NCST Technical Investigation of Hurricane Maria (Puerto Rico)

Performance of Critical Buildings Project

Project Leaders: Joseph Main and Marc Levitan

Objective: To characterize the performance of critical buildings in Hurricane Maria by evaluating damage and loss of function for representative hospitals, schools, and storm shelters with respect to the hazards they experienced, including an evaluation of selection criteria and design requirements for storm shelters.

Background and Motivation

Many engineered buildings with good structural performance suffered extensive ***nonstructural damage*** and ***loss of function*** due to rainwater penetration of the building envelope, caused by:

- roof covering and rooftop equipment damage from wind and windborne debris;
- window and door damage caused by wind and windborne debris;
- rainfall ponding on the roof due to excessive rainfall rates and debris blocking drains; and
- wind-driven rain penetration through undamaged cladding, such as windows and doors.

Loss of power and generator failures also disrupted the function of some schools and healthcare facilities.

Project Plan: 1. Data Collection

Initial Data Collection: Coordinate with Puerto Rico government agencies, federal partners, and others to identify and collect relevant existing data:

- characteristics and performance of hospitals, schools, and shelters
- shelter program information, including selection criteria and facilities used

Sample Selection: Select representative hospitals and schools/shelters for detailed evaluation, considering characteristics of buildings, hazards, other factors

Facility Evaluations: Collect information for selected critical facilities to document:

- physical characteristics of the buildings prior to Hurricane Maria
- damage to the buildings caused by Hurricane Maria, including impacts on life safety
- impacts to the function and operation of the facility caused by Hurricane Maria

Wind Tunnel Testing: Test scale models for a subset of the selected buildings

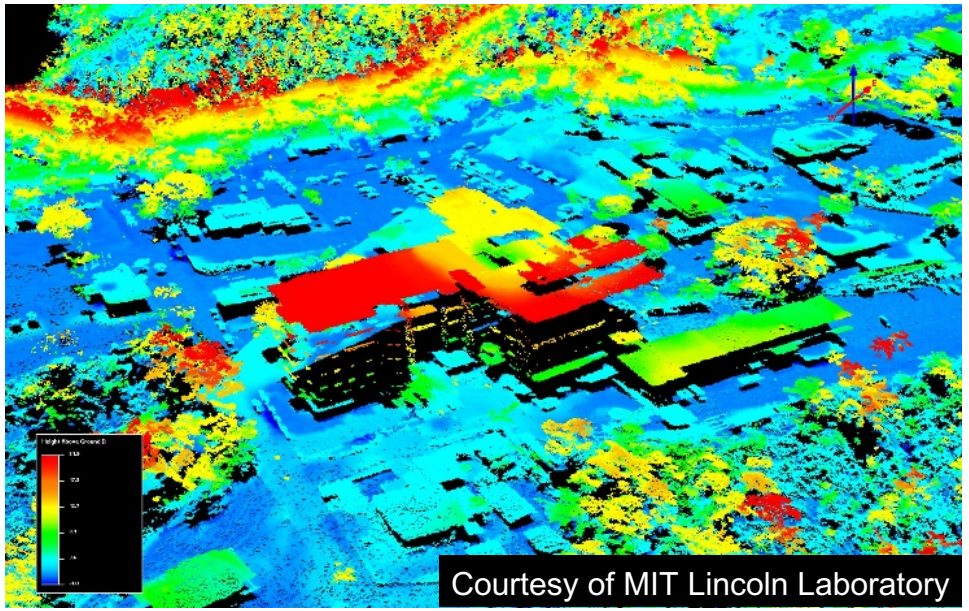
- building models will be extensively instrumented to measure wind loads
- effects of surrounding topography, buildings and terrain will be considered

Project Plan: 2. Data Analysis

- Evaluate the performance of selected critical buildings with consideration of:
  - wind loads and other hazards encountered during Hurricane Maria
  - impacts of these hazards on building function and life safety of occupants, including operational challenges encountered
  - adequacy of existing codes, standards, and practices
- Evaluate shelter selection criteria, design criteria, and operational guidance for the larger population of shelters with consideration of:
  - hazard levels encountered at shelter sites and damage to shelter buildings
  - shelter population per site over time, including relocation of occupants
  - adequacy of existing selection criteria, design criteria, and operations plans
- Develop recommendations, as necessary, for specific improvements to building standards, codes, and practices based on the findings, including consideration of seismic hazards

