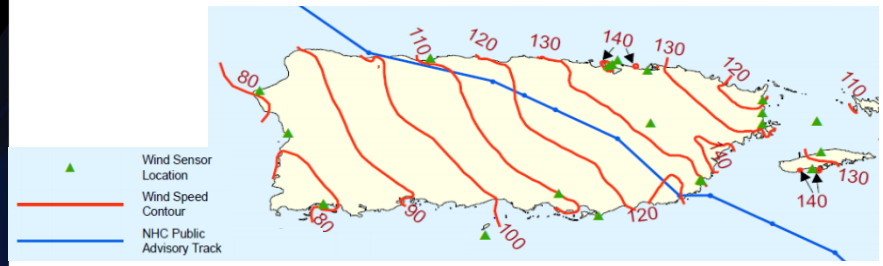
NCST Technical Investigation of Hurricane Maria's Impacts on Puerto Rico

Hazard Characterization Project

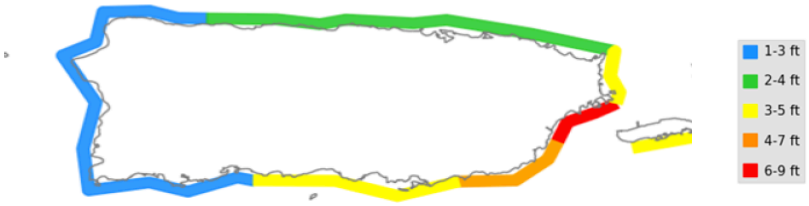
Project Leaders: DongHun Yeo and Scott Weaver

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.

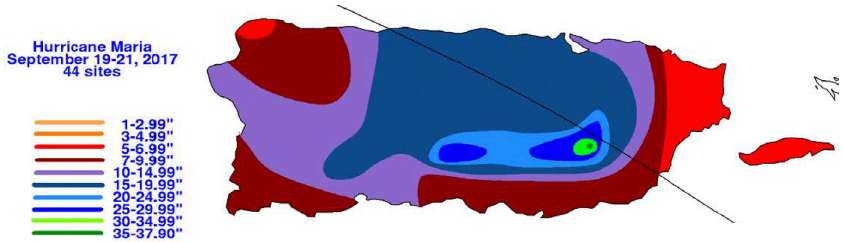
Background: Multiple Hazards from Hurricane Maria



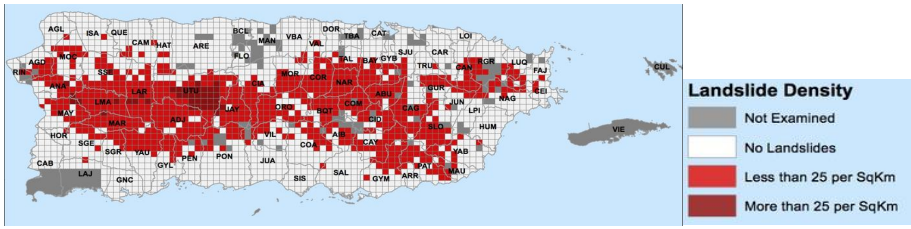
Peak gust wind speed at 10 m height over open terrain
(Created on Sept. 26, 2017)



Inundation above ground level
Source: NOAA/NHC



Precipitation in inches
Source: NOAA/WPC



Concentration of landslides
Source: USGS

Hurricane Maria subjected Puerto Rico to multiple hazards: peak gusts exceeded 140 mph, peak coastal inundation exceeded 6 ft, rainfall totaling up to 40 inches causing inland flooding. The storm damaged instrumentation, resulting in challenges to the metrology of the hazards related to the windstorm.

Hurricane Maria Wind Hazard Characterization

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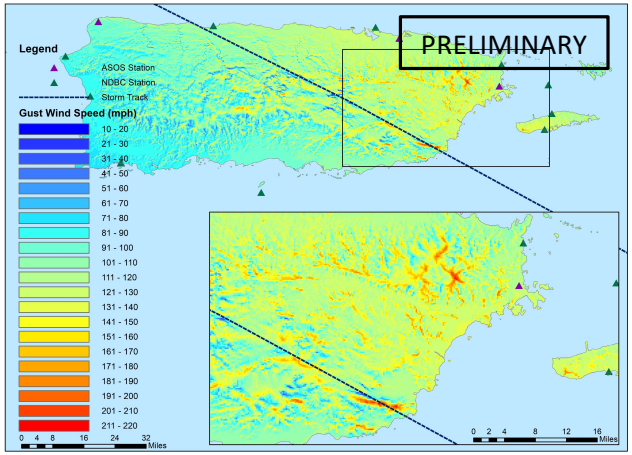
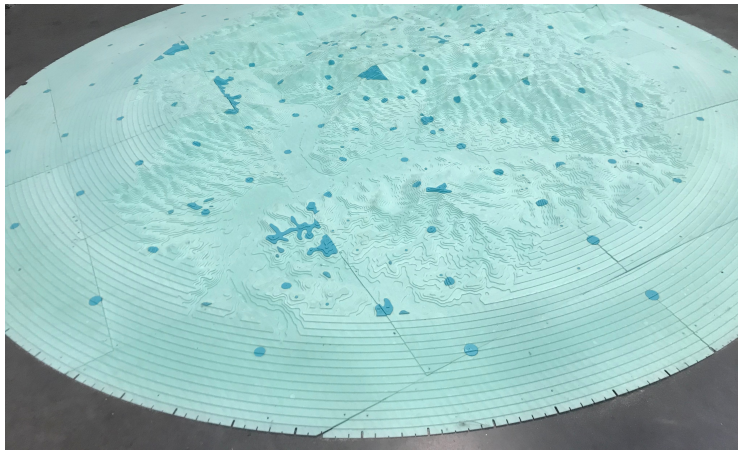
Topographic effects are a key consideration for characterization of the wind environment

