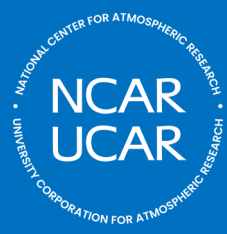# Optimal Protective and Mitigation Strategies Against Flooding and Future Climate Risk

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Abstract

Coastal regions are continuously under the threat of flooding induced by tropical cyclones worldwide. These threats continue to increase due to the effects of climate change such as sea-level rise. A number of available protective or mitigation strategies have been examined to address this threat and protect coastlines around the world. However, identifying the most effective strategy given limited resources is a complex question. Optimization methodologies as we have proposed integrate physical analysis and stakeholder feedback to come to a set of best mitigation strategies. This study examines physical and socio-economical aspects of flooding impacts to optimize these strategies. These are then examined including seawalls, elevated promenades, and strategic retreats.

Future Storm Modeling

- Historical record of storms at the Battery, NY (1920-2020) with threshold of 0.43m
- Warm-season storms: 2.33 per year; Cold-season storms: 6.76 per year
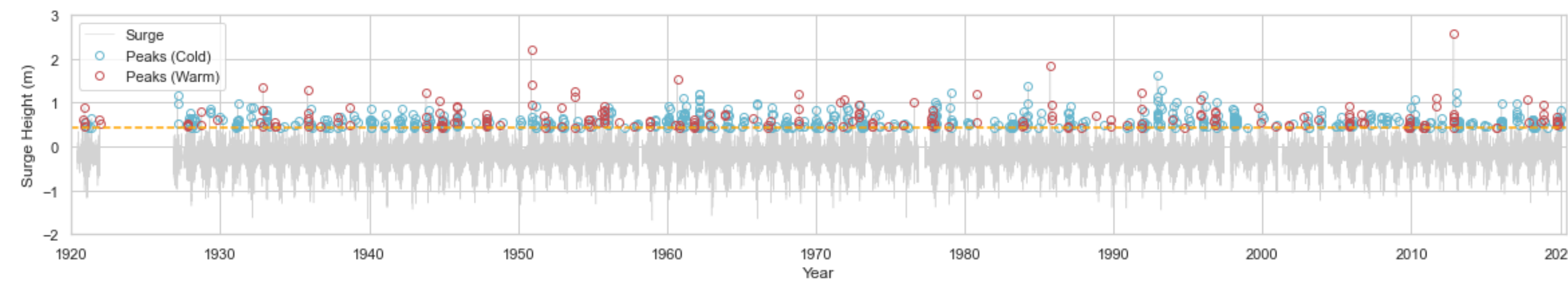
Sea-Level Rise Projections

|	Low Estimate (10th Percentile)	Middle Estimate (25th to 75th Percentile)	High Estimate (90th Percentile)
2050s	0.20 m	0.28 − 0.53 m	0.76 m
2080s	0.33 m	0.46 − 0.99 m	1.47 m
2100	0.38 m	0.56 − 1.27 m	1.91 m

