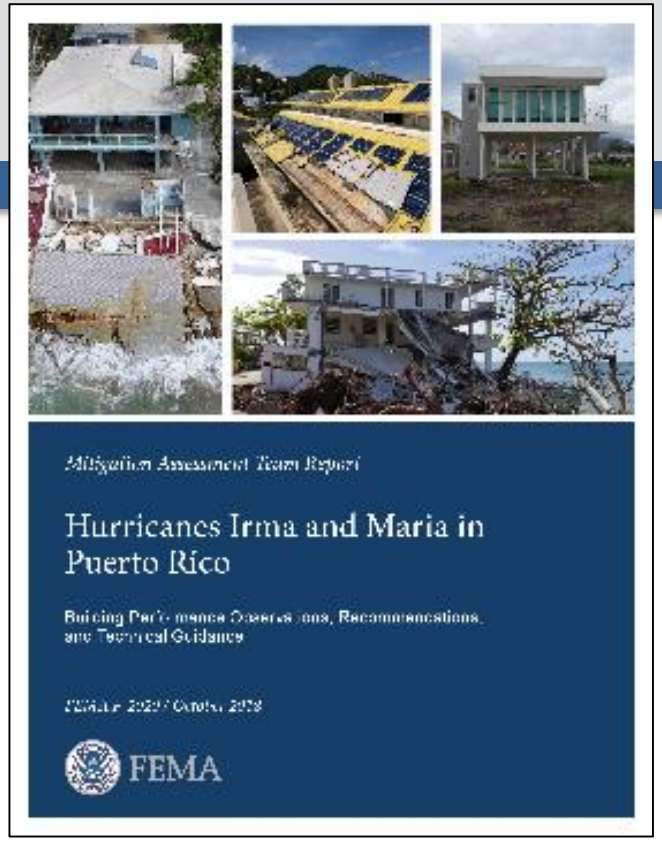
Impacto Combinado del Oleaje y las Marejadas Ciclónicas en Estructuras Costeras

Dr. Luis D. Aponte Bermúdez, P.E.
luisd.aponte@upr.edu
Catedrático - Departamento de Ingeniería Civil y Agrimensura
Universidad de Puerto Rico Mayagüez

SIMPOSIO SOBRE MANEJO DE RIESGOS COSTEROS
ALTERNATIVAS DE INTERVENCIÓN NATURALES, ESTRUCTURALES E HÍBRIDAS
22 DE NOVIEMBRE DE 2019
HOTEL VERDANZA-SAN JUAN, PR

Agenda

- Impacto Combinado del Oleaje y las Marejadas Ciclónicas en Estructuras Costeras
  - FEMA P-2020 | *Mitigation Assessment Team Report: Hurricanes Irma and Maria in Puerto Rico*
  - UPRM funded by USFWS ***Assessment of wind and wave-forcing, effects, and impacts of Hurricane María on reference coastal sites of the main island of Puerto Rico***
- Códigos de Construcción
  - *Puerto Rico Building Code 2018*
    - International Building Code 2018
      - ASCE 7 – *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*
      - ASCE 24 – *Flood Resistant Design and Construction*
- Guías para diseño residencial
  - FEMA P-55 | *Coastal Construction Manual*



FEMA P-2020 | Mitigation Assessment Team Report: Hurricanes Irma and Maria in Puerto Rico

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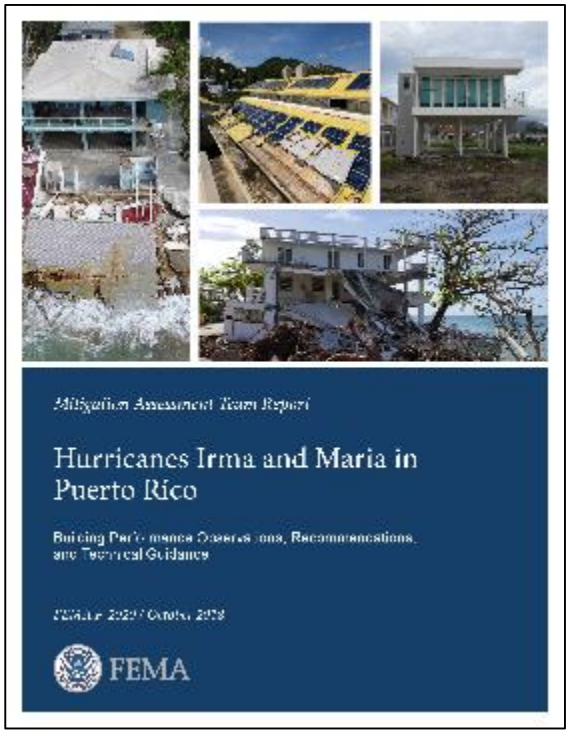
Report available at: https://www.fema.gov/media-library/assets/documents/173789

PR MAT Report

- Executive Summary
- Chapter 1. Introduction
- Chapter 2. Building Codes, Standards and Regulations
- Chapter 3. Performance of Residential and Low-Rise Buildings
- Chapter 4. Performance of Schools and Sheltering Facilities
- Chapter 5. Performance of Critical Facilities and Mid-Rise Buildings
- Chapter 6. Performance of Solar Installations
- Chapter 7. Conclusions and Recommendations
- References and Appendices



Punta Santiago, Humacao

- Impacts from Maria
  - High winds, storm surge, large waves
  - Some buildings saw 7-9 feet (2.1-2.7 meters) of surge
  - 2005 & 2009 FIRMs show AE and V Zones
  - Advisory Mapping adds Coastal A Zones
- Apartment building elevated on fill to 2009 BFE did not flood (but many at grade did)
- Elevated wood-framed building destroyed

Punta Santiago, Humacao

- Poorly constructed elevated buildings

Punta Santiago, Humacao

- Elevated wood-framed house that was destroyed (left) and that survived (right)

Punta Santiago, Humacao

- This elevated concrete house performed well

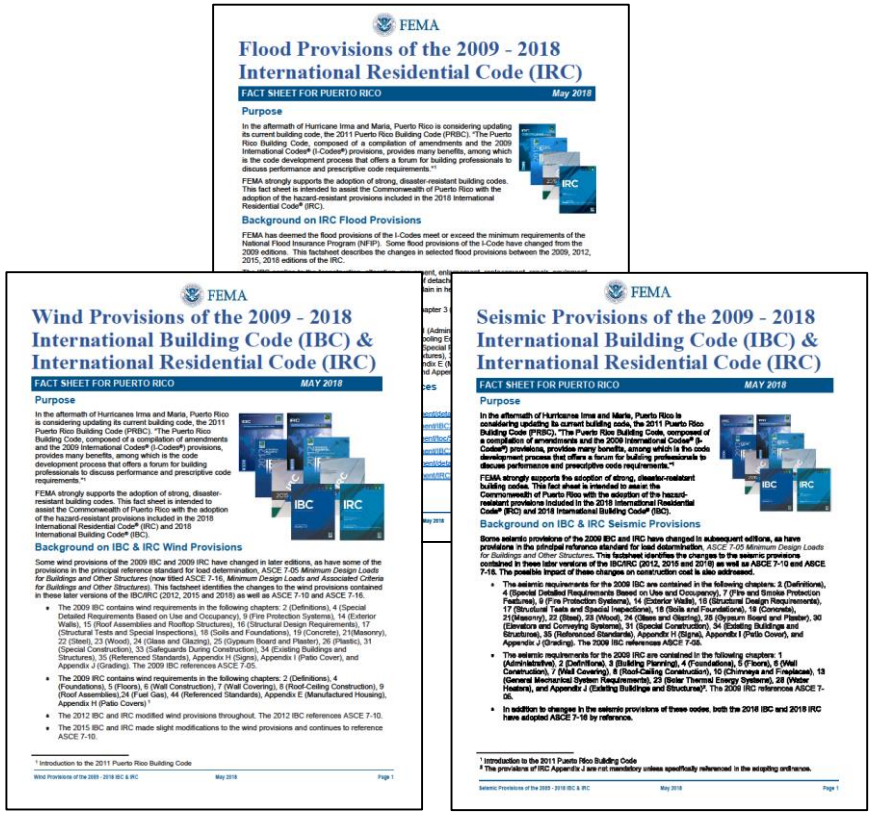
Punta Santiago, Humacao

- Storm-induced beach erosion

Support for Building Code Update to 2018 I-Codes

Puerto Rico Fact Sheets – Changes in the Hazard Provisions

- ***Flood Provisions*** *of the IBC & IRC (2009-2018)*
- ***Wind Provisions*** *of the IBC & IRC (2009-2018)*
- ***Seismic Provisions*** *of the IBC & IRC (2009-2018)*



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Flood Provisions of the 2009 - 2018 International Residential Code (IRC)

FACT SHEET FOR PUERTO RICO — May 2018

Purpose

Background on IRC Flood Provisions

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Wind Provisions of the 2009 - 2018 International Building Code (IBC) & International Residential Code (IRC)

FACT SHEET FOR PUERTO RICO — MAY 2018

Purpose

Background on IBC & IRC Wind Provisions

FEMA

Seismic Provisions of the 2009 - 2018 International Building Code (IBC) & International Residential Code (IRC)

FACT SHEET FOR PUERTO RICO — MAY 2018

Purpose

Background on IBC & IRC Seismic Provisions

FEMA

Flood Provisions of the IBC & IRC (2009-2018)

FEMA

Flood Provisions of the 2009 - 2018 International Residential Code (IRC)

FACT SHEET FOR PUERTO RICO *May 2018*

Purpose

In the aftermath of Hurricane Irma and Maria, Puerto Rico is considering updating its current building code, the 2011 Puerto Rico Building Code (PRBC). "The Puerto Rico Building Code, composed of a compilation of amendments and the 2009 International Codes® (I-Codes®) provisions, provides many benefits, among which is the code development process that offers a forum for building professionals to discuss performance and prescriptive code requirements."[1]

FEMA strongly supports the adoption of strong, disaster-resistant building codes. This fact sheet is intended to assist the Commonwealth of Puerto Rico with the adoption of the hazard-resistant provisions included in the 2018 International Residential Code® (IRC).

Background on IRC Flood Provisions

FEMA has deemed the flood provisions of the I-Codes meet or exceed the minimum requirements of the National Flood Insurance Program (NFIP). Some flood provisions of the I-Code have changed from the 2009 editions. This factsheet describes the changes in selected flood provisions between the 2009, 2012, 2015, 2018 editions of the IRC.

The IRC applies to the "construction, alteration, movement, enlargement, replacement, repair, equipment, use and occupancy, location, removal and demolition of detached one- and two-family dwellings and townhouses not more than three stories above grade plain in heights with a separate means of egress and their accessory structures."

Most of the IRC flood requirements are contained in Chapter 3 (Building Planning) and Chapter 4 (Foundations).

Flood requirements are also in the following chapters: 1 (Administrative), 2 (Definitions),13 (General Mechanical System Requirements), 14 (Heating and Cooling Equipment), 16 (Duct Systems), 17 (Combustion Air), 20 (Boilers and Water Heaters), 22 (Special Piping and Storage Systems, 24 (Fuel Gas), 26 (General Plumbing Requirements), 27 (Plumbing Fixtures), 30 (Sanitary Drainage), and 31 (Vents) Flood provisions are in the following appendices: Appendix E (Manufactured Housing Used as Dwellings), Appendix G (Swimming Pools, Spas, and Hot Tubs), and Appendix J (Existing Buildings and Structures).

Access to IBC, IRC and other Resources

Free text versions of the IBC and IRC can be found at:

- 2009 IBC https://codes.iccsafe.org/public/document/details/toc/745
- 2012 IBC https://codes.iccsafe.org/public/document/IBC2012
- 2015 IBC https://codes.iccsafe.org/public/document/toc/542/
- 2018 IBC https://codes.iccsafe.org/public/document/IBC2018
- 2009 IRC https://codes.iccsafe.org/public/document/details/toc/754
- 2012 IRC https://codes.iccsafe.org/public/document/IRC2012

[1] Introduction to the 2011 Puerto Rico Building Code

FEMA

Disposiciones para inundación del Código Residencial Internacional (IRC) de 2009 - 2018

HOJA INFORMATIVA PARA PUERTO RICO *MAYO DE 2018*

Propósito:

Después de los huracanes Irma y María, Puerto Rico está considerando actualizar su código de construcción actual, el Código de Construcción de Puerto Rico de 2011 (CCPR). "El Código de Construcción de Puerto Rico, compuesto de una compilación de enmiendas y las disposiciones de los Códigos Internacionalese (Códigos Ie) de 2009, ofrece muchos beneficios, como el proceso de desarrollo del código que presenta un foro para que profesionales de la construcción discutan el desempeño y los requisitos del código prescriptivo".[1]

FEMA apoya firmemente la adopción de códigos de construcción sólidos y resistentes a desastres. Esta hoja informativa tiene el propósito de ayudar al Estado Libre Asociado de Puerto Rico con la adopción de las disposiciones de resistencia a peligros incluidas en el Código Residencial Internacional® (IRC, por sus siglas en inglés) de 2018.

Trasfondo de las disposiciones para inundación del IRC

FEMA ha considerado que las disposiciones para inundación de los Códigos Internacionales cumplen o sobrepasan los requisitos mínimos del Programa del Seguro Nacional de Inundación (NFIP, por sus siglas en inglés). Algunas disposiciones para inundación del Código Internacional son diferentes a las ediciones de 2009. Esta hoja informativa describe los cambios en las disposiciones para inundación seleccionadas entre las ediciones de 2009, 2012, 2015, 2018 del IRC.

El IRC aplica a la "construcción, alteración, movimiento, expansión, remplazo, reparación, equipo, uso y ocupación, ubicación, recogido y demolición de viviendas unifamiliares y multifamiliares separadas y casas adosadas (*townhouses*) de no más de tres pisos sobre el suelo, en alturas con un medio separado de salida y sus estructuras adjuntas".

La mayoría de los requisitos para inundación del IRC aparecen en el Capítulo 3 (Planificación para Construcción) y Capítulo 4 (Cimientos).