Investigative Methods

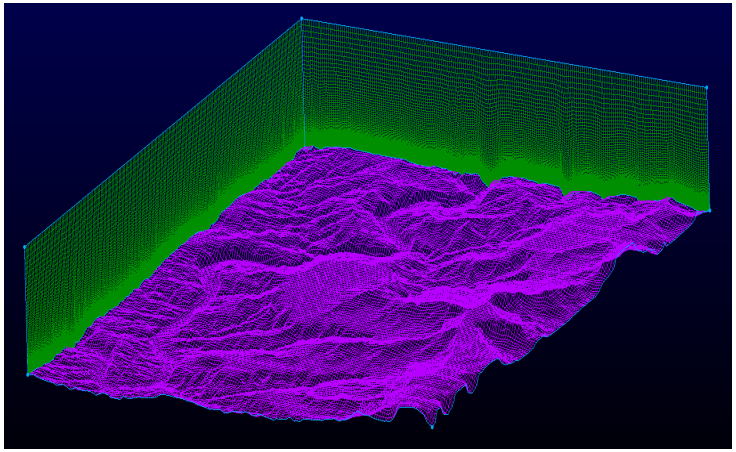


Wind Field Modeling



Wind Tunnel Testing

Field Measurements



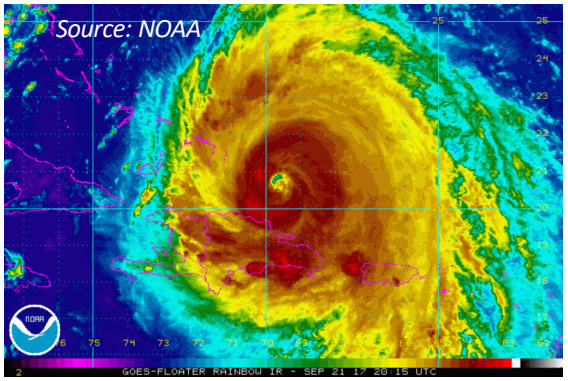
Numerical Simulation

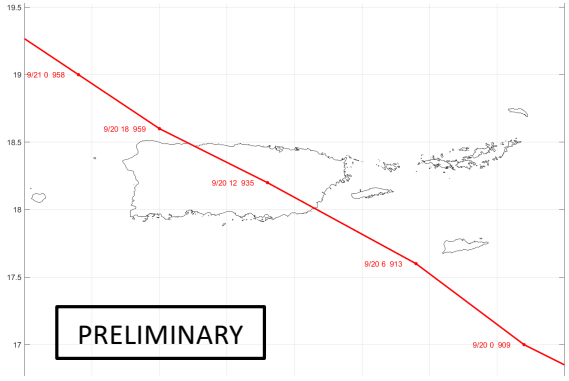
Wind Field Modeling

Purpose: Develop a time-dependent wind-field model of Hurricane Maria's impact on Puerto Rico that optimally matches available measured data

Contract awarded to Applied Research Associates to support wind field modeling tasks:

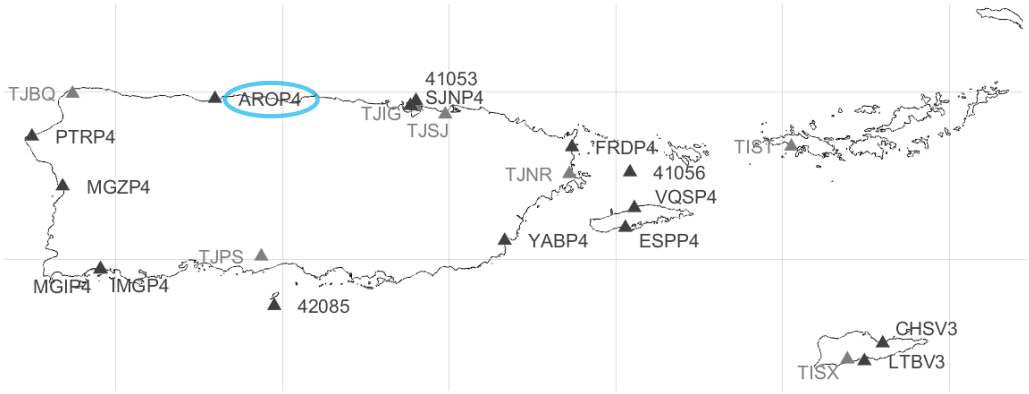
- Initial wind field model (completed):
  - Topographic effects incorporated using existing model
- Final wind field model:
  - Incorporation of additional surface-level meteorological observations (in progress)
  - Improved modeling of hurricane asymmetry (in progress)
  - Optimization of model fitting process and quantification of uncertainty in results (in progress)
  - Refinement of topographic effects model based on wind tunnel and numerical results