Gornitz, Vivien, et al. "Enhancing New York City's resilience to sea level rise and increased coastal flooding." Urban Climate 33 (2020): 100654.
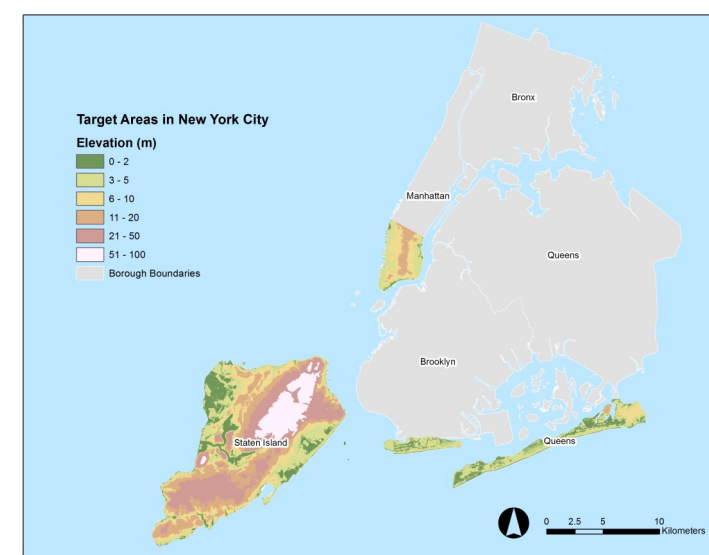
Return Period of "modified beta distribution" at the Battery, NY, with both upper and lower bounds
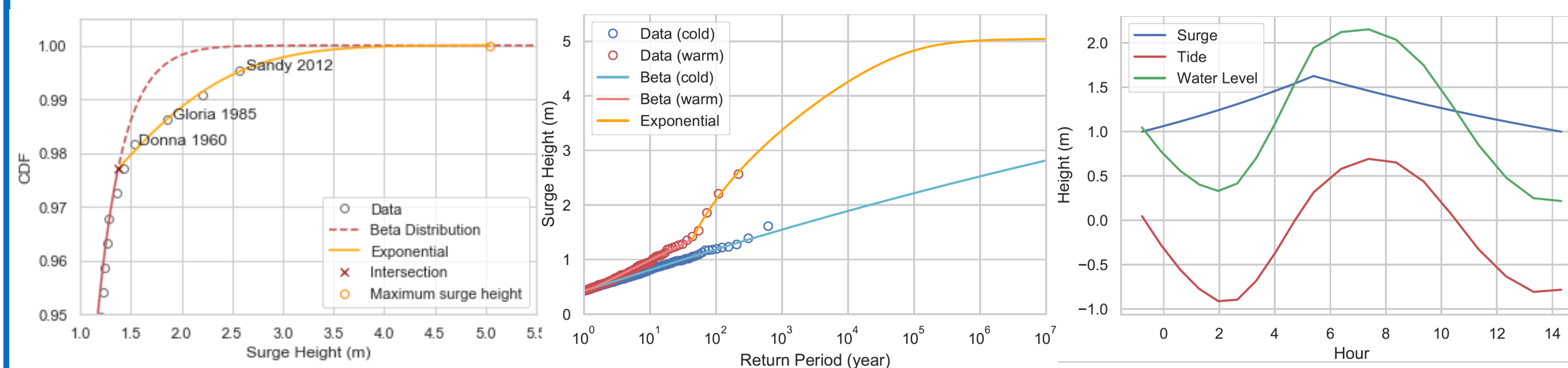
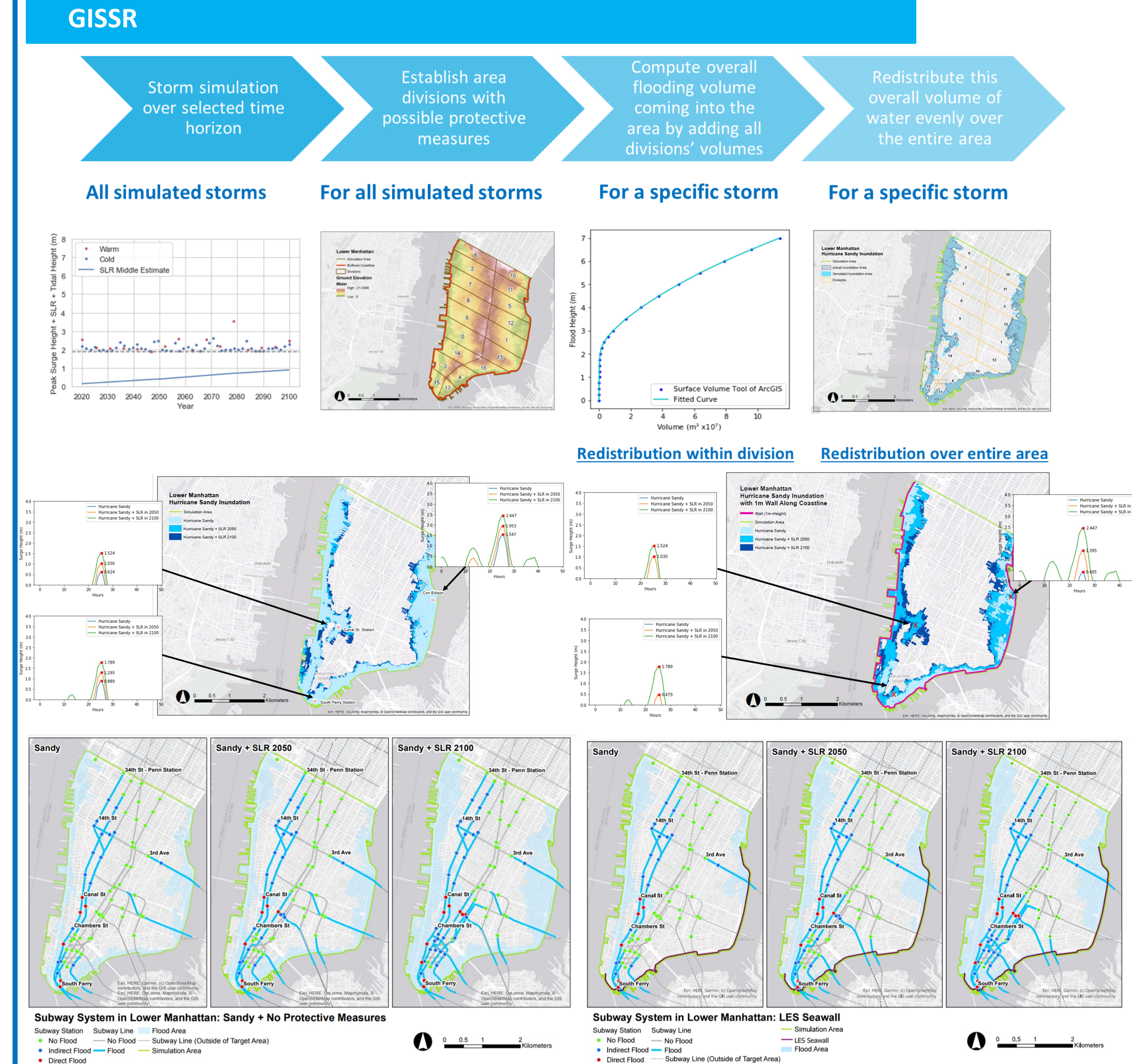
