooding and flash flooding, especially across the northern half of Puerto Rico." – National Weather Service, 2017.




NWS, Accessed 12/8/2019

# Background

NASA, Accessed 12/1/2019

USGS, Accessed 12/1/2019

## The 3D Elevation Program—Landslide Recognition, Hazard Assessment, and Mitigation Support

### 3D Elevation Information Underpins Our Understanding of Landslides

A core mission of the U.S. Geological Survey (USGS) is to provide information that leads to reduced loss of life and damage to property and infrastructure from landslides. Gathering this information relies on a detailed and accurate understanding of the landscape. The USGS Landslide Hazards Program (https://www.usgs.gov/science/mission-areas/natural-hazards/landslide-hazards) conducts landslide hazard assessments, pursues landslide investigations and forecasts, provides technical assistance to respond to landslide emergencies, and engages in outreach. All of these activities benefit from the availability of high-resolution, three-dimensional (3D) elevation information in the form of light detection and ranging (lidar) data and interferometric synthetic aperture radar (IfSAR) data.

Research on landslide processes addresses critical questions of where and when landslides are likely to occur as well as their size, speed, and effects (Schulz, 2005). This understanding informs the development of methods and tools for hazard assessment and situational awareness used to guide efforts to avoid or mitigate landslide impacts. Such research is essential for the USGS to provide improved information on landslide potential associated with severe storms, earthquakes, volcanic activity, coastal wave erosion, and wildfire burn areas. Decisionmakers in government and the private sector increasingly depend on information the USGS provides before, during, and following disasters so that communities can live, work, travel, and build safely. High-resolution 3D elevation data significantly aid in the refinement of assessments of where and when landslides will occur, improving information delivered to decisionmakers and the public (figs. 1 and 2). A nationwide program to provide a baseline of high-quality 3D elevation data is essential for supporting improved hazard assessments, response preparation, and effective response execution.

The 3D Elevation Program (3DEP) (Sugarbaker and others, 2014; see sidebar) is collecting 3D elevation data in response to a call for action to address landslide applications and a wide range of other urgent needs nationwide. 3DEP furnishes the programmatic infrastructure and provides data to users, reducing their costs and risks and allowing them to concentrate on their mission objectives. The programmatic infrastructure includes (1) data acquisition partnerships that leverage funding, (2) contracts with experienced private mapping firms, (3) technical expertise, standards, and specifications, and (4) most important, providing public access to high-quality 3D elevation data.

### 3D Elevation Program (3DEP)

The 3D Elevation Program (3DEP) is a national program managed by the USGS to acquire high-resolution elevation data (Sugarbaker and others, 2014). It produces point clouds, bare-earth digital elevation models (DEMs), and other products.

3DEP is backed by a comprehensive assessment of lidar, interferometric synthetic aperture radar (IfSAR), and related elevation data requirements (Dewberry, 2012) and is now an operational program. The goal of this high-priority cooperative program is to have complete coverage of quality level 2 lidar data for the conterminous United States, Hawaii, and the U.S. territories, and IfSAR data for Alaska, by the end of 2023.

### Reduced Acquisition Costs and Risks

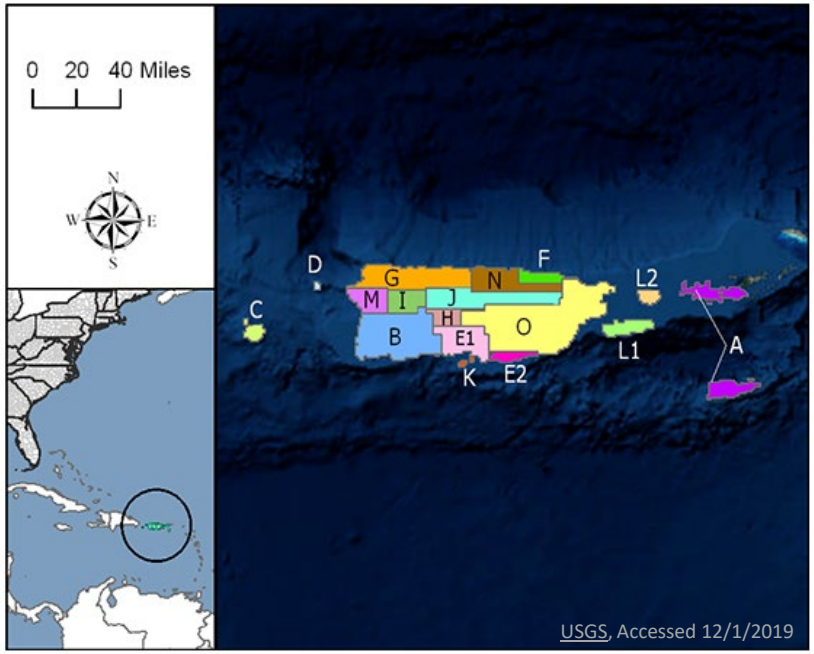
A funded national program will provide:

- *Economy of scale* by acquiring data for larger areas and reducing acquisition costs by 25 percent.
- *Predictable, efficient, and flexible Federal investments* that reduce costs for and allow better planning by Federal, State, Tribal, U.S. territorial, and local government partners, including the option of "buying up" to acquire higher quality data.
- *Consistent, high-quality, national coverage* that (1) provides data ready for applications that span project, jurisdictional, and watershed boundaries, (2) meets multiple needs,

USGS

3D Elevation Program

## 2018 Hurricane and Wildfire Supplemental Funding for 3DEP Lidar Acquisition




USGS, Accessed 12/1/2019

# Background

NASA, Accessed 12/1/2019

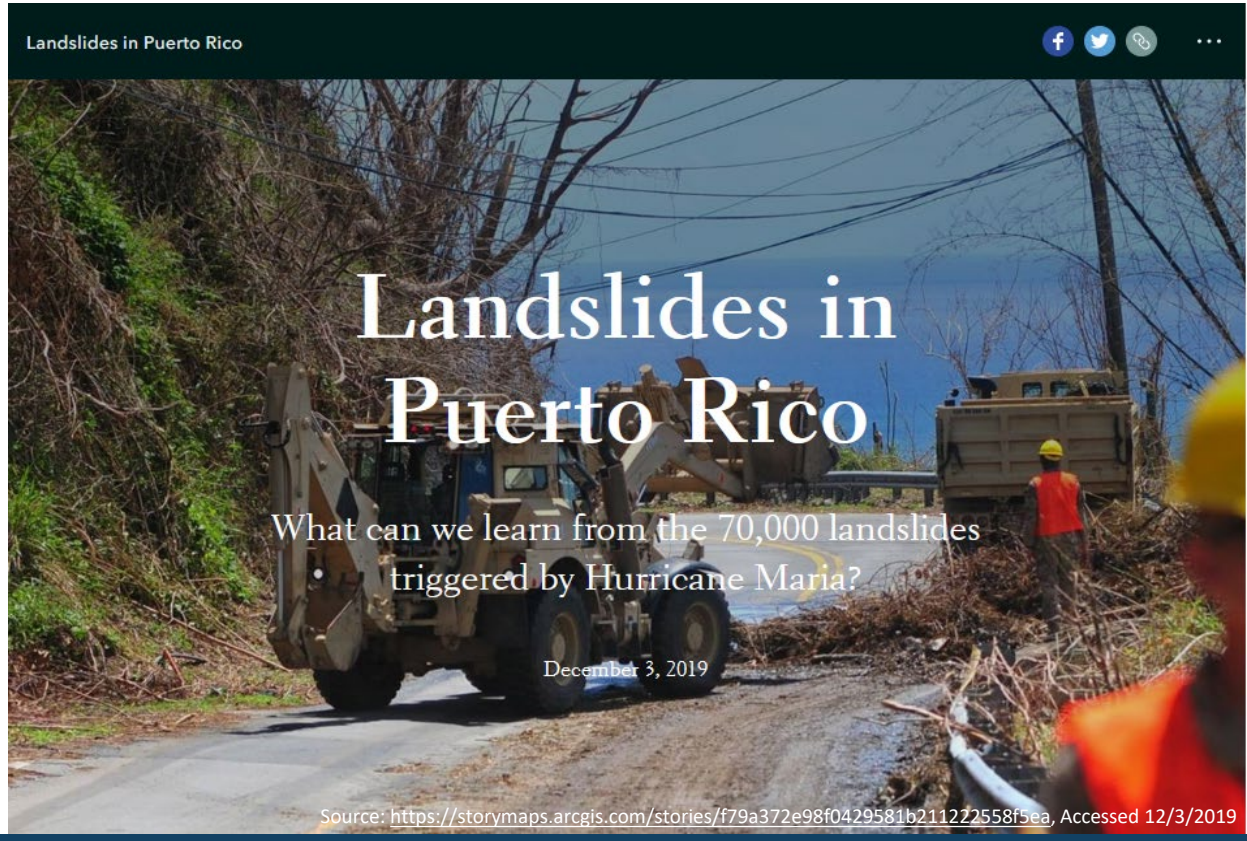
Credit: @TerzahTippinPoe via Twitter, Accessed 12/11/2019


