Numerical Simulations to Understand the Role of Geomorphic Complexity in Enhancing Civil Infrastructure Damage during Extreme Wind Events

Edward L. Cruz-García, BSCE[1,2,3], Luis D. Aponte-Bermúdez, Ph.D., P.E.[1,3], Forrest Master, Ph.D, P.E.[4], Patricia Chardón-Maldonado, Ph.D.[2,3]
[1]Department of Civil Engineering and Surveying, University of Puerto Rico at Mayagüez
[2]Caribbean Coastal Ocean Observing System, University of Puerto Rico at Mayagüez
[3]Center of Coastal Resilience, University of Puerto Rico at Mayaguez
[4]Department of Civil and Coastal Engineering, University of Florida

MOTIVATION

After the devastation caused by Hurricane María in September 20, 2017 in the island of Puerto Rico, a study to develop *Puerto Rico's Special Wind Region Maps* was funded by the Federal Emergency Management Agency (FEMA) and lead by the Strategic Alliance for Risk Reduction (STARR II) Dr. Aponte and Project Manager Stuart Adams. Wind speed-up data were developed through a wind tunnel study of Puerto Rico topography perform by the University of Florida professor Dr. Masters, and Applied Research Associates (ARA) Dr. Peter Vickery. ARA used the data with wind directionality modeling results obtained from the Monte Carlo simulations to perform 'microzonation'—i.e., development of local wind field map for a specified region with a complex terrain—for multiple mean recurrence intervals. The collective effort resulted in a special wind region map for the Commonwealth, as defined by Section 26.5.2 in the ASCE 7-16 Standard Minimum Design Loads and Associated Criteria for Buildings and Other Structures. Also, the new maps have been officially adopted in the Puerto Rico Building Code 2018 by the Permit Management Office (OGPe, by its acronym in Spanish).

Practitioner Structural and Wind Engineers use these types of maps, in conjunction with ASCE 7 analytical method (ASCE 7-16, Standard Minimum Design Loads and Associated Criteria for Buildings and Other Structures), to calculate wind loads on structures. However, the ASCE 7 analytical method is not accurate for the island of Puerto Rico complex terrain since it was developed for isolated landforms. In the regions with complex mountainous terrain, numerical modeling is a better fit tool to assess the geomorphic complexity effects of the terrain on the air flow. Hence, employing the Digital Elevation Model of Puerto Rico of the US Geological Survey, a computational fluid dynamic (CFD) numerical model was implemented to perform wind simulations using OpenFOAM®. Preliminary results are currently under evaluation to shed some light to better understand the turbulent speed-up phenomena over complex terrain, and its vertical profile form. The vertical profile distribution from the numerical simulations will help to fit the gap and limitations from the original wind tunnel studies.

CULEBRA AND CULEBRITA MODELS

- Numerical simulations of the wind flow over the islands of Culebra and Culebrita (Figure. 1) were carried out to identify and understand the effects of complex terrain on the wind field.
- Two cases were simulated:
  1. Winds blowing from West to East at 65 m s^{-1} over Culebra
  2. Winds blowing from West to East at 40 s^{-1} over Culebrita

