University of Puerto Rico Mayagüez
College of Engineering

NOAA's 2021 Hurricane Webinar series:
¿Cómo se está recuperando Puerto Rico? Cuatro años después del huracán María

May 10, 2021 · **Revisiting Hurricane Maria's impact to Puerto Rico: Topographic wind speed-up in complex terrains and lessons learned**

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with contributions from

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Edward L. Cruz-García, Department of Civil Engineering and Surveying, University of Puerto Rico at Mayagüez

Department of Civil Engineering and Surveying

Agenda

- Hurricane Maria: Motivation for advance research towards Hazard Mitigation
  - Multiple projects → composite goals
  - FEMA STARR II Project → (short fuse) large scale BLWT study
    - New 2018 Puerto Rico Hurricane design Maps
  - NSF EAGER Project (ongoing) – University of Florida & University of Puerto Rico Mayagüez
    - FEMA STARR II data → shallow neural network to predict "point" speedup
    - Particle image velocity (PIV) → neural network to predict ABL properties
    - Assessment of numerical weather prediction tools to simulate speedup
- Lessons learned to address informal construction challenges in Puerto Rico
  - 2018 Puerto Rico Building Code Prescriptive Residential Design Plans

Hurricane Maria (2017)

- Category 4 at landfall (155 mph sustain winds)
- Worst storm to strike Puerto Rico in 80 yrs
- More than 3000 people killed
- Damage estimate > $100B
- Country is still recovering …



The Saffir-Simpson Hurricane Wind Scale

The Saffir-Simpson Team (Timothy Schott, Chris Landsea, Gene Hafele, Jeffrey Lorens, Arthur Taylor, Harvey Thurm, Bill Ward, Mark Willis, and Walt Zaleski)

Updated 2 January 2019 to include central North Pacific examples

The Saffir-Simpson Hurricane Wind Scale is a 1 to 5 categorization based on the hurricane's intensity at the indicated time. The scale – originally developed by wind engineer Herb Saffir and meteorologist Bob Simpson – has been an excellent tool for alerting the public about the possible impacts of various intensity hurricanes[1]. The scale provides examples of the type of damage and impacts in the United States associated with winds of the indicated intensity. In general, damage rises by about a factor of four for every category increase[2]. The maximum sustained surface wind speed (peak 1-minute wind at the standard meteorological observation height of 10 m [33 ft] over unobstructed exposure) associated with the cyclone is the determining factor in the scale. (Note that sustained winds can be stronger in hilly or mountainous terrain – such as the over the Appalachians or over much of Puerto Rico - compared with that experienced over flat terrain[3].) The historical examples provided in each of the categories correspond with

Relación de Velocidad de Viento de:

Escala Saffir-Simpson → Velocidad de Diseño ASCE 7

La escala de vientos huracanados Saffir-Simpson: Define **vientos sostenidos de 1 minuto** medido a 10 m de altura en una exposición abierta al mar.

→

La velocidad de diseño según el ASCE 7 se define como una **ráfaga de viento de 3 segundos** medido a 10m de altura en una exposición de terreno abierto

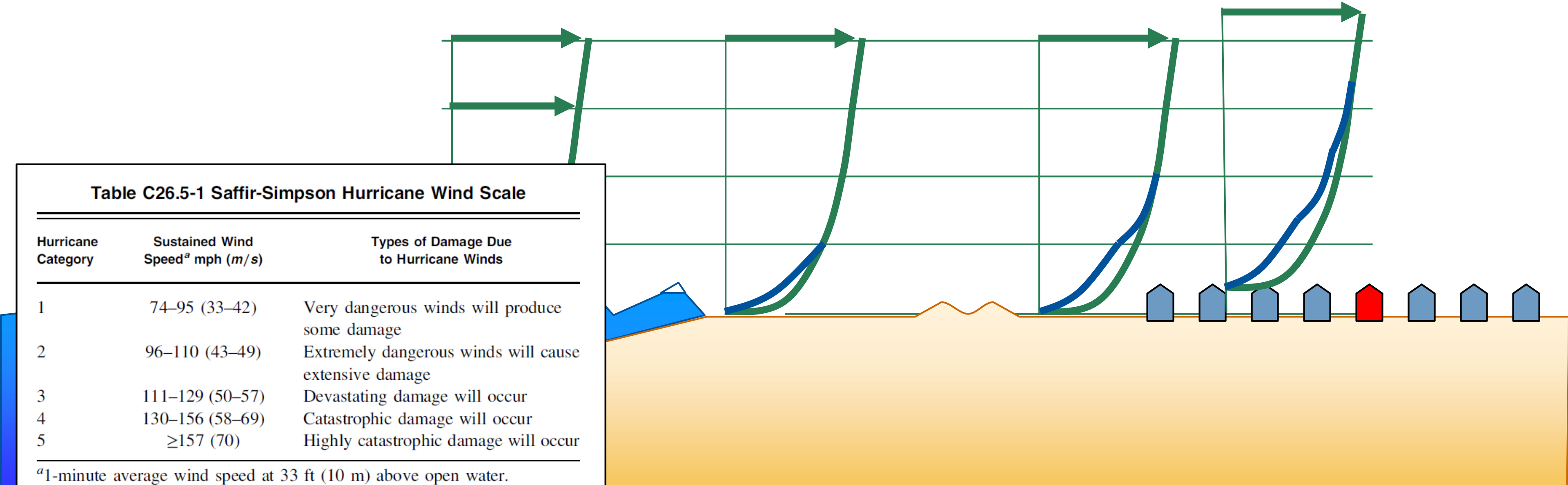


Table C26.5-1 Saffir-Simpson Hurricane Wind Scale

Hurricane Category	Sustained Wind Speed[a] mph (m/s)	Types of Damage Due to Hurricane Winds
1	74–95 (33–42)	Very dangerous winds will produce some damage
2	96–110 (43–49)	Extremely dangerous winds will cause extensive damage
3	111–129 (50–57)	Devastating damage will occur
4	130–156 (58–69)	Catastrophic damage will occur
5	≥157 (70)	Highly catastrophic damage will occur

[a]1-minute average wind speed at 33 ft (10 m) above open water.

Slide courtesy of Dr. Forrest Masters, University of Florida
Modified by Dr. Luis D. Aponte: University of Puerto Rico at Mayagüez

Relación de Ráfagas de Diseño a la escala Saffir-Simpson

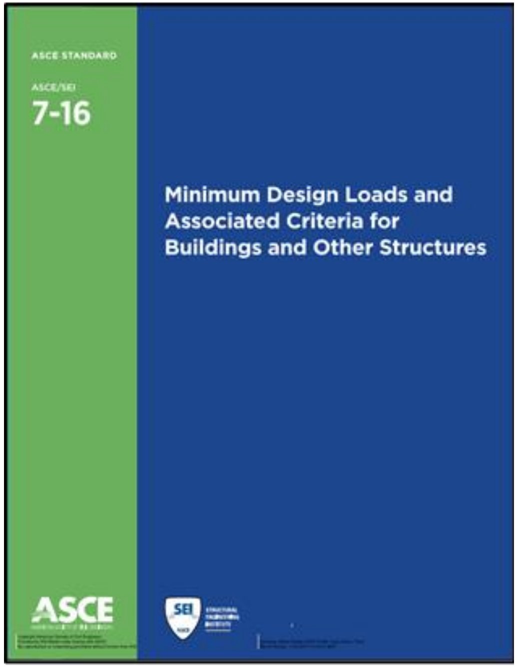
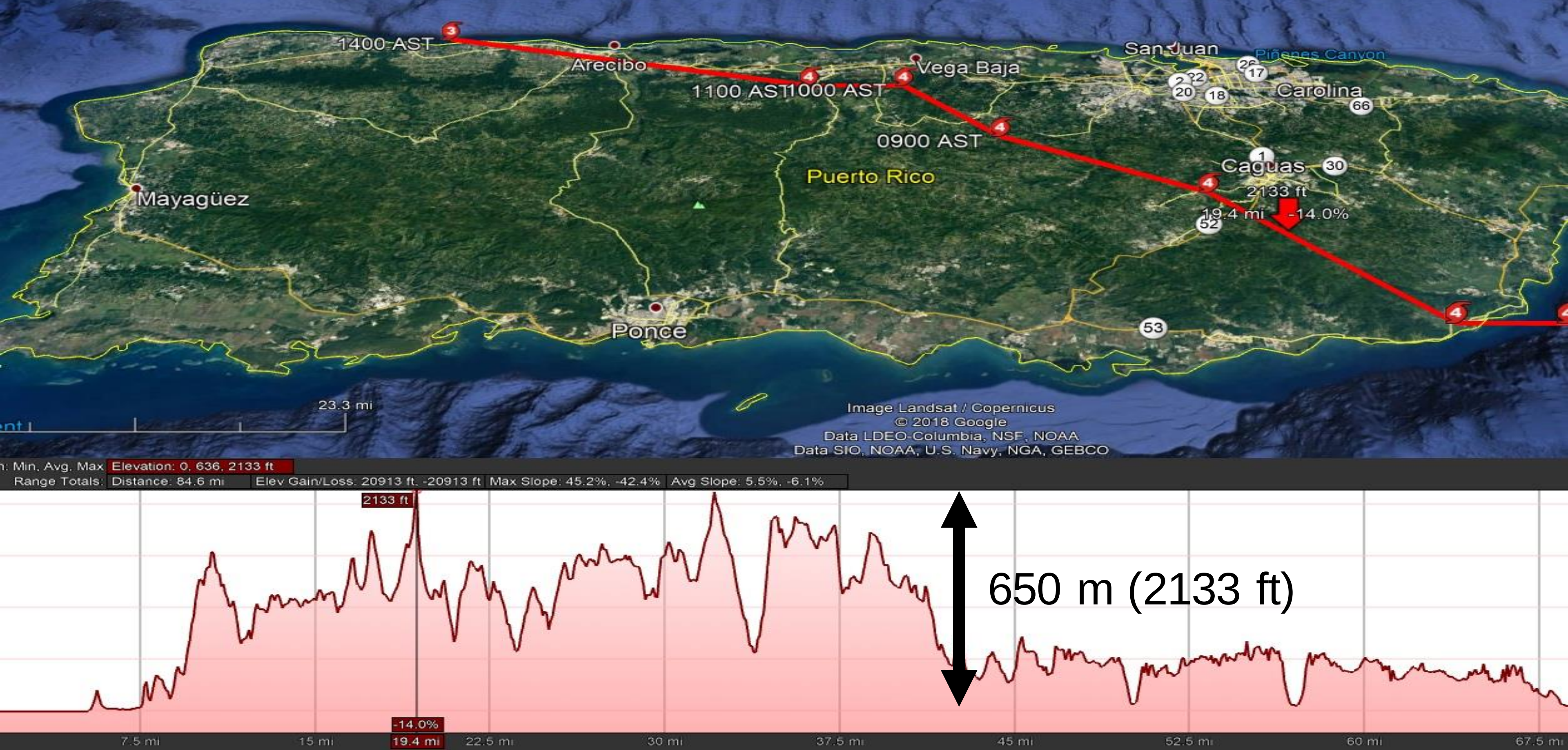


Table C26.5-2 Approximate Relationship between Wind Speeds in ASCE 7 and Saffir-Simpson Hurricane Wind Scale

Saffir-Simpson Hurricane Category	Sustained Wind Speed over Water[a]		Gust Wind Speed over Water[b]		Gust Wind Speed Over Land[c]	
	mph	m/s	mph	m/s	mph	m/s
1	74–95	33–42	90–116	40–51	81–105	36–47
2	96–110	43–49	117–134	52–59	106–121	48–54
3	111–129	50–57	135–157	60–70	122–142	55–63
4	130–156	58–69	158–190	71–84	143–172	64–76
5	>157	>70	>191	>85	>173	>77

[a]1-min average wind speed at 33 ft (10 m) above open water.
[b]3-s gust wind speed at 33 ft (10 m) above open water.
[c]3-s gust wind speed at 33 ft (10 m) above open ground in Exposure Category C. This column has the same basis (averaging time, height, and exposure) as the basic wind speed from Figs. 26.5-1 and 26.5-2.

Ground elevation along Maria’s track



Evidence of topographic wind speedup

(left pane) Loiza, PR after Hurricane Georges. Photo obtained from the FEMA (1999) Building Performance Assessment Report

(right pane) Yabucoa, PR after Hurricane Maria (1997). Photo obtained from the NSF RAPID Award CMMI-1761461 (PI Tracy Kijewski-Correa) and the FEMA Mitigation Assessment Team

Figure 1. Damage associated with topographic wind speed up

This group grew and became StEER in the NHERI program

Puerto Rico’s Radar – Cayey, PR

Tweet

NWS San Juan @NWSSanJuan · Sep 24, 2017
Actual situation of Doppler radar after Hurricane María.
Situación actual del radar Doppler luego del paso del huracán María. #prwx #usviwx

114 2.8K 1.7K

Replies

Remy Mermelstein | WeatherInTheHud @Weatherl... · Sep 24, 2017
Replying to @NWSSanJuan
How are you forecasting w/out radar? Or do you have mobile unit already?

4 1 6

WEATHER NEWS

Puerto Rico's Radar Restored 9 Months After Hurricane Maria's Wrath

June 18, 2018

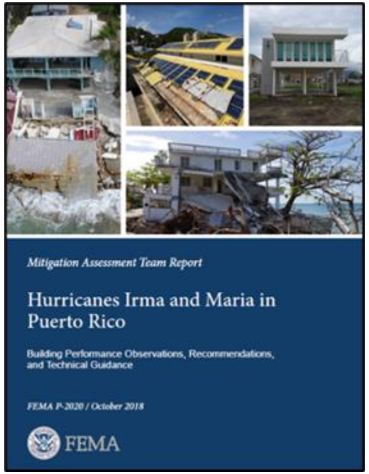
The image above shows a radome being lifted onto a tower in San Juan, Puerto Rico. Nine months after being ravaged by Hurricane Maria, the U.S. territory has restored its radar.

(Facebook/US Nexrad Radar Operations Center)

Past research (experimental, strong winds)

- BLWT studies dominantly focused on flows over hills and other simple landforms, e.g., Teunissen et al., 1987; Salmon et al., 1988, Kondo et al., 2002; Ngo and Letchford, 2009; Kilpatrick et al, 2016
- Field experiments (e.g., FLUXNET, Perdigão, MATERHORN) have played a critical role in this work, elucidating flow separation, the effect of surface roughness and canopy morphology on flows, etc.
- Far fewer studies of complex topography (our focus), e.g., Chock and Cochran, 2005; Rasouli et al., 2009; McAuliffe and Larose, 2012
- Recent summary: Finnegan et al., 2020: Boundary layer flow over complex topography, *Boundary-Layer Meteorology*, DOI: 10.1007/s10546-020-00564-3

Evidence of topographic wind speedup



FEMA P-2020 Hurricanes Irma and Maria in Puerto Rico: Conclusion PR-36

Topography affected (increased) wind speeds through mountain areas of Puerto Rico: The MAT observed the effects of topography on the wind speeds across the islands. Many locations were observed to have experienced higher wind speeds due to the channeling of the wind through the mountains. Designing for these effects involves using a complicated method for estimating wind speed-up in ASCE 7 (incorporated by referenced by the IBC). ***To improve performance of buildings in the_portions of the island where wind speed-up occurs, better design guidance is required along with an outreach campaign***. Most locations impacted on the island did not appear to have hardened buildings to resist the higher wind speeds.