# Purpose

## Pre- and Post-Hurricane Volumetric Change Detection for Puerto Rico using Lidar Data

What can change detection be used for?

- Identification of Geomorphic Processes
- Infrastructure Planning & Management
- Emergency Planning & Management
- Resilience Planning & Management
- And So Much More…

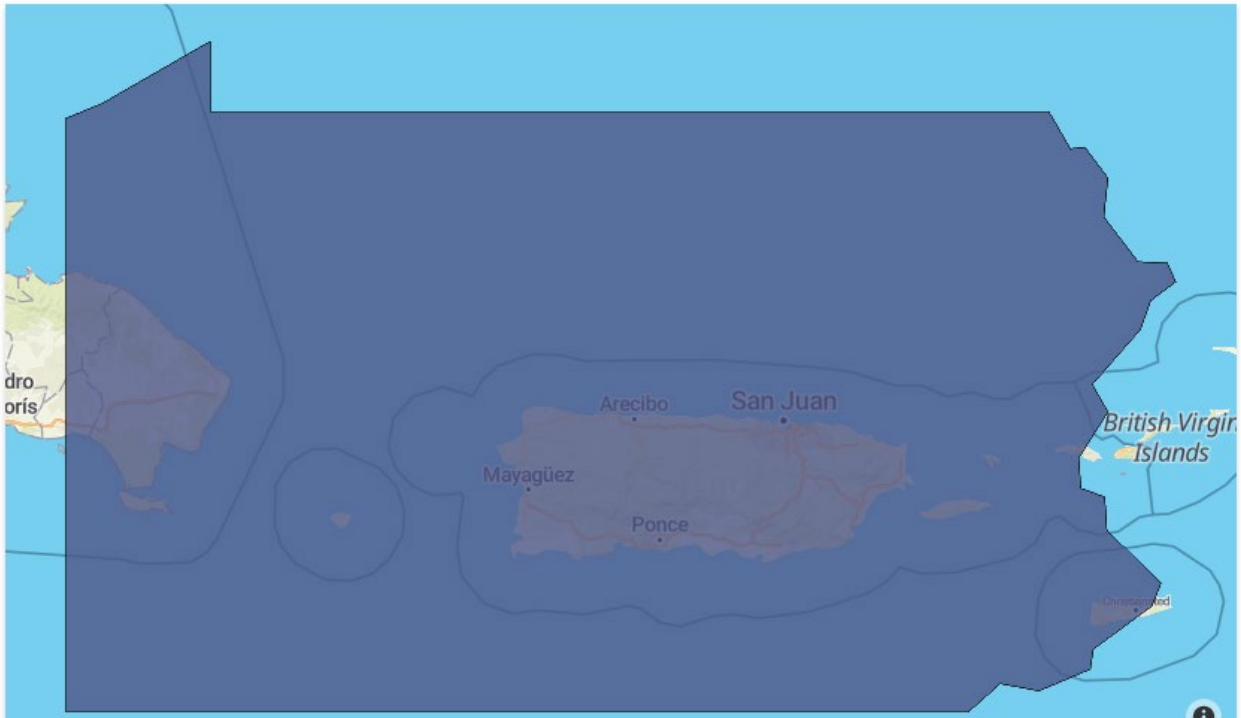


# Impact

NASA, Accessed 12/1/2019

## Puerto Rico is about 13 times *smaller* than Pennsylvania.

Pennsylvania is approximately 116,075 sq km, while Puerto Rico is approximately 9,104 sq km. Meanwhile, the *population* of Pennsylvania is ~12.7 million people (9.4 million *fewer* people live in Puerto Rico). We have positioned the outline of Pennsylvania near the middle of Puerto Rico.