Los requisitos para inundación también aparecen en los siguientes capítulos: 1 (Administrativo), 2 (Definiciones), 13 (Requisitos generales del sistema mecánico), 14 (Equipo de calefacción y aire acondicionado), 16 (Sistemas de conductos), 17 (Aire de combustión), 20 (Calderas y calentadores de agua), 22 (Sistemas especiales de tubería y almacenamiento, 24 (Gas combustible), 26 (Requisitos generales de plomería), 27 (Accesorios de plomería), 30 (Drenaje sanitario) y 31 (Rejillas de ventilación) Las disposiciones para inundación aparecen en los siguientes apéndices: Apéndice E (Casas prefabricadas usadas como vivienda), Apéndice G (Albercas, spas y jacuzzis) y Apéndice J (Edificios y estructuras existentes).

Acceso al IBC, al IRC y otros recursos

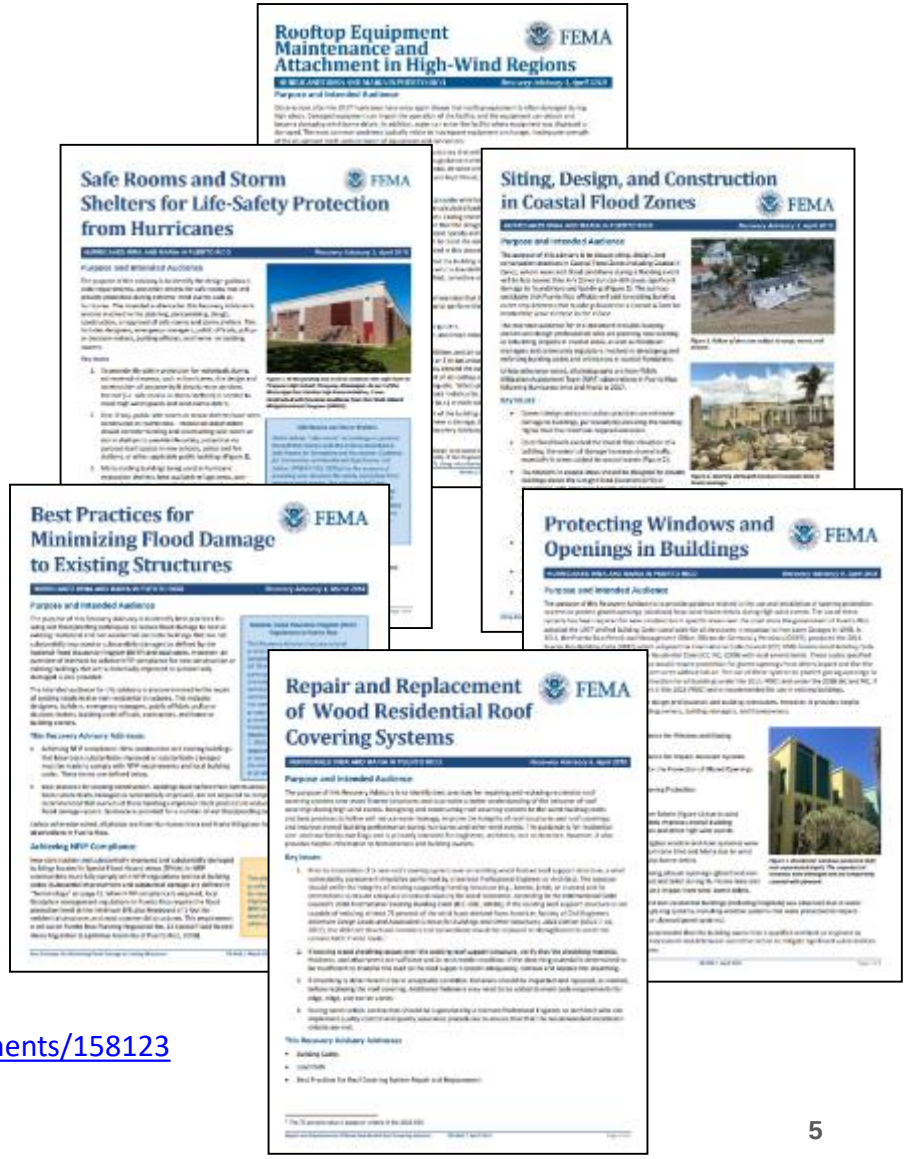
Puede encontrar versiones gratis del IBC y del IRC en:

- IBC de 2009 https://codes.iccsafe.org/public/document/details/toc/745
- IBC de 2012 https://codes.iccsafe.org/public/document/IBC2012
- IBC de 2015 https://codes.iccsafe.org/public/document/toc/542/
- IBC de 2018 https://codes.iccsafe.org/public/document/IBC2018
- IRC de 2009 https://codes.iccsafe.org/public/document/details/toc/754
- IRC de 2012 https://codes.iccsafe.org/public/document/IRC2012

[1] Introducción al Código de Construcción de Puerto Rico de 2011

Puerto Rico Recovery Advisories

- **RA-1** *Rooftop Equipment Maintenance and Attachment in High-Wind Regions*
- **RA-2** *Siting, Design, and Construction in Coastal Flood Zones*
- **RA-3** *Safe Rooms and Storm Shelters for Life Safety Protection from Hurricanes*
- **RA-4** *Best Practices for Minimizing Flood Damage to Existing Structures*
- **RA-5** *Protecting Window and Openings in Buildings*
- **RA-6** *Repair and Replacement of Wood Residential Roof Covering Systems*



Web page link: https://www.fema.gov/es/media-library/assets/documents/158123

RA-2 Siting, Design, and Construction in Coastal Flood Zones

Siting, Design, and Construction in Coastal Flood Zones

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HURRICANES IRMA AND MARIA IN PUERTO RICO — *Recovery Advisory 2, April 2018*

Purpose and Intended Audience

The purpose of this advisory is to discuss siting, design, and construction practices in Coastal Flood Zones including Coastal A Zones, where wave and flood conditions during a flooding event will be less severe than in V Zones but can still cause significant damage to foundations and buildings (Figure 1). The authors anticipate that Puerto Rico officials will add to existing building codes requirements that buildings located in a Coastal A Zone be treated the same as those in the V Zone.

The intended audience for this document includes building owners and design professionals who are planning new building or rebuilding projects in coastal areas, as well as floodplain managers and community regulators involved in developing and enforcing building codes and ordinances in coastal floodplains.

Unless otherwise noted, all photographs are from FEMA Mitigation Assessment Team (MAT) observations in Puerto Rico following Hurricanes Irma and Maria in 2017.

Figure 1. Failure of structure subject to surge, waves, and erosion.

Figure 2. Severely damaged structure in Coastal Zone in Punta Santiago.

FEMA MATs have observed many instances of damage from small waves consistent with Coastal A Zone conditions along shorelines of communities impacted by Hurricane Maria.

Key Issues

- Correct design and construction practices can minimize damage to buildings, particularly by elevating the building higher than the minimum required elevation.
- Once flood levels exceed the lowest floor elevation of a building, the extent of damage increases dramatically, especially in areas subject to coastal waves (Figure 2).
- Foundations in coastal areas should be designed to elevate buildings above the Design Flood Elevation (DFE) in accordance with American Society of Civil Engineers *Standard for Flood Resistant Design and Construction* (ASCE 24-14, 2014), while withstanding flood forces, high winds, scour and erosion, and floating debris in *Minimum Design Loads and Associated Criteria for Buildings and Other Structures* (ASCE 7-16, 2017).
- Foundations used for inland construction are generally not suitable for coastal construction. Some examples of foundation systems that have a history of poor performance in erosion prone areas are slab-on-ground, spread footings, and mat (or raft) foundations.
- Open foundations (pile or pier) designed to resist all base flood conditions, including waves, high velocity flow, erosion and scour, and flood-borne debris should be used in V and Coastal A Zones.
- Land purchase and siting decisions for buildings should take into consideration the long-term impacts of storm surge, waves, and erosion and not be based only on the present-day shoreline location and conditions.

Ubicación, diseño y construcción en zonas de inundación costera

FEMA

HURACANES IRMA Y MARÍA EN PUERTO RICO — *Boletín Informativo de Recuperación 2, Abril de 2018*

Propósito y público al que va dirigida la información

El propósito de este boletín informativo es discutir las prácticas de ubicación, diseño y construcción en las Zonas de Inundación Costera, incluyendo las Zonas Costeras A, donde las condiciones de olas e inundación durante un evento de inundación serán menos severas que en las Zonas V, pero aún pueden causar daños significativos a los cimientos y los edificios (Imagen 1). Los autores prevén que los funcionarios de Puerto Rico añadirán a los requisitos existentes de los códigos de construcción que los edificios ubicados en una Zona Costera A reciban el mismo trato que los dela Zona V.

El público al que se dirige este documento incluye a dueños de edificios y profesionales del diseño que están planificando nuevos proyectos de construcción o de reconstrucción en zonas costeras, así como administradores de valles de inundación y reglamentadores de la comunidad que participan en la elaboración y aplicación de los códigos y las ordenanzas de construcción en los valles de inundación costeros.

A menos que se indique lo contrario, todas las fotografías son de las observaciones del Equipo de Evaluación de Mitigación (MAT, por sus siglas en inglés) de FEMA en Puerto Rico después de los huracanes Irma y María en 2017.

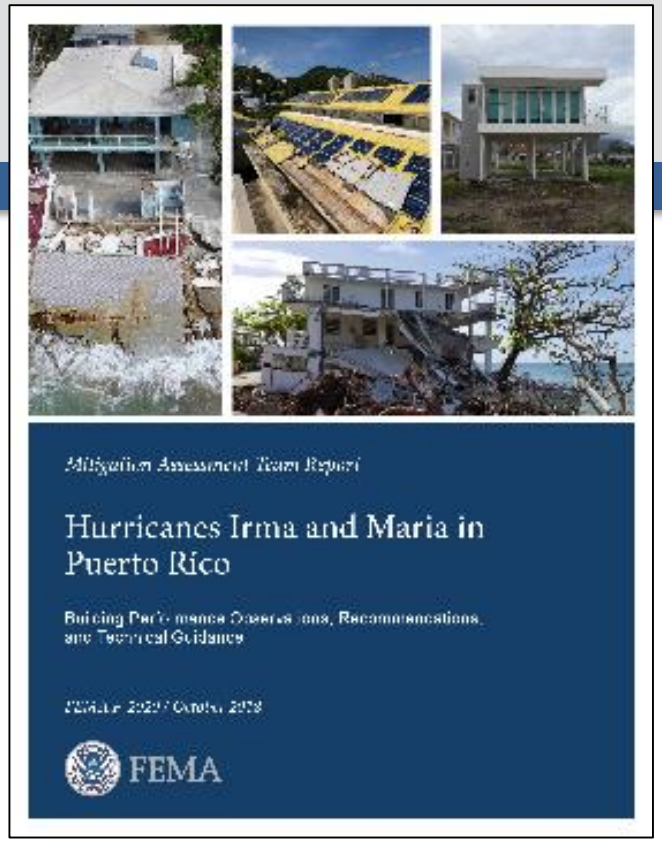
Imagen 1. Falla de la estructura sujeta a oleaje, olas y erosión.

Imagen 2. Estructura con daños severos en la Zona Costera de Punta Santiago.

Los MAT de FEMA han observado muchos casos de daños por olas pequeñas debido a las condiciones de la Zona Costera A a lo largo de las costas de las comunidades afectadas por el huracán María.

Asuntos claves

- Las prácticas correctas de diseño y construcción pueden minimizar el daño a los edificios, particularmente elevando el edificio sobre la elevación mínima requerida.
- Una vez los niveles de inundación sobrepasan la elevación del piso más bajo de un edificio, el alcance de los daños aumenta considerablemente, especialmente en áreas sujetas a oleaje costeras (Imagen 2).
- Los cimientos en áreas costeras deben ser diseñados para elevar los edificios sobre el nivel de la inundación del diseño (DFE, por sus siglas en inglés), para cumplir con el *Estándar para el Diseño y la Construcción Resistente a Inundaciones* de la Sociedad Americana de Ingenieros Civiles (ASCE 24-14, 2014), mientras resisten las fuerzas de inundación, los vientos fuertes, el desgaste y la erosión, y los escombros flotantes en las *Cargas Mínimas del Diseño y Criterios Relacionados para Edificios y Otras Estructuras* (ASCE 7-16, 2017).
- Los cimientos utilizados para la construcción tierra adentro, por lo general, no son adecuados para la construcción costera. Algunos ejemplos de sistemas de cimientos que tienen un historial de bajo rendimiento en áreas propensas a la erosión son losas de cemento sobre el terreno, zapatas aisladas y cimientos superficiales (o flotantes).
- En las Zonas V y Zonas Costeras A, deben utilizarse cimientos abiertos (pilotes o pilares) diseñados para resistir todas las condiciones de inundación base, como las olas, el flujo de alta velocidad, la erosión y el desgaste, y los escombros arrastrados por las inundaciones.
- Las decisiones sobre la compra de tierras y la ubicación de los edificios deben tomar en cuenta los impactos a largo plazo de la marejada, las olas y la erosión, y no deben basarse únicamente en la ubicación y las condiciones actuales de la costa.



