High-Resolution Computational Modeling of Hurricane Irma to Develop Building Damage Functions Based on Location-Based Data

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Introduction

Damage Functions

- Building damage functions relate hydrodynamic parameters (i.e., depth, velocity, wave height, etc.) to the associated damage a building sustains during an event.
- These damage functions are used to assess how structural damage varies for different locations and structures.
- Damage functions can be applied to other studies to estimate building damages for modeled storm events.

Location-Based Data (LBD)

- Location-Based Data (LBD) is generated from cellphone data.
- Home and work locations are derived from the LBD, giving the locations of structures used in this study.
- LBD also provides info on which buildings were abandoned after Hurricane Irma at which other critical services (i.e., power, schools) were restored, indicating the abandoned buildings were damaged beyond livability.

Research Objectives

- **Hindcast Hurricane Irma and generate hydrodynamic parameters at a fine scale**
- **Combine hydrodynamic parameter outputs and LBD to develop building damage functions**
- **Investigate the validity of LBD for building damage functions**

Hurricane Irma and Study Area

Hurricane Irma

- In September 2017, Irma made landfall in the Florida Keys as a Category 4 hurricane.
- In Florida alone, Irma resulted in over $50 billion in damages.

Study Area

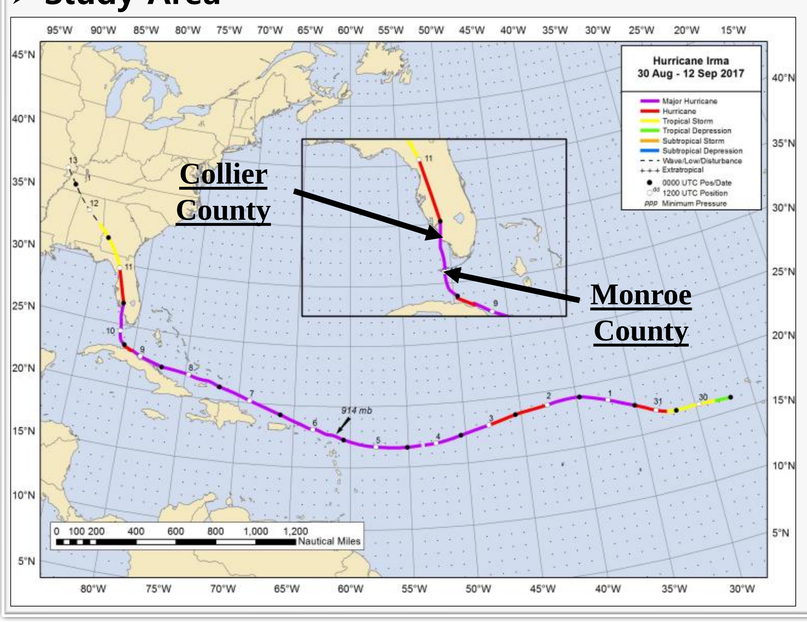


Figure 1. Hurricane Irma best track positions from the National Hurricane Center (Cangialosi et al., 2021). Collier and Monroe Counties are labeled as the two study sites.

Methods

Delft3D-FM Coupled Models

D-Flow FM

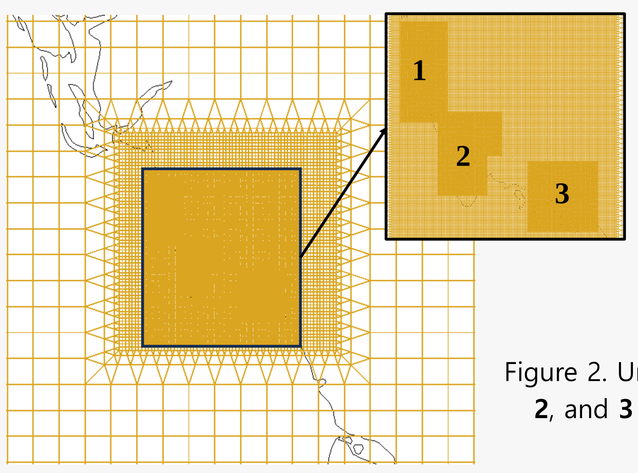
- Simulates hydrodynamic parameters such as depth and velocity.
- Uses meteorological and astronomical tidal forcings to drive the model.

D-Waves (SWAN, *Simulating WAves Nearshore)*

- Simulates wave generation, propagation, and dissipation.
- Uses hydrodynamic parameters from D-Flow FM and the wind field to drive the model.

- Coupled models produce storm tide with significant wave heights.