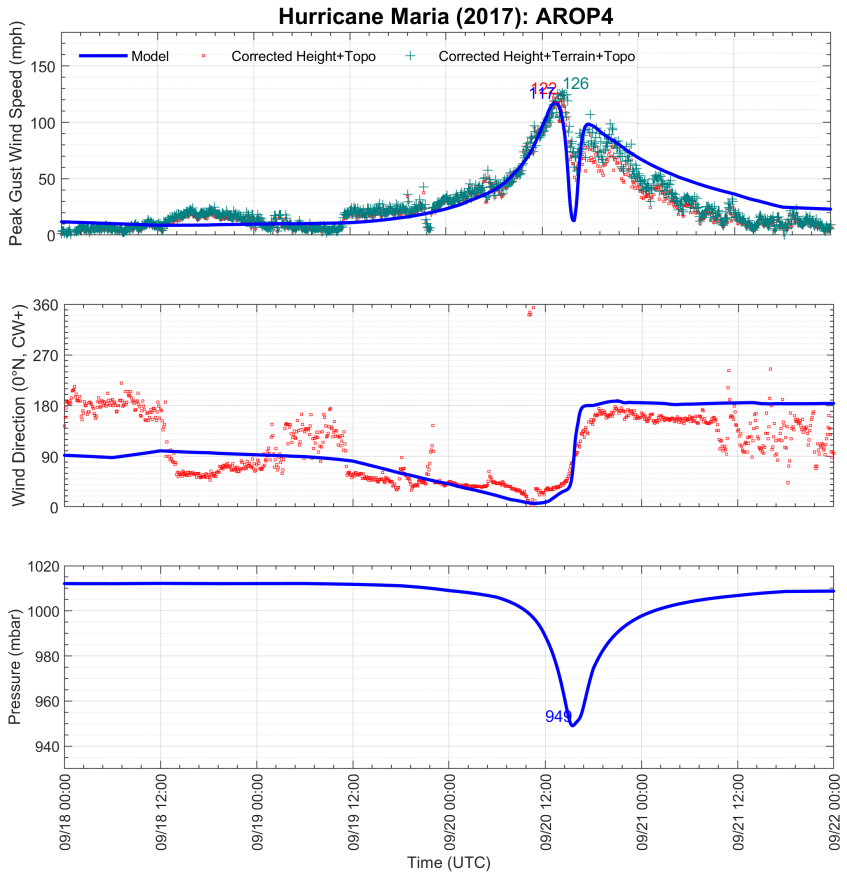


Initial Wind Field Model

Comparison of modeled peak gust wind speeds with measurements at selected stations:



Station that recorded wind speed and direction during the duration of the hurricane



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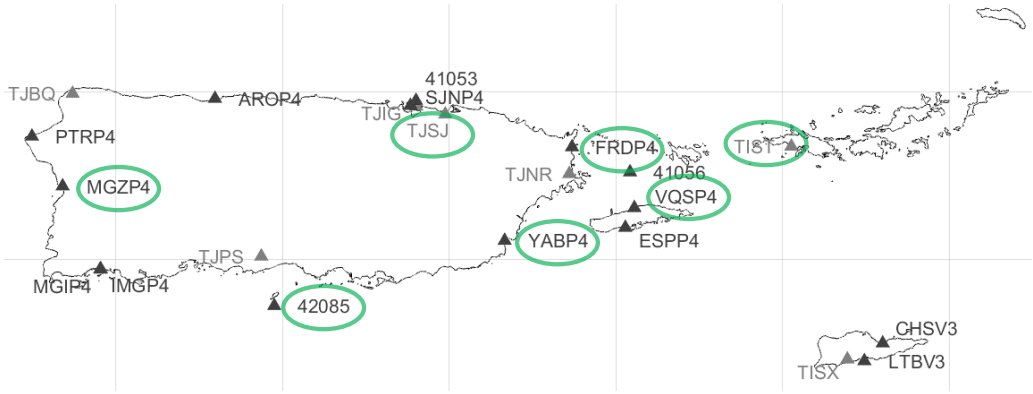
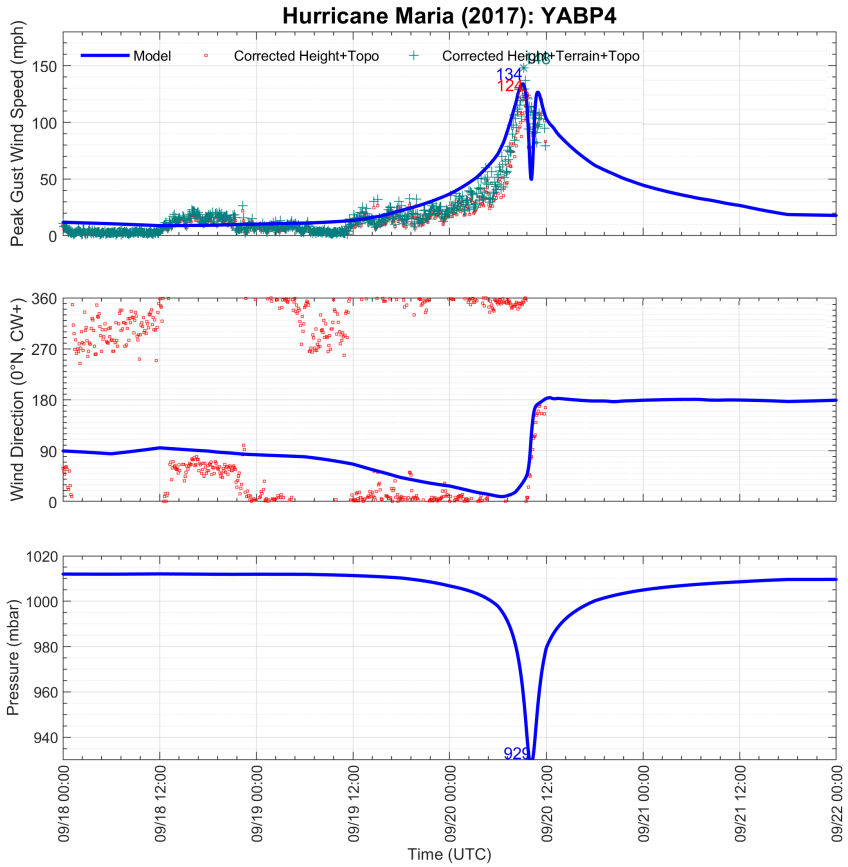


