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NCST Advisory
Committee Meeting

# NCST Technical Investigation of Hurricane Maria's Impacts on Puerto Rico:

## Preliminary Project Plan for Characterization of Hazards

Joseph Main
*Associate Leader, NCST Investigation of Hurricane Maria*
*National Institute of Standards and Technology*

# Goal 1: The Wind Environment and Technical Conditions Associated with Deaths and Injuries

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*this presentation*

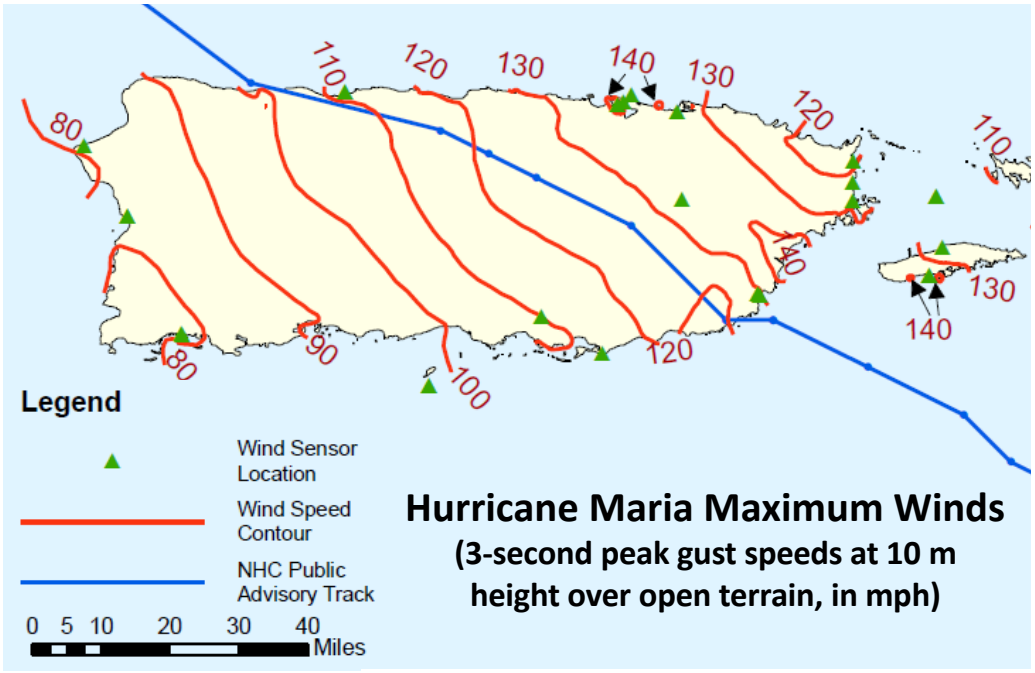
# Project: Characterization of Hazards

**Objective:** To characterize the wind environment associated with Hurricane Maria's impact on Puerto Rico, using measurements and modeling of the time-dependent hurricane wind-field in conjunction with wind tunnel studies of topographic effects, and to document other hazards associated with the hurricane, including storm surge, rainfall, flooding, and landslides.

# Background

Hurricane Maria subjected Puerto Rico to multiple hazards:

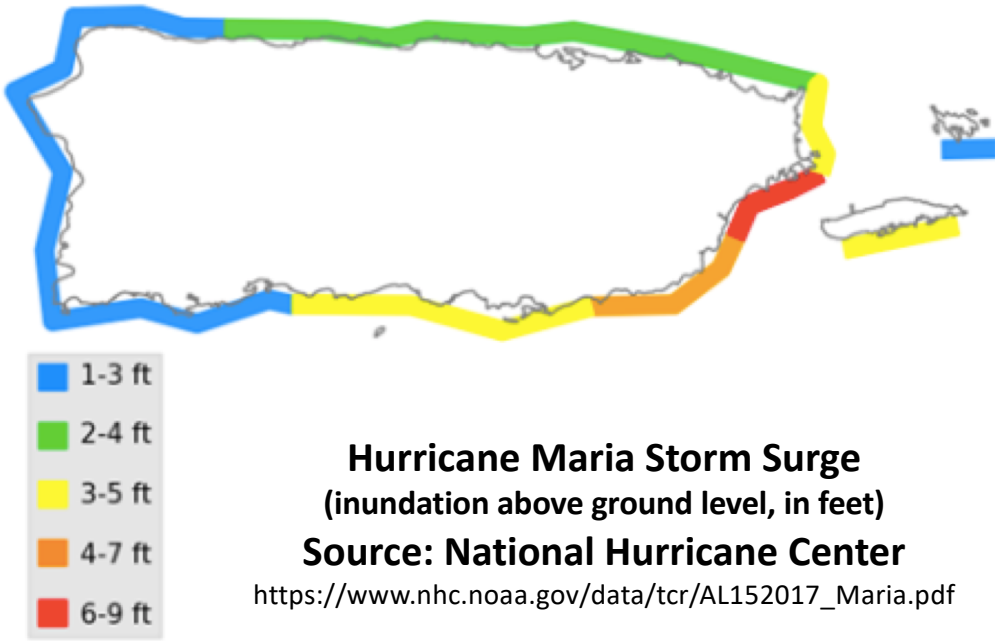
- High winds: peak gusts exceeded 140 mph