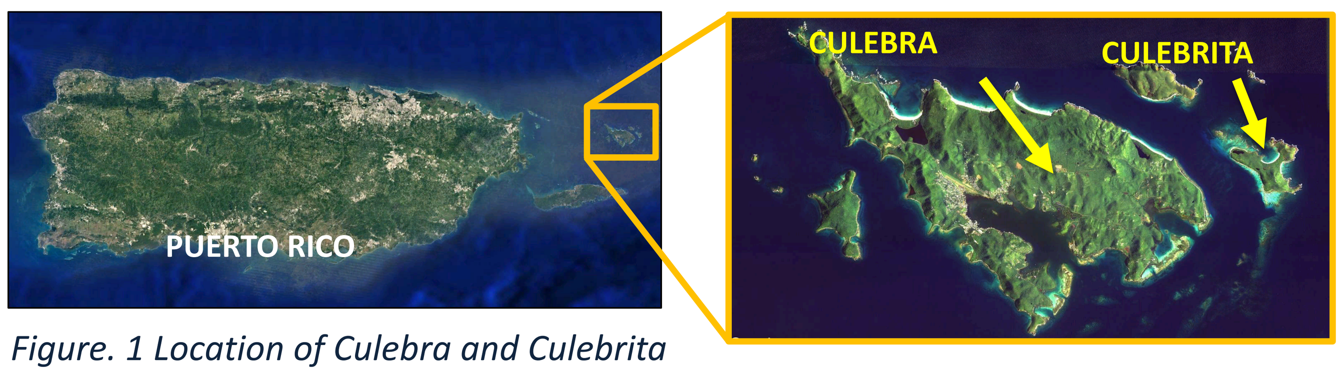
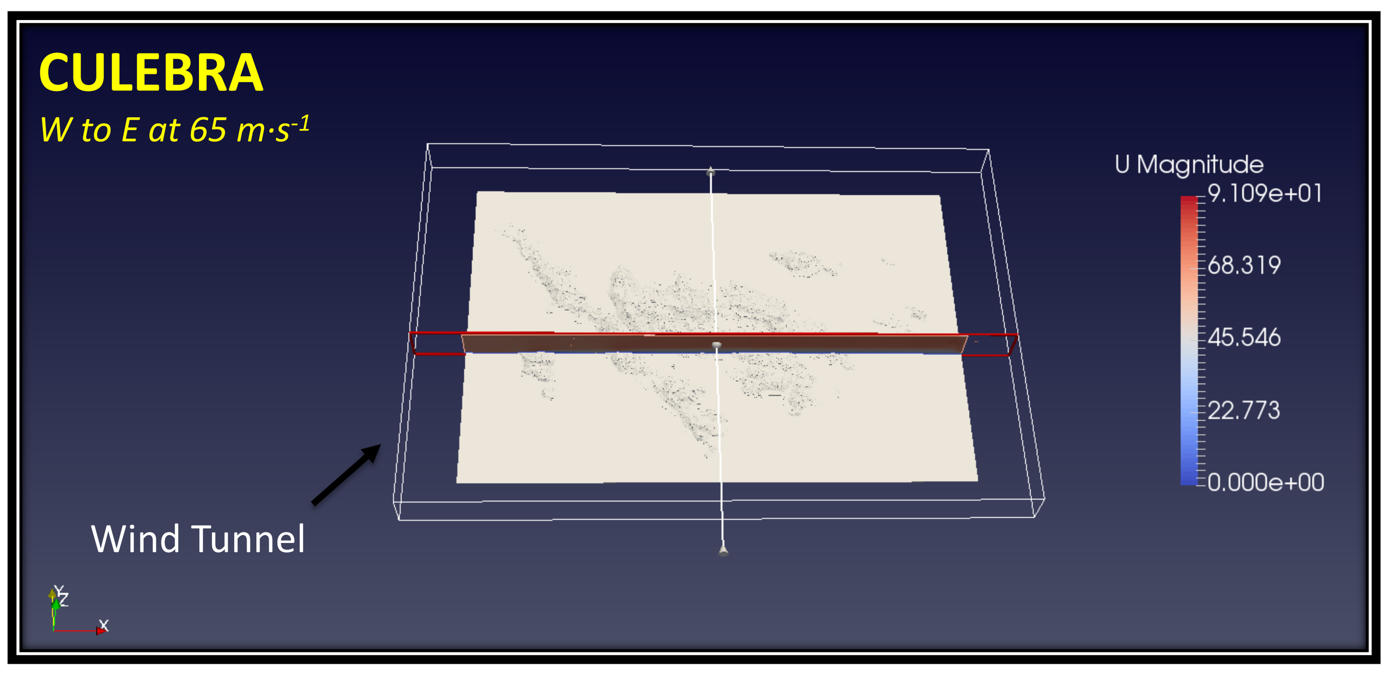