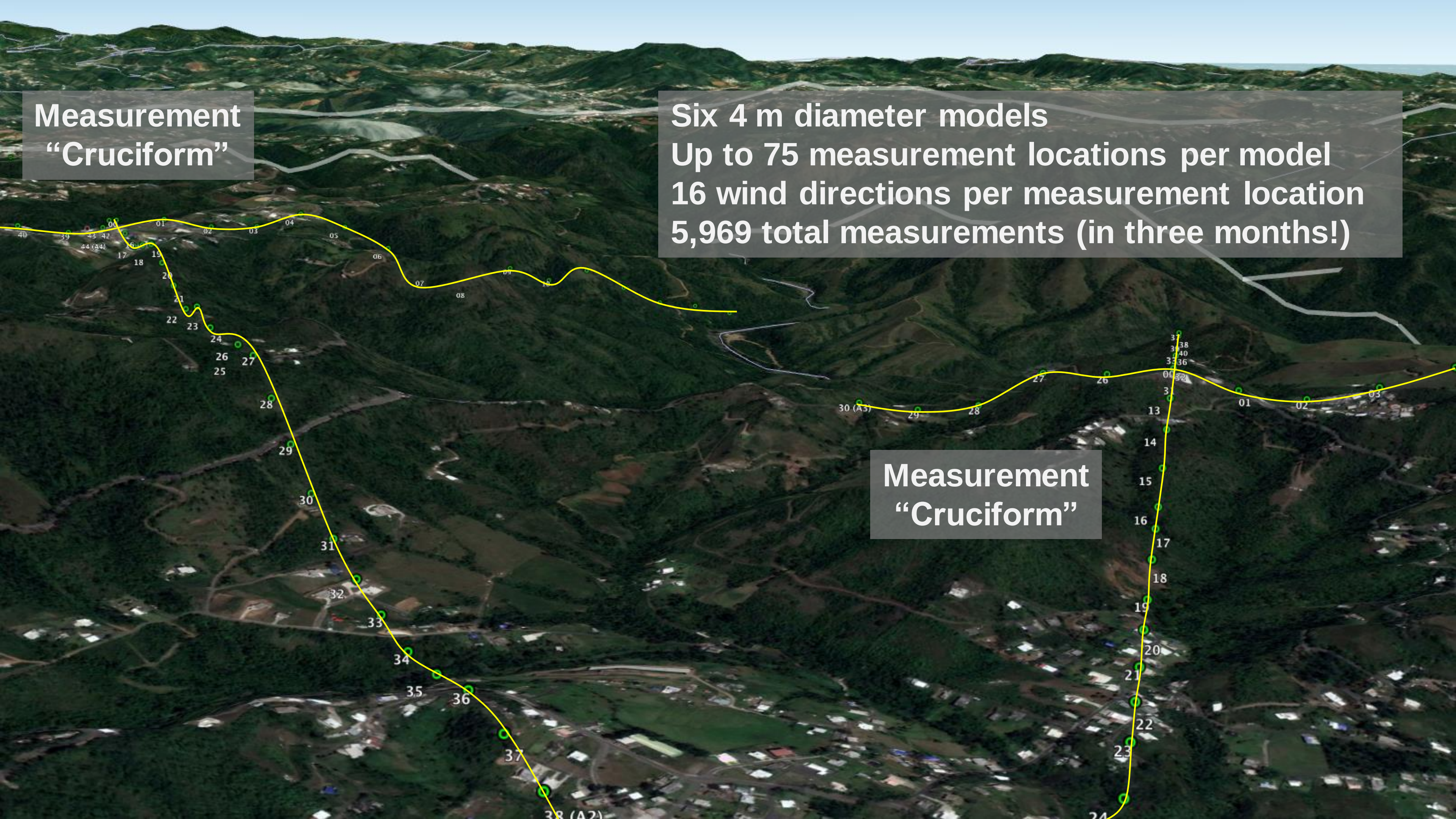
> Recommendation PR-36. **Develop new design guidance for wind speed-up in Puerto Rico.** Puerto Rico should develop and include guidance on topographic effects in the PRBC. A study to ***produce guidance or wind maps similar to what was produced for Hawaii*** would provide a more useful approach for designers to address wind speed-up appropriately in building design. If this guidance can be developed and adopted in Puerto Rico, it can be proposed for incorporation into the next edition of ASCE 7.

FEMA STARR II

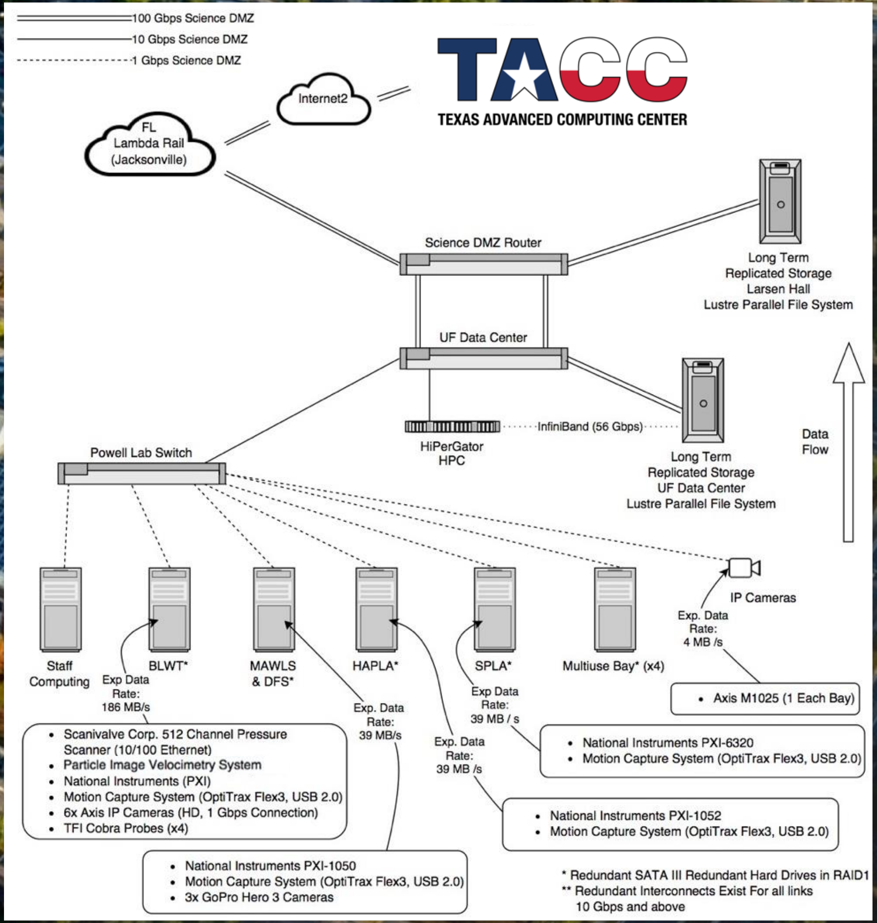
- STARR II Production and Technical Services Architectural and Engineering contracted **Applied Research Associates** (ARA) to create a special wind region map for the mountainous areas in Puerto Rico, as defined by Section 26.5.2 in the ASCE 7-16 Standard *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*
  - Also known as **Microzonation**
- The map depicts the ultimate wind speed contours to design civil infrastructure, accounting for (a) hurricane climatology and surface wind field characteristics and (b) **Topographic wind speed up** caused by Puerto Rico's extensive mountainous terrain
- The **University of Florida** supported this effort by experimentally characterizing speedup on the main island of Puerto Rico and the municipal Islands of Vieques and Culebra in a boundary layer wind tunnel (BLWT), with the goal of collecting data for ARA to validate wind speedup predictions informed by studies of geographic regions outside of Puerto Rico

Six study regions

1:3100 scale | 12.2 km diameter in the projected state plane coordinate system


Measurement "Cruciform"
Six 4 m diameter models
Up to 75 measurement locations per model
16 wind directions per measurement location
5,969 total measurements (in three months!)
Measurement "Cruciform"


Powell Laboratory
High Performance Computing Center


100 Gbps Science DMZ
10 Gbps Science DMZ
1 Gbps Science DMZ
TACC
TEXAS ADVANCED COMPUTING CENTER
Internet2
FL Lambda Rail (Jacksonville)
Science DMZ Router
Long Term Replicated Storage Larsen Hall Lustre Parallel File System
UF Data Center
InfiniBand (56 Gbps)
HiPerGator HPC
Long Term Replicated Storage UF Data Center Lustre Parallel File System
Data Flow
Powell Lab Switch
Staff Computing
BLWT*
MAWLS & DFS*
HAPLA*
SPLA*
Multiuse Bay* (x4)
IP Cameras
Exp. Data Rate: 4 MB /s
Exp Data Rate: 186 MB/s
Exp. Data Rate: 39 MB/s
Exp Data Rate: 39 MB / s
Exp. Data Rate: 39 MB /s
• Axis M1025 (1 Each Bay)
• Scanivalve Corp. 512 Channel Pressure Scanner (10/100 Ethernet)
• Particle Image Velocimetry System
• National Instruments (PXI)
• Motion Capture System (OptiTrax Flex3, USB 2.0)
• 6x Axis IP Cameras (HD, 1 Gbps Connection)
• TFI Cobra Probes (x4)
• National Instruments PXI-6320
• Motion Capture System (OptiTrax Flex3, USB 2.0)
• National Instruments PXI-1052
• Motion Capture System (OptiTrax Flex3, USB 2.0)
• National Instruments PXI-1050
• Motion Capture System (OptiTrax Flex3, USB 2.0)
• 3x GoPro Hero 3 Cameras
* Redundant SATA III Redundant Hard Drives in RAID1
** Redundant Interconnects Exist For all links 10 Gbps and above

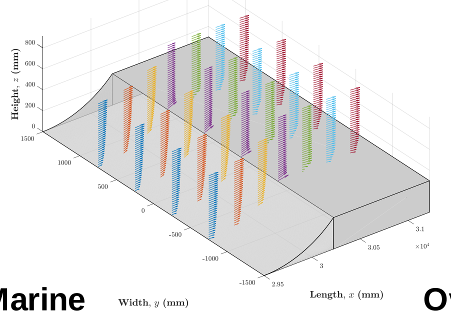
Boundary Layer Wind Tunnel (BLWT)

Specifications

120 ft L X 20 ft W X 10 ft H
+/- 3 deg adjustable ceiling pitch
8 vaneaxial fans (270 bhp each)
1-4 m adjustable turntable
Overhead gantry

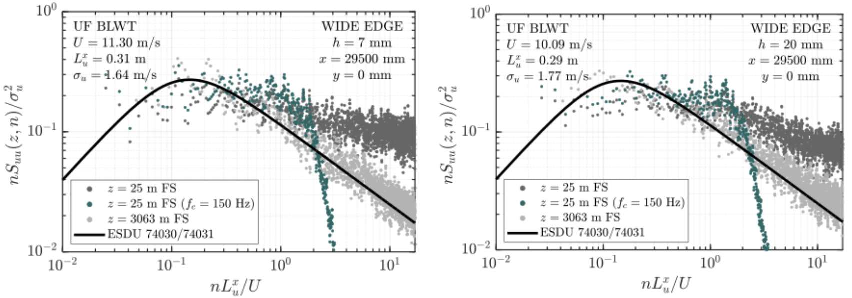
Limitations (and tradeoffs) of physical modeling

- 1:3100 geometric scale < 1:5000 allowed by ASCE 49
- Hill height Re ~ 250,000 > 100,000 recommended by Bowen (2003) ... But ratio of FS/MS Re ~ 7,000
- Simulated rough wall boundary layer behavior in the freestream but measured in the eddy surface layer
- Probe interference → 8 mm (25 m instead of 10 m FS)
- Turbulence intensity vs. router fabrication time
  - At this scale, roughness elements are generally modelled as disproportionately large to maintain turbulence
  - Tested "calibration ramp" with a slope that linearly varied from 0-45 degrees. Terrace heights = smooth, 1, 3 and 5 mm
  - 5 mm caused rise in mechanical turbulence along ramp
  - 1 mm routing takes three times as long to fabricate
  - Chose 3 mm (9.3 m FS) ...
- Approach flow transition from development section to model where complex terrain is present led to use of 7 deg tapered sections ...



Marine
z_0 = 0.005 m FS

Overland
z_0 = 0.3 m FS



FS z_0 = 0.005 m   FS z_0 = 0.300 m

Figure 4. Power spectra

Eddy surface layer anisotropic spectral decay proportional to k^{-1} is visible at the $z = 8$ mm measurement height, and an isotropic spectral decay proportional to $k^{-5/3}$ in the inertial subrange at $z = 988$ mm in the outer layer indicate high-Reynolds-number flow has been achieved (McAuliffe and Lorose, 2012).