Recent Progress: Initial Data Collection

- Memorandums of Agreement (MOAs) established with FEMA for information sharing on damages to schools and healthcare facilities caused by Hurricane Maria:
  - U.S. Army Corps of Engineers school and hospital assessments (MOA: Nov. 2019)
  - Damage information from FEMA Public Assistance Program (MOA: March 2020)
- Hospital information obtained from HHS and Puerto Rico Department of Health
- Shelter program data obtained from Puerto Rico Department of Housing
- Aerial Lidar data obtained from MIT Lincoln Laboratory for selected sites in Puerto Rico
- GIS information obtained for hospitals, schools, and shelters; hazard levels evaluated at building sites
- Data extracted from USACE school assessments to create an initial database of school/shelter characteristics and damages

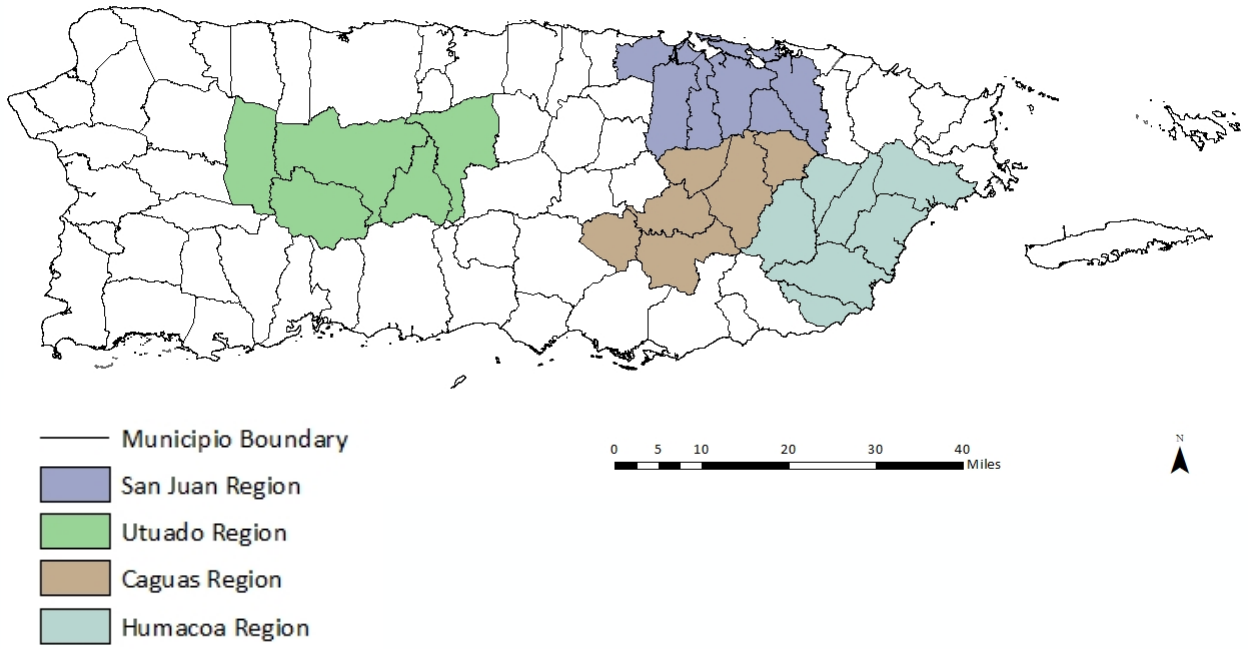


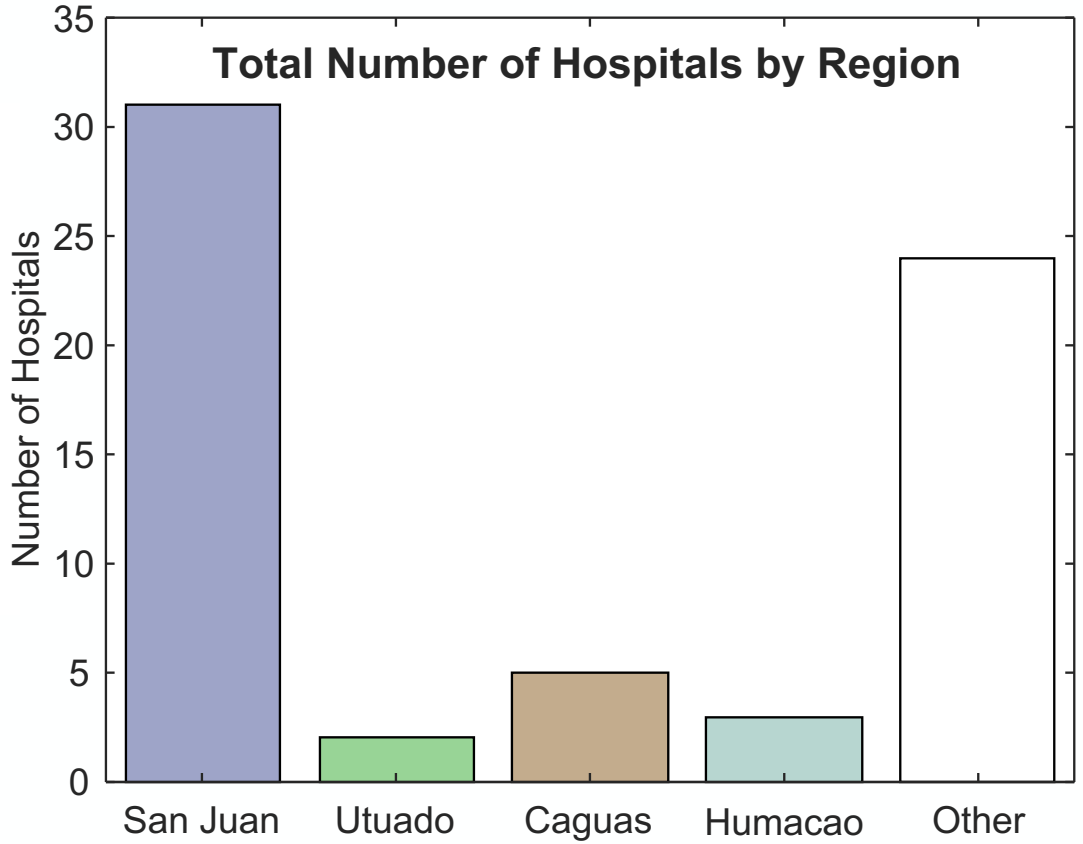
Lidar Data for Hospital Bella Vista

Recent Progress: Sample Selection

Sampling strategy developed to select hospitals for evaluation

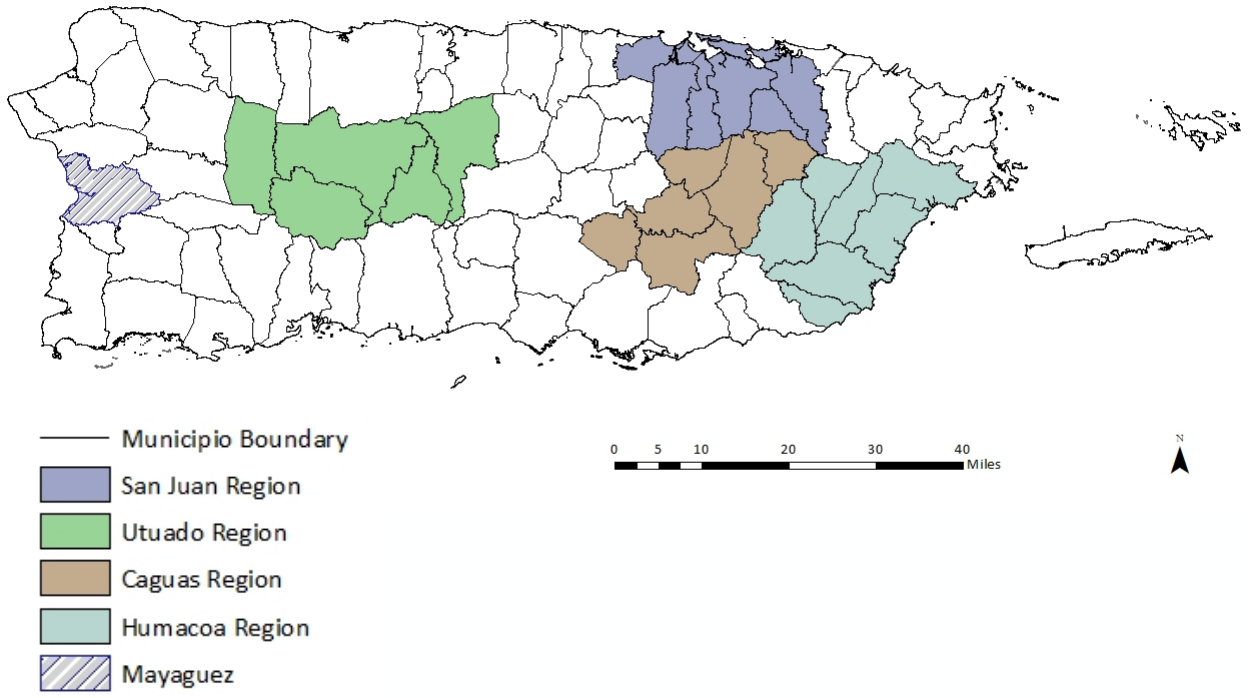
- Each hospital assigned a score based on consideration of available data
- Scores used to rank the hospitals within each selected region
- At least one hospital from each selected region included in sample