FEMA P-2020 | Mitigation Assessment Team Report: Hurricanes Irma and Maria in Puerto Rico

FEMA

Report available at: https://www.fema.gov/media-library/assets/documents/173789

Beach Erosion Working Group
Natural and Cultural Resources Recovery Support Function

Assessment of wind and wave-forcing, effects, and impacts of Hurricane María on reference coastal sites of the main island of Puerto Rico

Final Performance Report
May 15, 2019

Submitted to:

Miguel A. García-Bermúdez, Ph.D.
U.S. Fish and Wildlife Service
Caribbean Landscape Conservation Cooperative
Jardín Botánico Sur 1201; Calle Ceiba
San Juan, PR 00962

Prepared by:

Luis D. Aponte-Bermúdez, PhD., P.E.
Professor – Structural and Wind Engineer
Department of Civil Engineering and Surveying
University of Puerto Rico-Mayagüez

Miguel S. Canals-Silander, Ph.D.
Associate Professor – Coastal Engineering
Engineering Sciences and Materials Department
University of Puerto Rico-Mayagüez

Patricia Chardon-Maldonado, Ph.D.
Research Assistant – Coastal Engineering
CariCOOS
University of Puerto Rico-Mayagüez

Jonathan Muñoz-Barreto, Ph.D.
Assistant Professor – Surveying Group
Department of Civil Engineering and Surveying
University of Puerto Rico-Mayagüez

Ernesto L. Díaz, M.S., MEM.
Director - Coastal Zone Management Program
Department of Natural and Environmental Resources
Executive Secretariat of the Puerto Rico Climate Change Council

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DEPARTAMENTO DE RECURSOS NATURALES Y AMBIENTALES

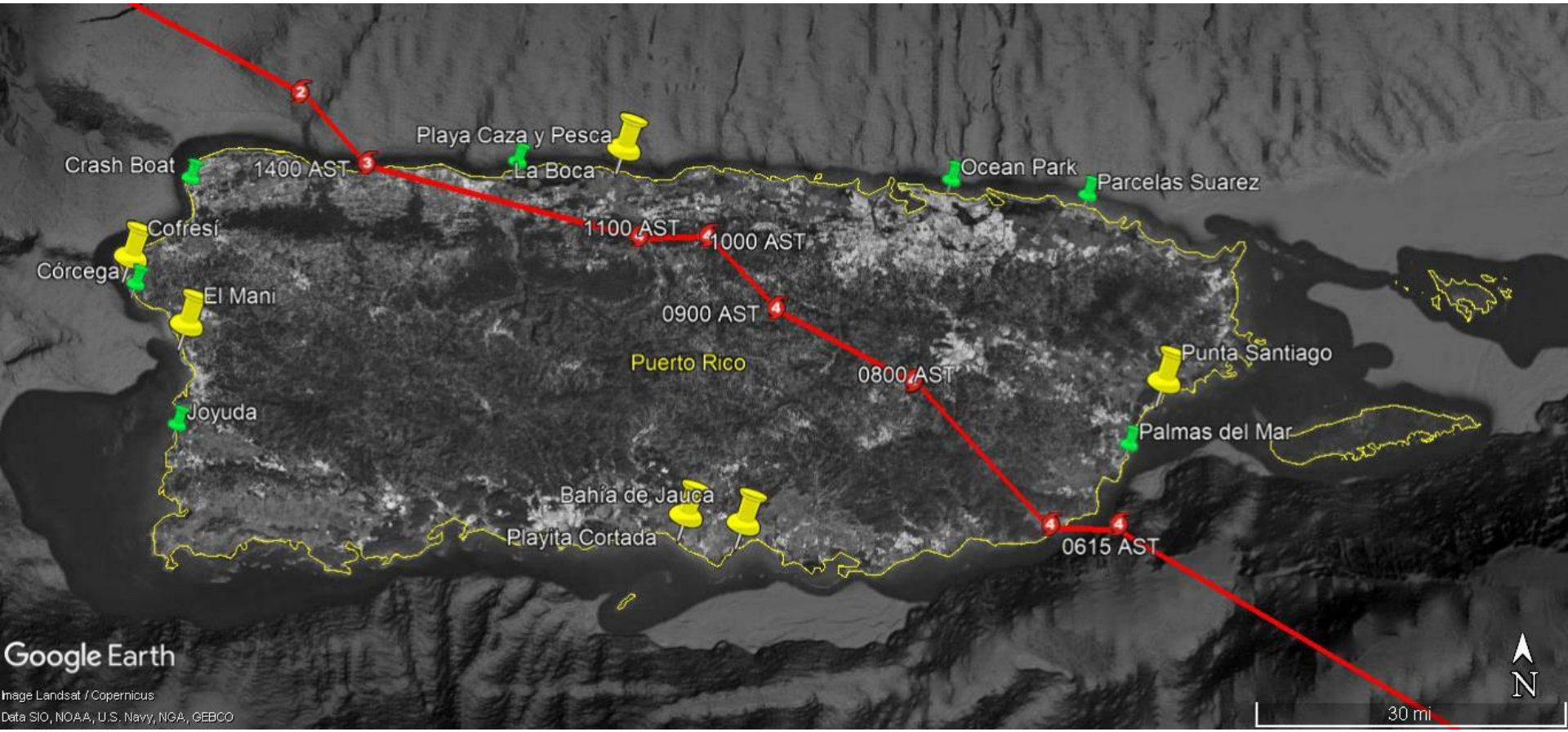
PROGRAMA DE MANEJO
ZONA COSTANERA

Beach Erosion - Report

Studied areas

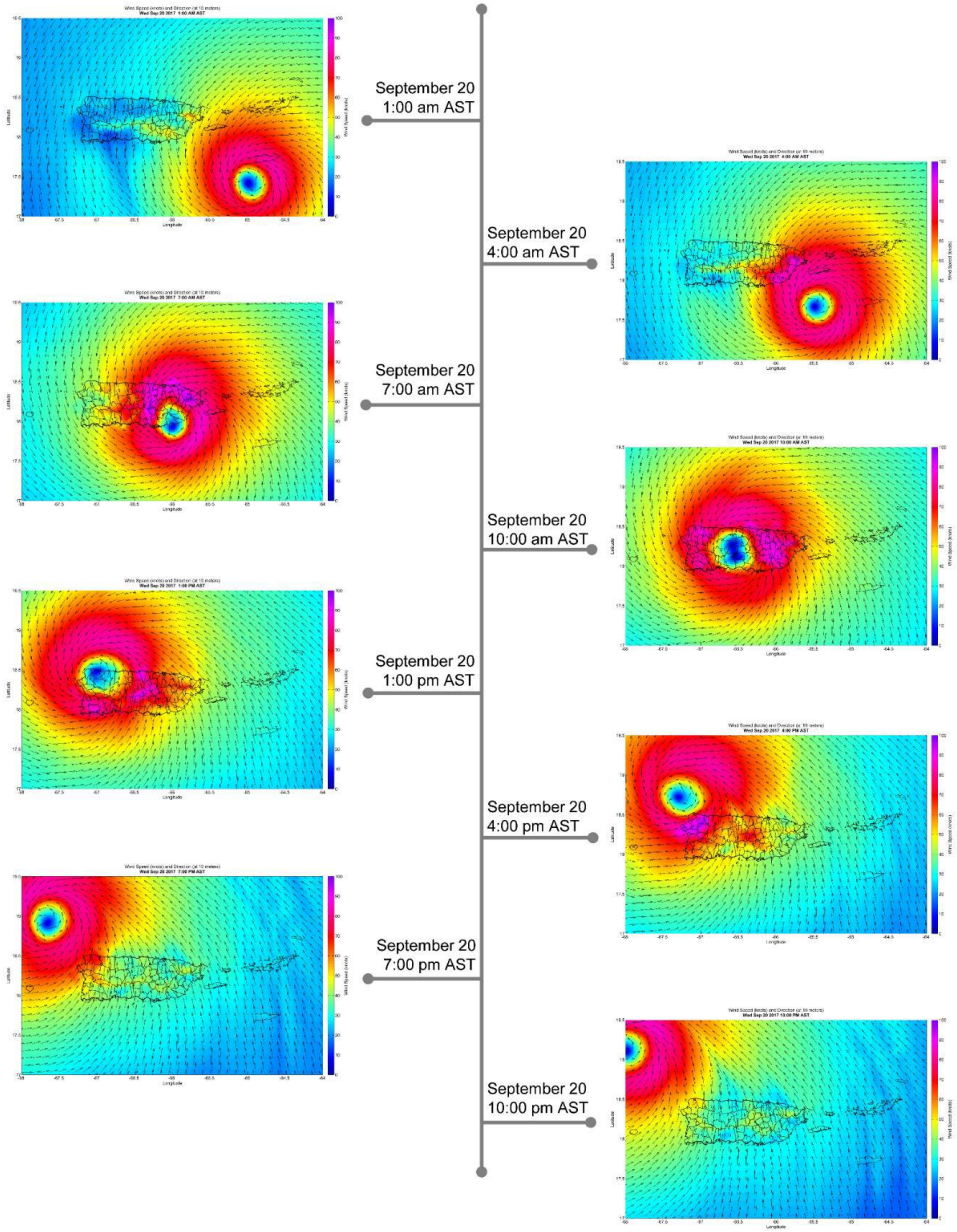
- Cofresí, Rincón, PR (west coast)
- El Maní, Mayagüez, PR (west coast)
- Playita Cortada, Santa Isabel, PR (south coast)
- Bahía de Jauca, Santa Isabel, PR (south coast)
- Punta Santiago, Humacao, PR (southeast coast)
- La Boca, Barceloneta, PR (north coast)

Beach Erosion - Report

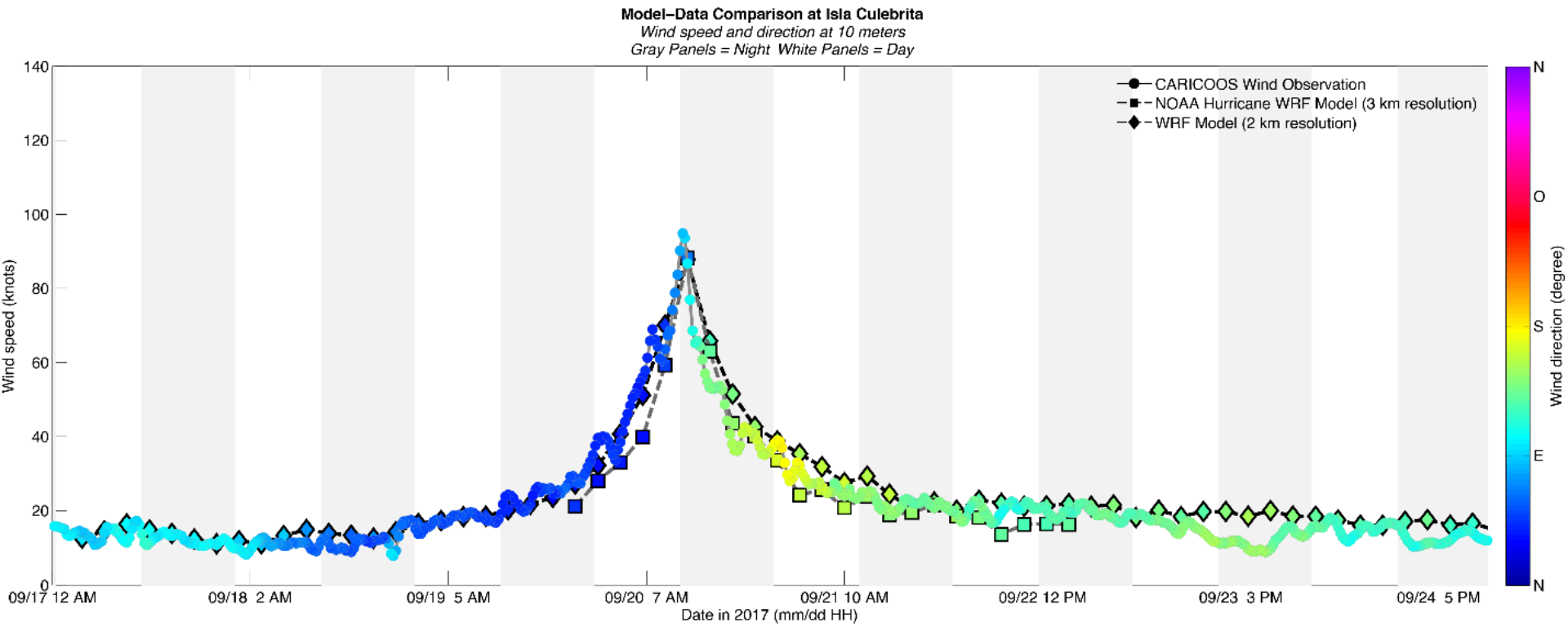


Hurricane Maria Wind Hindcast

Maps of wind speed and direction at 10 meters above ground level when Hurricane María was close to the selected CARICOOS meteorological stations.