# Background

Hurricane Maria subjected Puerto Rico to multiple hazards:

- High winds: peak gusts exceeded 140 mph
- Storm surge: peak coastal inundation exceeded 6 ft

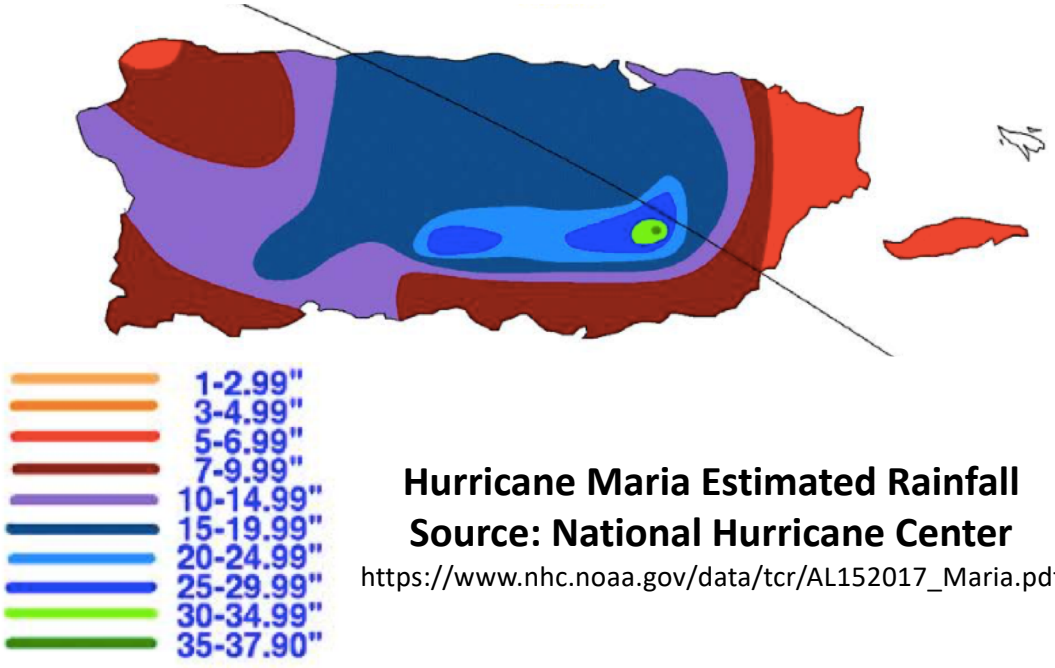



**Hurricane Maria Storm Surge**
**(inundation above ground level, in feet)**
**Source: National Hurricane Center**
https://www.nhc.noaa.gov/data/tcr/AL152017_Maria.pdf

# Background

Hurricane Maria subjected Puerto Rico to multiple hazards:

- High winds: peak gusts exceeded 140 mph
- Storm surge: peak coastal inundation exceeded 6 ft
- Rainfall, flooding: total rainfall of 5 - 40 inches