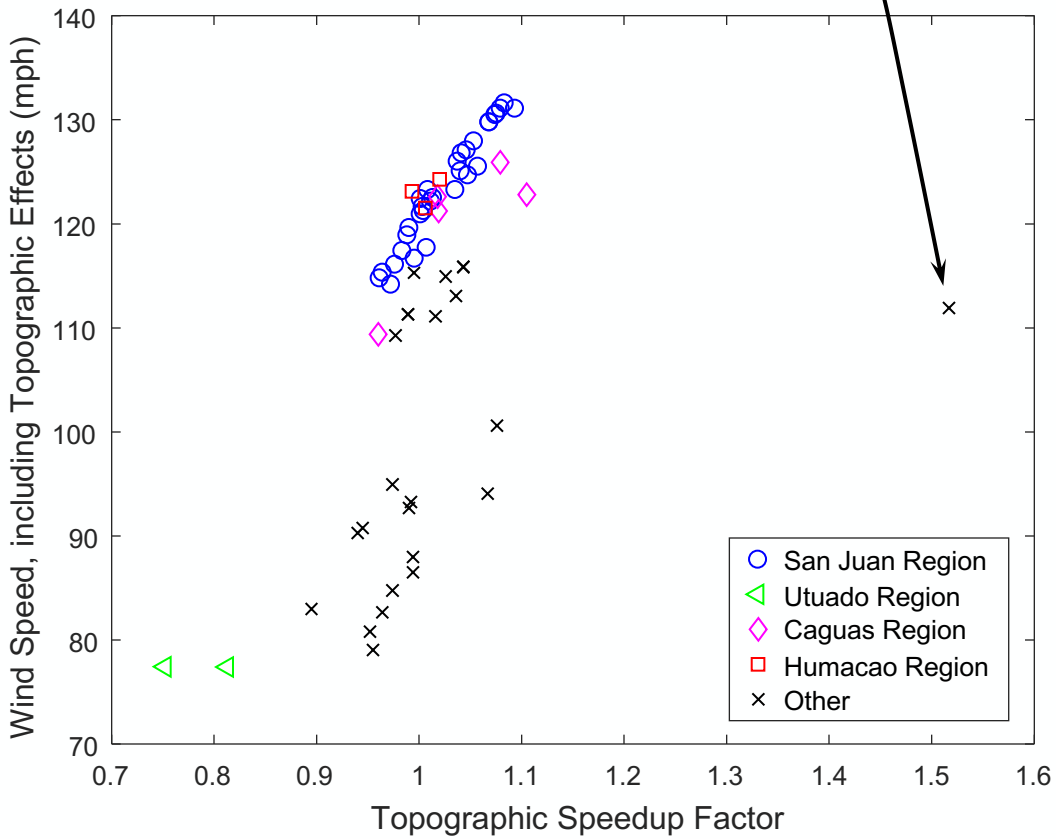




Recent Progress: Sample Selection

- Selecting hospitals from each region provides variation in the hazard exposure:
  - Lowest wind speeds in Utuado region (topographic sheltering)
  - Highest wind speeds in San Juan region
- Highest topographic speedup factor for Hospital Bella Vista in Mayagüez





Recent Progress: Facility Evaluations

- Site visits and meetings with staff at two hospitals in October/November 2019, coordinated through the Puerto Rico Department of Health:
  - Introduction and overview of the NIST Hurricane Maria Program
  - Facility walkdowns and discussion of the impacts of Hurricane Maria

University Pediatric Hospital, San Juan