Marine
z_0 = 0.005 m FS

Overland
z_0 = 0.3 m FS

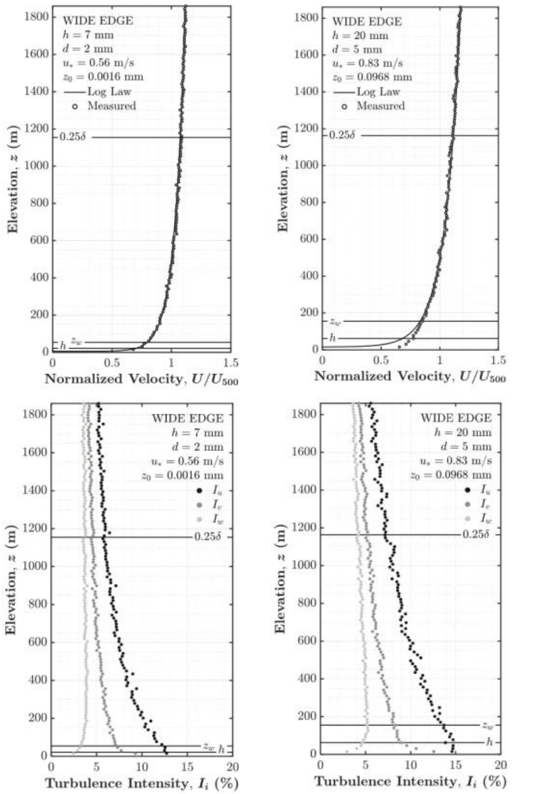
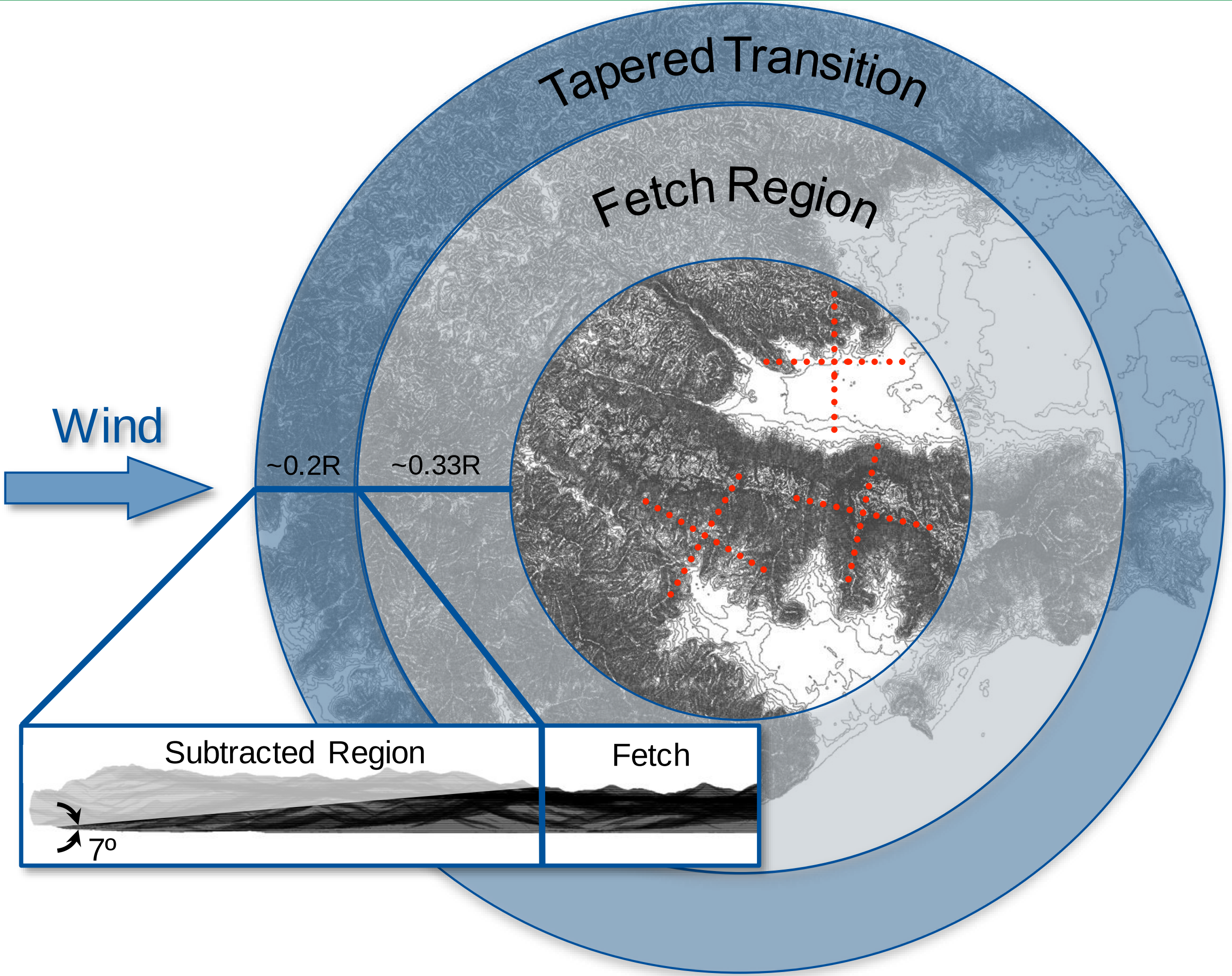
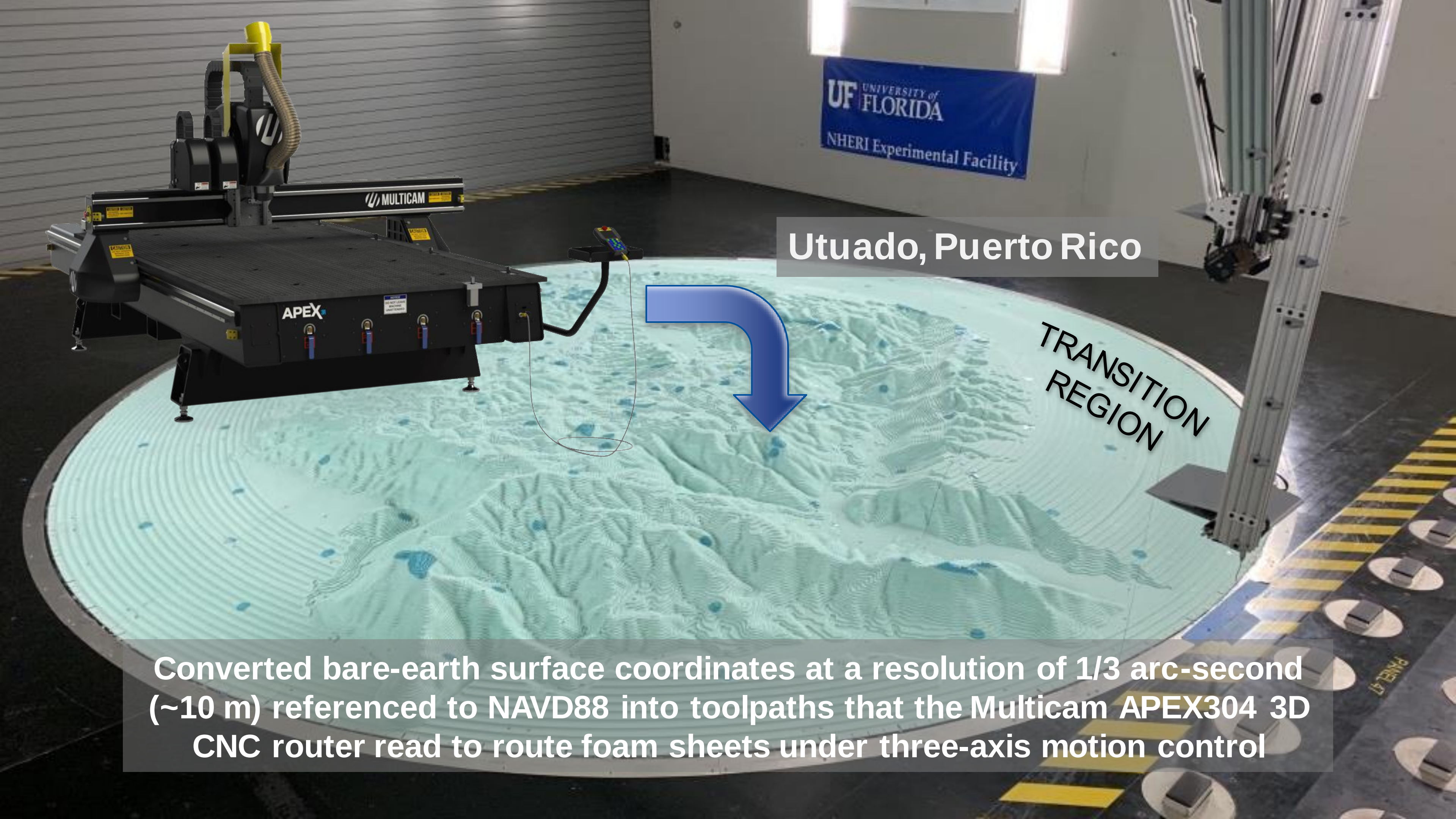
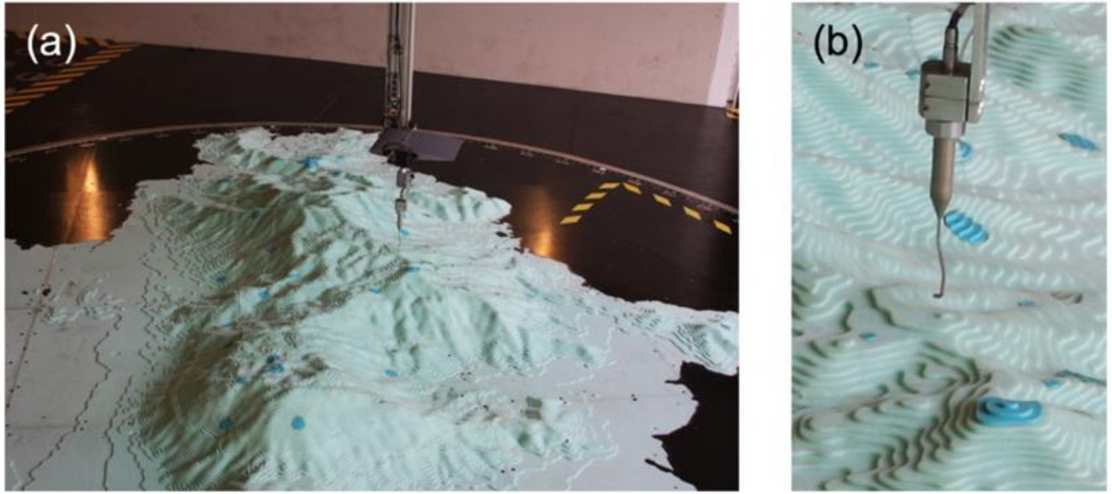


Figure 4-13. Representative mean velocity and turbulence intensity profiles for the approach flow.




UF UNIVERSITY of FLORIDA
NHERI Experimental Facility
MULTICAM
APEX
Utuado, Puerto Rico
TRANSITION REGION
Converted bare-earth surface coordinates at a resolution of 1/3 arc-second (~10 m) referenced to NAVD88 into toolpaths that the Multicam APEX304 3D CNC router read to route foam sheets under three-axis motion control

3D instrument control of the Cobra Probe Rake for measurement of surface flows. Positional accuracy = +/- 1 mm

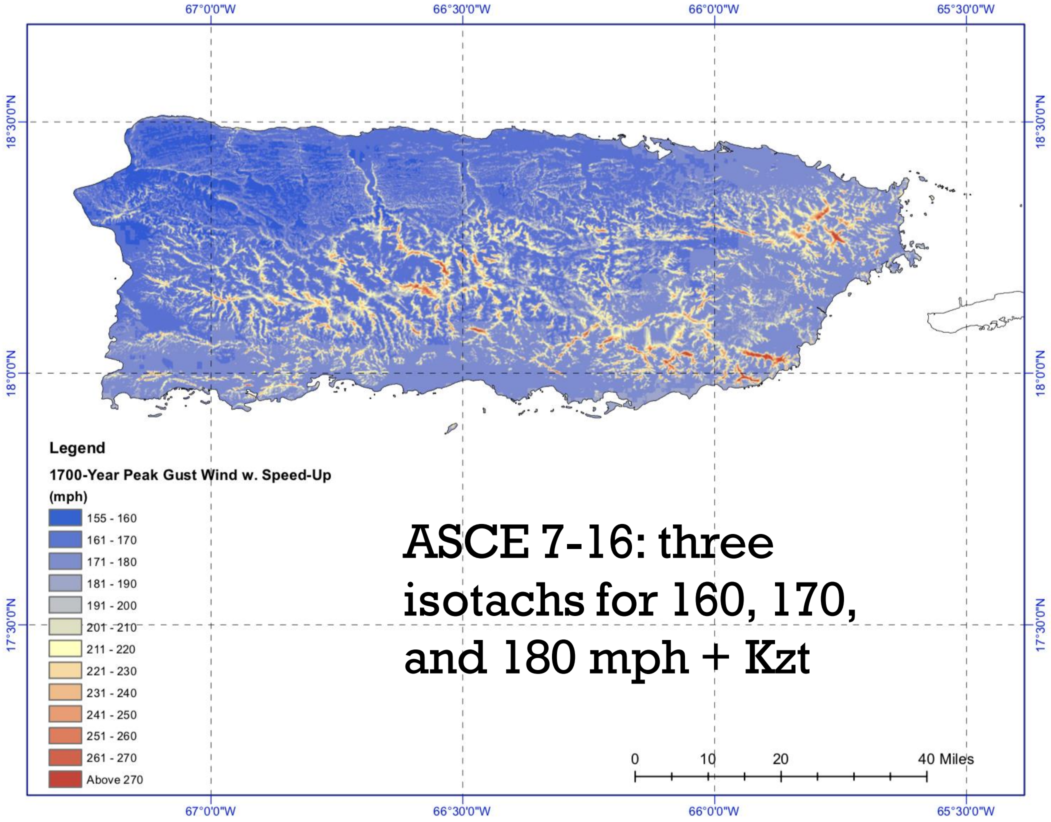


(a) Cobra Probe installed in instrument traverse

(b) Zoomed in view of the Cobra Probe over the topographic model surface

Outcomes

- ARA used data to validate speedup maps in adopted in the 2018 Puerto Rico Building Code
- Incorporated into the Applied Technology Council (ATC) *Hazards by Location* Tool
- Currently under consideration for adoption in ASCE 7-22
- A wealth of data to validate speedup models and numerical weather prediction



NIST – Disaster & Failure Studies

Hurricane Maria | NIST

nist.gov/topics/disaster-failure-studies/hurricane-maria

An official website of the United States government Here's how you know

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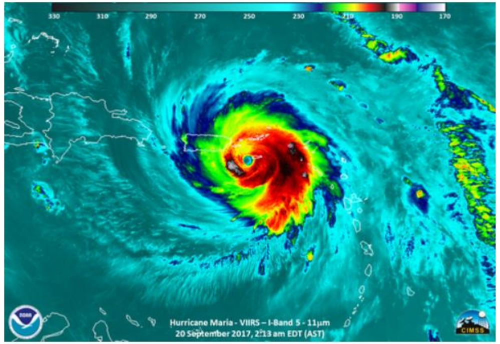
Hurricane Maria

NIST Research and Investigation

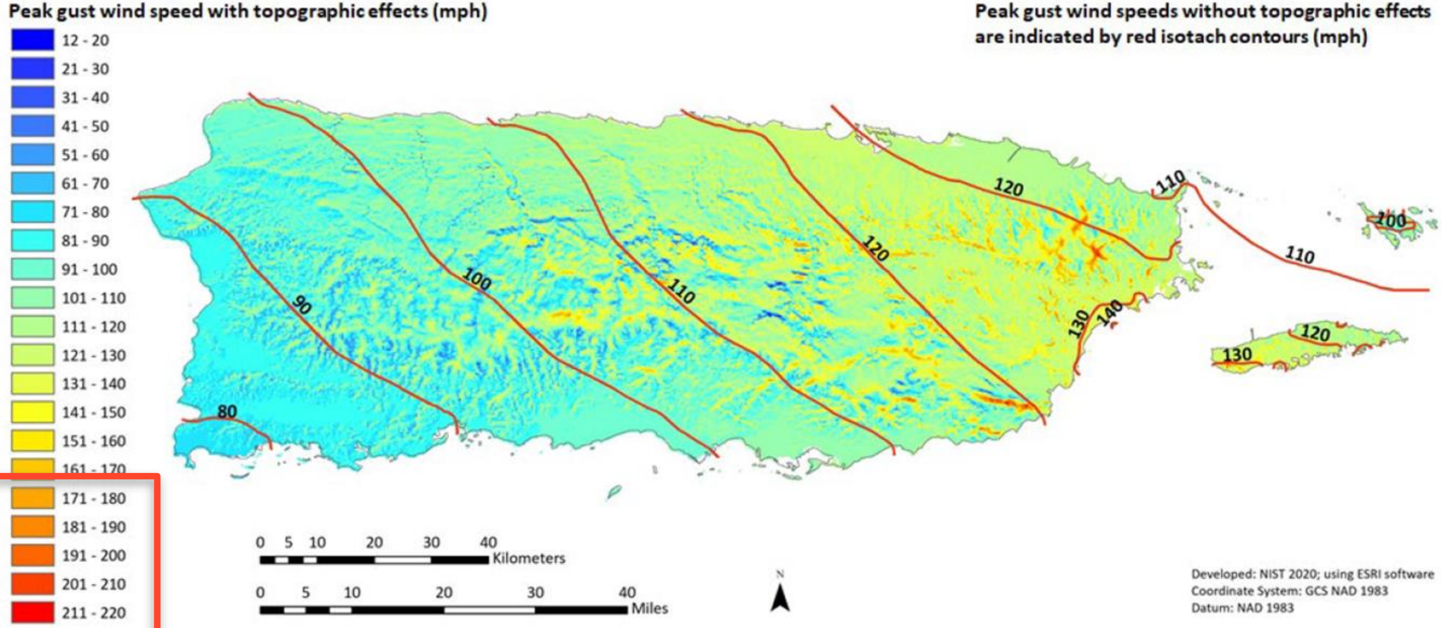
Español sitio web

On September 20, 2017, Hurricane Maria devastated much of Puerto Rico, damaging buildings that its communities relied on for medical care, safety, communications and more. To better understand how the buildings and infrastructure failed, and how we can prevent such failures in the future, in 2018 NIST launched a multi-year effort to study how critical buildings performed during the storm, as well as how emergency communications systems worked.

The goal of this effort is to make recommendations to improve building codes, standards and practices to make communities across the U.S. more resilient to hurricanes and other disasters. NIST has



NIST progress report (January 2021)



Cat. 5 > 173 mph

Figure 5. Estimated peak gust wind speeds with and without topographic effects from initial wind field model for Hurricane Maria.