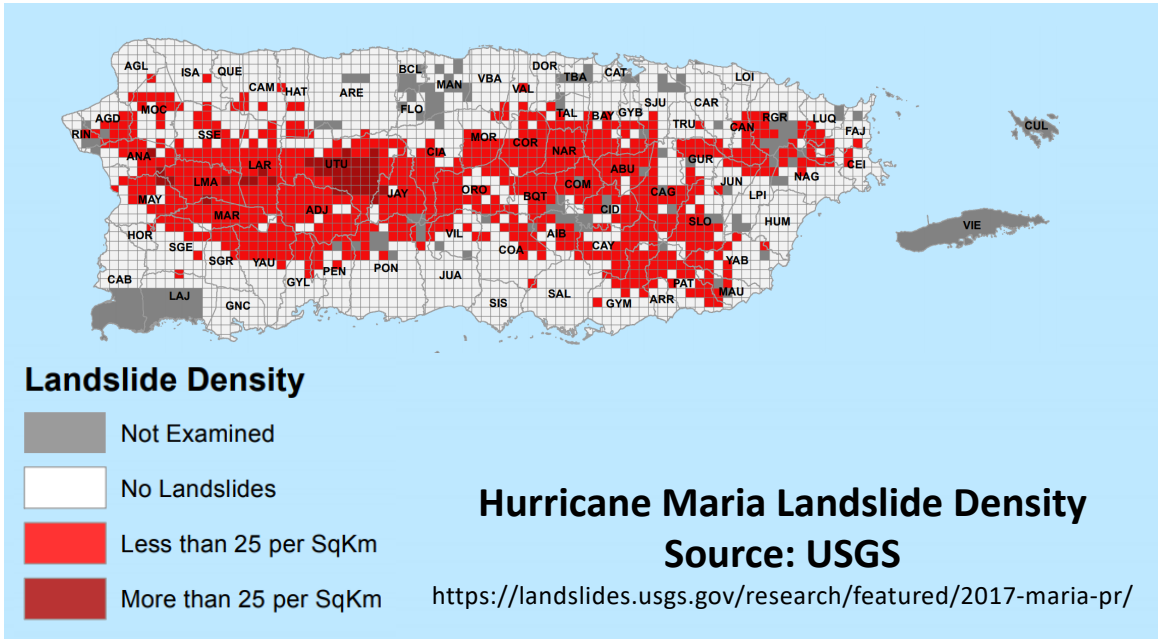



**Hurricane Maria Estimated Rainfall**
**Source: National Hurricane Center**
https://www.nhc.noaa.gov/data/tcr/AL152017_Maria.pdf

# Background

Hurricane Maria subjected Puerto Rico to multiple hazards:

- High winds: peak gusts exceeded 140 mph
- Storm surge: peak coastal inundation exceeded 6 ft
- Rainfall, flooding: total rainfall of 5 - 40 inches
- Landslides: many hundreds occurred

