Protecting Coastal Infrastructure in a Changing Climate by Integrating Optimization Modeling and Stakeholder Observations

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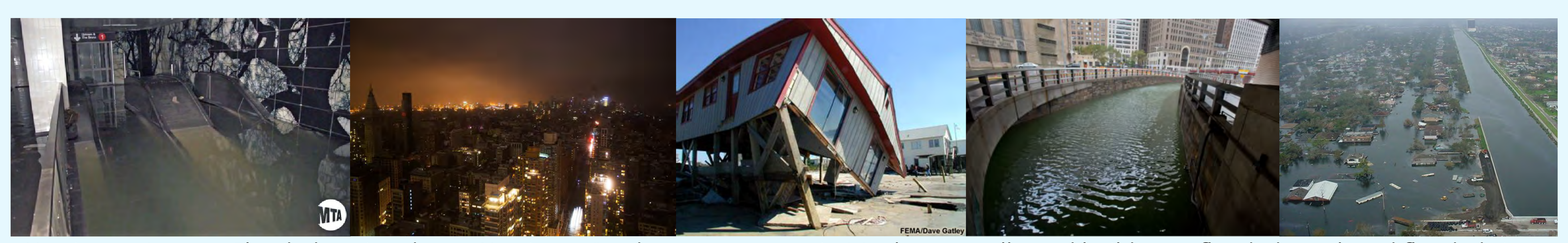
Abstract

Interdependent critical infrastructures including transportation, the power-grid, and emergency services in coastal regions are threatened by storm-induced flooding. Massive hurricane events such as Hurricane Sandy and Katrina have demonstrated the need for plans to protect our infrastructure. On the other hand, the events only reflect a possible future threat and do not fully address the unknown probability and impacts of all possible future threats. This uncertainty is only amplified by climatic effects such as sea-level rise.

The project goal addresses the threat of storm-induced flooding to interdependent critical structures by developing a methodology that can search for optimal adaptation strategies. The proposed methodology would optimize strategies to maximize their protective abilities over time and space constrained by budgetary considerations. The resulting methodology will be validated using New York City due to its complex infrastructure and the high quality data available.



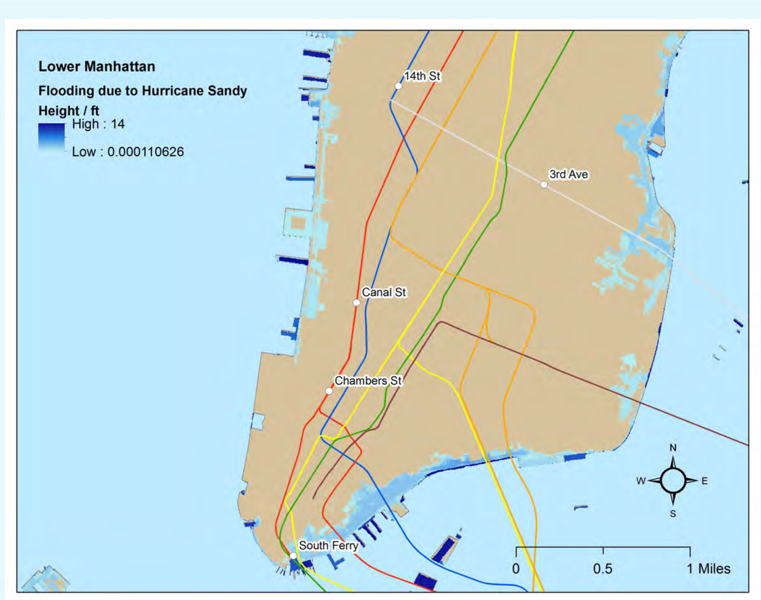
Hurricanes Impact: Flooded station due to Hurricane Sandy, power outage in Manhattan, collapsed building, a flooded canal, and flooded city.

Flood Models

GIS Model

- Fast but simplified model
- Compute flooding and stream links based on each cell's elevation value