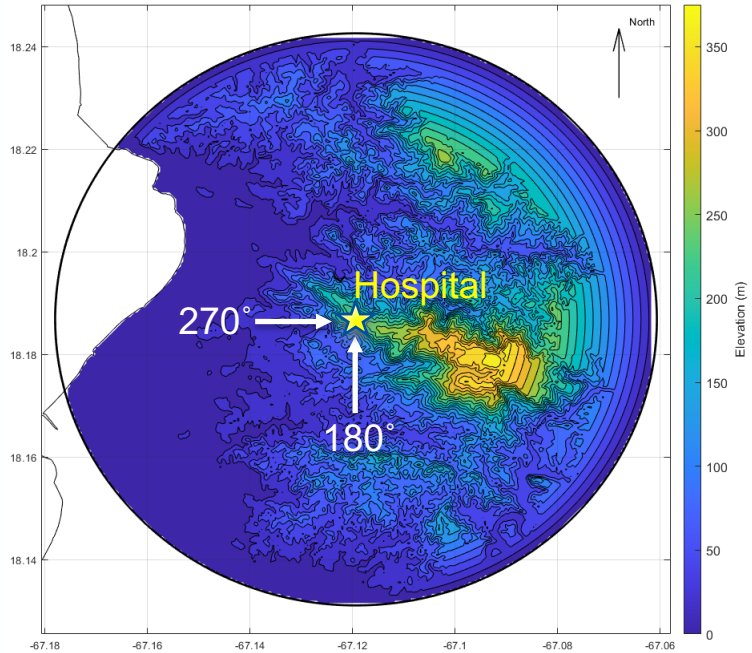
Hospital Bella Vista, Mayagüez

Recent Progress: Facility Evaluations

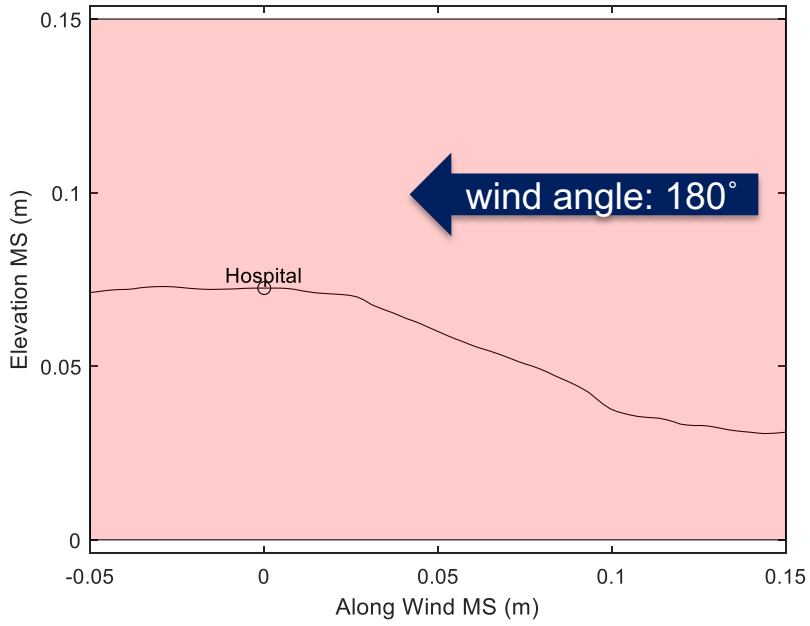
- Contract awarded to Stantec Consulting Services (March 2020)
  - **Project Manager:** Dr. Juan C. Virella Crespo
  - **Field Team Leader:** Dr. Luis Aponte-Bermúdez (NCST Member)
- Project Work Plan developed (April 2020)
- Coordinated with Stantec team in development of plans and documents:
  - Communication plan, templates, and letters
  - Facility evaluation protocols, data collection form, and interview guide
  - Data management plan
- Phase 1 evaluations commencing shortly for an initial set of hospitals: initial document collection and review (remote)