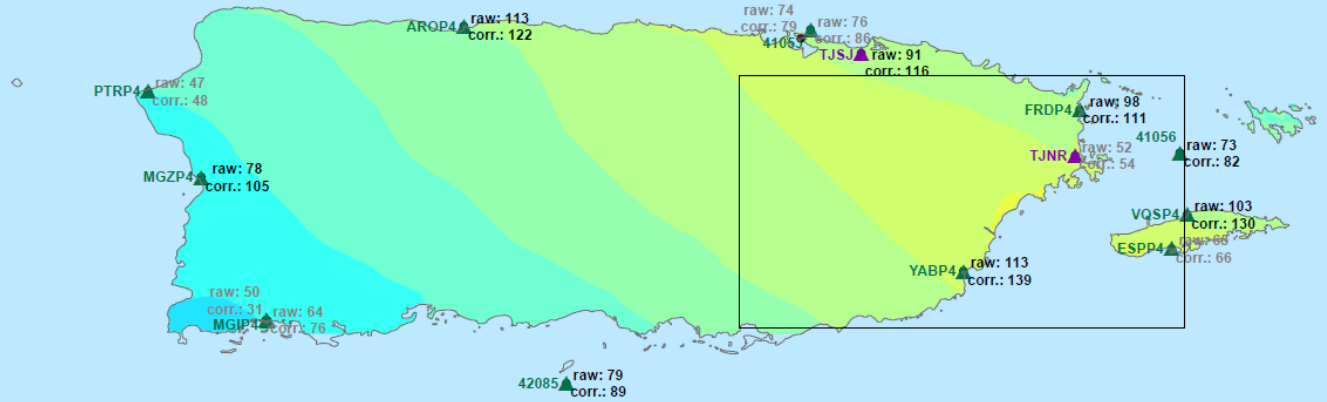
Stations that measured near peak wind speeds before failures



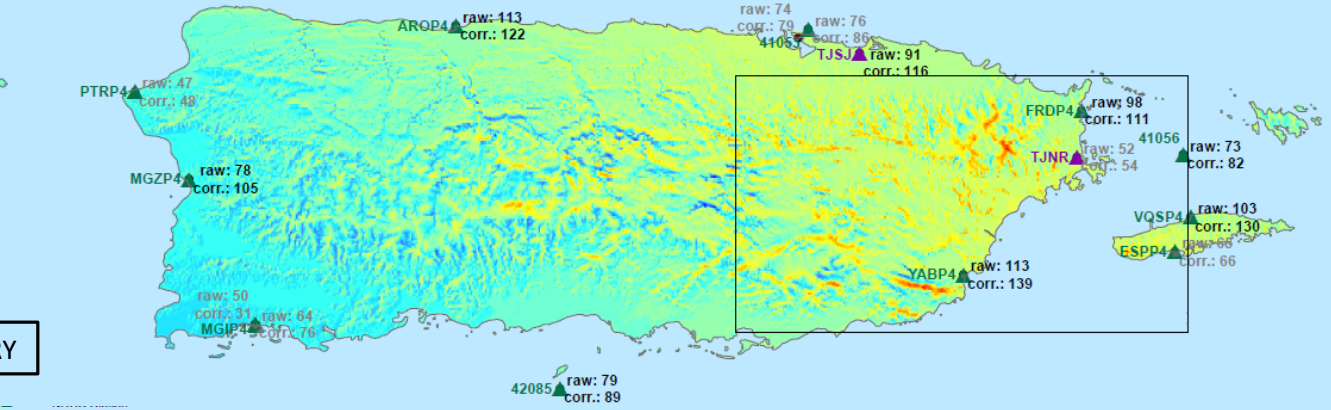
Initial Wind Field Model

Peak gust wind speeds for Hurricane Maria with and without topographic effects:

Without topographic effects (flat terrain: 100 m grid)



With topographic effects (local terrain: 100 m grid)