Grid Generation



- D-Flow FM: Single, Unstructured Grid
  - Coarse (10km) → Fine (80m)
- D-Waves: Nested, Structured Grids
  - Coarse (10km) → Fine (150m)
- Refined at areas with LBD and modeled storm tide

Figure 2. Unstructured grid for Collier County where **1**, **2**, and **3** correspond to Naples, Marco Island, and Everglades City, respectively.

Validation

- Tidal constituents from the Oregon State University Tidal Inversion Software (OTIS) were used to develop tide boundary conditions (Egbert and Erofeeva, 2002).
- Wind and pressure fields were developed with the Holland Model (Holland et al., 2010) and the radius to maximum winds relation (Nederhoff et al., 2019) with data from HURDAT2 and EBTRK.

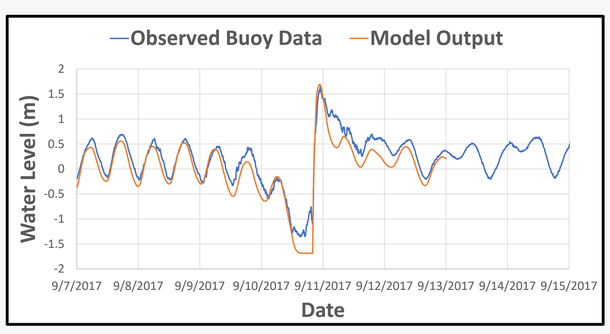


Figure 3: Storm tide validation.

Results

Mapping Model Outputs

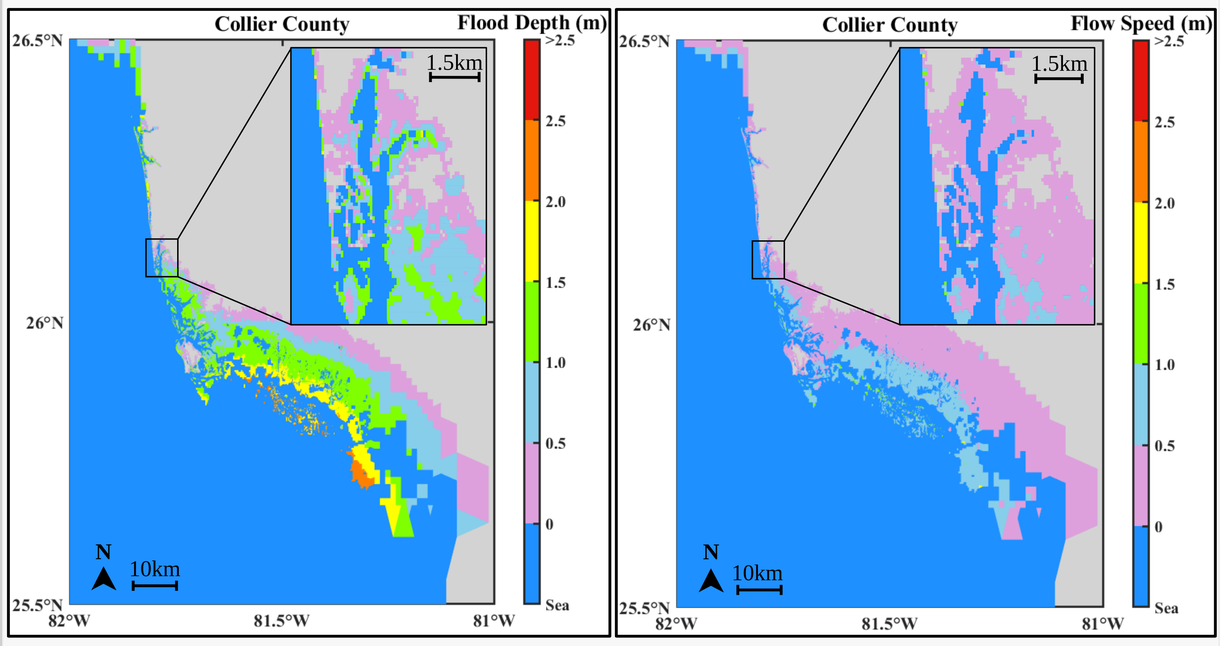


Figure 4. Maximum depths (left) and flow speeds (right) for Collier County.