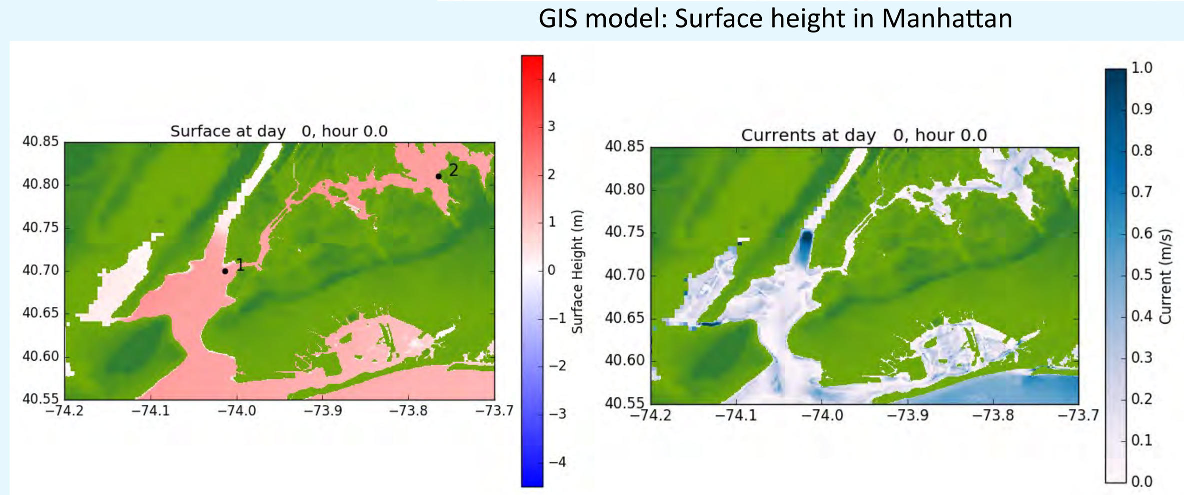
After first iterations of optimizations



GIS model: Surface height in Manhattan

GeoClaw Model

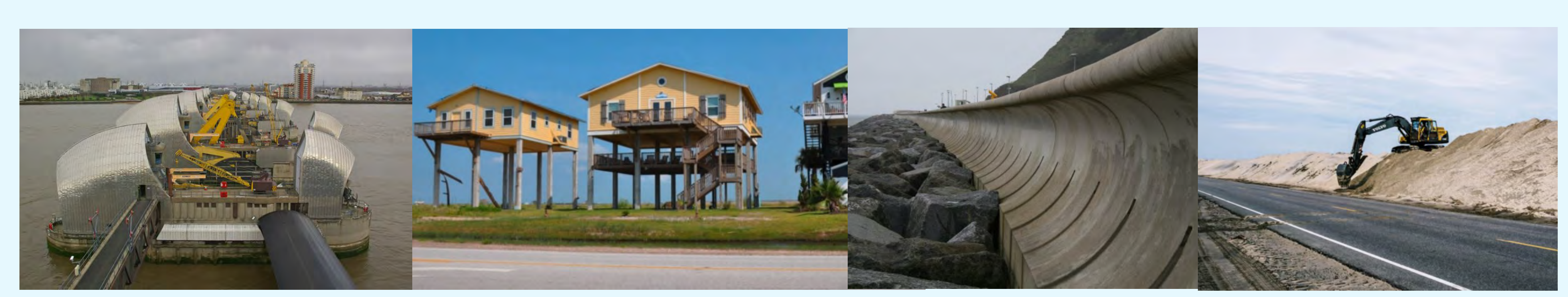
- Accurate but computationally expensive
- Can compute momentum and height of water at certain locations



GeoClaw model: Surface height and momentum (speed).

Formulating Adaptation Strategies

Each new iteration through the loop above starts here with a new strategy based on previous evaluations of past strategies. Each strategy consists of a set of predefined measures that have been parameterized in such a way that allows them to vary yet remain realistic. One example of this could be the placement and height of a seawall. Each iteration may suggest to lower or heighten the sea-wall, increase or decrease its length, or move it to a more effective location. This step is also the entry point to the loop if starting from some initial guess as to what strategy might be ideal. Input from stakeholders and at-risk communities will be incorporated into the formulation of strategies, with increasing refinement as the project progresses.



Possible strategies: barriers, rising buildings, sea-wall, and artificial dunes.

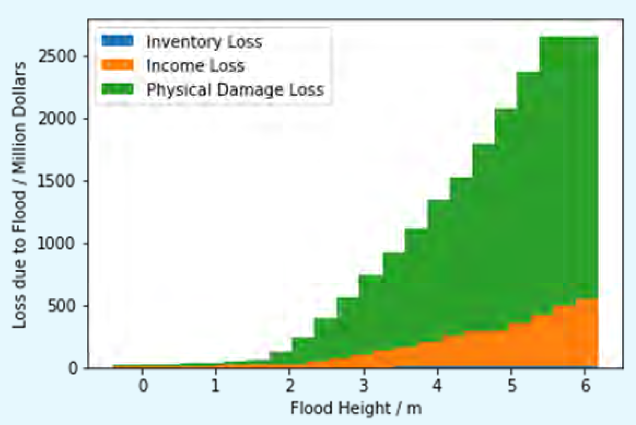
Stakeholder Interviews

Local stakeholders who have technical and first-hand knowledge about transportation, electrical, and emergency infrastructure in New York City have been interviewed.

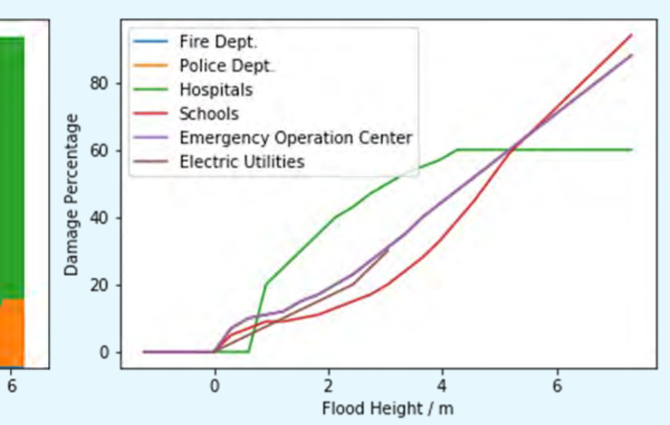
Their understandings and perceptions of the ways that critical infrastructure is impacted by storm surge, and how the impacts are extended and amplified through infrastructure interdependencies will be inputs for the optimization loop.

Infrastructure Damage Cost Estimates

To identify direct and indirect loss to the above and below ground civil infrastructure in a targeted area, a tool based on GIS and Python can be used in conjunction with flood models.



Damage Cost Estimation



Physical Damage Function from HAZUS

Flooding map with buildings in Manhattan

Optimization

The optimization tasks to find optimal strategies present interesting challenges due in part to the scale and scope of the underlying problem, but primarily due to deep nonlinearities in the model, and uncertain and noisy data. To address this we will draw on prior work and knowledge studying power grid failure based on optimization techniques that root out potential failures, and estimate their likely impact, in an agnostic manner. At the outset optimization will be used only as a guide to help discover effective mitigation strategies as opposed to an exact planning tool. The optimizer will also use the GIS based model in first iterations of the optimization in order to save time and only use the more expensive GeoClaw based simulation when closer to an optimal strategy.

References

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HAZUS: https://www.fema.gov/hazus-software

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