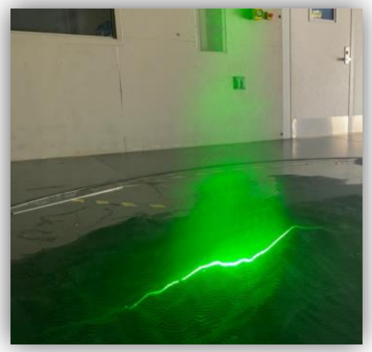
Reference: Main, J. A., Dillard, M., Kuligowski, E. D., Davis, B., Dukes, J., Harrison, K., Helgeson, J., Johnson, K., Levitan, M., Mitrani-Reiser, J., Weaver, S., Yeo, D., Aponte-Bermúdez, L. D., Cline, J., & Kirsch, T. (2021). Learning from Hurricane Maria's Impacts on Puerto Rico: A Progress Report. National Institute of Standards and Technology. https://doi.org/10.6028/NIST.SP.1262

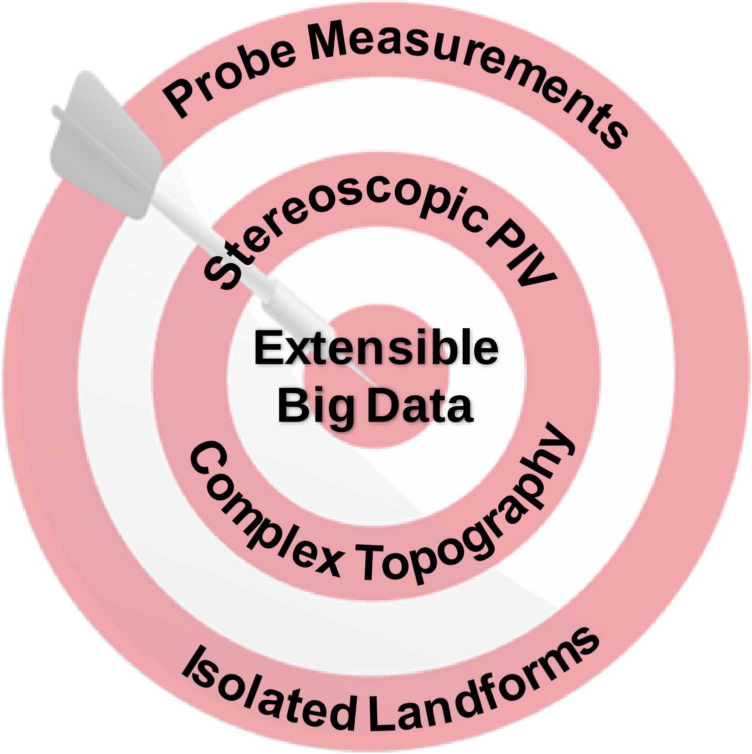
FEMA STARR II → NSF EAGER

- Investigate machine learning and multiscale atmospheric simulations—i.e., computational fluid dynamics (CFD) nested within a numerical weather prediction (NWP) framework—to assess their potential for predicting wind ‘speedup’ in mountainous areas and other regions with steep slopes
  - Added CFD-LES work in OpenFoam
- EAGER = NSF’s high-risk, high-reward program
  - Relies heavily on high throughput automation and data processing
  - Produce preliminary data for future studies
- Cobra probe → stereoscopic PIV measurements under instrument control

Anemometric measurements

Particle Image Velocity (PIV)





Validation

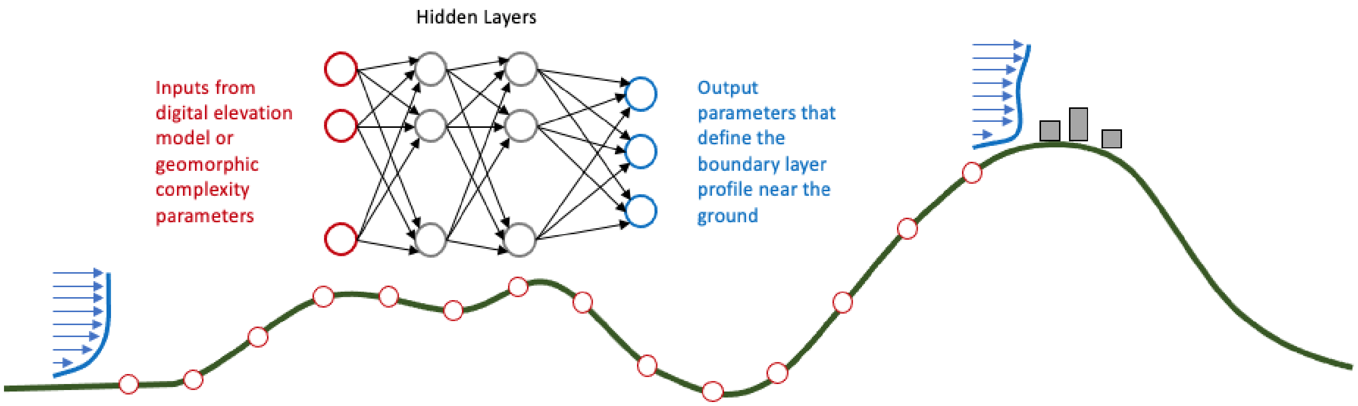
- Semi-empirical methods
- Computational fluid dynamics (CFD)
- Numerical weather prediction (NWP)

Training

- Machine learning (ML) approaches
- ML + CFD/NWP

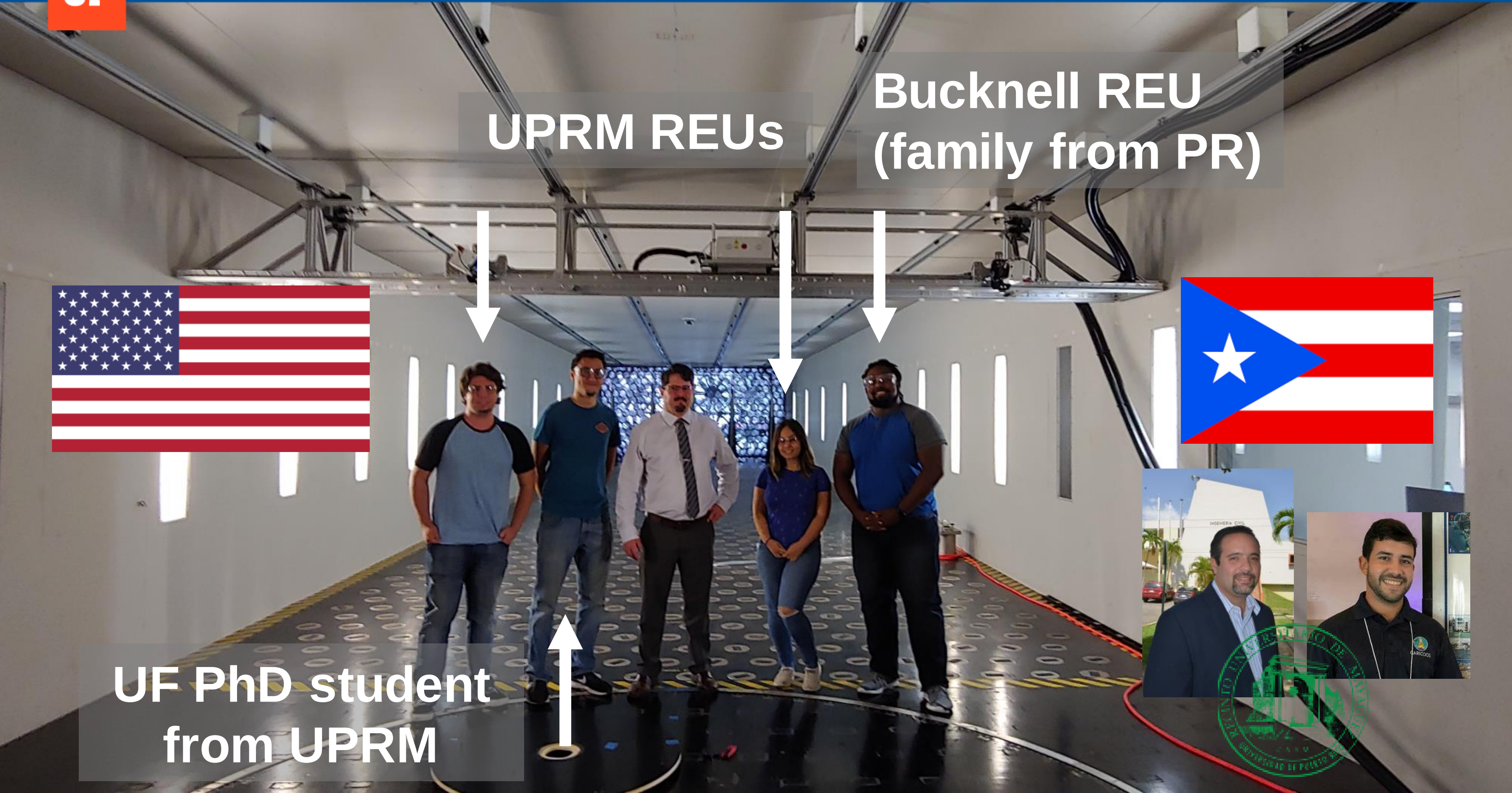
FEMA STARR II → NSF EAGER

- Investigate machine learning and multiscale atmospheric simulations—i.e., computational fluid dynamics (CFD) nested within a numerical weather prediction (NWP) framework—to assess their potential for predicting wind 'speedup' in mountainous areas and other regions with steep slopes
  - Added CFD-LES work in OpenFoam (not covered today)



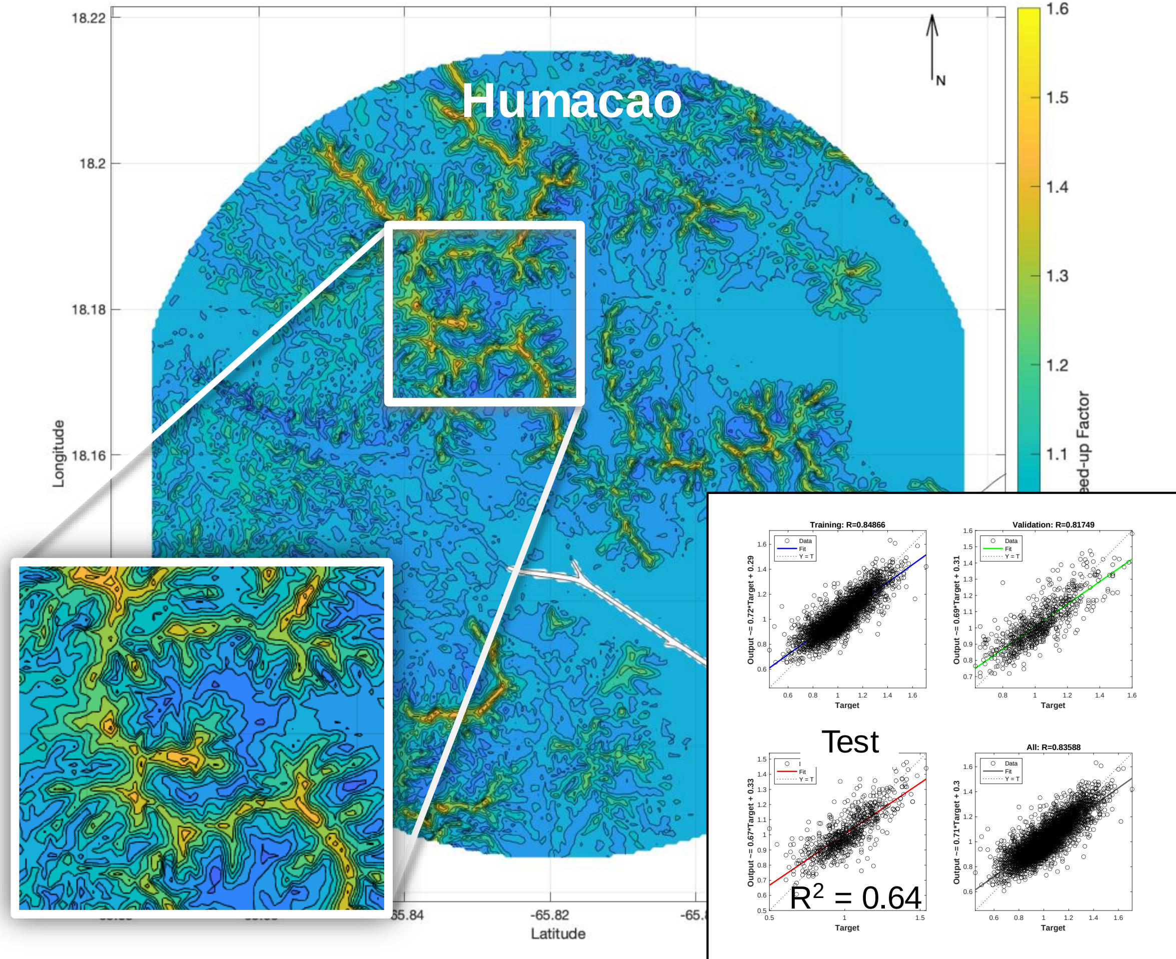
FEMA STARR II → NSF EAGER

- Investigate machine learning and multiscale atmospheric simulations—i.e., computational fluid dynamics (CFD) nested within a numerical weather prediction (NWP) framework—to assess their potential for predicting wind 'speedup' in mountainous areas and other regions with steep slopes
  - Added CFD-LES work in OpenFoam
- EAGER = NSF's high-risk, high-reward program
  - Relies heavily on high throughput automation and data processing
  - Produce preliminary data for future studies
- Cobra probe → stereoscopic PIV measurements under instrument control → complete profile measurements (not omnidirectional point measurements)
- **My favorite part of the project …**

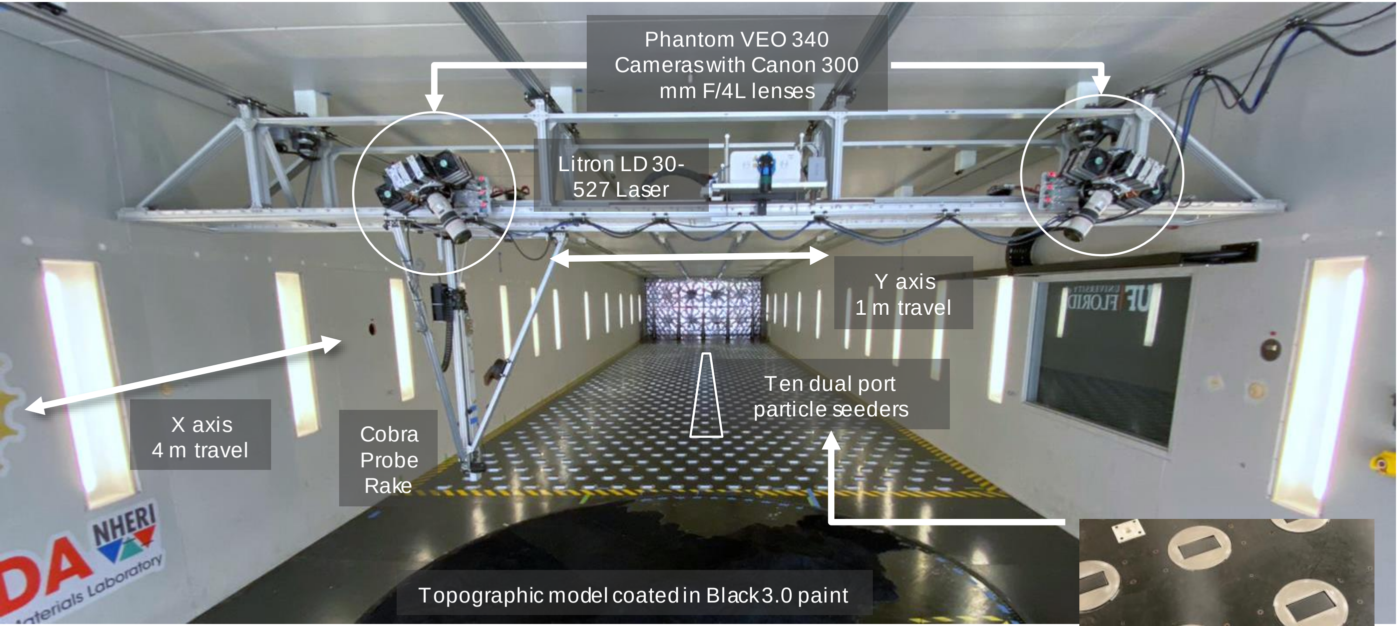

UPRM REUs
Bucknell REU
(family from PR)
UF PhD student
from UPRM

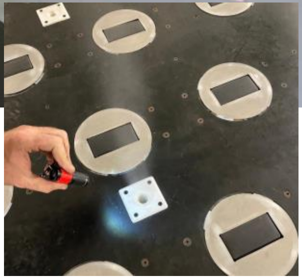
ML prediction

- Two-layer feedforward network with 15 neurons (tangent sigmoid) using the Levenberg-Marquardt backpropagation training algorithm
- Inputs = elevation data sampled at 100 m intervals over 2 km upwind and 1 km downwind (33 values)
- Outputs = maximum speedup ratio for all directions measured by the Cobra probes at 25 m FS (8 mm above model)
- Data divided into 70% training (3470 samples), 15% validation (743 samples), and 15% testing (743 samples)
- Produced 50 m resolution map over 113 km^2 in ~5 mins (training + fitting) with a single compute core
- Predicting point speedup, not profiles