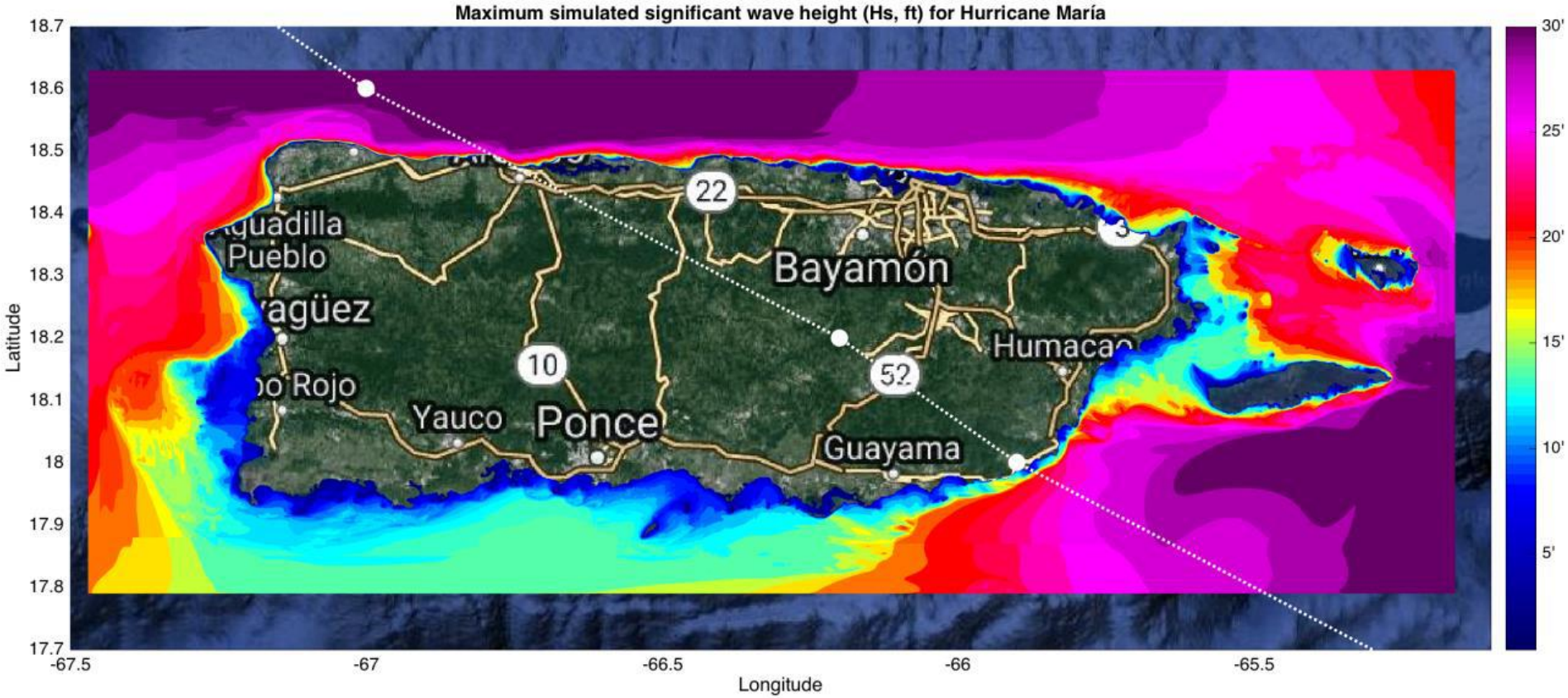


Hurricane Maria Wind Hindcast

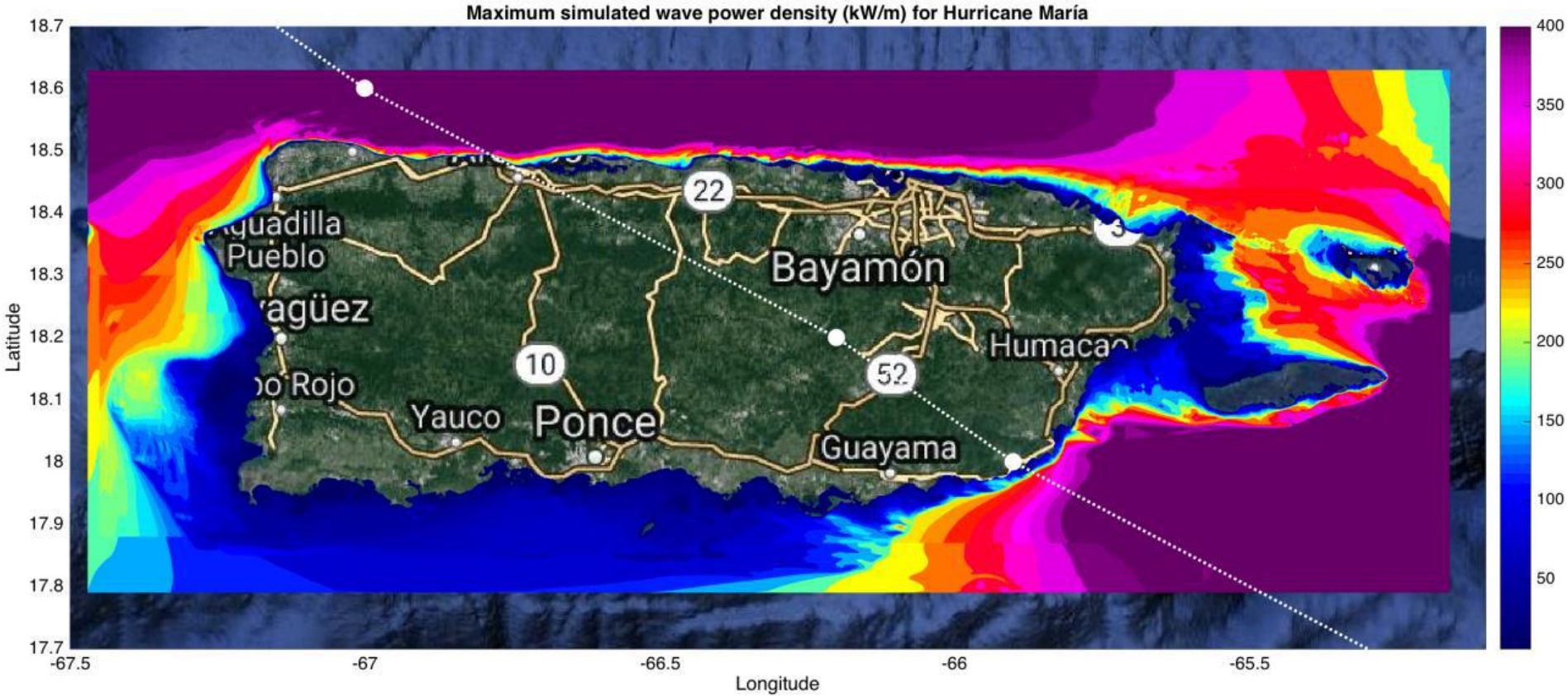


Comparison between simulated (HWRF: square marker and WRF: diamond marker) and observed (circle marker) wind speed and wind direction at the CARICOOS Culebrita meteorological station.