Source: https://www.mylifeelsewhere.com/country-size-comparison/puerto-rico/pennsylvania-usa, Accessed 12/3/2019

NWS, Accessed 12/1/2019


# Objectives

## Volumetric Change Detection:

- Identification of Geomorphic Processes
  - Landslide Identification and Assessment
  - Coastal Change including Shoreline, Beach, & Dune Migration
- Identification of Infrastructure Changes
- Identification of Vegetation Changes

## Products to be Generated:

- Pre-Hx Maria Lidar-Derived Models
- Post-Hx Maria Lidar-Derived Models
- Volumetric Change Detection Models
- Online Narrative to Host All Models

## With the Aim of:

- Informing Citizens
- Aiding Natural Resource Management
- Aiding Emergency Planning & Management
- Aiding Resilience Planning & Management


# Data & Software

## Pre-Hurricane Maria Lidar

- ACQUIRED: 2016-2017
- DATA FORMAT: LAS v1.4
- COORDINATE SYSTEM: State Plane Puerto Rico USVI Zone 5200
- HORIZONTAL DATUM: NAD83
- VERTICAL DATUM: PRVD02
- POINT DENSITY: 2ppsm / QL2
- METADATA INFO: Acquired to meet 10cm vertical RMSE (QL2)

## Post-Hurricane Maria Lidar

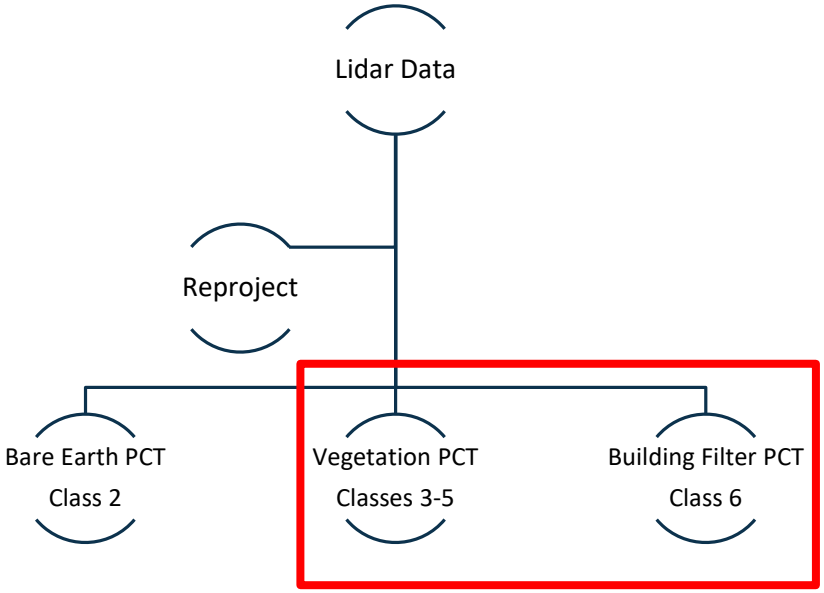
- ACQUIRED: 2018-2019
- DATA FORMAT: LAS v1.4
- COORDINATE SYSTEM: State Plane Puerto Rico USVI Zone 5200
- HORIZONTAL DATUM: NAD83
- VERTICAL DATUM: PRVD02
- POINT DENSITY: 8ppsm / QL1
- METADATA INFO: Acquired to meet 10cm vertical RMSE (QL1)

## LP360 Software

- Lidar Point Cloud Processing Software from the GeoCue Group
- Available as Standalone and in Arc Environment
- Standard or Advanced License Required to Leverage Interactive Classification Tools