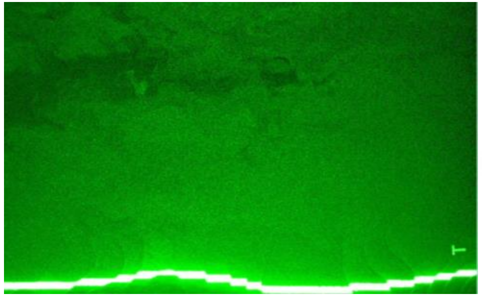
Stereoscopic PIV System





- Stereoscopic PIV setup captures 3D flow component
- Litron LD 30-527 Nd:YLF Laser
- 1KHz double pulse
- Records 15 s of data at 300 fps
- 3-5 Gbps throughput → 5 min per run
- Scheimpflug mounts provide in-plane focus at any height
- 55 deg angle helps camera "see" into valleys but images must be dewarped
- Olive Oil particles (Stokes number < 1) mixed with the flow upwind

Planar image stabilization and pre-processing in Dynamic Studio



Correct for vibrations

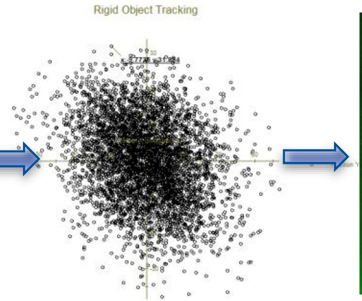
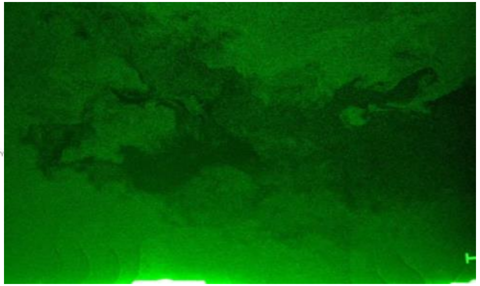
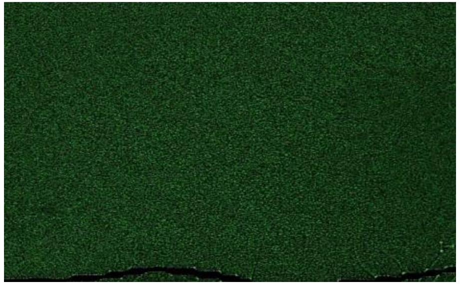


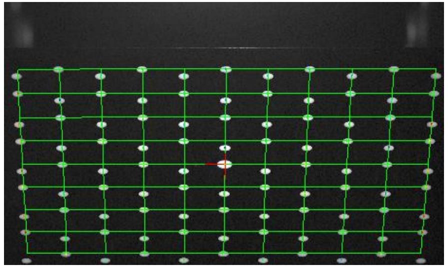
Image stabilization tracks the movement of the camera



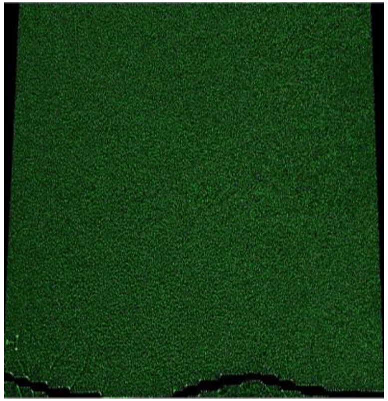
Vibration eliminated



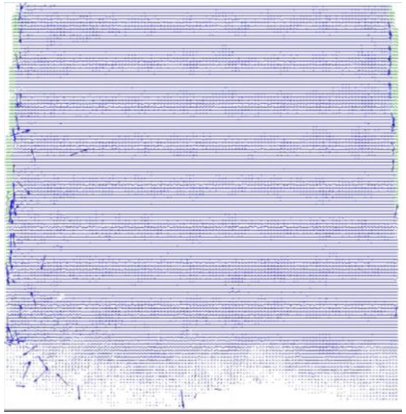
Normalization of the pixels to remove glare



Setup of real coordinate system reference to the laser light sheet

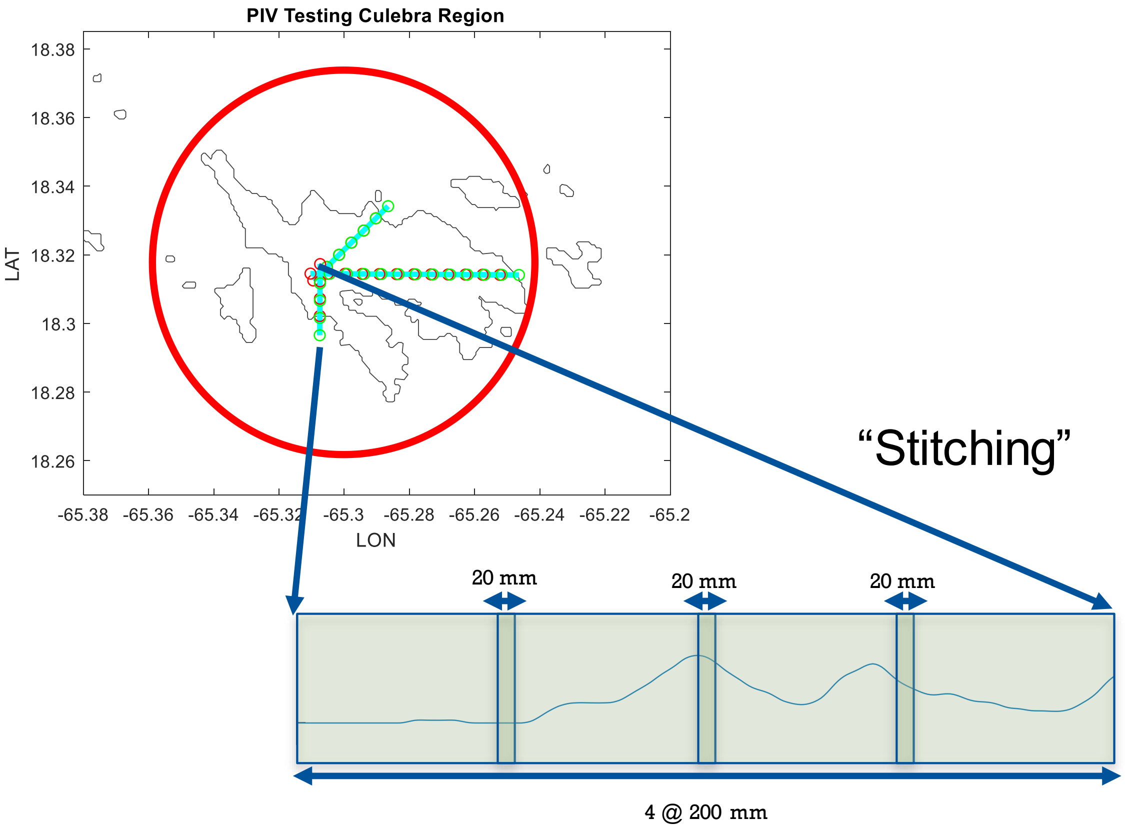


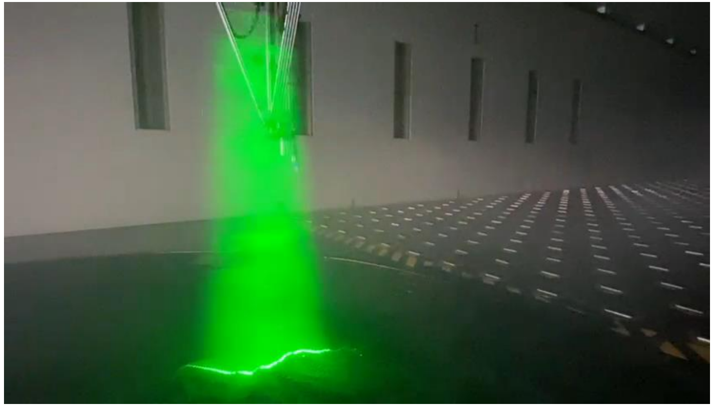
Dataset is de-warped into real coordinate system



PIV processing results in detailed flow field

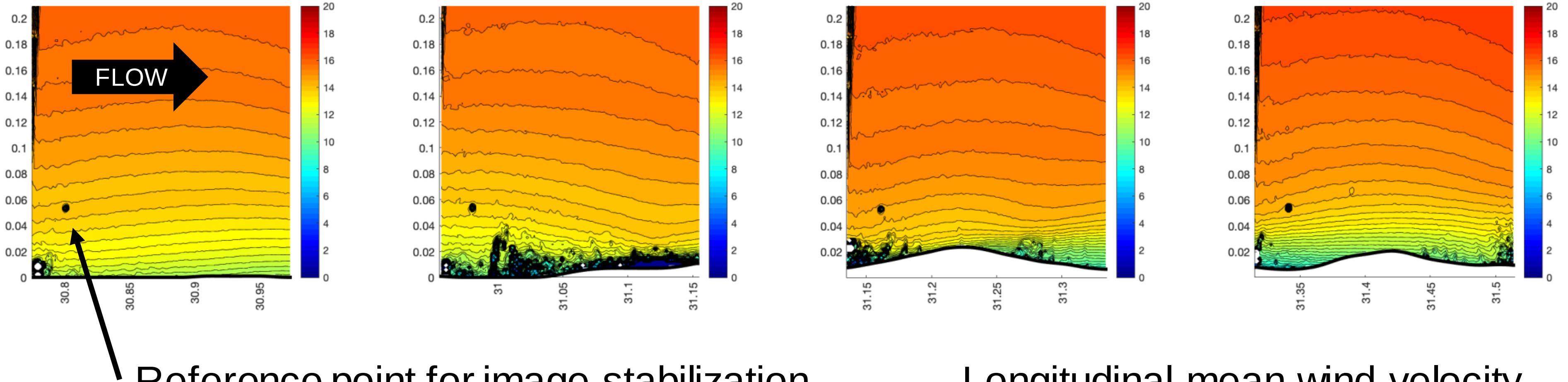
PIV data collection





Testing now underway …

- Work is still ongoing (thank you, COVID-19)
- Culebra data received just last night (118 levels from ~5-600 m FS)



Reference point for image stabilization

Longitudinal mean wind velocity

- Produce 13 transects with up 15 frames each (~9 km FS) → 100+ TB

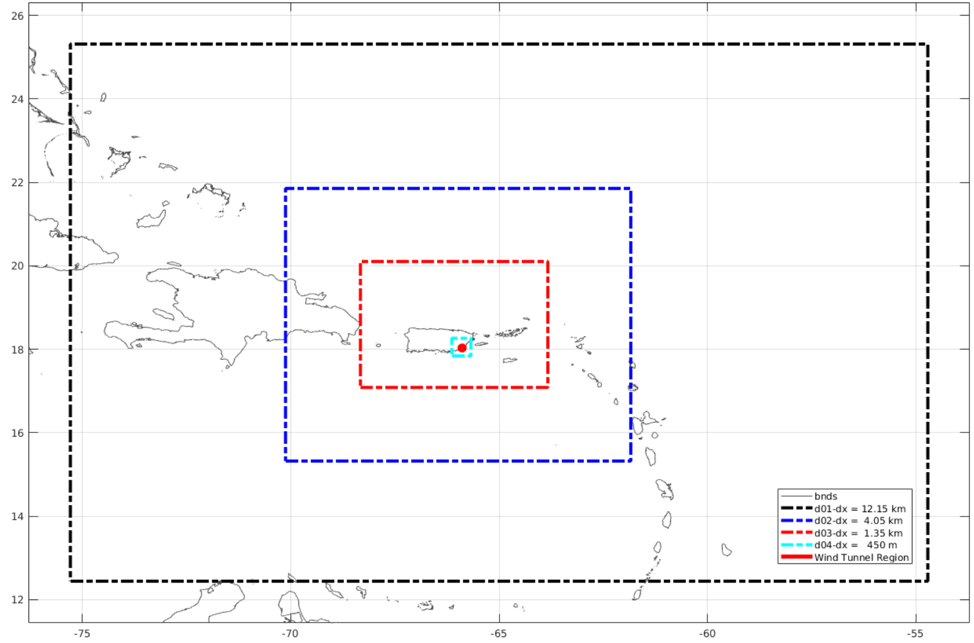
NWP Modeling – WRF-ARW (LES)

- The simulations were performed using the **Advanced Research WRF (WRF-ARW) model**, version 4.2.2 from NWS UEMS 21.1.2 using the computational capabilities of the Texas Advanced Computing Center (TACC) of The University of Texas at Austin.
- The model initial and boundary conditions were obtained from the Global Forecast System Analysis (GFS-ANL) data set of 0.5° (~55.6 km)
- Sea Surface Temperature (SST) data was obtained from 8.33 km Global data set
- The model consists of six (6) one-way nesting domain configuration ranging from a 12.15 km course horizontal **resolution down to 50 m** using a 1/3 ratio, with 61 vertical levels and a large time step of 40 second for the parent domain. Time is also scale down using a 1/3 ratio
- Physics schemes shown to right …

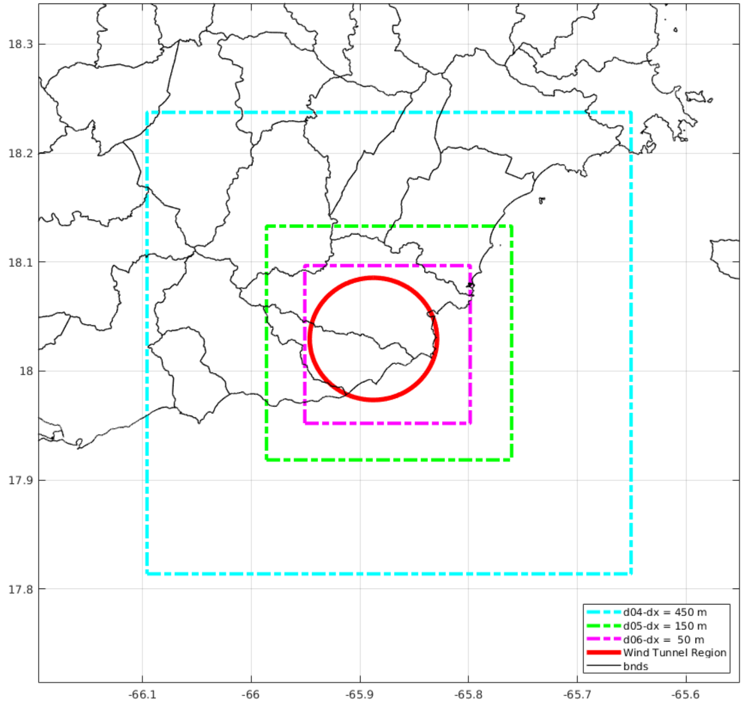
Planetary Boundary Layer	1	Yonsei University scheme	Skamarock et. al. 2005
Cumulus	14	Kim Simplified Arakawa-Schubert (KASA) [Only for Parent Domain]	Han and Pan, 2011
Land Surface	2	NOAH Land Surface Model	Chen and Dudhia, 2001
Microphysics	24	WRF Single Moment 7-Class (WSM7)	Bae et. al., 2018
Radiation (LW/SW)	1/1	(RRTM) / (Dudhia scheme)	Mlawer et. al., 1997) and Dudhia, 1989
Surface Layer	1	Revised MM5 - Monin-Obukhov scheme	