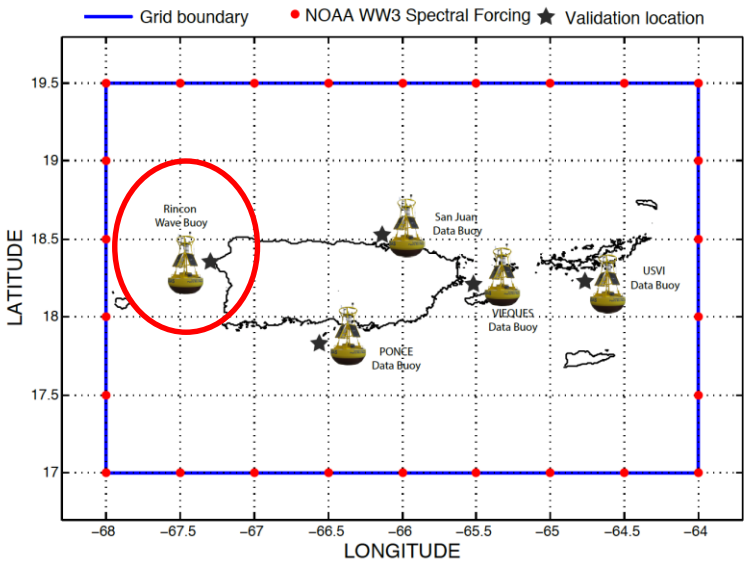
Hurricane Maria Wave Hindcast



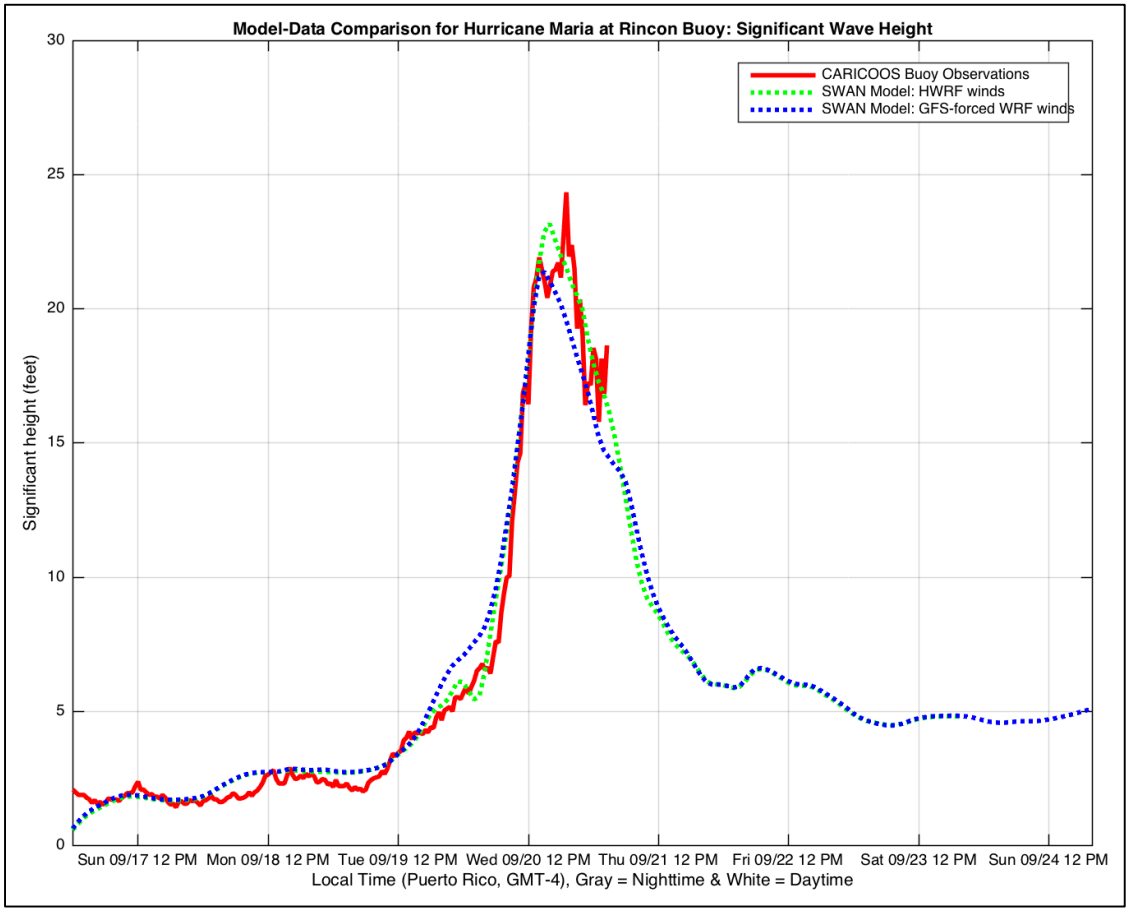
Hurricane Maria Wave Hindcast



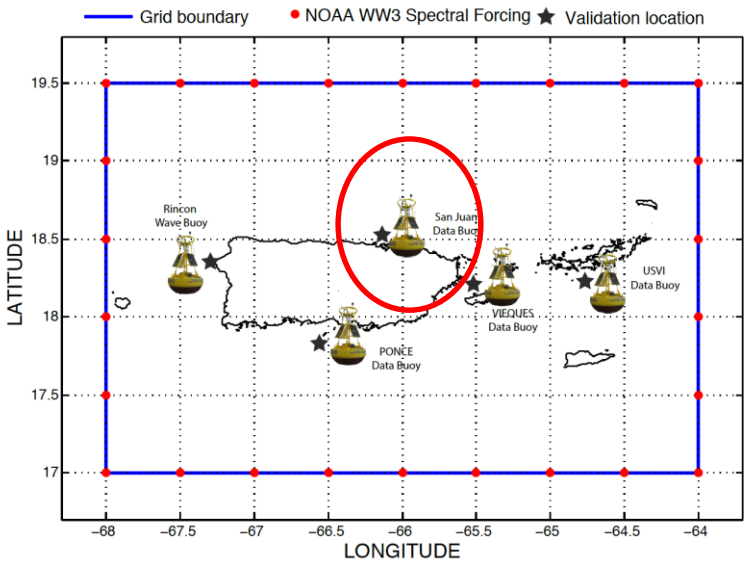
Hurricane Maria Wave Hindcast

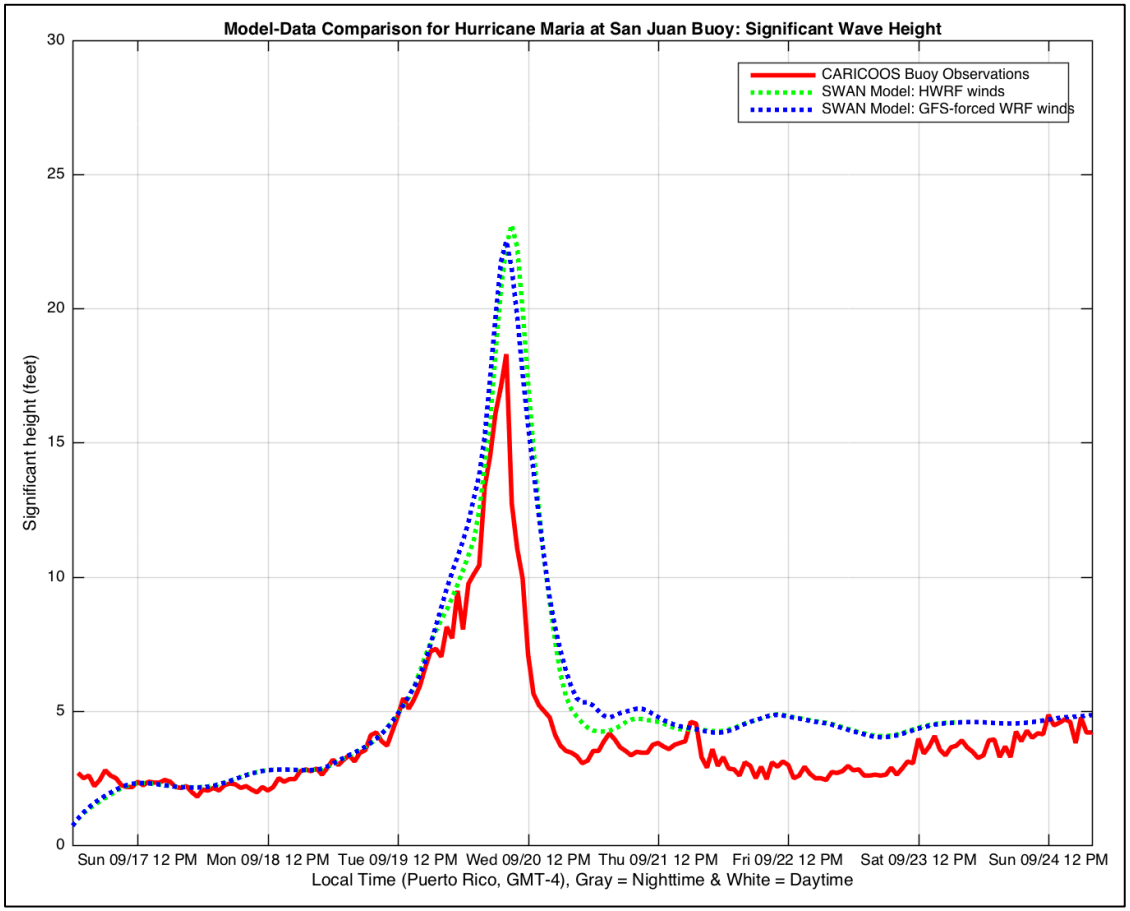


CARICOOS RINCON BUOY



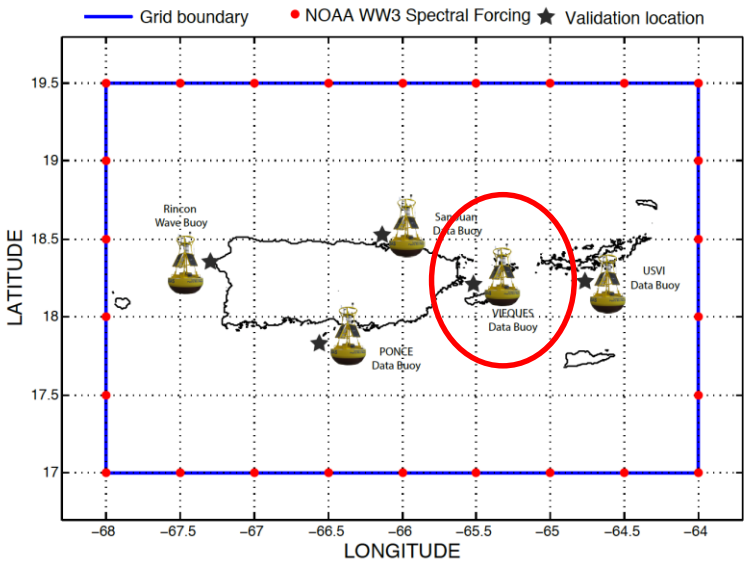
Hurricane Maria Wave Hindcast



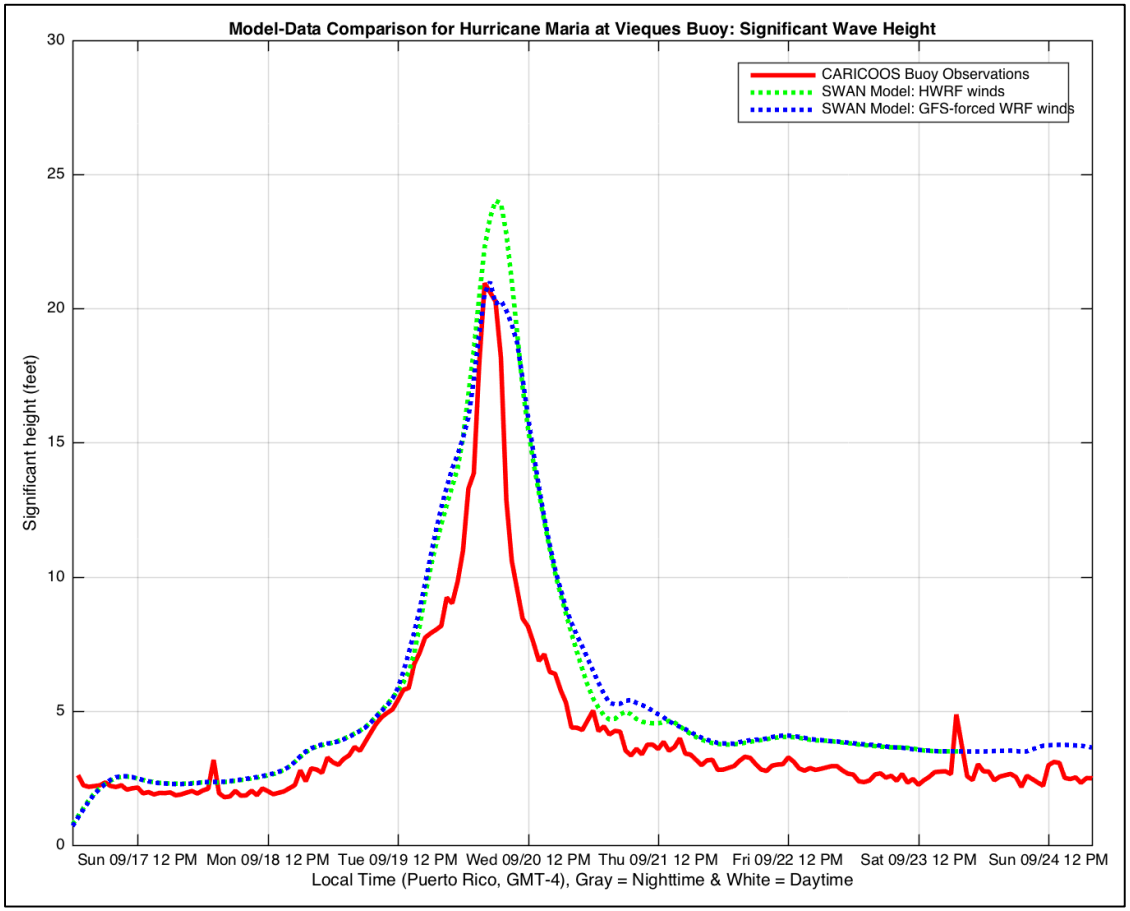


CARICOOS SAN JUAN BUOY

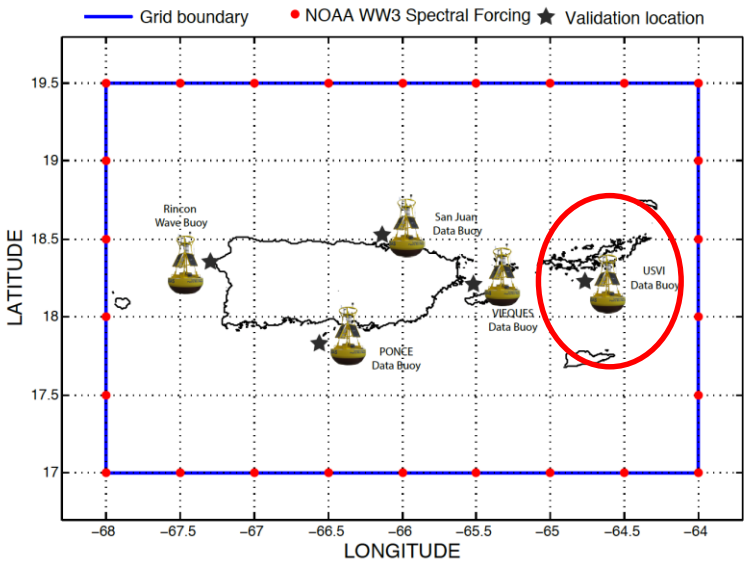
Hurricane Maria Wave Hindcast



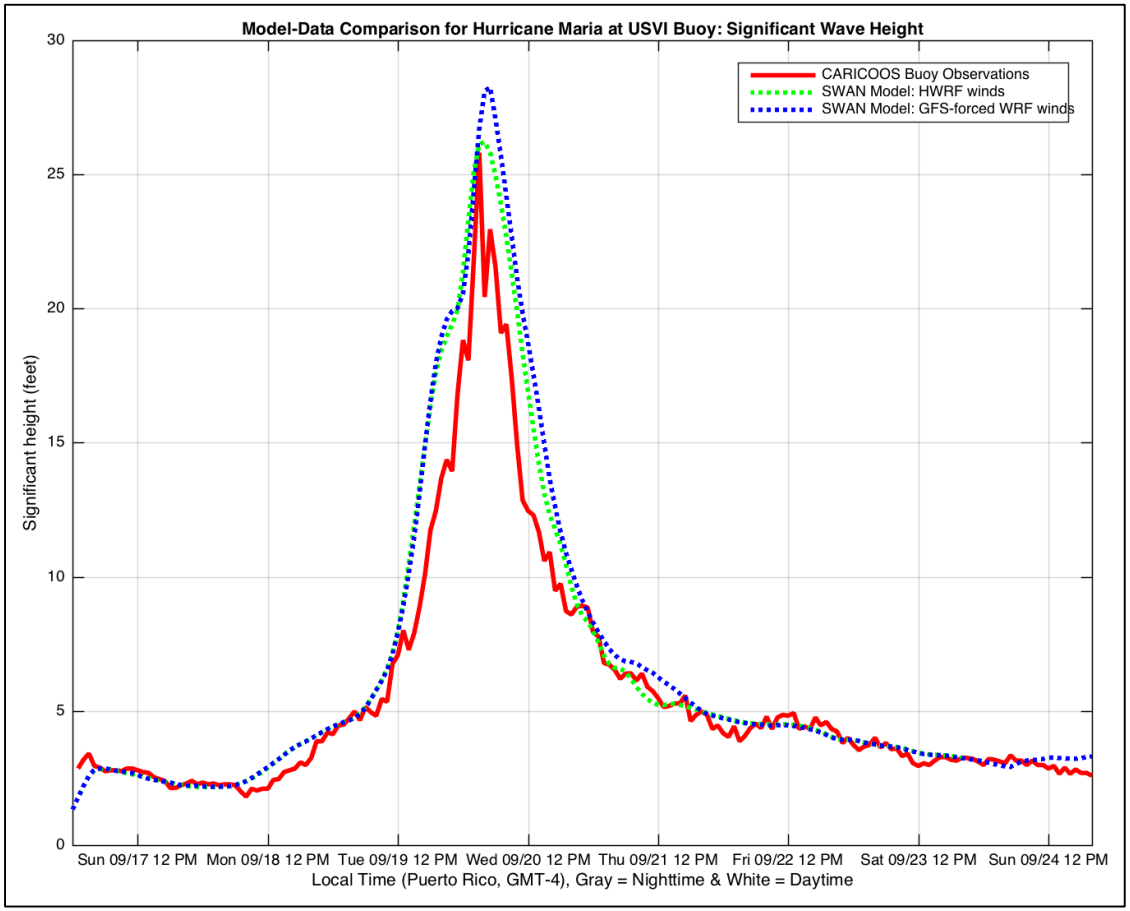
CARICOOS VIEQUES BUOY



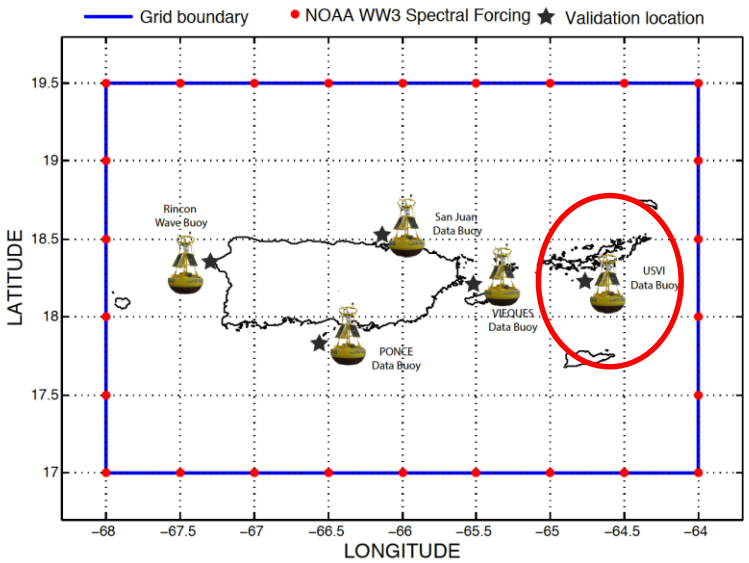
Hurricane Maria Wave Hindcast



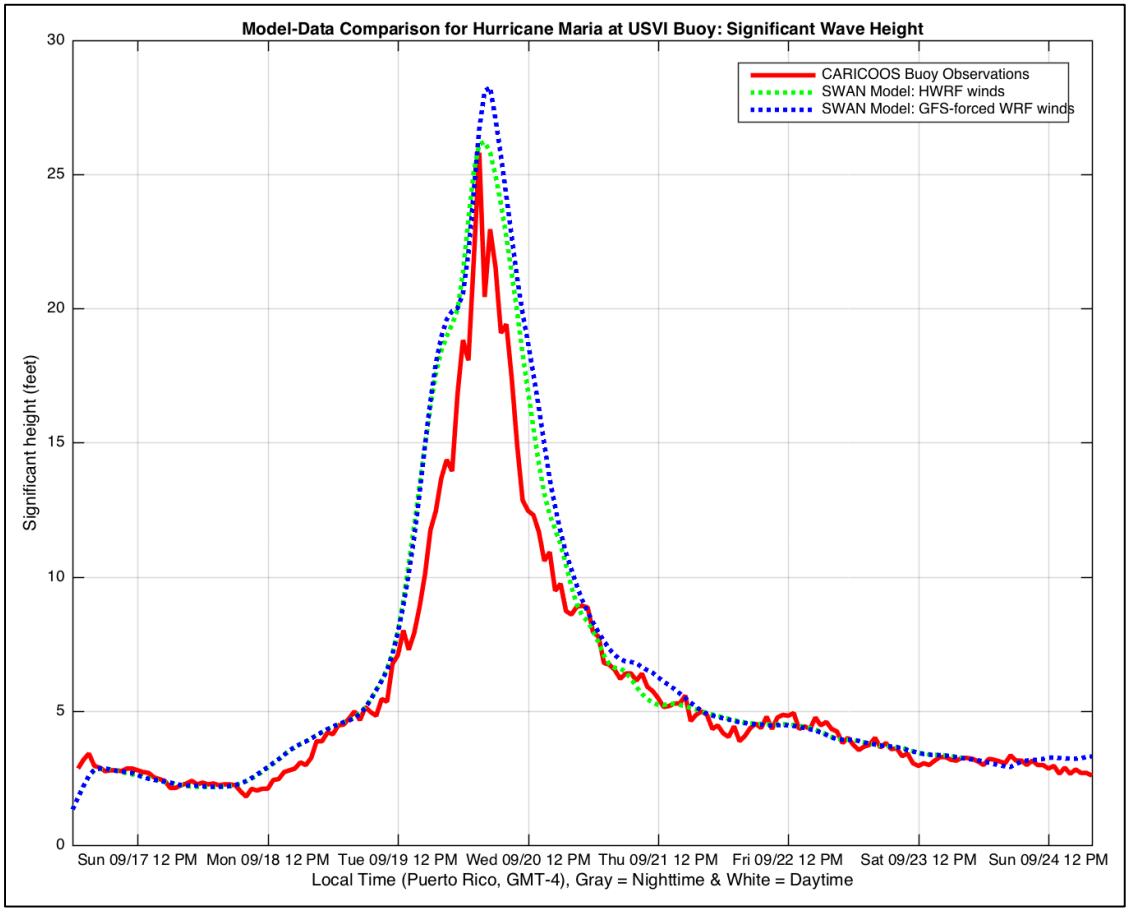
CARICOOS US VIRGIN ISLANDS BUOY



Hurricane Maria Wave Hindcast