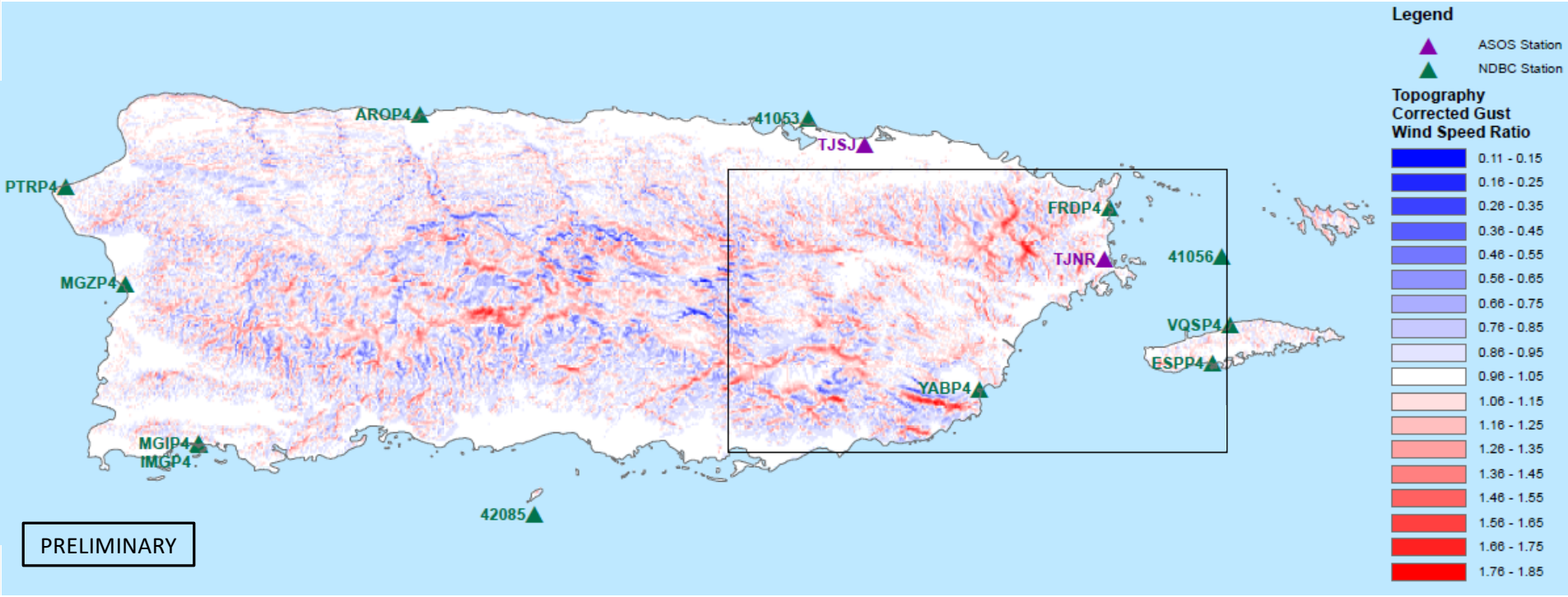


PRELIMINARY

Initial Wind Field Model

$$\text{Topographic Speedup Factor} = \frac{\text{Peak Gust Wind Speed with Topographic Corrections}}{\text{Peak Gust Wind Speed without Topographic Corrections}}$$

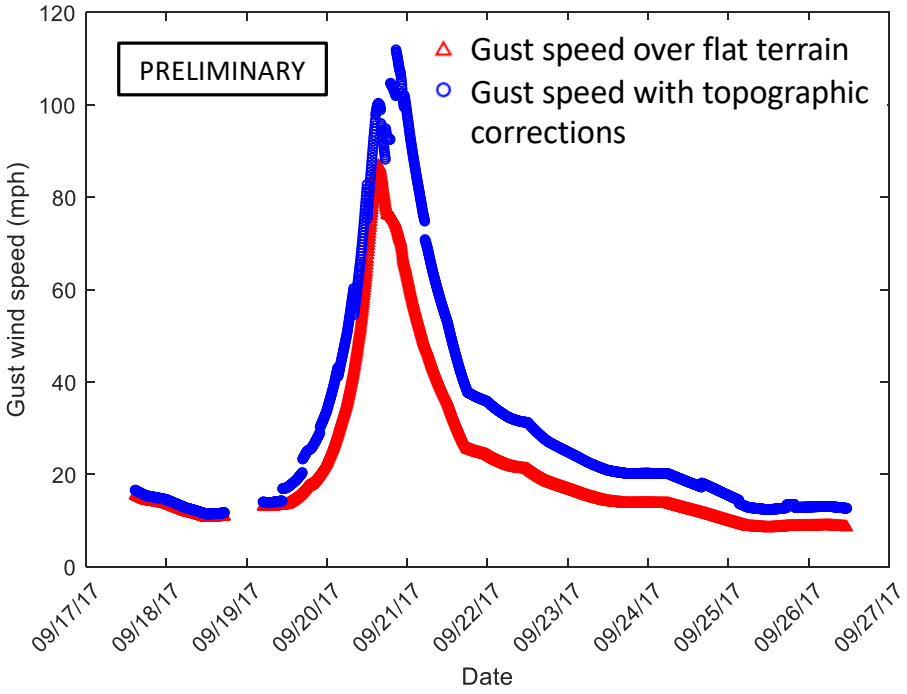
These values of the Topographic Speedup Factor are specific to Hurricane Maria:

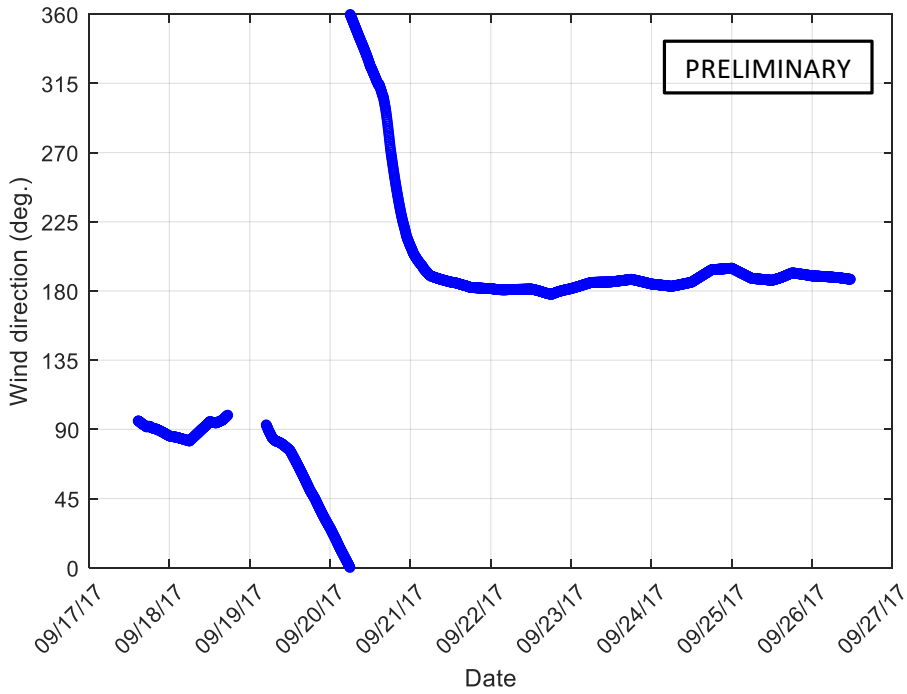


Initial Wind Field Model

Time histories of wind speed and direction at a selected hospital during Hurricane Maria:

- Topographic Speedup Factor at peak gust wind: 1.52



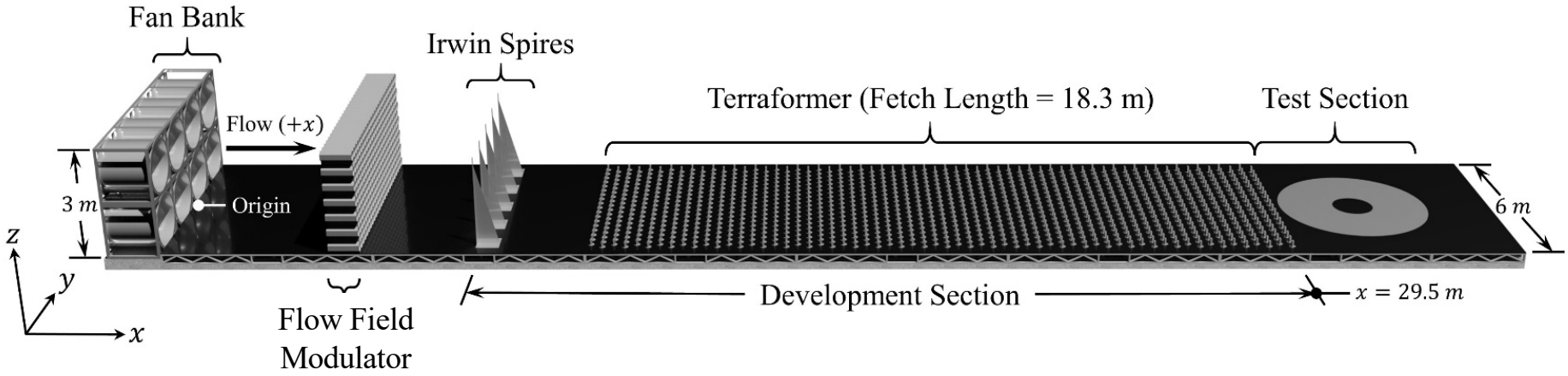


Wind Tunnel Testing

Purpose: Obtain flow-field measurements from wind tunnel testing of topographic features to provide experimental data with quantified uncertainties for characterization of topographic speedup effects and for validation of numerical models

Contract awarded to University of Florida to support wind tunnel testing tasks:

- Fabrication and wind tunnel testing of topographic models
- Fabrication and wind tunnel testing of building models (supports Buildings Project)



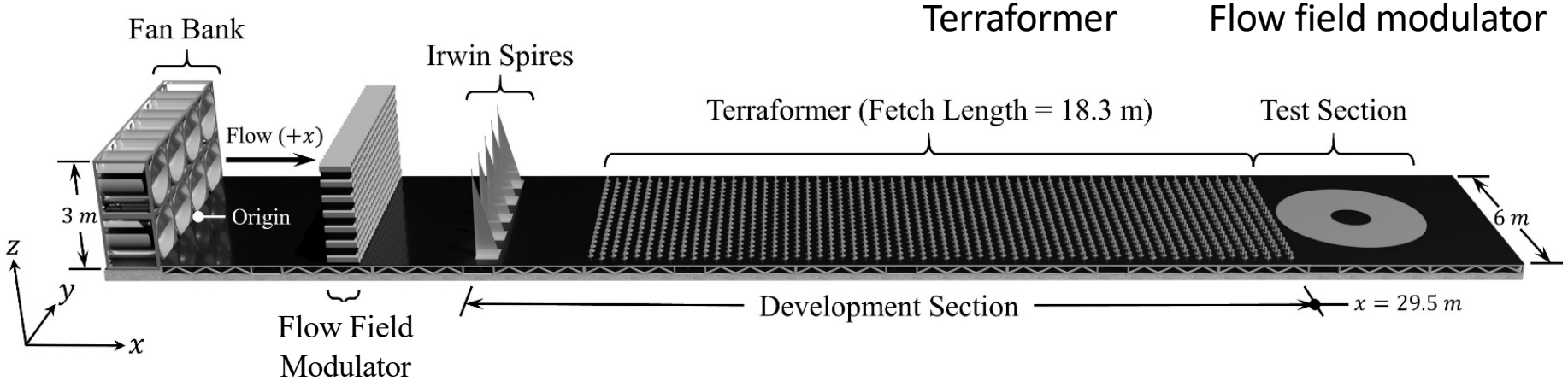
Wind Tunnel Testing: Flow Control Systems

Flow control systems for achieving target characteristics of approach flow:

- **Terraformer:** controls surface roughness of approach fetch
- **Flow field modulator:** high-resolution control of incoming flow profile

Terraformer

Flow field modulator



Wind Tunnel Testing: Flow Measurement Systems

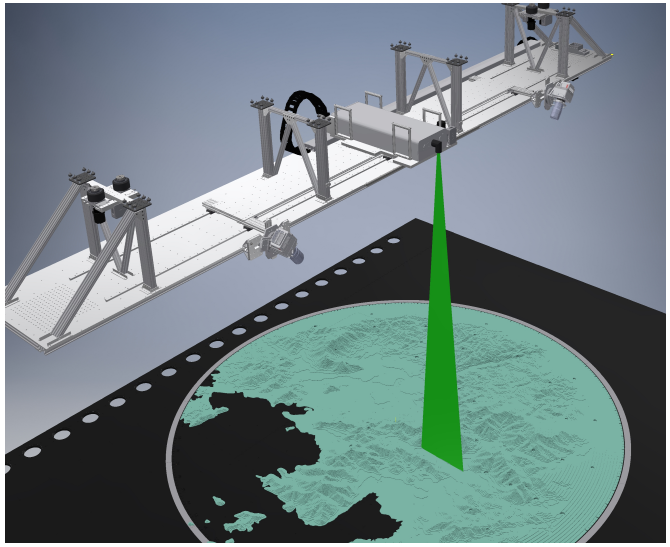
Velocity Measurements:

- Three-component velocity probes
- Stereoscopic Particle Image Velocimetry (PIV) system

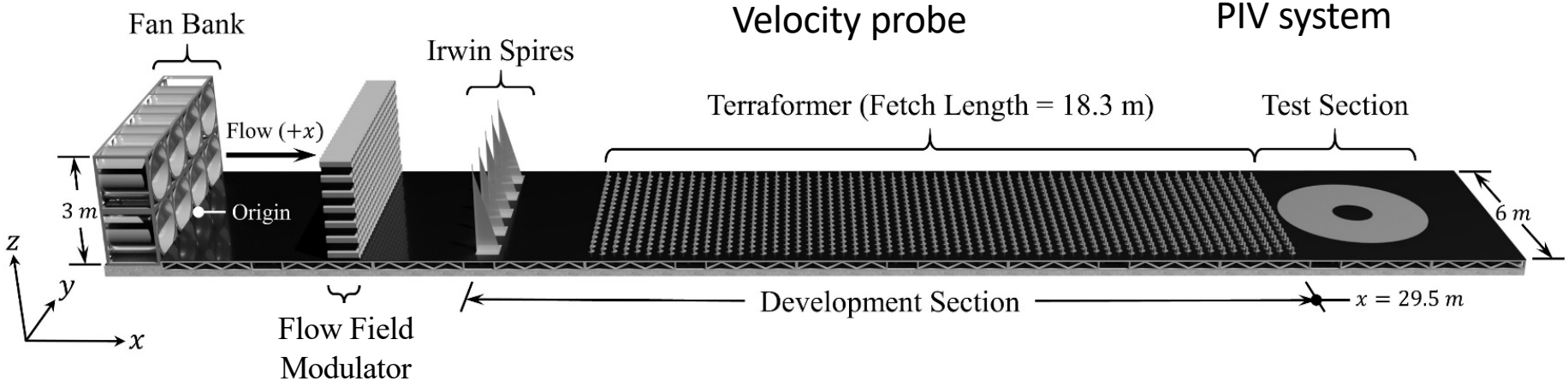
Pressure Measurements:

- Multi-channel pressure scanning system

Velocity probe



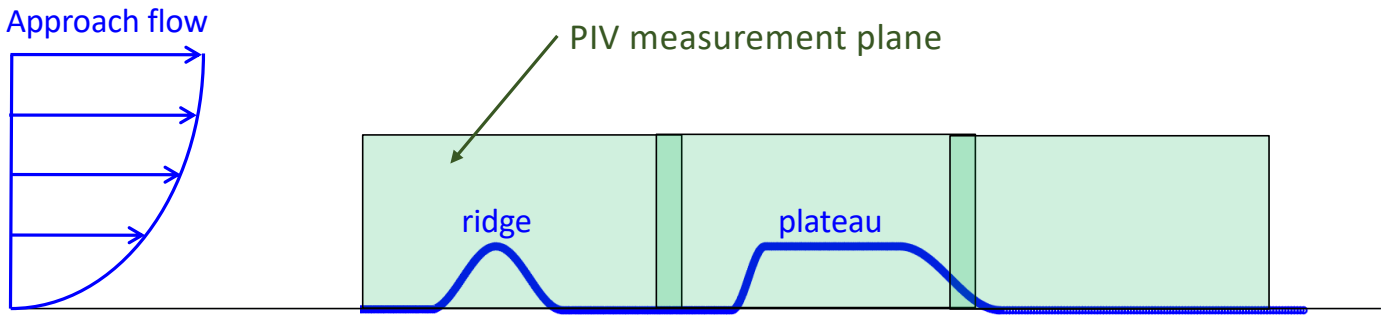
PIV system



Wind Tunnel Testing: Generic 2D Topographic Features

Purpose: Obtain flow-field measurements for validation of computational fluid dynamics (CFD) models for simulation of wind flow over topographic features

- Flow characteristics of interest: flow separation, reattachment, recirculation
- Each model consists of a 2D ridge and a 2D plateau under stationary flow at 1:3100 scale
- Three models will be fabricated with different surface conditions (smooth, roughened, terraced) to investigate the influence of surface roughness on the flow characteristics
- Each model will be tested in different configurations (e.g., ridge windward, plateau windward) and with varying separation distance between the ridge and the plateau

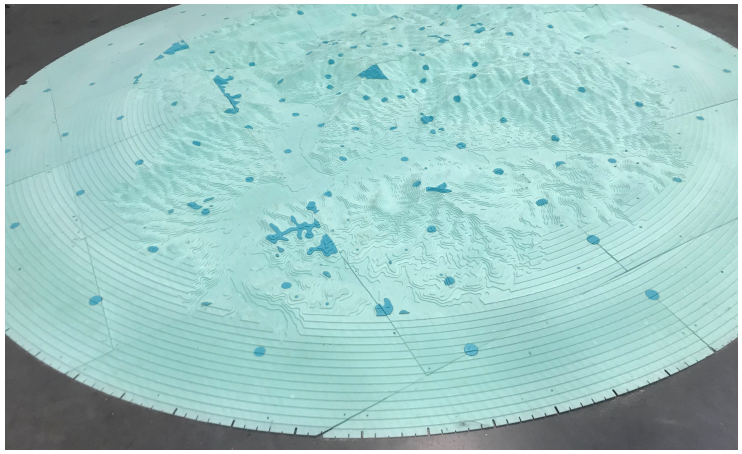


Wind Tunnel Testing: Topography of Puerto Rico

Purpose: Obtain flow-field measurements over topographic models of Puerto Rico to