NWP Modeling – WRF-ARW (LES) - Model Setup

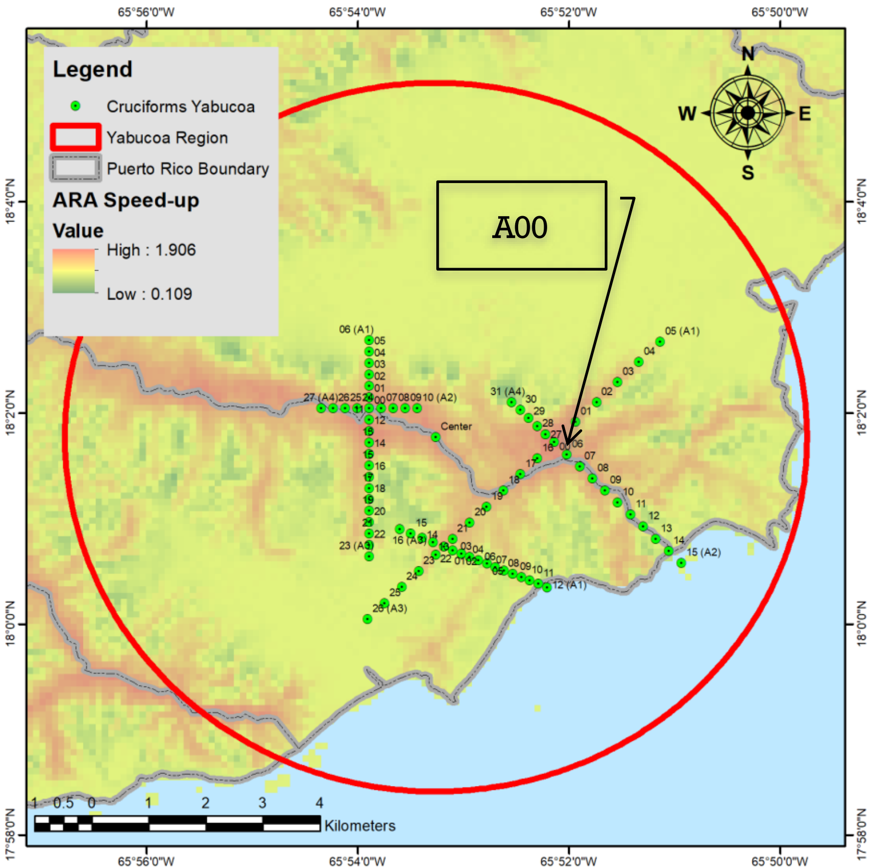
Domains d01, d02, & d03

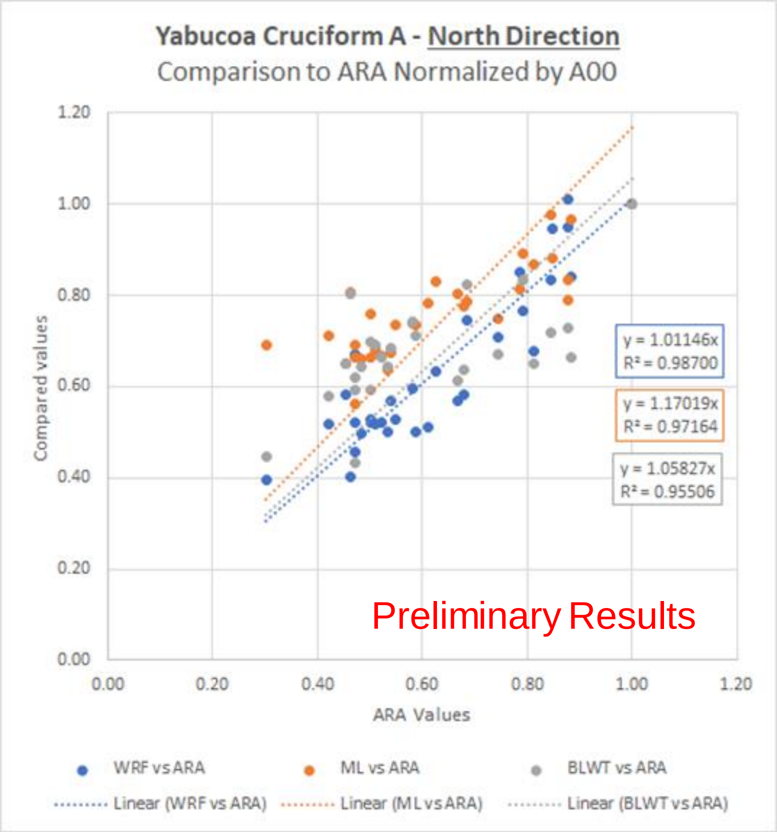


Yabucoa Region (d04, d05, & d06)

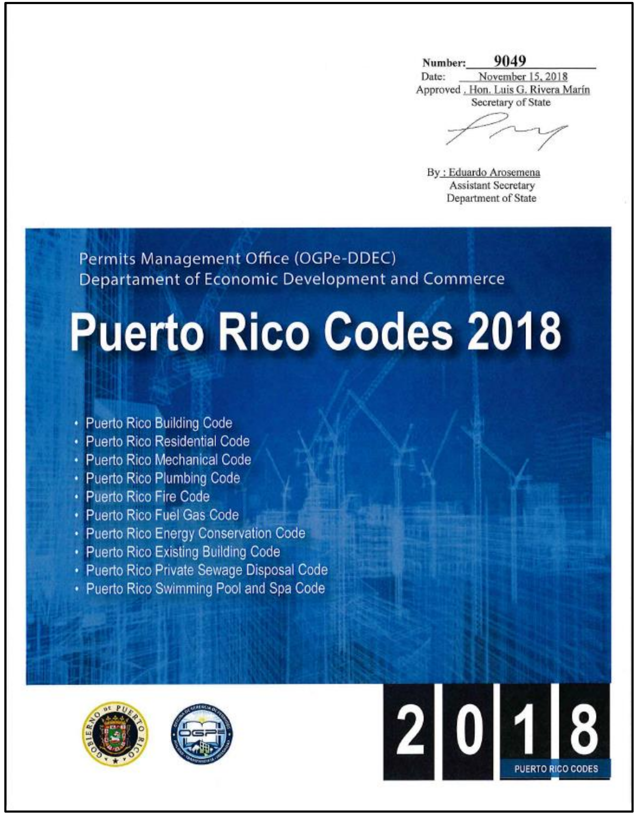


Cruciform A – Wind Direction NNE Normalized by A05





Product: Puerto Rico Building Code 2018 New Wind Map



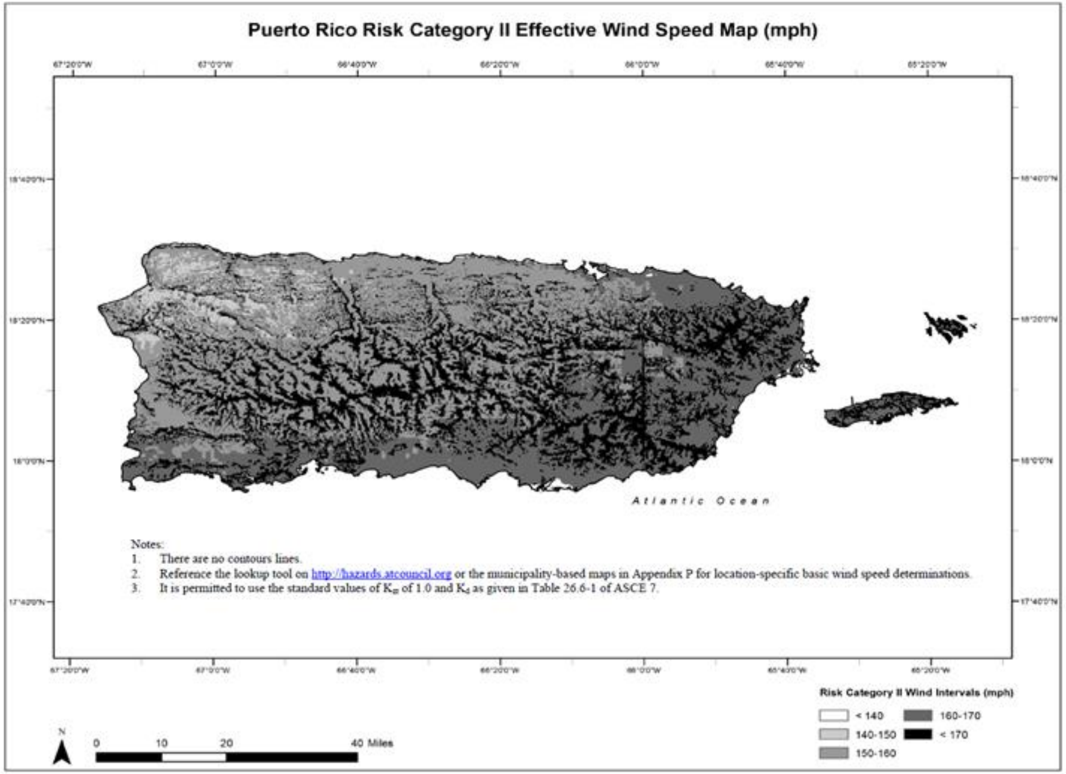


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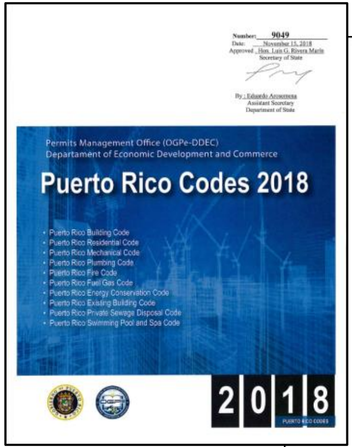
FIGURE 1609.3(9)
BASIC DESIGN WIND SPEEDS, V, FOR RISK CATEGORY II BUILDINGS AND OTHER STRUCTURES (PUERTO RICO)

Product: Puerto Rico Building Code 2018 New Wind Map



APPENDIX P

MICROZONE WIND MAPS FOR PUERTO RICO

The maps provided in this appendix should be considered as the reference for wind design criteria.

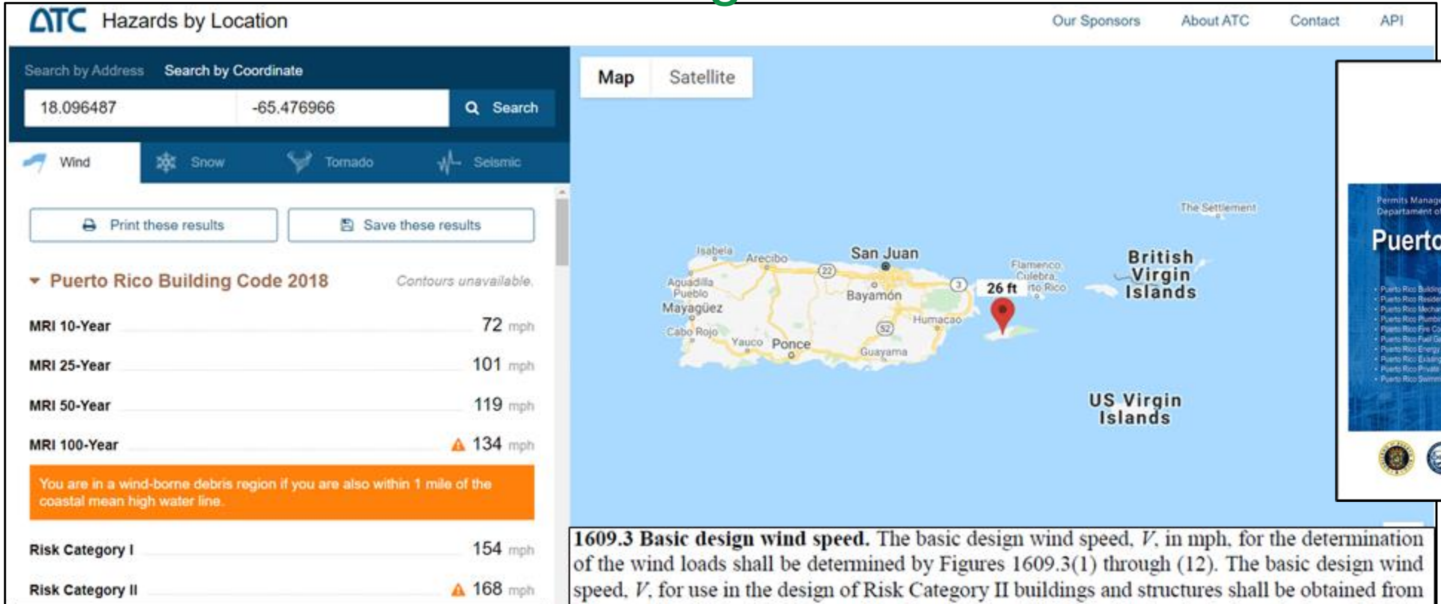
USER NOTE:

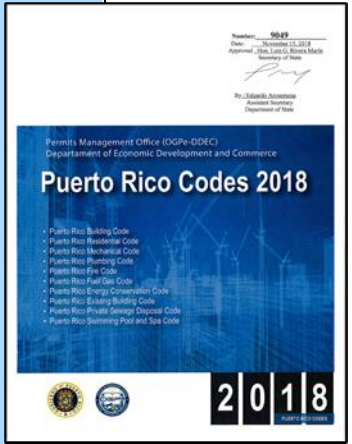
About this appendix: *This wind speed maps for Puerto Rico were specifically developed to consider areas with significant topographic features. Puerto Rico can evaluate the wind speed from these revised basic wind speed maps that consider topographic effects as a simplified and acceptable, alternative method to determine wind loads and pressures (using K_{zt}=1.0 during calculation) on a building or structure. The revised basic wind maps do not change the design wind criteria of ASCE 7. For location-specific basic wind speed determinations reference the lookup tool on http://hazards.atcouncil.org or the municipality-based maps in this Appendix.*

Product: Puerto Rico Building Code 2018 New Wind Map

Municipio de Vieques
Risk Category II Effective Wind Speed Map (mph)

Product: Puerto Rico Building Code 2018 New Wind Map





1609.3 Basic design wind speed. The basic design wind speed, *V*, in mph, for the determination of the wind loads shall be determined by Figures 1609.3(1) through (12). The basic design wind speed, *V*, for use in the design of Risk Category II buildings and structures shall be obtained from Figures 1609.3(1), 1609.3(5), and for Puerto Rico 1609.3(9). The basic design wind speed, *V*, for use in the design of Risk Category III buildings and structures shall be obtained from Figures 1609.3(2), 1609.3(6) , and for Puerto Rico 1609.3(10). The basic design wind speed, *V*, for use in the design of Risk Category IV buildings and structures shall be obtained from Figures 1609.3(3), 1609.3(7) , and for Puerto Rico 1609.3(11). The basic design wind speed, *V*, for use in the design of Risk Category I buildings and structures shall be obtained from Figures1609.3(4), 1609.3(8) , and for Puerto Rico 1609.3(12). The basic design wind speed, *V*, for the special wind regions indicated near mountainous terrain and near gorges shall be in accordance with local jurisdiction requirements. The basic design wind speeds, *V*, determined by the local jurisdiction shall be in accordance with Chapter 26 of ASCE 7.