Recent Progress: Wind Tunnel Testing

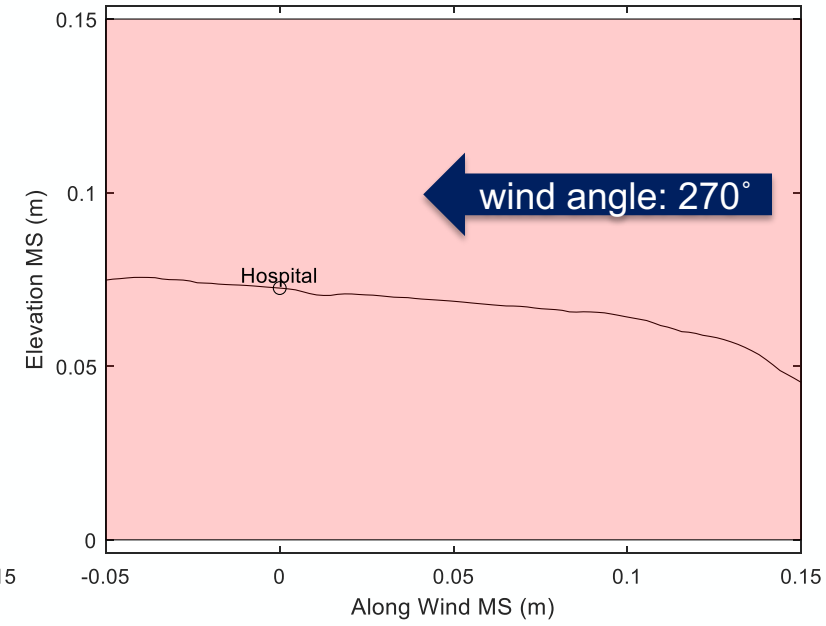
- Hospital Bella Vista planned as first facility for wind tunnel testing
- Plans developed to characterize topographic effects on incoming flow:
  - Topographic model of Mayaguez region to be tested at 1:3100 scale
  - Flow field at hospital site to be measured using Particle Image Velocimetry (PIV) for wind angles from 180˚ to 360˚ in 10˚ increments
- Design of model, measurement systems, and testing plan in progress



Topographic Model of Mayaguez



Elevation Profile: 180˚ Wind Angle



Elevation Profile: 270˚ Wind Angle

Next Steps

Sample Selection:

- Develop sampling strategy and select representative schools and storm shelters for detailed evaluation
- Prioritize selection of hospital and school/shelter facilities with consideration of available resources

Facility Evaluations:

- Phase 1 evaluations: initial document collection and review
- Phase 2 evaluations: interviews, additional document collection (and field investigation)
- Conduct auxiliary tasks as needed (e.g., drone photography to support wind tunnel models)

Wind Tunnel Testing:

- Complete design of building and area models and fabricate models for two facilities
- Complete requirements for approach flow conditions and measurements, and perform testing
- Combine measured data with time-dependent hurricane wind-field model to evaluate wind load histories for Hurricane Maria

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Project Leaders: Joseph Main and Marc Levitan
Project Team: Jazalyn Dukes, Katherine Johnson, Cynthia Rivas, DongHun Yeo, Camila Young

Questions?

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