1. Evaluate topographic speedup effects
2. Validate computational fluid dynamics (CFD) models
3. Define approach flow characteristic for subsequent wind tunnel testing of building models

- Testing will use a combination of new and existing topographic models of Puerto Rico
- Models will be at 1:3100 scale, representing circular regions 12.4 km in diameter
- Models will be tested under stationary incoming flow
- Flow field measurements will be performed using a combination of velocity probes and PIV



Existing Model of Utuado Region

Existing Model of Culebra

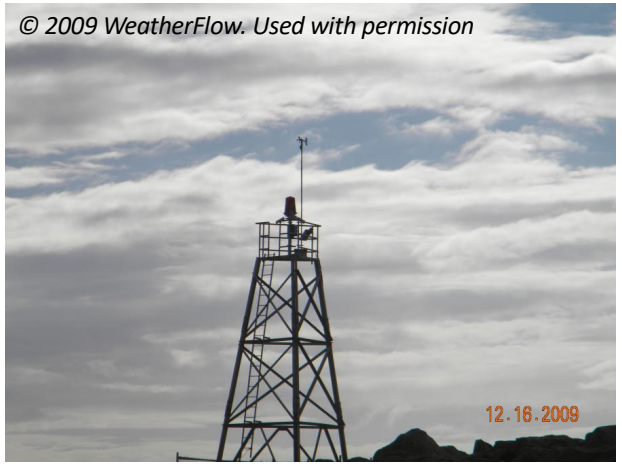
Field Measurement of Winds in Puerto Rico

Purpose: Obtain full-scale measurements of winds in regions of topographic interest in Puerto Rico, to provide information for validation of wind tunnel test results and numerical models

Deployment of weather stations will be conducted through a contract with University of Florida

Planned tasks:

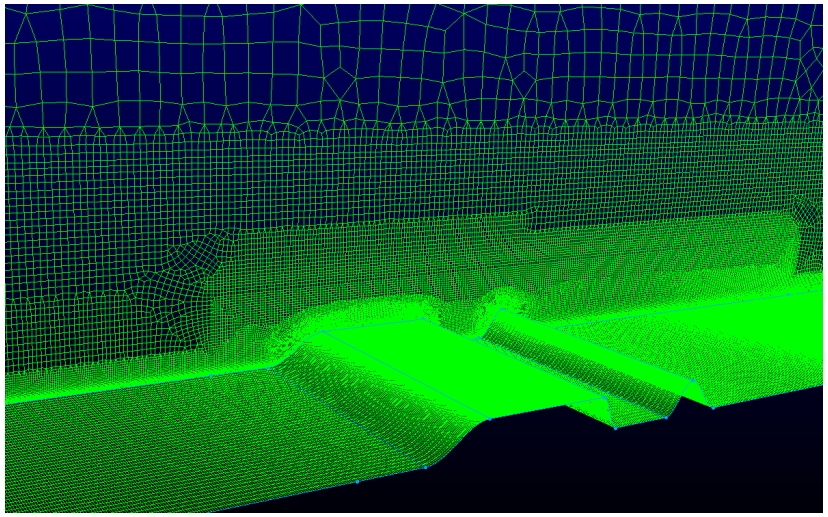
- Select sites for field deployment (in progress)
- Install weather stations on existing towers, with anemometers at 3 elevations per tower
- Collect wind data at three weather stations for one year
- Analyze data and compare with wind tunnel and numerical results



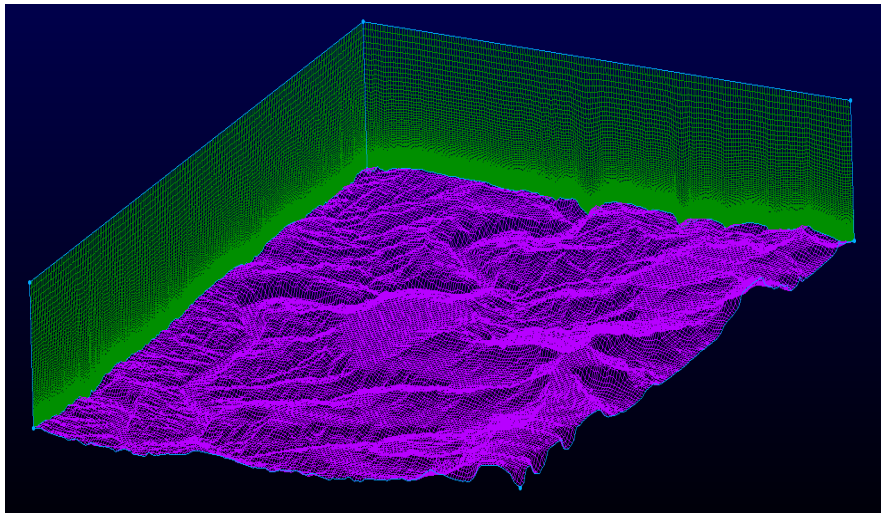
Computational Fluid Dynamics Simulations

Purpose: Develop computational fluid dynamics (CFD) models for topographic effects on winds, verify CFD simulations, validate CFD results against wind tunnel and field measurement data, and use the validated CFD models to evaluate and characterize topographic speedup effects in Puerto Rico

- CFD simulations of generic 2D topographic features
- CFD simulations of topography in Puerto Rico



NIST CFD model of generic 2D topography



NIST CFD model of actual topographic features

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Questions?