Puerto Rico Building Code 2018
Section 1609.3
New Special Wind Regions
Maps are available at
https://hazards.atcouncil.org/

2018 Puerto Rico Building Code Prescriptive Residential Design Plans

- Recommendation PR-27.
  - OGPe, with support from stakeholders, should develop prescriptive design plans
  - and make them available to support affordable, code-compliant construction of homes and residential buildings.

- Reconstruction post-Hurricanes Irma and Maria (DR-4339) and Puerto Rico Earthquakes (DR-4473)

Workgroup · 2018 Puerto Rico Building Code Prescriptive Residential Design Plans

FEMA

COLEGIO DE ARQUITECTOS Y ARQUITECTOS PAISAJISTAS DE PUERTO RICO

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GOBERNADOR DE PUERTO RICO

DEPARTAMENTO DE LA VIVIENDA
Gobierno de Puerto Rico

STARR II Strategic Alliance for Risk Reduction

PLANO SEGURO - https://ddec.gobierno.pr/en/plano-seguro-en/

Four Prototypes identified

1 Story House: CMU Walls with Flat Concrete Roof

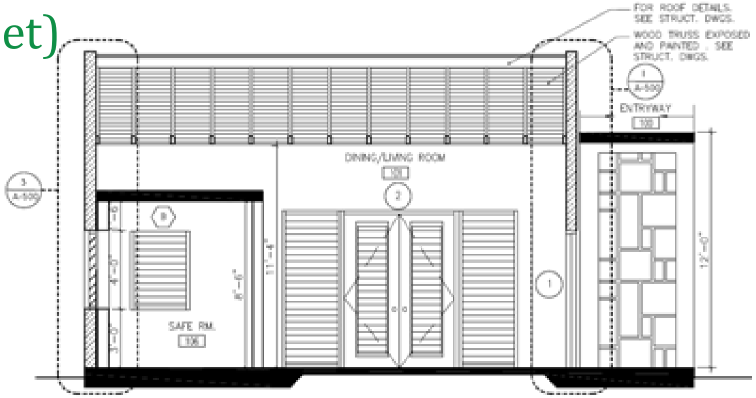
1 Story House: CMU Walls with Wood Roof

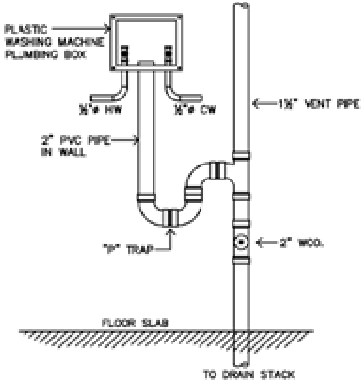
1 Story House: Wood Walls with Wood Roof

2 Story House: 1st Floor CMU Walls with Concrete 2nd Floor and Wood Walls at 2nd Floor with Wood Roof

Similar Components Across Prototypes

- Main Structure Plan Dimensions (24 feet x 20 feet)
- Two Optional Modules (10 feet x 24 feet each)
- FEMA P-361 Safe Room
- Concrete Floors
- Jalousie Windows
- Bathroom and Kitchen with Equipment
- Optional Entryway Porch
- Optional Potable Water and Rain Water Cisterns
- Optional Washer and Dryer Machine Hookups
- Optional A/C Unit Hookup



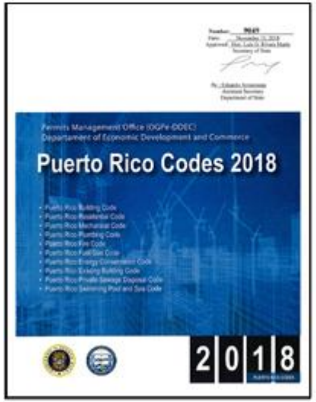


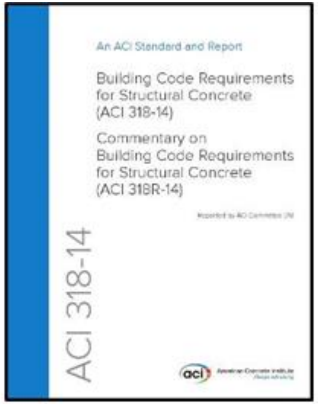
CLOTH WASHER PLUMBING BOX INSTALLATION DETAIL

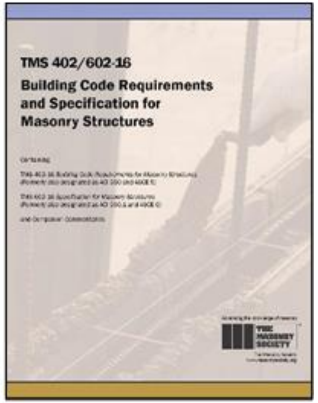
Purpose

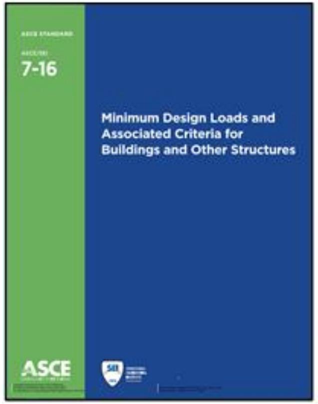
- **How are these plans supposed to be used?**
  - These plans are meant to be a guide, to all interested parties, to provide code-compliant home designs
  - These plans are not meant to be a substitute for a stamped drawing set and shall be reviewed and stamped by a registered design professional
  - These plans are based upon a flat site that should be modified for particular site conditions and home-owner construction preferences

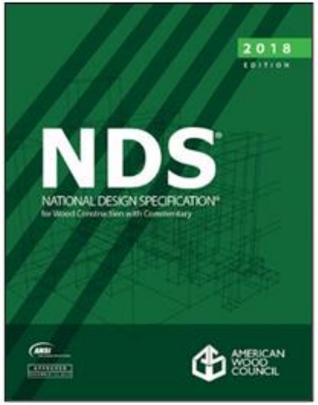
Design Criteria: Codes and Standards

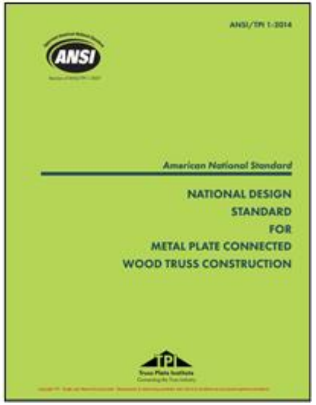












Design Loads: Primary Structure and Modules

Dead Load	
The weight of all permanent construction including but not limited to: walls, floors, ceilings, roof cladding.	
Roof	Self Weight

Live Load	
Roof	20 PSF
Second Floor	40 PSF
Grade Level	40 PSF

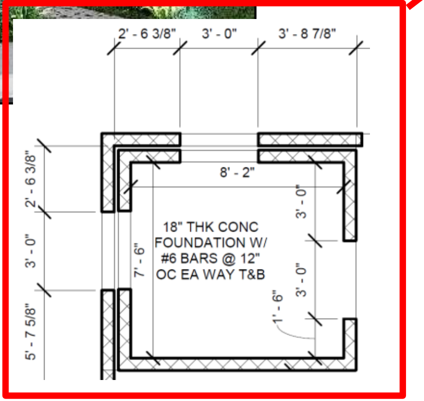
Design Loads: Primary Structure and Modules

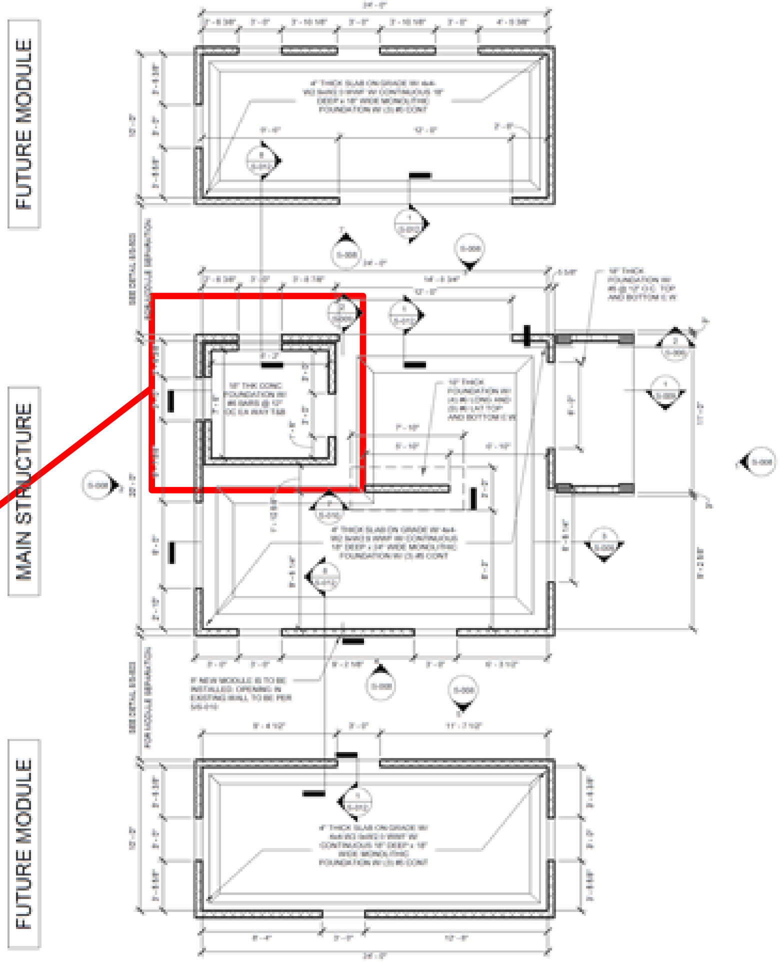
Wind Load	
Basic Wind Speed (Ultimate)	190 MPH
Basic Wind Speed (Nominal)	147 MPH
Risk Category	II
Exposure Category	D
Enclosure Classification	Partially Open
Internal Pressure Coefficients	+/- 0.18

Design Loads: Primary Structure and Modules

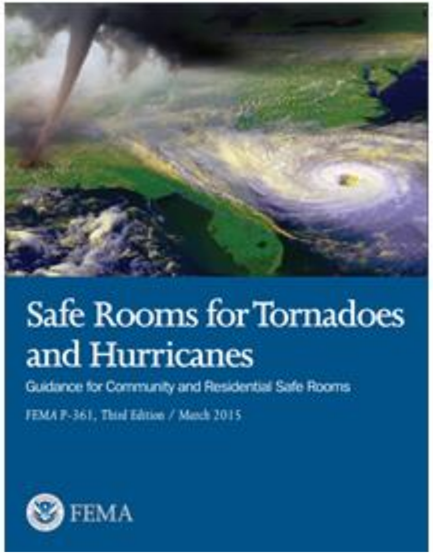
Seismic Load	
Seismic Importance Factor	1.0
S_S	1.35
S_1	0.53
Site Class	D (Stiff Soil)
S_{DS}	0.9
S_{D1}	0.642
Seismic Design Category	D

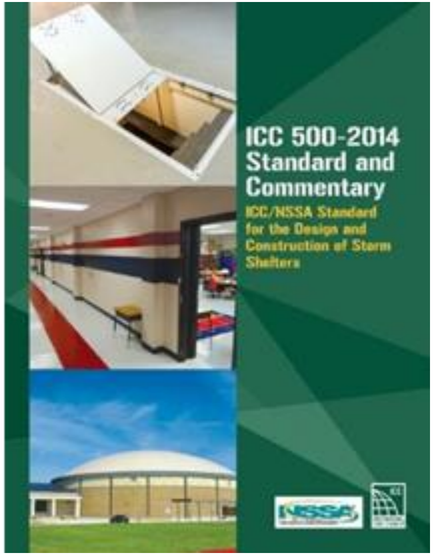
Prototype 1 – CMU with Concrete Roof: Rendering & Foundation Plan





Design Criteria of Safe Room: Codes, Standards, & Guidance





Design Loads of Safe Room

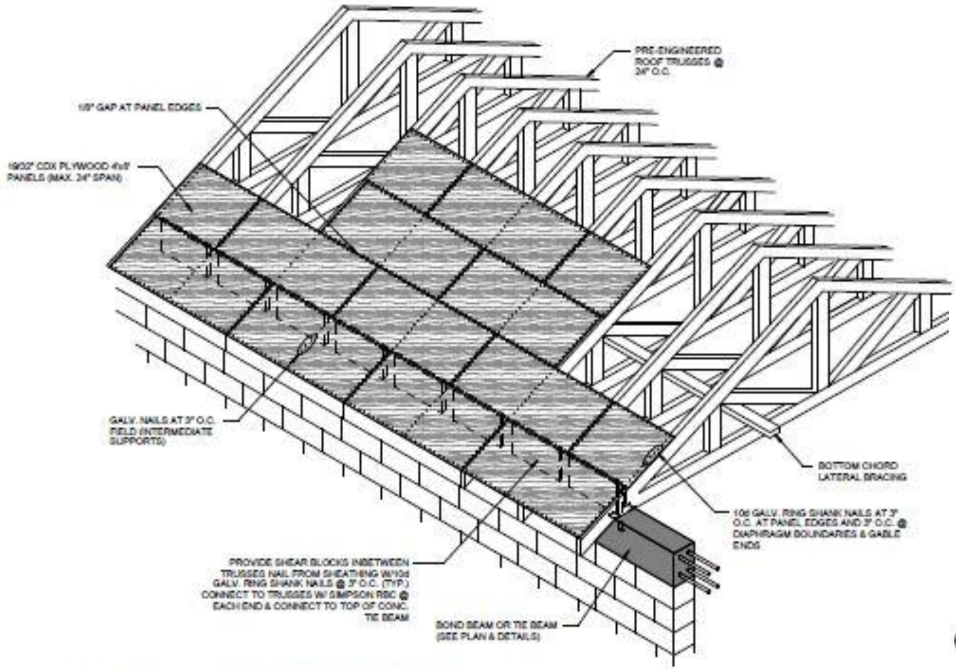
Dead Load	
The weight of all permanent construction including but not limited to: walls, floors, ceilings, roof cladding.	
Roof	Self Weight
Collateral Load	5 PSF

Live Load	
Roof	150 PSF

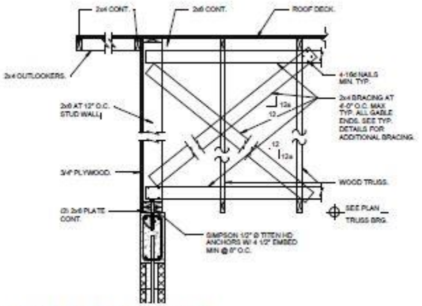
Design Loads of Safe Room

Wind Load	
Basic Wind Speed (Ultimate)	250 MPH
Basic Wind Speed (Nominal)	194 MPH
Risk Category	II
Exposure Category	D
Enclosure Classification	Partially Enclosed
Internal Pressure Coefficients	+/- 0.55
Safe Room Door and Window Shutter	
Missile Impact Criteria	
Vertical Surfaces	15 LB 2 x 4 AT 100 MPH
Horizontal Surfaces	15 LB 2 x 4 AT 67 MPH

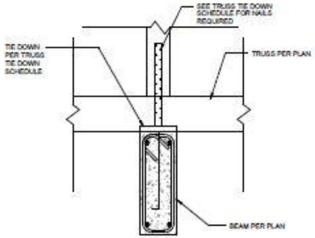
Prototype 2 – CMU with Wood Roof: Rendering & Roof Framing Plan