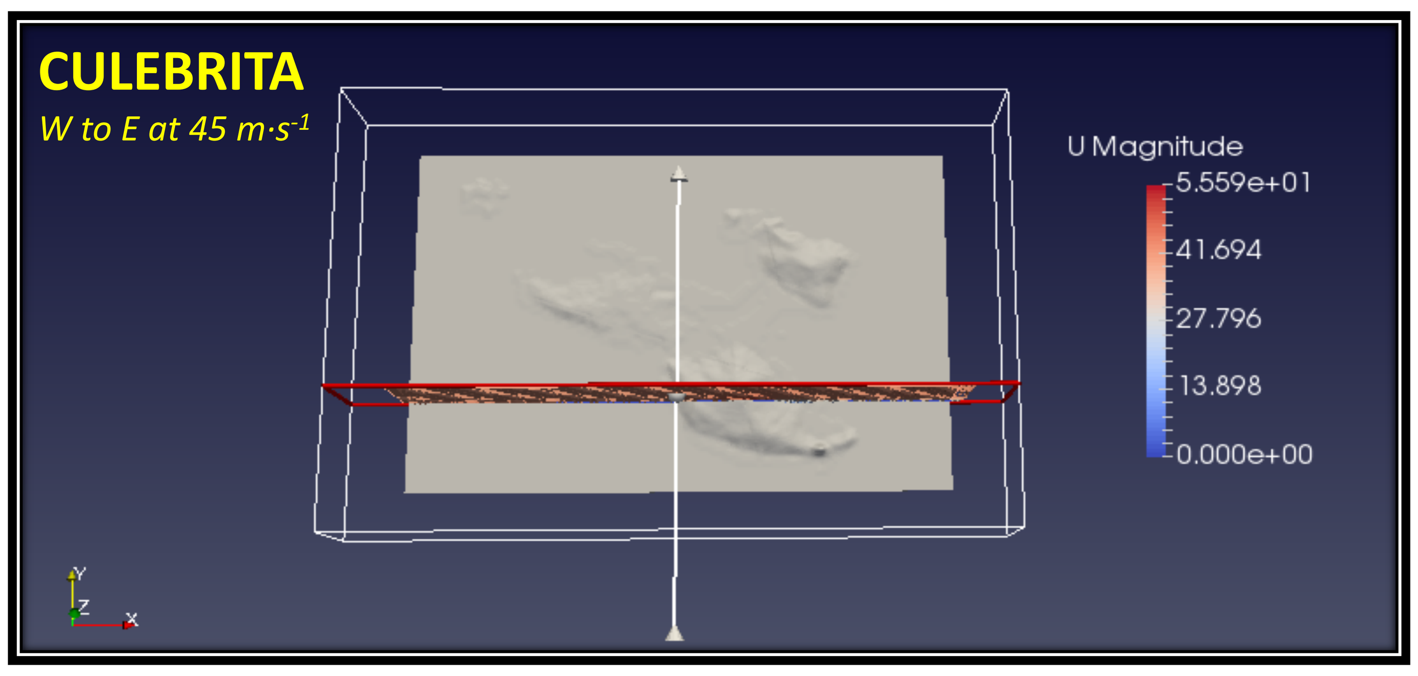
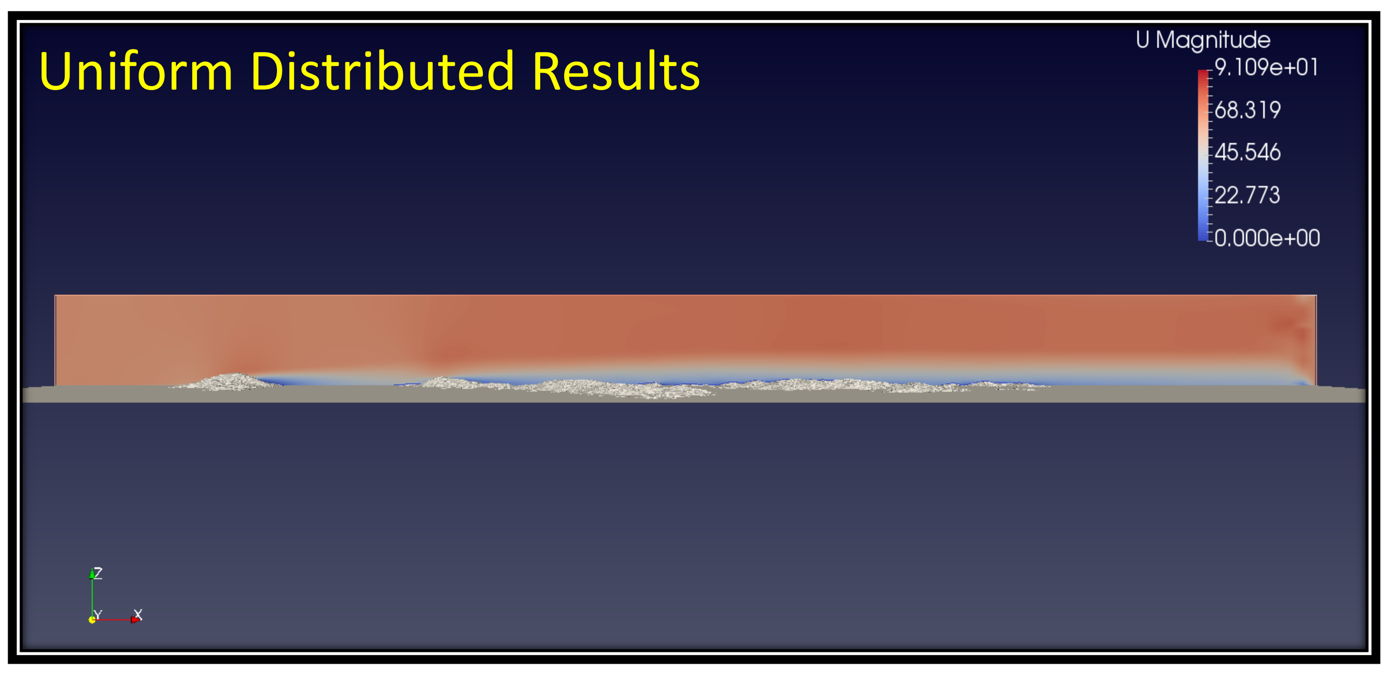