1,000 simulations of the period of 2020-2100
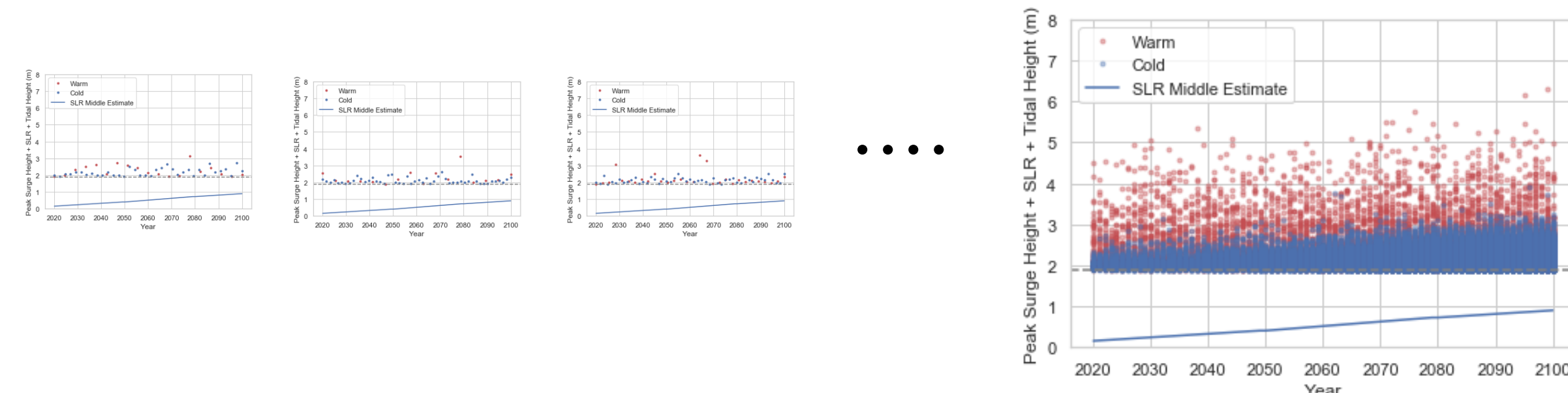
Miura, Y., Qureshi, H., Ryoo, C., Dinenis, P. C., Li, J., Mandli, K. T. ... & Morss, R. (2021). A methodological framework for determining an optimal coastal protection strategy against storm surges and sea level rise. Natural Hazards, 107 (2), 1821-1843.