1 ROOF NAILING PLAN W/ BLOCKING
SCALE: 3/8" = 1'-0"

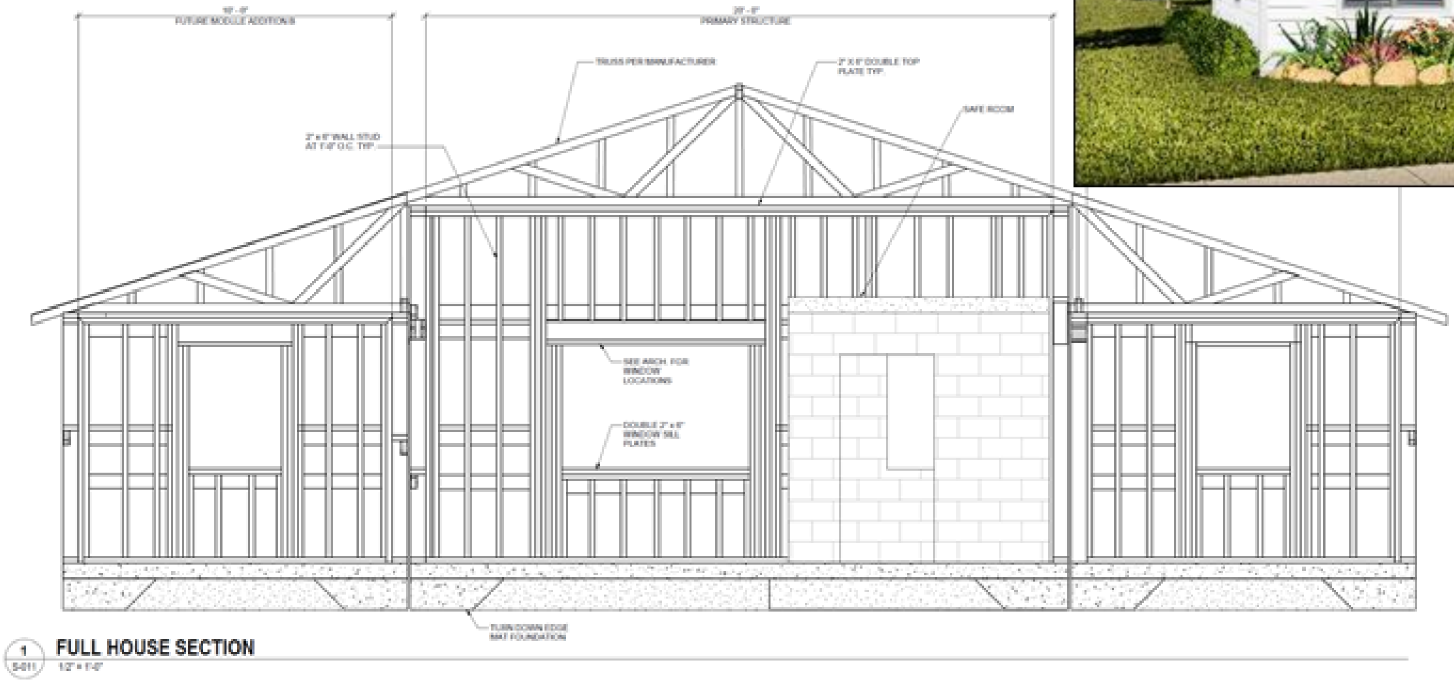


3 GABLE END SECTION
SCALE: 3/4" = 1'-0"

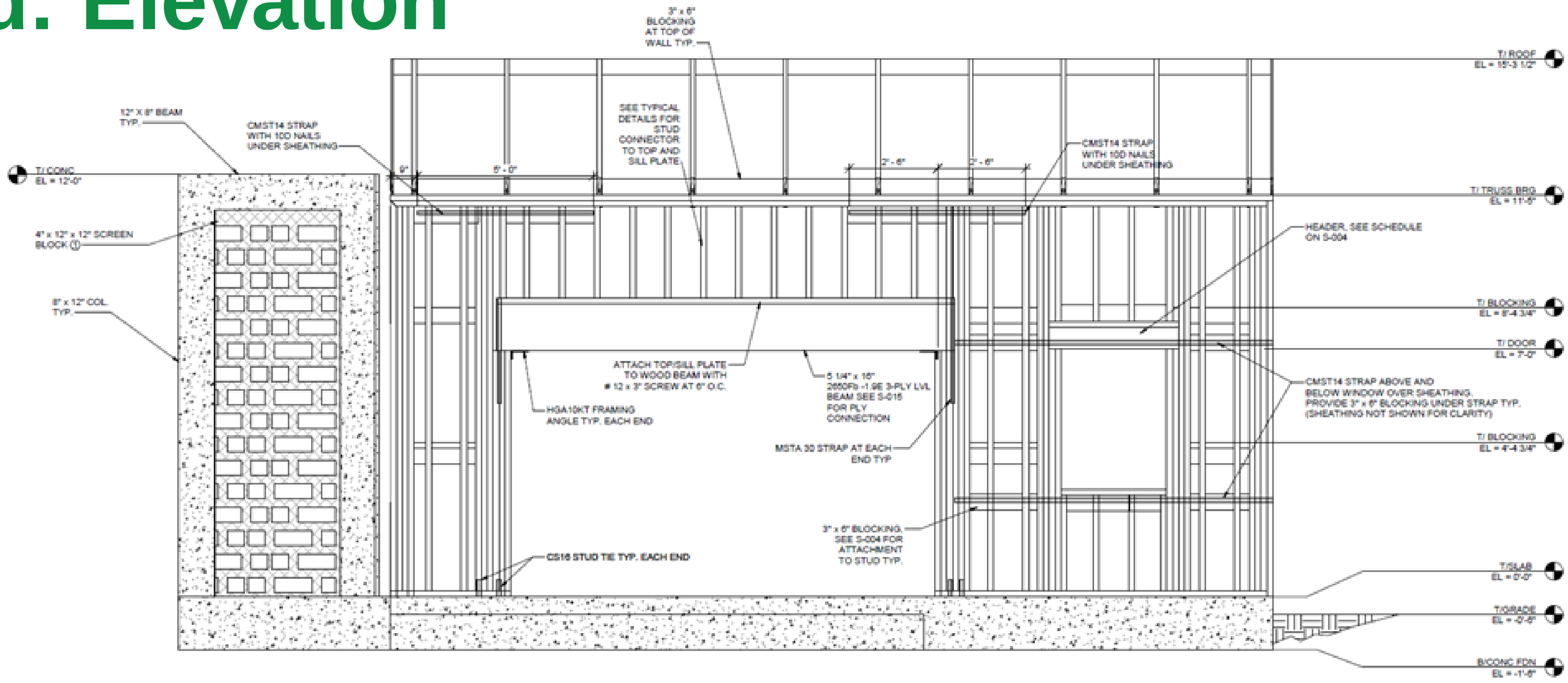


4 TRUSS MIDDLE CONNECTOR
SCALE: 1 1/2" = 1'-0"

Prototype 3
Wood: Rendering & Elevation



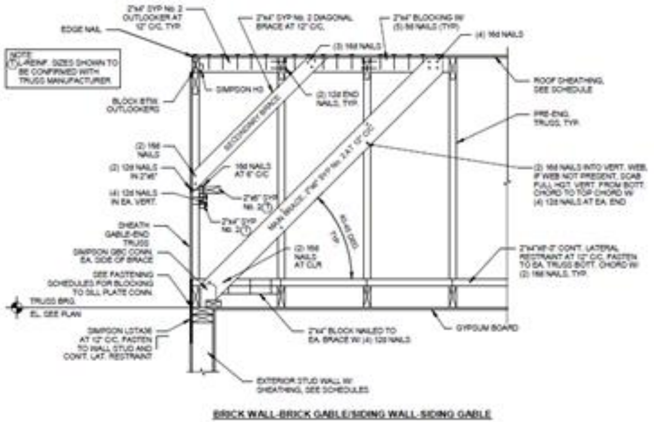
Prototype 3
Wood: Elevation



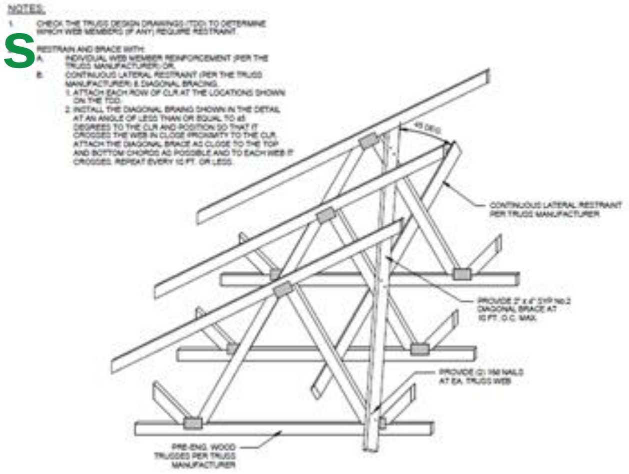
1 S-009 RIGHT ELEVATION PRIMARY RESIDENCE

1/2" = 1'-0"

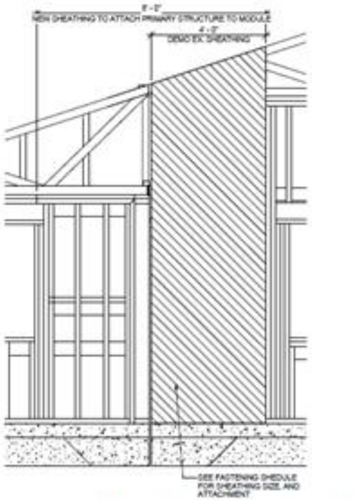
Prototype 3 – Wood: Details



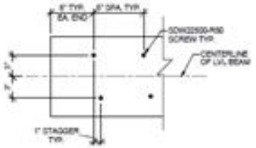
1 TYPICAL GABLE END BRACING DETAILS
S-015 3/4" = 1'-0"



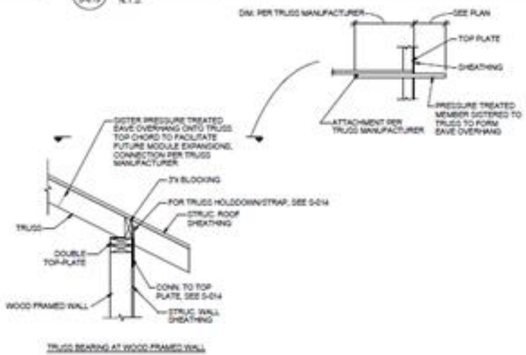
2 BRACING AT CONTINUOUS LATERAL RESTRAINT (CLR)
S-015 N.T.S.



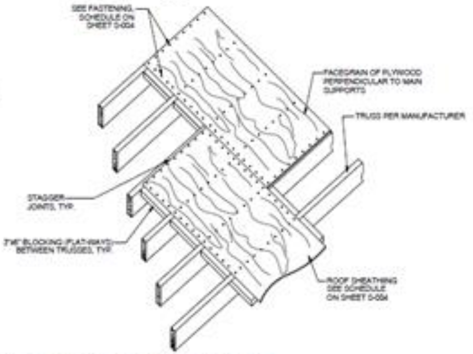
3 PARTIAL ELEVATION SHOWING MODULE ATTACHMENT TO PRIMARY STRUCTURE
S-015 1/2" = 1'-0"



4 TYPICAL LVL BEAM PLY CONNECTION
S-015 1 1/2" = 1'-0"

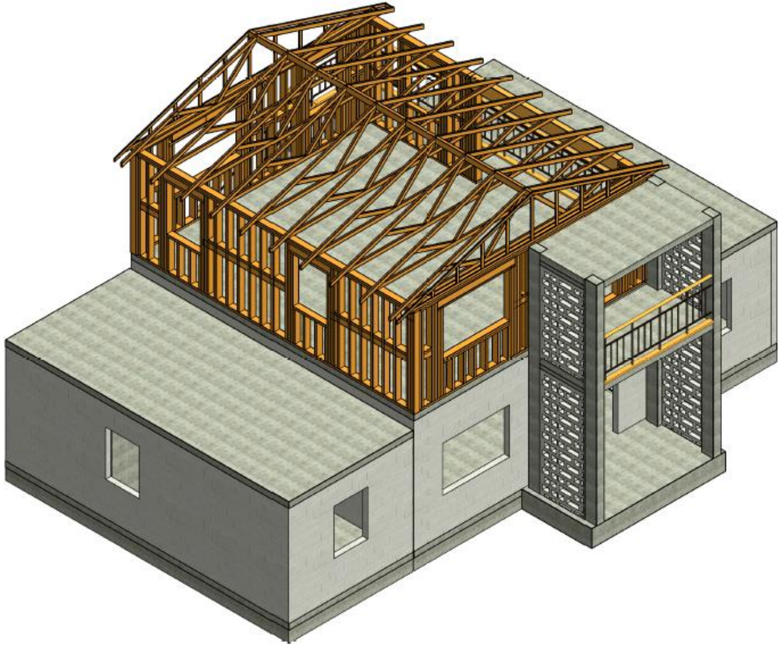


5 TYPICAL ROOF TRUSS BEARING
S-015 3/4" = 1'-0"



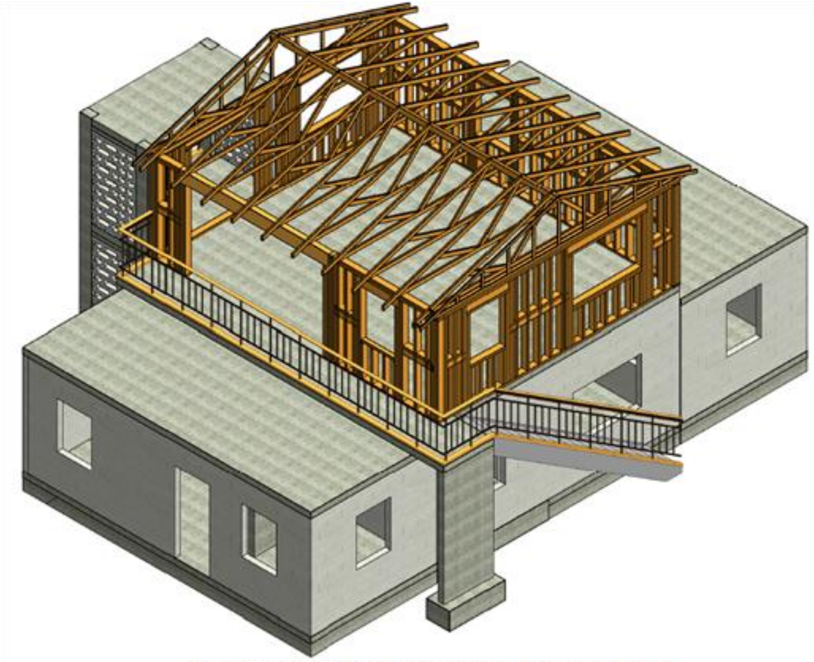
6 TYPICAL ROOF SHEATHING DETAIL
S-015 N.T.S.

Prototype 4 – CMU 1st Floor with Wood 2nd Floor: Rendering & Isometric Views



ISOMETRIC VIEW OF PRIMARY STRUCTURE WITH MODULES ATTACHED

Prototype 4 – CMU 1st Floor with Wood 2nd Floor: Rendering & Isometric Views



ISOMETRIC VIEW OF PRIMARY STRUCTURE WITH MODULES ATTACHED

Acknowledgements

- NSF NHERI Experimental Facility at UF
  - Award No. 2037725. *Natural Hazards Engineering Research Infrastructure: Experimental Facility with Boundary Layer Wind Tunnel 2021-2025*
  - Award No. 1520843. *Natural Hazards Engineering Research Infrastructure: Experimental Facility with Boundary Layer Wind Tunnel, Wind Load and Dynamic Flow Simulators, and Pressure Loading Actuators*
- NSF Award No. 1841979. *EAGER: Exploring Machine Learning and Atmospheric Simulation to Understand the Role of Geomorphic Complexity in Enhancing Civil Infrastructure Damage during Extreme Wind Events*
- FEMA. *Modelling of Wind Speed Up for Microzoning of Design Wind Speeds in Puerto Rico. Strategic Alliance for Risk Reduction (STARR II)*
- 2018 Puerto Rico Building Code Prescriptive Residential Design Plans: Presentation