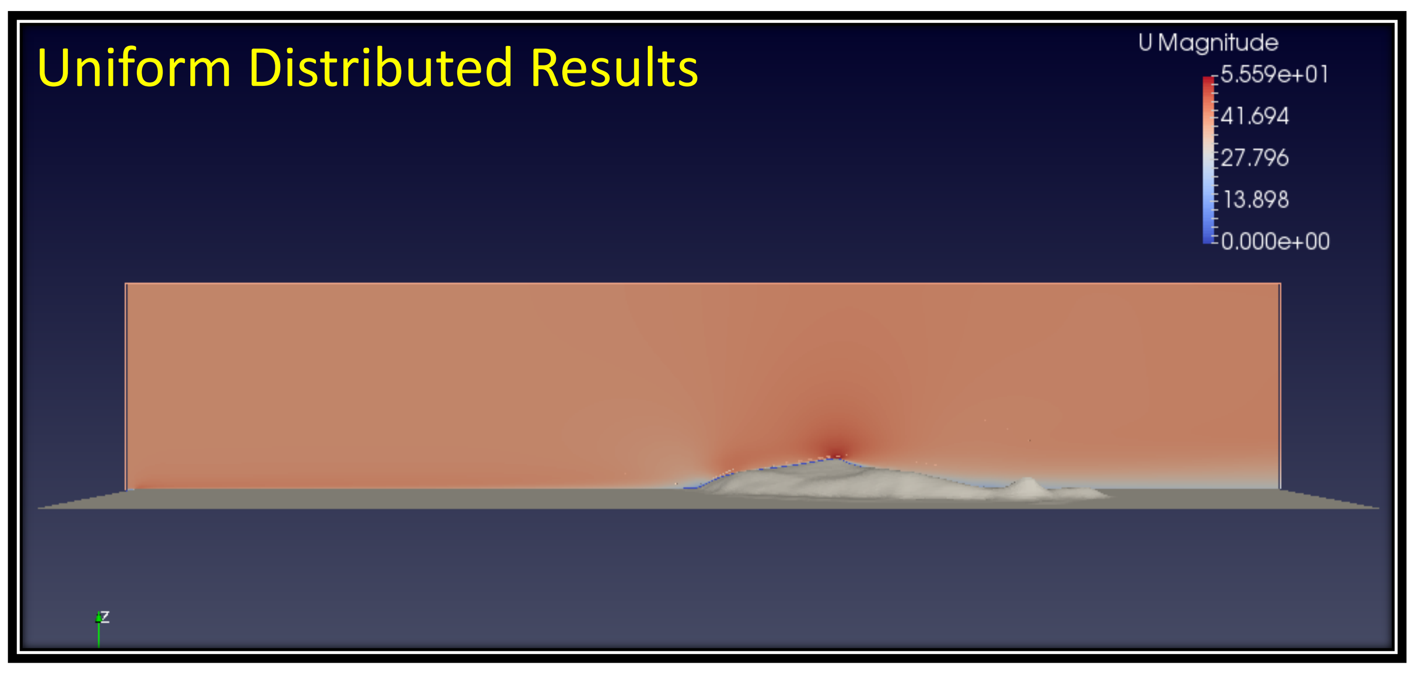
Figure. 1 Location of Culebra and Culebrita