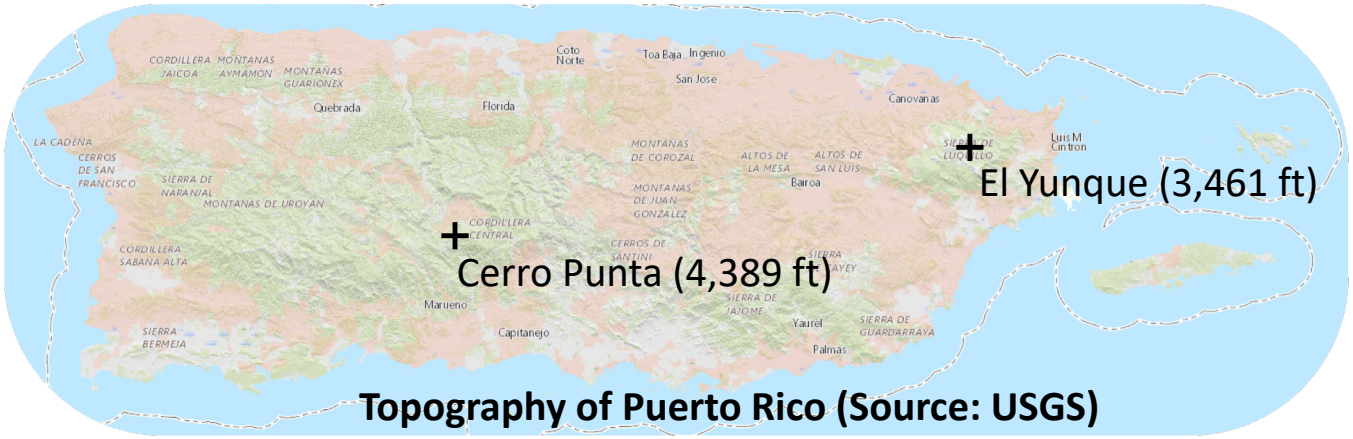


# Preliminary Project Plan: (1/4) Overview

- Hazard characterization will support multiple aspects of the investigation:
  - Deaths and injuries
  - Performance of critical buildings and designated safe areas
  - Dependence of critical buildings on lifelines
  - Emergency communications systems: performance and public response
- Primary focus will be on characterization of the wind environment, including topographic effects
- To document other hazards, outreach to other federal agencies is planned (NOAA, NASA, USGS) to identify relevant data sources and modeling capabilities

# Preliminary Project Plan: (2/4) Topographic Effects

- Much of Puerto Rico has mountainous topography, which can result in significant speed-up of winds
- ASCE 7-16 topographic factors apply only to isolated topographic features
- Potential magnitude of topographic effects: Topographic factors from wind tunnel studies of Oahu (peak elevation: 4,003 ft) and Kauai (peak elevation: 5,148 ft) were as high as 1.6 in urban areas (60% increase in wind pressure), and as high as 2.5 in mountainous regions*



**Topography of Puerto Rico (Source: USGS)**

* http://martinchock.com/_library/documents/papers/hawaiistatebuildingcodewindprovisions.pdf

# Preliminary Project Plan: (3/4) Wind Environment

- Develop a time-dependent wind-field model of Hurricane Maria's impact on Puerto Rico that optimally matches available measured data:
  - **Initial model:** topographic effects incorporated using existing data
  - **Final model:** improved modeling of topographic effects, quantified uncertainty in model results
- Characterize topographic wind speed-up effects based on wind tunnel modeling of Puerto Rico's topography
- Perform computational fluid dynamics (CFD) modeling to evaluate topographic effects for regions not tested in the wind tunnel

# Preliminary Project Plan: (4/4) Other Hazards

- Coordination with other agencies is planned to identify relevant data sources and modeling capabilities to characterize other hazards:
  - Storm surge: NOAA
  - Rainfall and flooding: NOAA, NASA, USGS, UCAR
  - Landslides: USGS and NASA
- Both spatial and temporal variability of hazards will be considered
- Interaction of hazards can be significant and will be considered:
  - Wind-driven rain
  - Storm surge and rain-induced flooding
  - Effect of prior rainfall from Hurricane Irma on preconditioning the landsurface.

# FY18 Planning Tasks

(Presented at NCST Advisory Committee Meeting on May 16, 2018)

1. Other agencies with relevant data sources and modeling capabilities for hazard characterization will be identified
2. Regions of Puerto Rico will be identified where wind-tunnel testing of topographic effects is needed and requirements will be established for modeling and measurements
3. Plans will be developed for in-house modeling of topographic effects using computational fluid dynamics (CFD)
4. Contract specifications will be developed:
   - Wind-tunnel testing of topographic effects
   - Wind-field modeling and probabilistic wind hazard analysis

# FY18 Planning Tasks – PROGRESS (1/4)

1. Other agencies with relevant data sources and modeling capabilities for hazard characterization will be identified

   **Wind** – Identified potential new data source for offshore wind using NASA GYGNSS satellite. Unlike previous systems, this satellite system can measure high-resolution wind field in heavy rainfall regions (hurricane eyewall).

   **Rainfall** – Currently identifying potential sources of in situ and remotely sensed data from NOAA and NASA centers.

   **Storm Surge** – Met with USGS regarding available in situ measurements. Identifying scope of time evolution based storm surge data available from NOAA.

   **Flooding** – Exploring data availability and potential applicability of a new approach that uses data from the NASA CYGNSS satellite for high resolution inundation mapping (UCAR/Cal Tech/U. of Colorado research group).