# Proposed Methodology

Preparation of Pre-Hx Lidar and Post-Hx Lidar



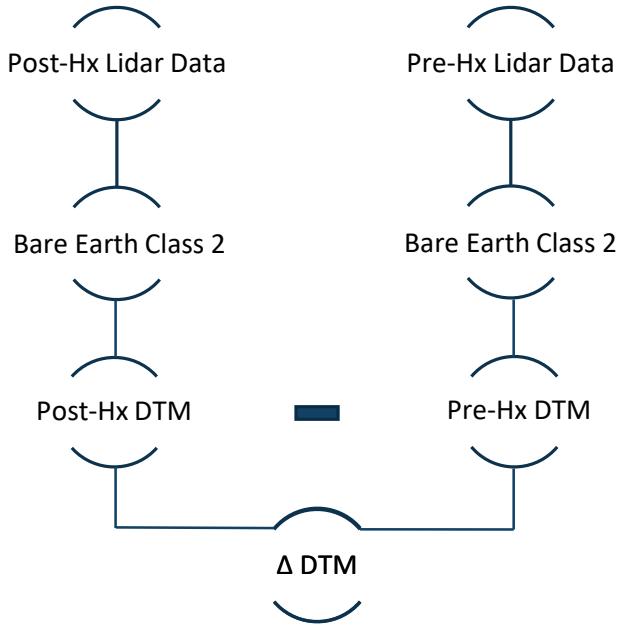

*Additional Classification if Time Permits

| LAS Schema | Description |
|---|---|
| Class 1 | Processed, but Unclassified |
| Class 2 | Bare Earth |
| Class 3 | Low Vegetation |
| Class 4 | Medium Vegetation |
| Class 5 | High Vegetation |
| Class 6 | Building |
| Class 7 | Low Noise |
| Class 18 | High Noise |

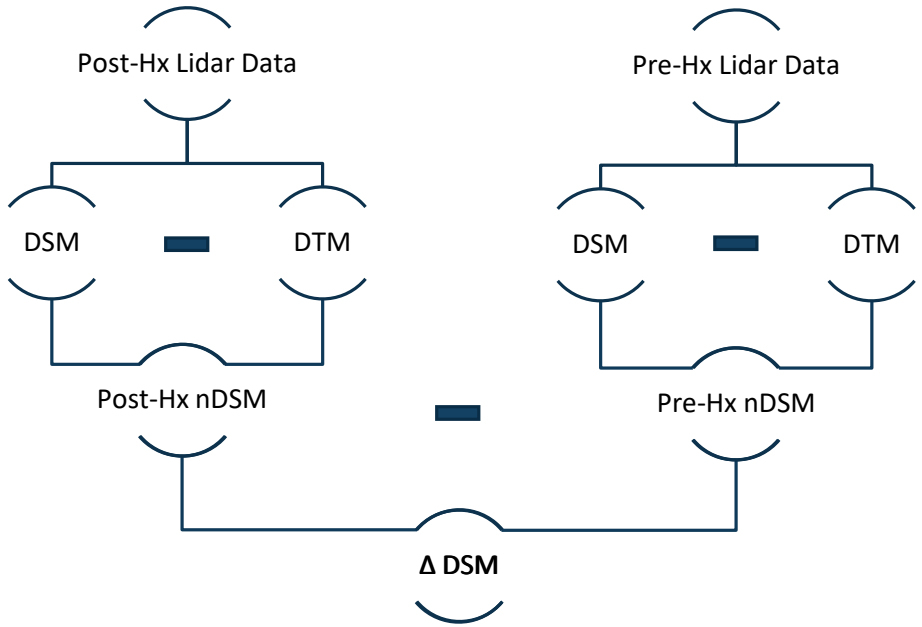
Developed from USGS, Accessed 11/10/2019