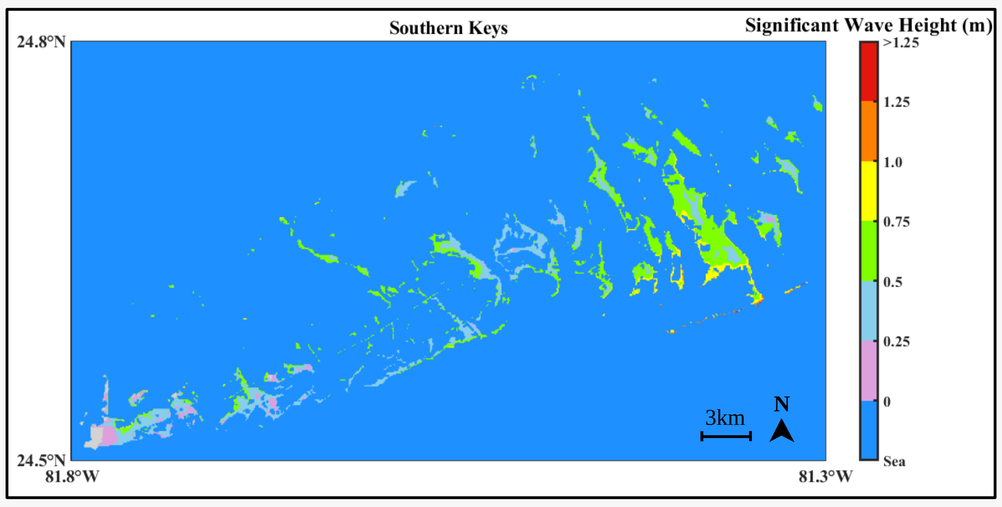


Figure 5. Maximum significant wave heights for Florida's southern Keys.

Developing Damage Functions

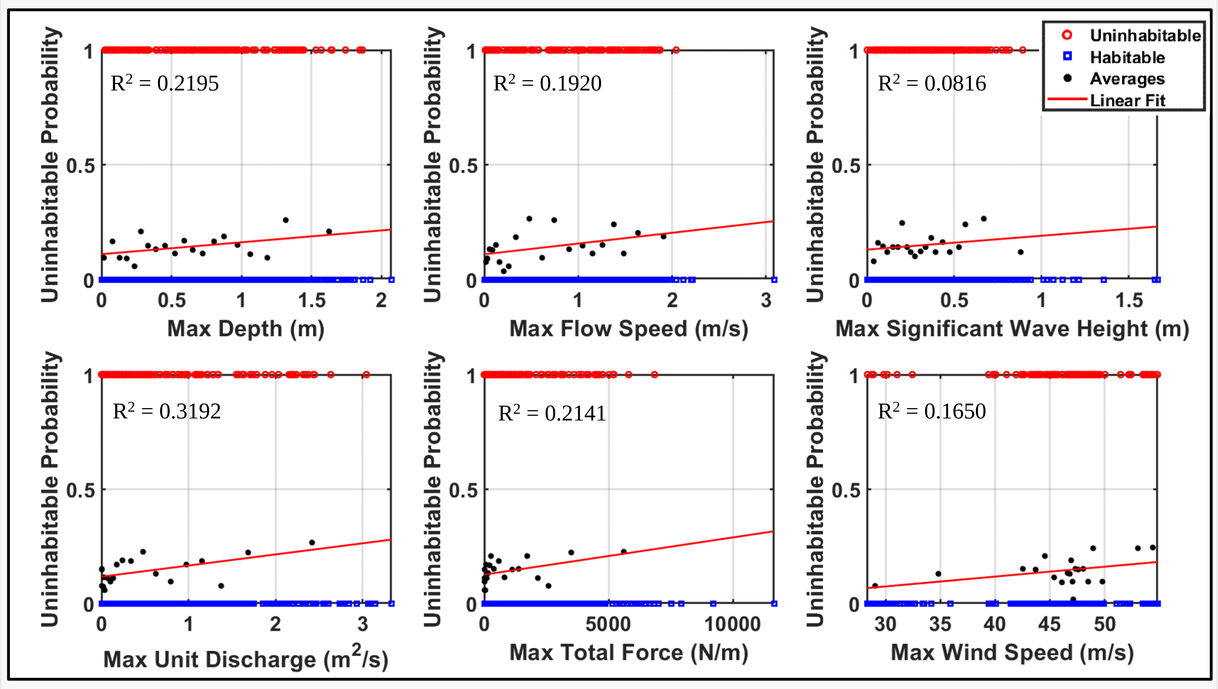


Figure 6. Damage functions relating maximum depth, flow speed, significant wave height, unit discharge, total force, and wind speed to the uninhabitability probably of structures in Collier and Monroe Counties. Uninhabitable LBD points are those where people did not return for 3 consecutive days by the end of September 2017.

Conclusions

- Tide boundary conditions and meteorological forcing were developed and validated to hindcast Hurricane Irma.
- Hydrodynamic outputs from the Delft3D-FM coupled model of Hurricane Irma were combined with LBD to develop damage functions southern Florida.
- The maximum unit discharge a location experienced has the highest correlation to damage, while the maximum significant wave height has the worst correlation.
- LBD's applicability for developing damage functions will be validated using insurance data from the National Flood Insurance Program.

Acknowledgements

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