   **Landslides** – Identified data sources and ongoing analysis efforts at NASA and USGS in landslide mapping.

# FY18 Planning Tasks – PROGRESS (2/4)

2. Regions of Puerto Rico will be identified where wind-tunnel testing of topographic effects is needed and requirements will be established for modeling and measurements

- The strategy for identification of focus locations for wind tunnel testing of topographic effects will incorporate the following considerations
  - Need to test a wide range topographic features
  - Sampling areas for the overall Investigation
  - Specific buildings where wind tunnel testing will be conducted, and/or buildings where topographic speedup effects were anticipated to have been significant or unusual
  - Areas of PR where wind tunnel test data on topographic effects will already be available through a FEMA-funded project
  - Results of the FEMA project and NIST computational fluid dynamics (CFD) modeling will inform testing location decisions
  - Additional wind tunnel testing is planned under NIST contract around summer of 2019, after above considerations have been analyzed and locations identified

# FY18 Planning Tasks – PROGRESS (3/4)

3. Plans will be developed for in-house modeling of topographic effects using CFD

- Detailed literature review
  - Alternative CFD approaches for topographic studies
  - Modeling approaches for terrain roughness
- CFD simulation of simple geometries
  - Evaluation of alternative CFD approaches
  - Grid sensitivity studies
  - Uncertainty quantification
  - Validation against wind tunnel test data
- CFD simulation of selected regions in Puerto Rico
  - Validation against wind tunnel test data
- Simulation of entire main island of Puerto Rico
  - Simulations will need to be performed for multiple wind directions over a 360° range
  - Steady Reynolds-Averaged Navier Stokes (RANS) seems promising as a computationally efficient approach to capture the mean flow for such a large computational domain
  - Resulting topographic speed-up factors will contribute to final wind field model

# FY18 Planning Tasks – PROGRESS (4/4)

4. Contract specifications will be developed:
   - Wind-tunnel testing of topographic effects
   - Wind-field modeling and probabilistic wind hazard analysis

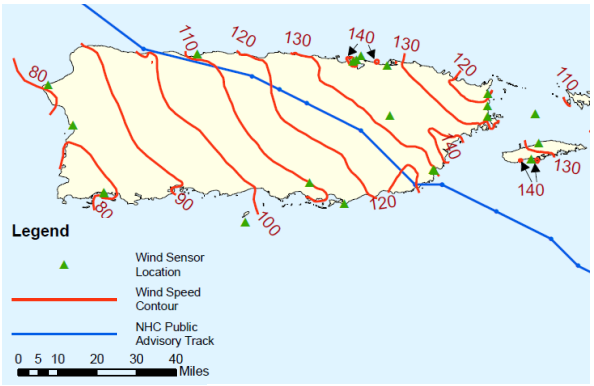
- Specifications for both contracts have been developed, and are working their way through the NIST approval and procurement process
- Anticipated contract awards/start dates in Fall 2018
- Planned wind tunnel testing and wind field modeling approaches are described in the following slides

# Planned Approach: Wind Tunnel Testing of Topographic Effects

- Project workplan will be developed with consideration of previous wind tunnel testing funded by FEMA
- Wind tunnel testing of turntable-mounted topographic models in boundary-layer approach flow
- Detailed flow measurements using Particle Image Velocimetry (PIV)
  - Validation of CFD models
  - Support development of topographic speed-up factors for wind field modeling and mapping
  - Provide approach flow profiles for wind tunnel testing of buildings

# Planned Approach: H. Maria Wind Field Modeling (1/2)

- Initial forensic wind field model
  - Build on the rapid wind field model created last fall, where parameters of the hurricane model used in ASCE 7-16 wind maps were adjusted to provide the best fit to Maria's observed wind speeds, directions, and atmospheric pressures
  - Integrate topographic correction factors currently being developed (through the FEMA-funded wind map project to aid with the rebuilding) into the current Hurricane Maria wind field model
  - Produce gridded time histories of wind speeds and directions across the Commonwealth, and at locations of specific facilities of interest
  - Anticipated results in early 2019



# Planned Approach: H. Maria Wind Field Modeling (2/2)

- Planned wind field modeling advances
  - Improve the modeling procedure to better handle strongly asymmetric hurricane wind fields
  - Add air density to the hurricane wind field model and outputs (to improve estimation of wind loads)
  - Incorporate results of wind tunnel and CFD modeling into the topographic correction factors
  - Develop formal process for optimizing the fit of the hurricane model to the observed data, based on experimental design techniques and statistical assessment of goodness-of-fit, including quantification of uncertainty
    - Test the optimized fitting process on other historical storms for which there is more measured wind field data, including Hurricane Irma in both Florida and in Puerto Rico
- Final forensic wind field model to incorporate all of the above improvements