# Proposed Methodology

Detection of Volumetric Terrain Change



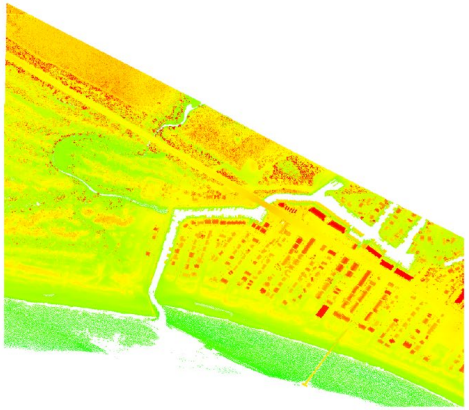

Detection of Volumetric Structural Change



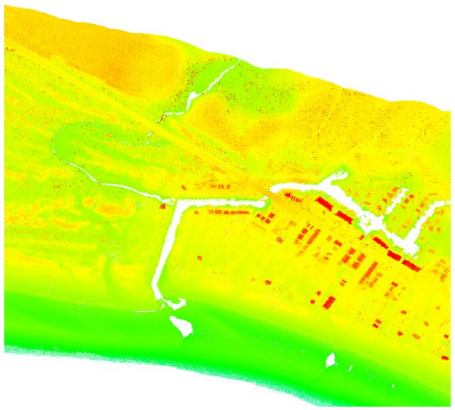
# Anticipated Results

NASA, Accessed 12/1/2019

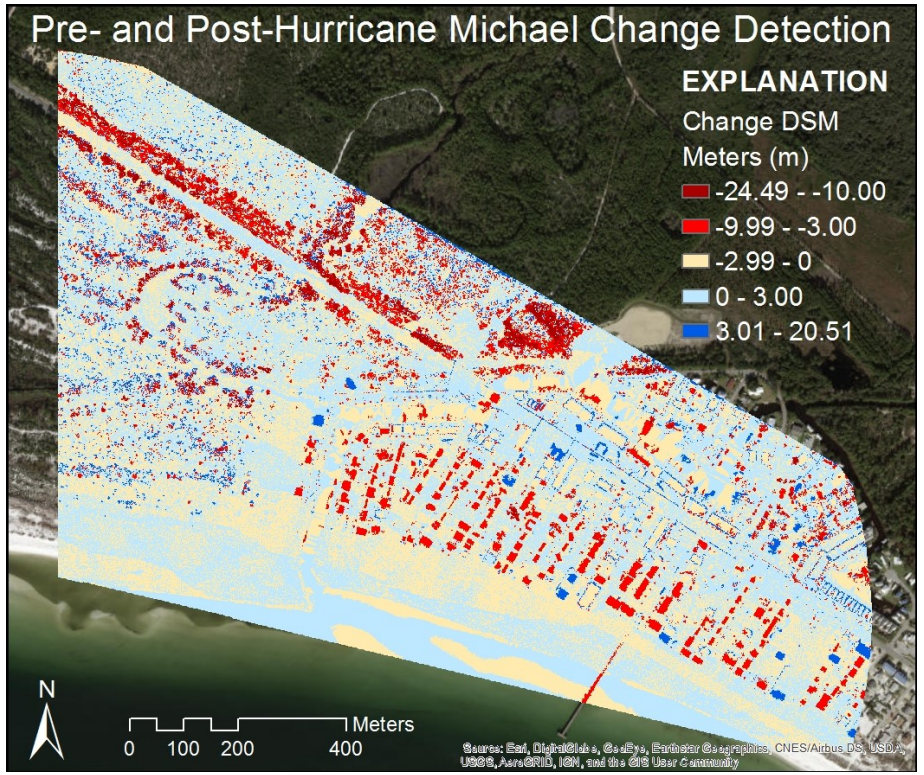
Similar to Pilot Study Conducted in Mexico Beach, FL to Detect Change from Hurricane Michael



Pre-Hurricane Michael Lidar Data
Source: 2015 USACE National Coastal Mapping Program



Post-Hurricane Michael Lidar Data
Source: 2018 USACE JALBTCX Flight for FEMA




Fredericks, PSU GEOG 481, 2018

# Timeline

NASA, Accessed 12/1/2019

Capstone Project Proposal

Dec 2019

Jan-Mar 2020

Data Preparation & Analysis; Develop Narrative Framework

End of Mar 2020

Summarize & Present Results

May 2020

Incorporate Final Revisions

# Presentation Venue

NASA, Accessed 12/1/2019

GEO WEEK

A YEAR OF GEOSPATIAL BUSINESS IN JUST ONE WEEK

COMPRISING

asprs THE IMAGING & GEOSPATIAL INFORMATION SOCIETY

INTERNATIONAL LIDAR MAPPING FORUM

MAPPS

ASPRS Annual Conference

March 23-25, 2020

Washington, DC

# References


Carswell, W.J., Jr., 2016. The 3D Elevation Program—Summary for Puerto Rico: U.S. Geological Survey Fact Sheet 2015–3088, 2 p., available at https://doi.org/10.3133/fs20153088.