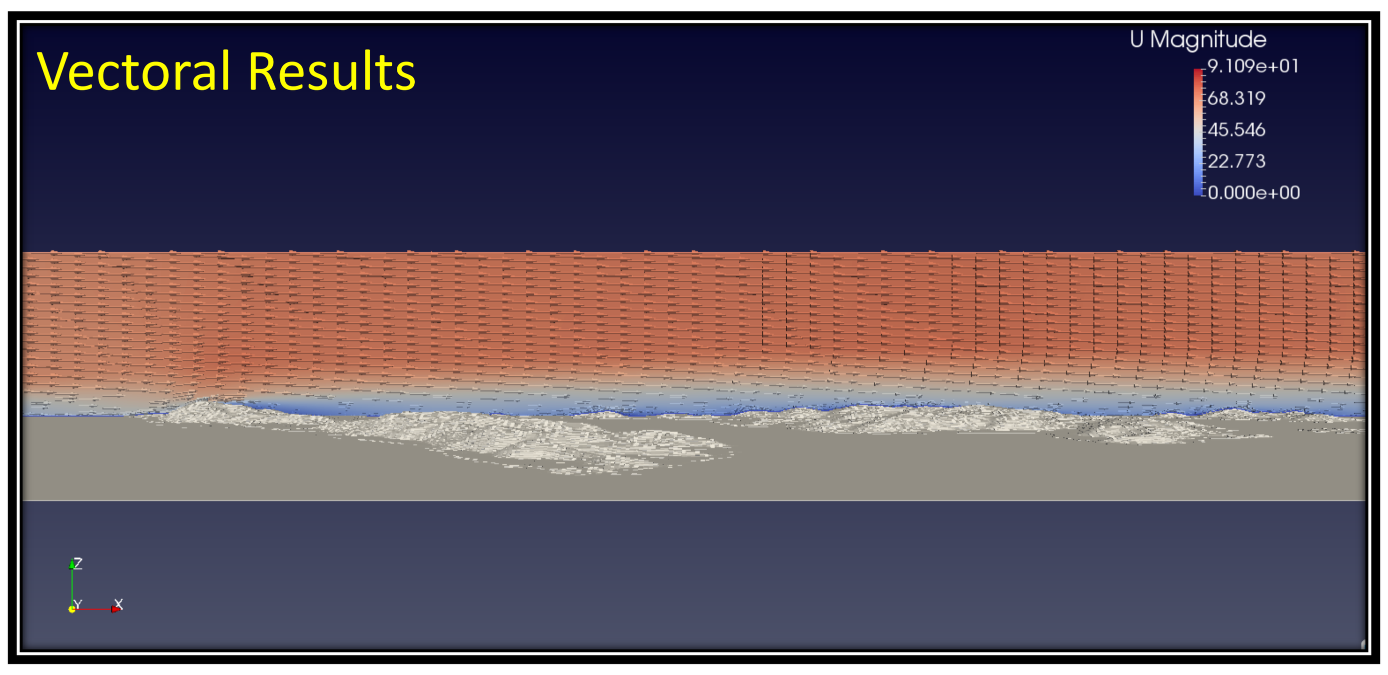
PRELIMINARY RESULTS

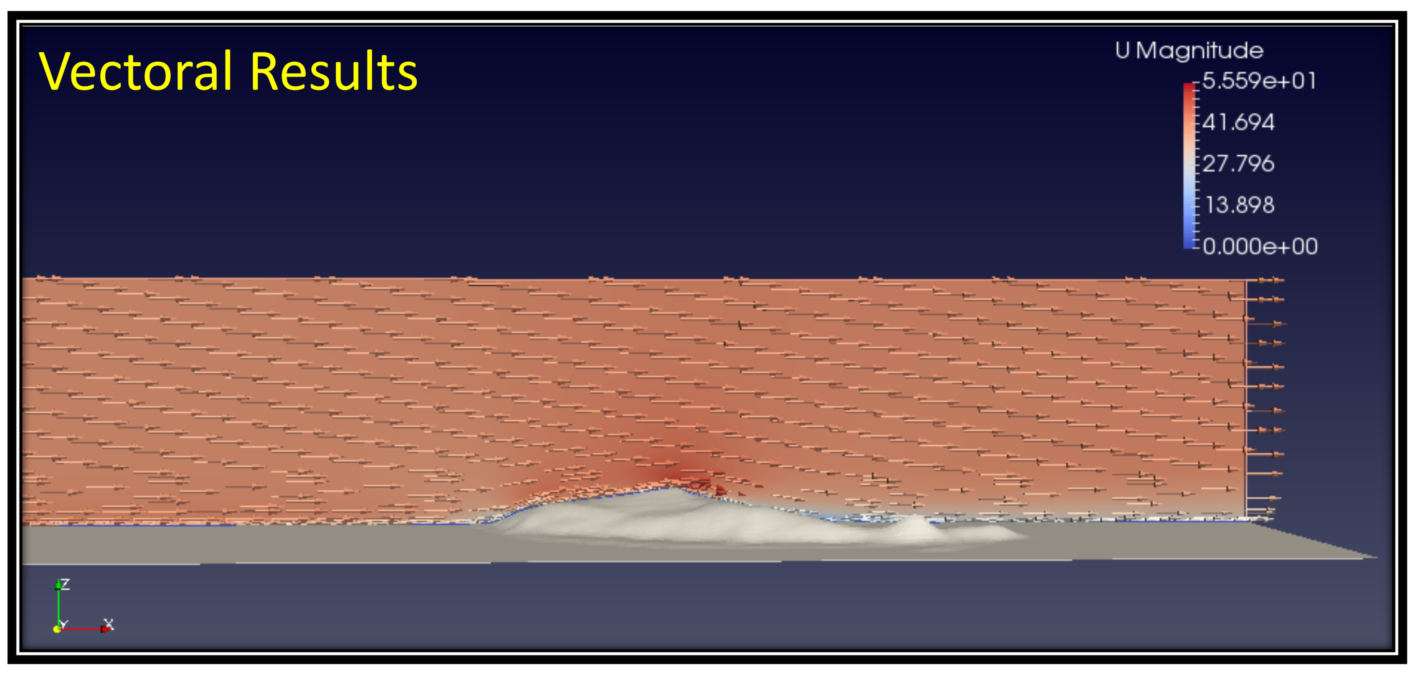












FUTURE WORK

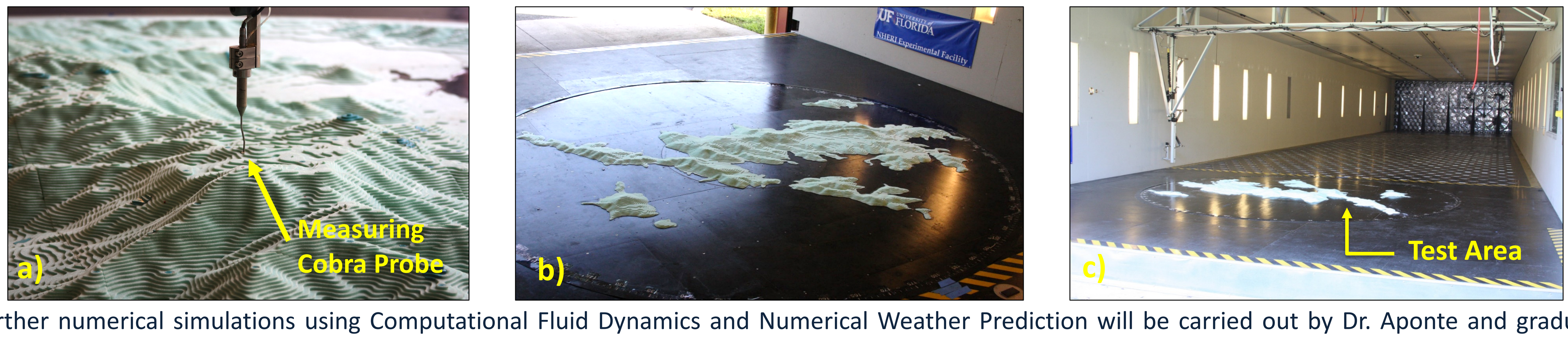


Figure. 2 Photographs of:
(a) Cobra probe measuring all three components of mean and fluctuating velocities and static pressure
(b) experimental setup
(c) Overall view of Culebra terrain model at UF Terraformer Boundary Layer Wind Tunnel

- Further numerical simulations using Computational Fluid Dynamics and Numerical Weather Prediction will be carried out by Dr. Aponte and graduate student Edward L. Cruz-García for the main island of Puerto Rico and the Municipal Islands of Vieques and Culebra considering 16 different cardinal wind directions.
- These results will then be validated using data obtained by using a Cobra probe (Fig. 2a) mounted to the Terraformer Boundary Layer Wind Tunnel at the NSF Natural Engineering Research Infrastructures (NHERI) Experimental Facility in the University of Florida (Fig. 2c).
- During the summer months, Dr. Master and graduated student Jorge X. Santiago-Hernández, levering from the original FEMA study will carry out additional wind tunnel tests on the Puerto Rico models using a precision particle image velocimetry (PIV) system.

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