CARICOOS US VIRGIN ISLANDS BUOY



Daños Costeros - Rincón, PR

Daños Costeros – Punta Santiago, Humacao, PR

Daños Costeros – Punta Santiago, Humacao, PR

Daños Costeros La Boca Barceloneta, PR

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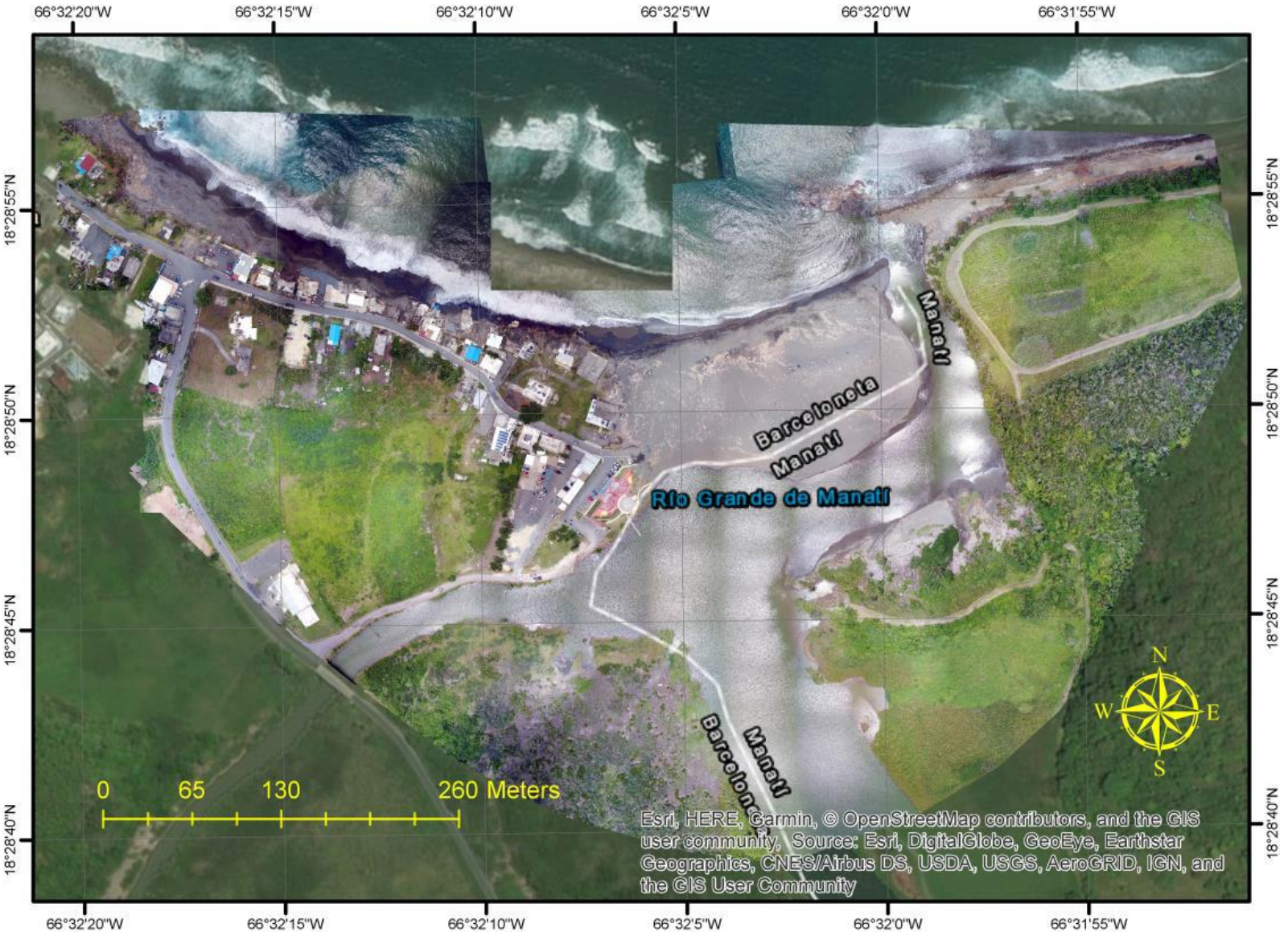
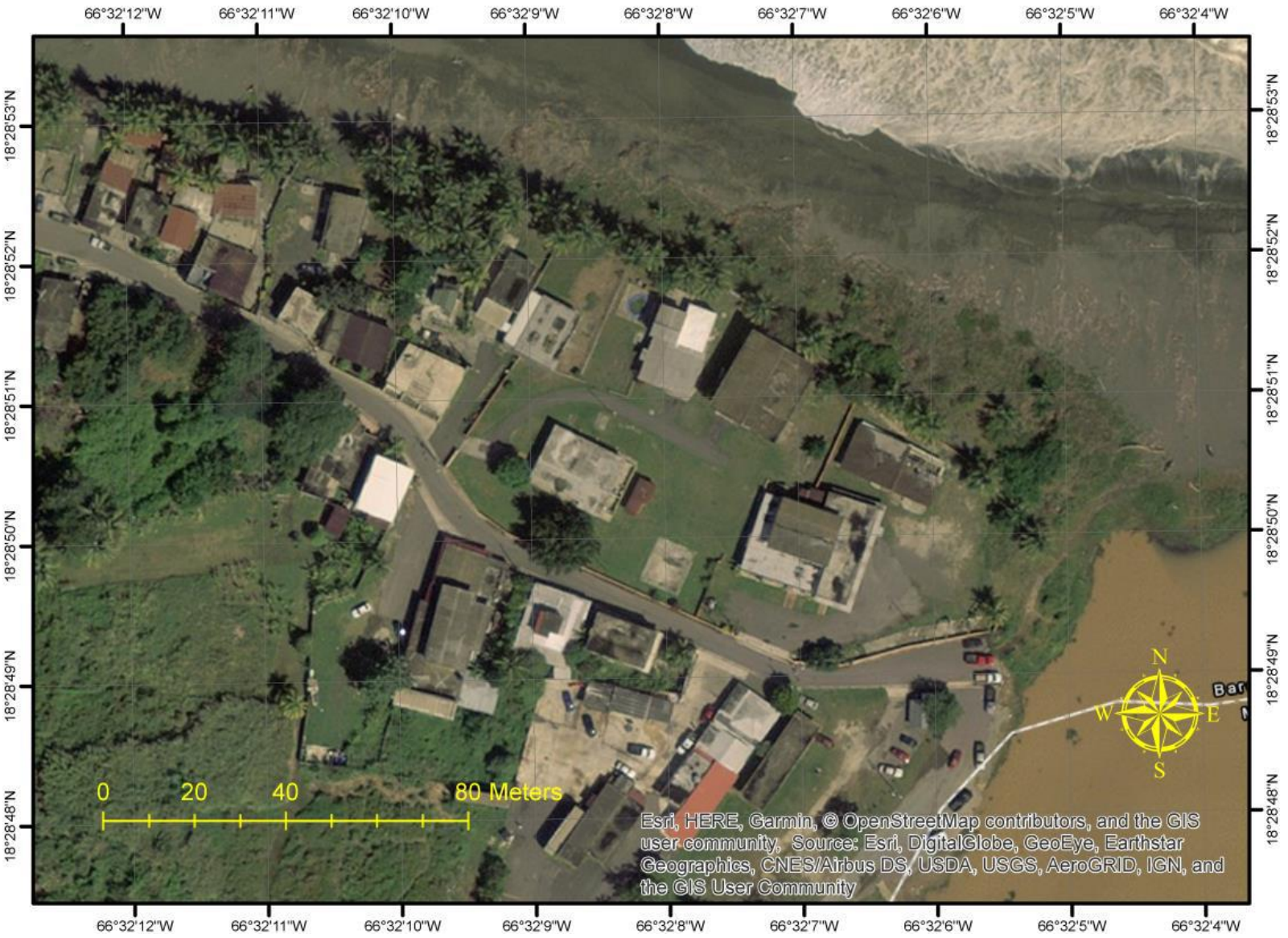


Daños Costeros La Boca Barceloneta, PR



Daños Costeros La Boca Barceloneta, PR

Daños Costeros La Boca Barceloneta, PR

Daños Costeros Playita Cortada, Santa Isabel, PR

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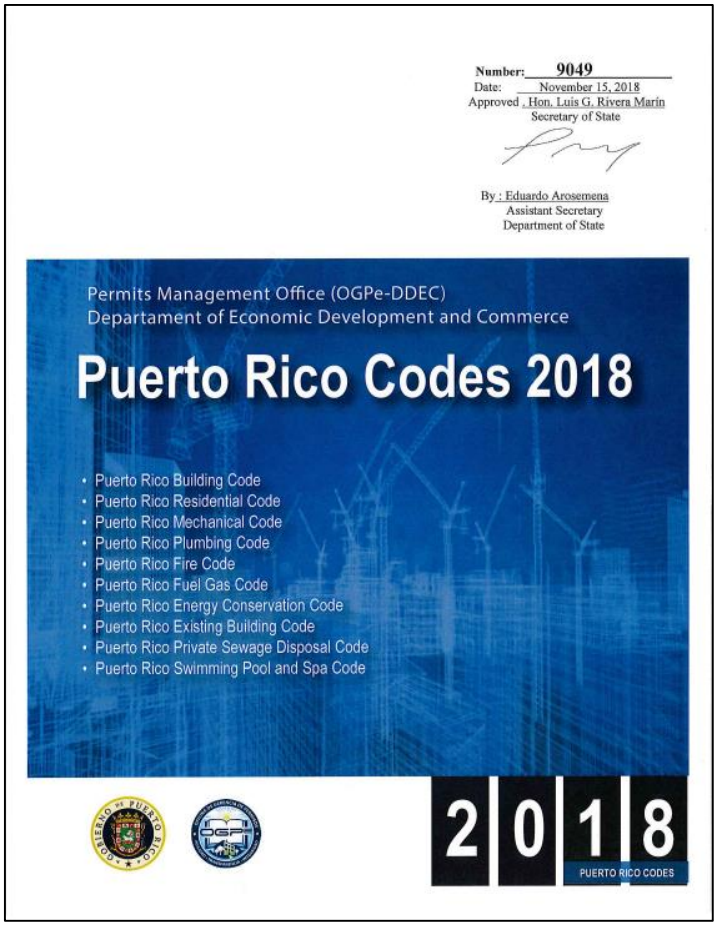
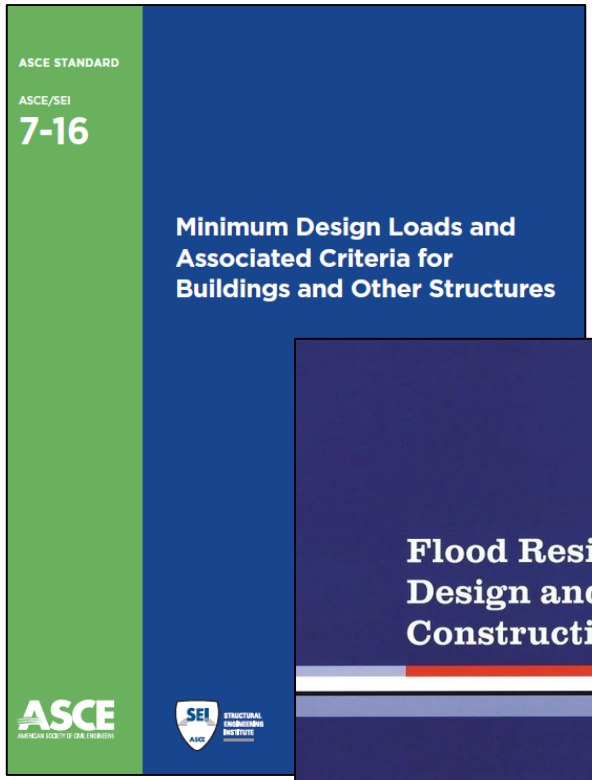
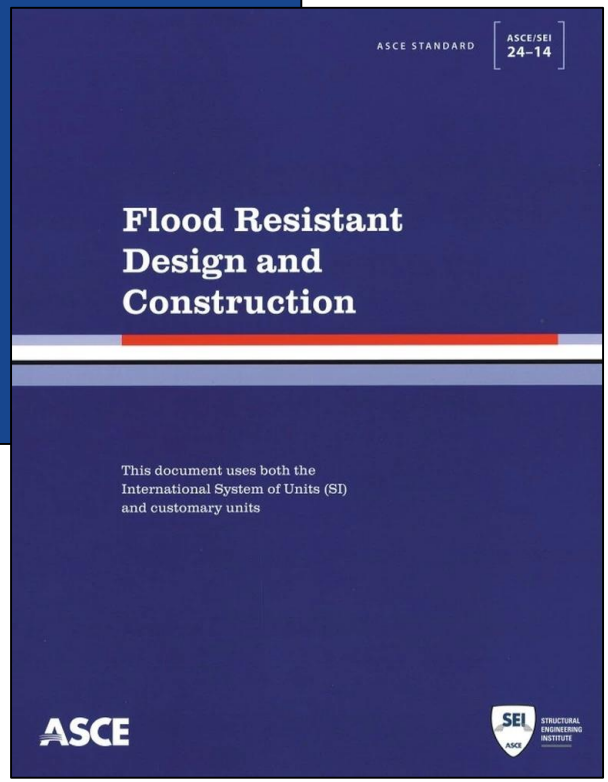
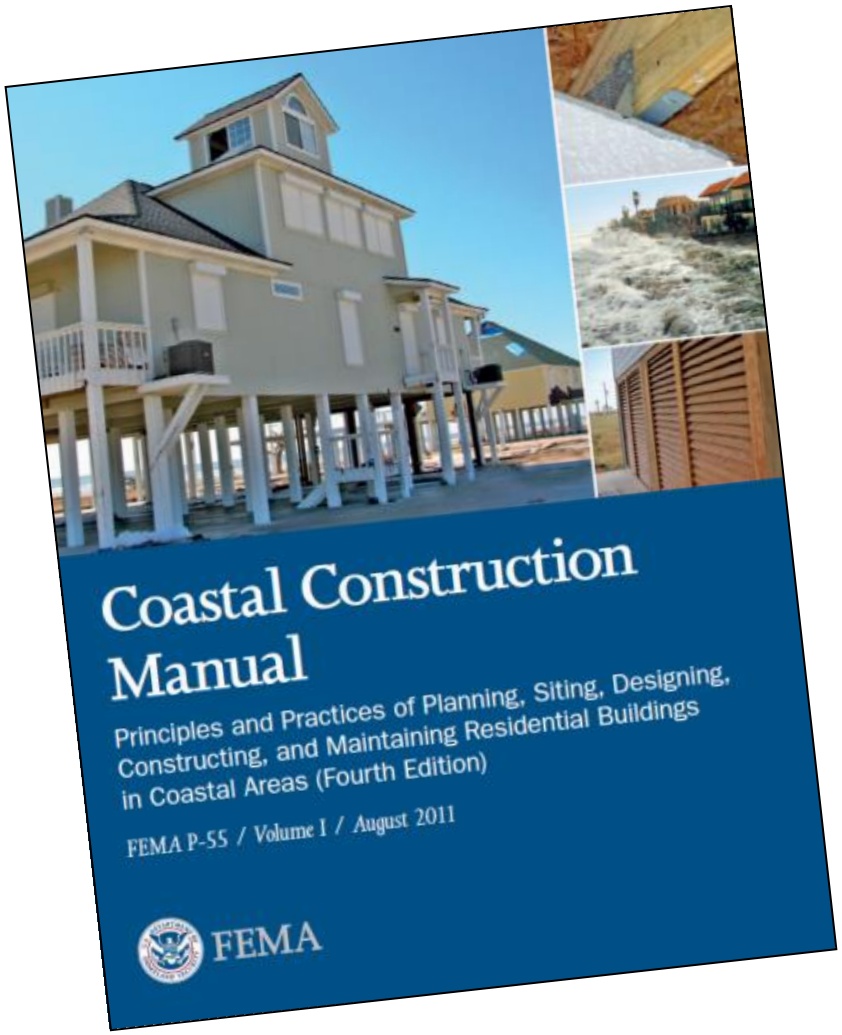
Puerto Rico Building Code 2018