Hsiao, K.H., Liu, J.K., Yu, M.F., & Tseng, Y.H. 2004. Change detection of landslide terrains using ground-based LiDAR data, *XXth ISPRS Congress, Istanbul, Turkey, Commission VII, WG,* 7(5) pg: 5.

Jones, B. M., Stoker, J. M., Gibbs, A. E., Grosse, G., Romanovsky, V. E., Douglas, T. A., and Richmond, B. M. 2013. Quantifying landscape change in an arctic coastal lowland using repeat airborne LiDAR, *Environmental Research Letters*, 8(4) pg: 045025.

Lukas, V., and Carswell, W.J., Jr., 2017. The 3D Elevation Program—Landslide recognition, hazard assessment, and mitigation support: U.S. Geological Survey Fact Sheet 2016–3094, 2 p., available at https://doi.org/10.3133/fs20163094.

National Weather Service. (April 2018). *Major Hurricane Maria – September 20, 2017.* Accessed December 8, 2019 from https://www.weather.gov/sju/maria2017.

Nourbakhsbeidokhti, S., Kinoshit, A.M., Chin, A., and Florsheim, J.L. 2019. A Workflow to Estimate Topographic and Volumetric Changes and Errors in Channel Sedimentation after Disturbance, *Remote Sensing*, 11(586) pg: 18.

Renslow, M.S. (July 2012). *Manual of Airborne Topographic Lidar, Chapter 1: Introduction.* Accessed December 1, 2019 from https://courseware.e-education.psu.edu/courses/remotesensing/Textbooks/Renslow_ATLM/Renslow_Chapter01.pdf.

Snyder, G.I., 2012. The 3D Elevation Program--Summary of Program Direction: U.S. Geological Survey Fact Sheet 2012-3089, 2 p., available at https://pubs.usgs.gov/fs/2012/3089/.

Sugarbaker, L.J., Constance, E.W., Heidemann, H.K., Jason, A.L., Lukas, Vicki, Saghy, D.L., and Stoker, J.M. 2014. The 3D Elevation Program initiative—A call for action: U.S. Geological Survey Circular 1399, 35 p., available at https://dx.doi.org/10.3133/cir1399.

# References


USACE. (Dec 2016). *2015 USACE NCMP Topobathy Lidar: Florida Gulf Coast Point Cloud files with Orthometric Vertical Datum North American Vertical Datum of 1988 (NAVD88) using GEOID12B*. Accessed November 9, 2019 from https://coast.noaa.gov/htdata/lidar2_z/geoid12b/data/5183/.

USACE. (Oct 2018). *2018 USACE FEMA Post-Michael Topobathy Lidar: Florida Panhandle Point Cloud files with Orthometric Vertical Datum North American Vertical Datum of 1988 (NAVD88) using GEOID12B*. Accessed November 9, 2019 from https://coast.noaa.gov/htdata/lidar2_z/geoid12b/data/8625/.

USGS. (Oct 2019). *2018 Hurricane and Wildfire Supplemental Funding for 3DEP Lidar Acquisition*. Accessed December 1, 2019 from https://www.usgs.gov/core-science-systems/ngp/3dep/2018-hurricane-and-wildfire-supplemental-funding-3dep-lidar.

USGS. (Oct 2019). *Lidar Base Specification version 2.1*. Accessed November 10, 2019 from https://www.usgs.gov/media/files/lidar-base-specification-version-21.

USGS. (Aug 2018). *USGS Lidar Point Cloud PR Puerto Rico 2015 LAS 2018: U.S. Geological Survey*. Accessed November 10, 2019 from https://viewer.nationalmap.gov/basic/#productSearch.

USGS. (Oct 2019). *What is 3DEP?*. Accessed December 1, 2019 from https://www.usgs.gov/core-science-systems/ngp/3dep/what-is-3dep.

Young, A.P. and Ashford, S.A. 2006. Application of airborne LIDAR for seacliff volumetric change and beach-sediment budget contributions. *Journal of Coastal Research,* 22(2) pg: 307–318.

Zhou, G., and Xie, M. 2009. Coastal 3-D Morphological Change Analysis Using LiDAR Series Data: A Case Study of Assateague Island National Seashore, *Journal of Coastal Research*, 25(2) pg. 435–400.

# Questions? Comments? Missing Pieces?