Coastal Construction Manual: FEMA P-55 (2011)

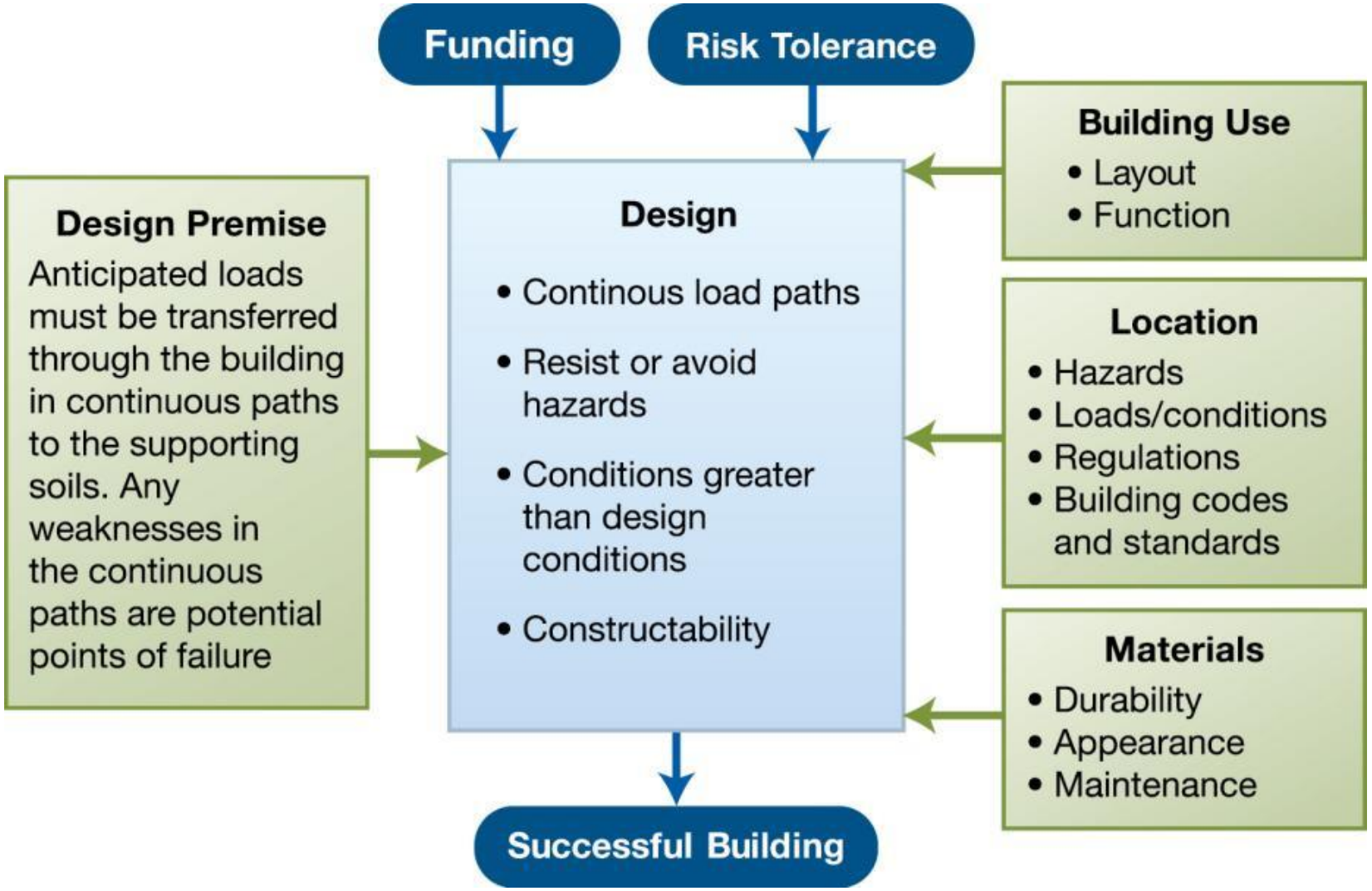


- Course textbook
- Residential Coastal Construction Web site: http://www.fema.gov/residential-coastal-construction
- CD-ROM
- CCM equation calculator

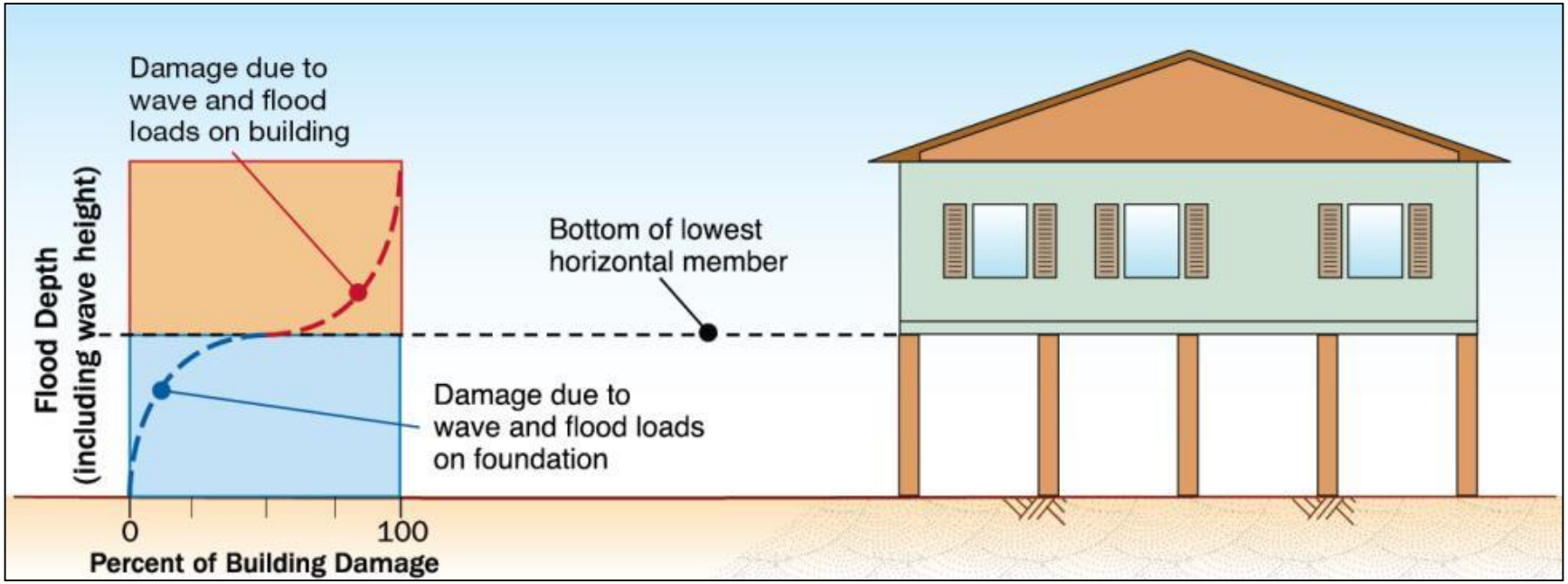
FEMA Residential Coastal Construction Course Overview

Unit	Title	Related CCM Chapters
I	Introduction and Course Overview	1, 2
II	Overview of Building Design Concepts	3, 6, 7
III	Identifying Hazards	3
IV	Siting	4
V	Using Flood Hazard Information	3, 5, 6
VI	Design and Construction of Elevated Buildings (Wind, Seismic, Building Envelope)	8, 9, 11
VII	Design and Construction of the Foundation (Flood Loads and Conditions, Load Combinations)	8, 9, 10, 13, 14
VIII	Other Issues (Utilities, Decks, Slabs, etc.)	9, 12, 14, 15

Design Framework



Avoid Flood (Especially Waves)



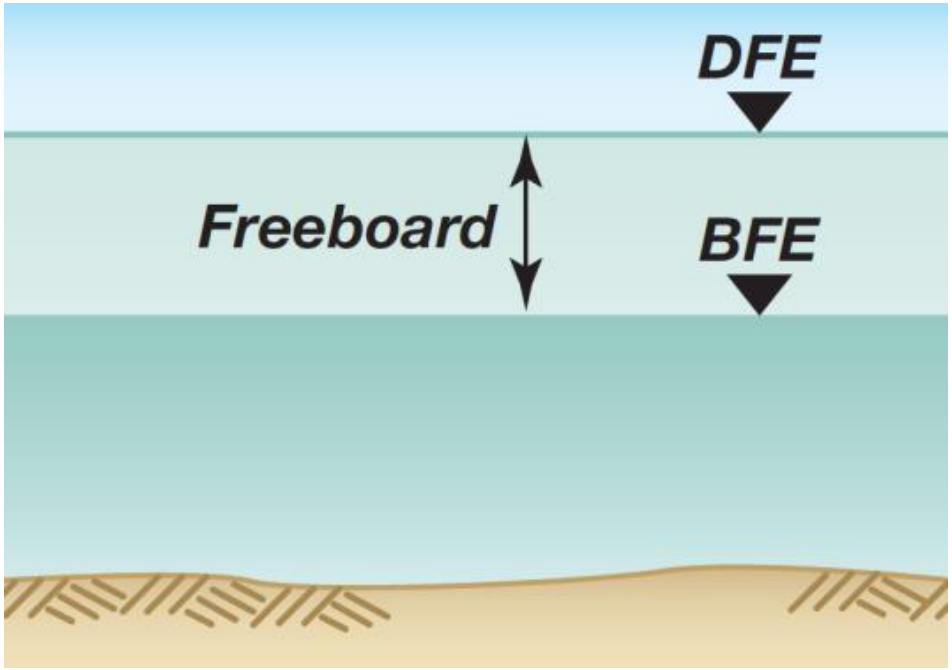
Avoid Flood (Especially Waves)

- Elevate to BFE + freeboard
- Open foundations – Zone V and Coastal A Zones
- No obstructions below BFE
- Orient structure elements below water perpendicular to primary wave direction

Hurricane Ivan, 2004, Gulf Shore, AL

Elevation

- **Freeboard**, usually expressed in feet above the BFE, is building additional elevation above the minimum NFIP requirement
- Freeboard can be mandated by a State or community floodplain



Design Flood Elevation (DFE)

DFE = Locally adopted regulatory flood elevation

If community regulates to minimum NFIP requirements:

- DFE = BFE

If community exceeds minimum NFIP requirements:

- DFE > BFE

DFE ≥ BFE

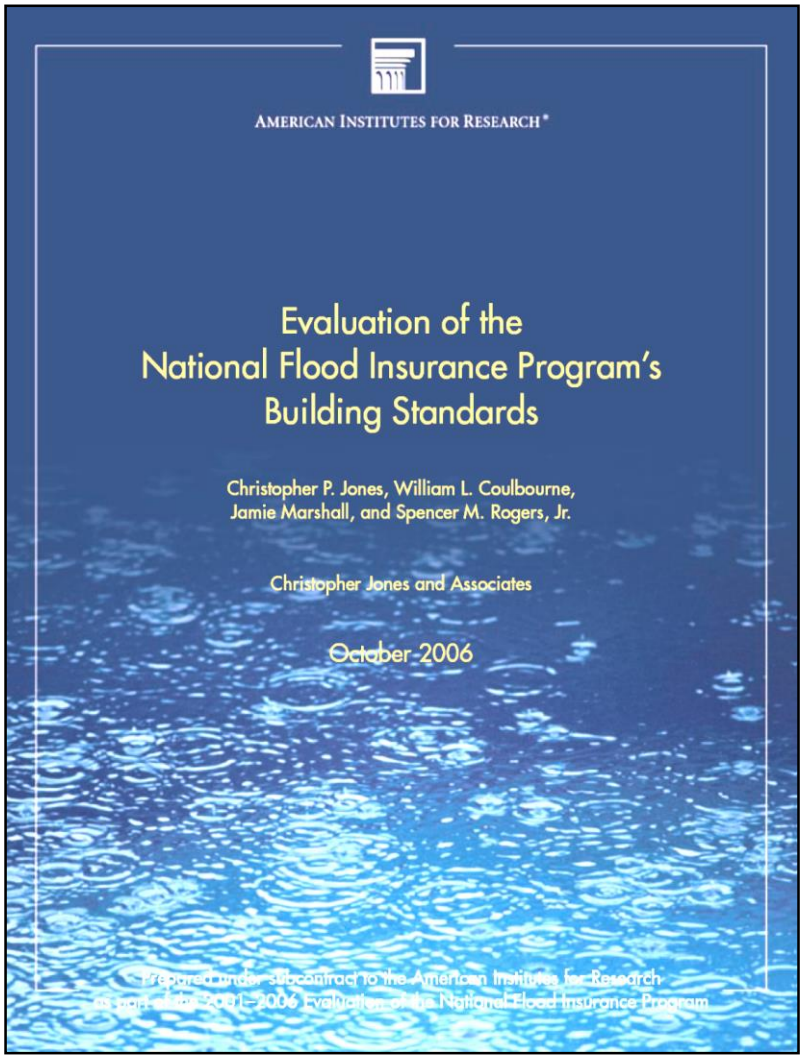
FEMA P-55 and codes

- Use DFE as minimum elevation for flood-resistant design and construction

Freeboard

For most foundations, each foot of freeboard added ***at the time of construction*** adds 0.25% to 1.0% of the at-BFE construction cost
For a Zone V example (DR = 7%, UL = 30 years), the study found it is worth spending up to:

- 3% additional to add 1 ft
- 5% additional to add 2 ft
- 7% additional to add 3 ft
- 8% additional to add 4 ft



Reference:
https://www.fema.gov/media-library-data/20130726-1602-20490-5110/nfip_eval_building_standards.pdf

Risk Management through Mitigation

- Siting, design, and construction
  - Building setbacks
  - Freeboard
  - Wind-, debris-, and rain-resistant building envelope
- Protective works
  - Dune/bluff stabilization
  - Erosion control structures
  - Beach nourishment

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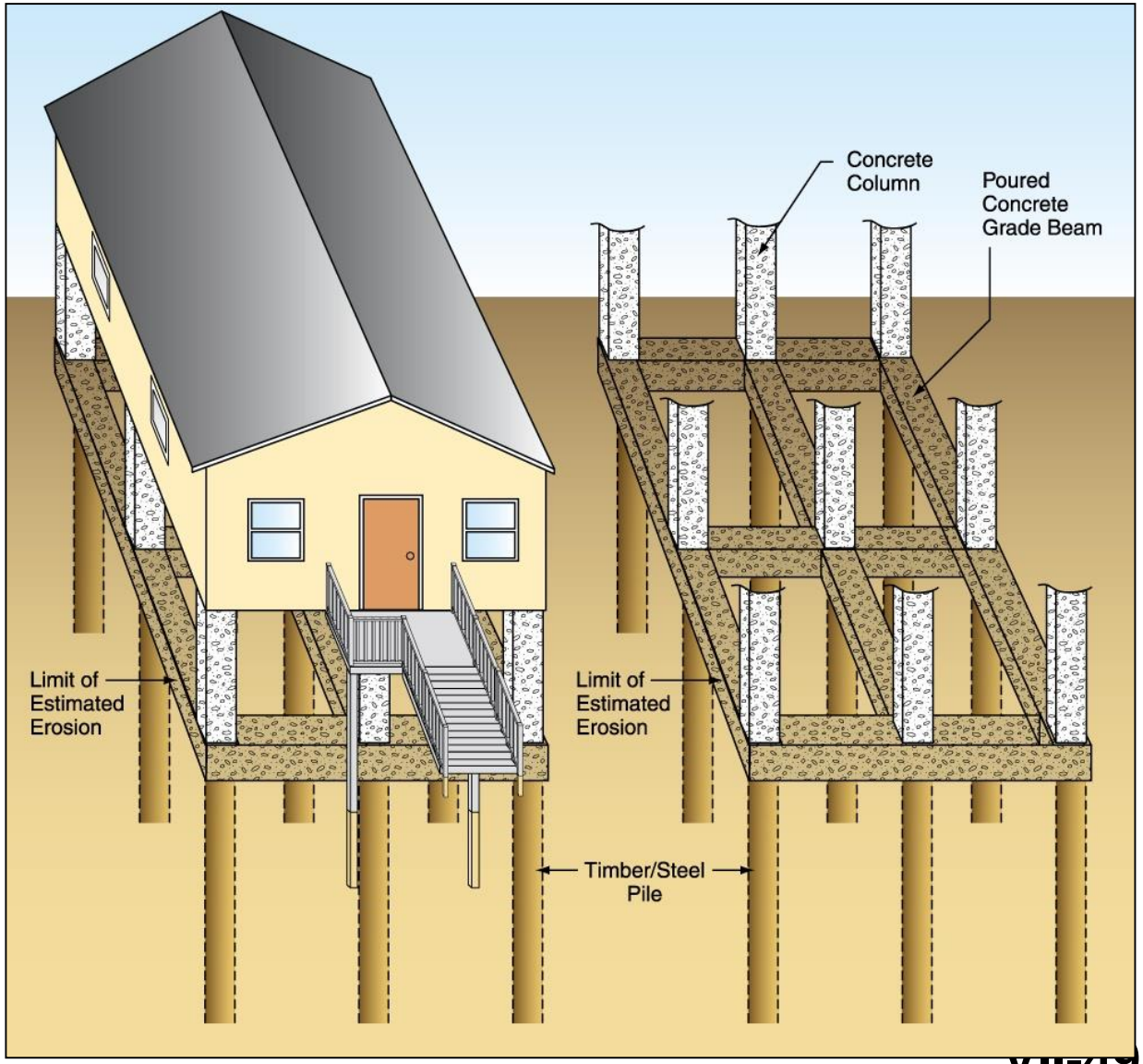
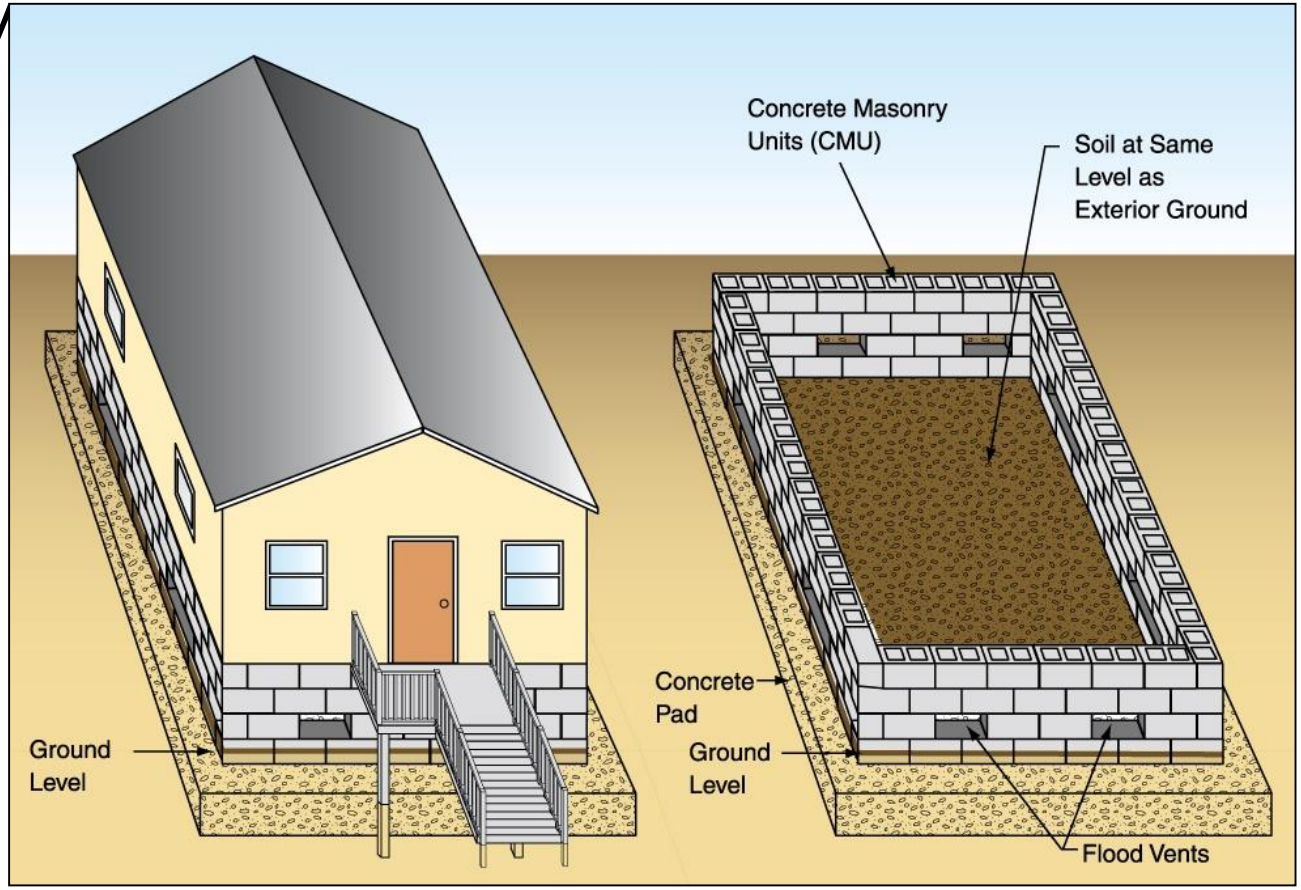
Open Foundations



Closed Foundations

Closed foundations are not recommended in Coastal A Zones and are not allowed in Zone V



Foundation Failures

Hurricane Ike, 2008, Bolivar Peninsula, TX

Foundation Failures

Hurricane Ike, 2008, Bolivar Peninsula, TX

Hurricane Sandy, 2012, Normandy Beach, NJ

FEMA

Foundation Failures

Hurricane Maria, 2017,
Rincón, Puerto Rico

Hurricane Maria, 2017,
Joyuda, Puerto Rico

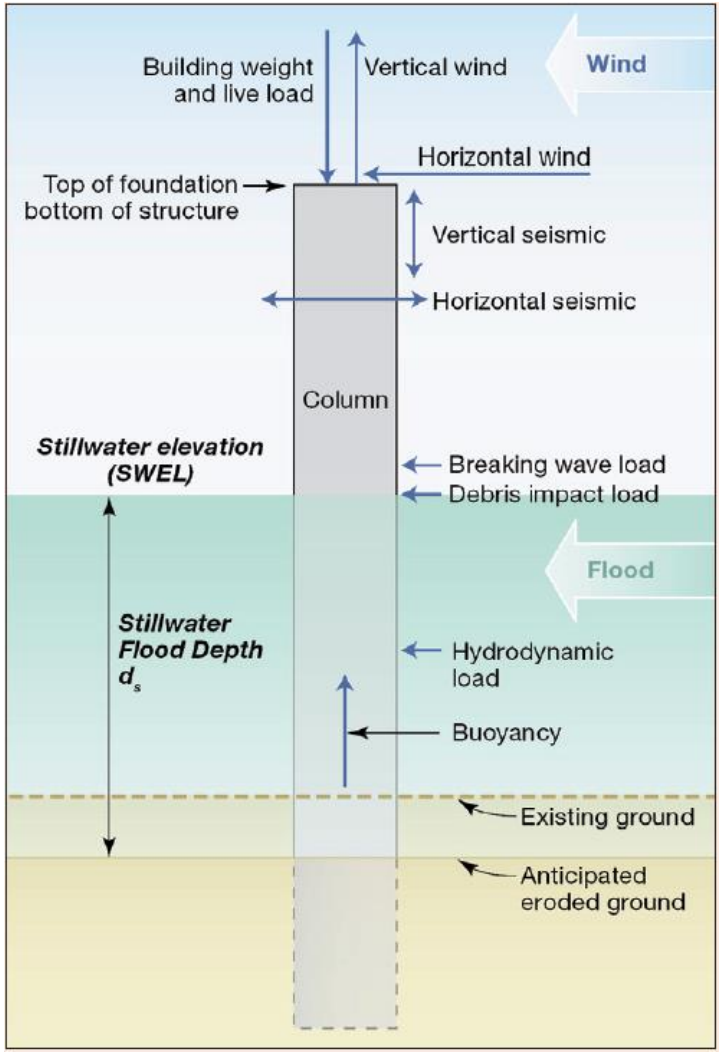
Foundation Failures

Hurricane Maria, 2017,
Rincón, Puerto Rico

Hurricane Maria, 2017,
Joyuda, Puerto Rico

Flood Loads

- Magnitude of load
- Location of load application on structure
- Future loads are applied to structures as follows:
  - **Lateral hydrostatic loads:** at two-thirds depth point of stillwater elevation
  - **Breaking wave loads:** at stillwater elevation
  - **Hydrodynamic loads:** at mid-depth point of stillwater elevation
  - **Debris impact loads:** at stillwater elevation




QUESTIONS
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Impacto Combinado del Oleaje y las Marejadas Ciclónicas en Estructuras Costeras

Dr. Luis D. Aponte Bermúdez, P.E.
luisd.aponte@upr.edu
Catedrático - Departamento de Ingeniería Civil y Agrimensura
Universidad de Puerto Rico Mayagüez

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22 DE NOVIEMBRE DE 2019
HOTEL VERDANZA-SAN JUAN, PR