Flood Estimation Models

GISSR

All simulated storms	For all simulated storms	For a specific storm	For a specific storm
Storm simulation over selected time horizon	Establish area divisions with possible protective measures	Compute overall flooding volume coming into the area by adding all divisions' volumes	Redistribute this overall volume of water evenly over the entire area

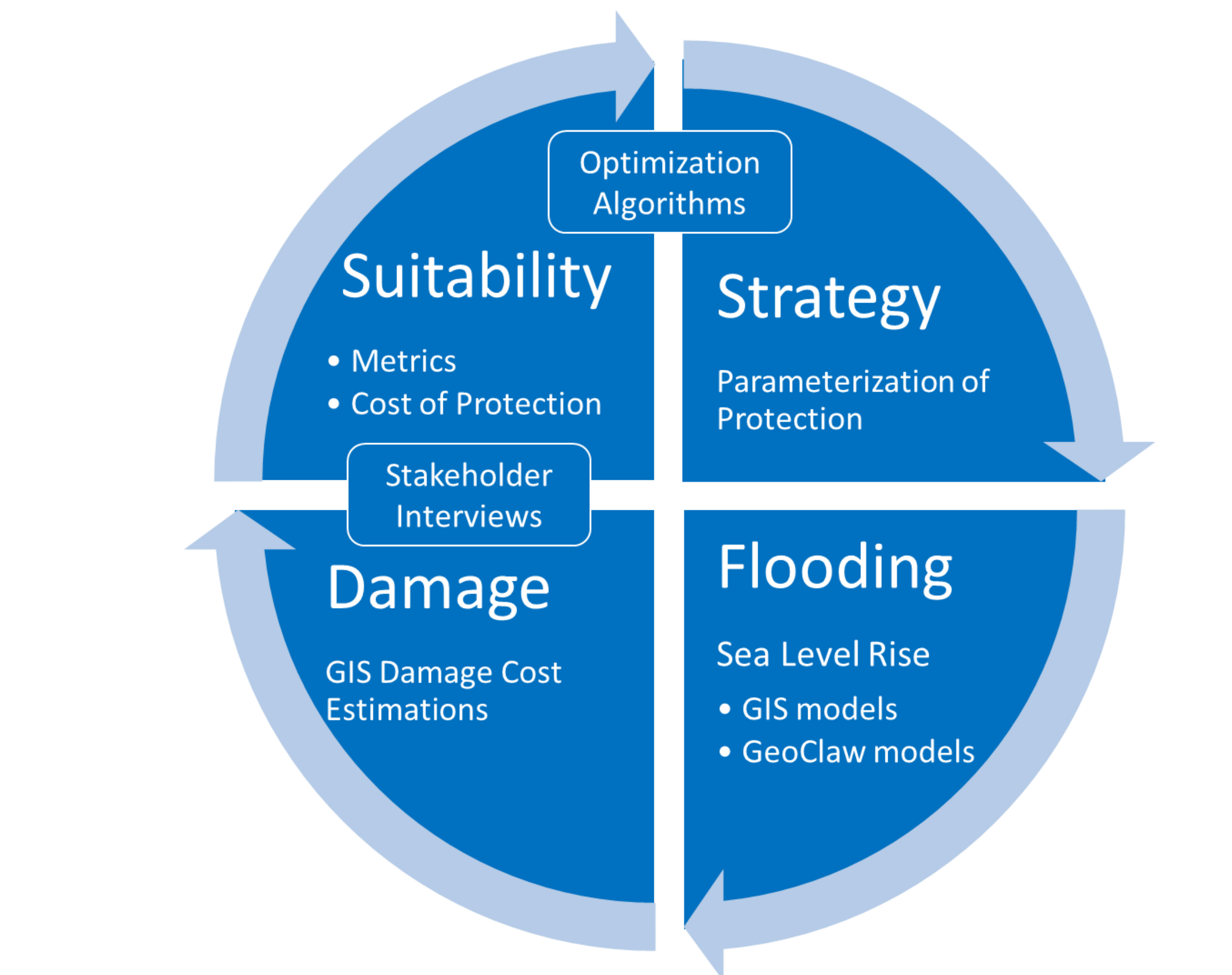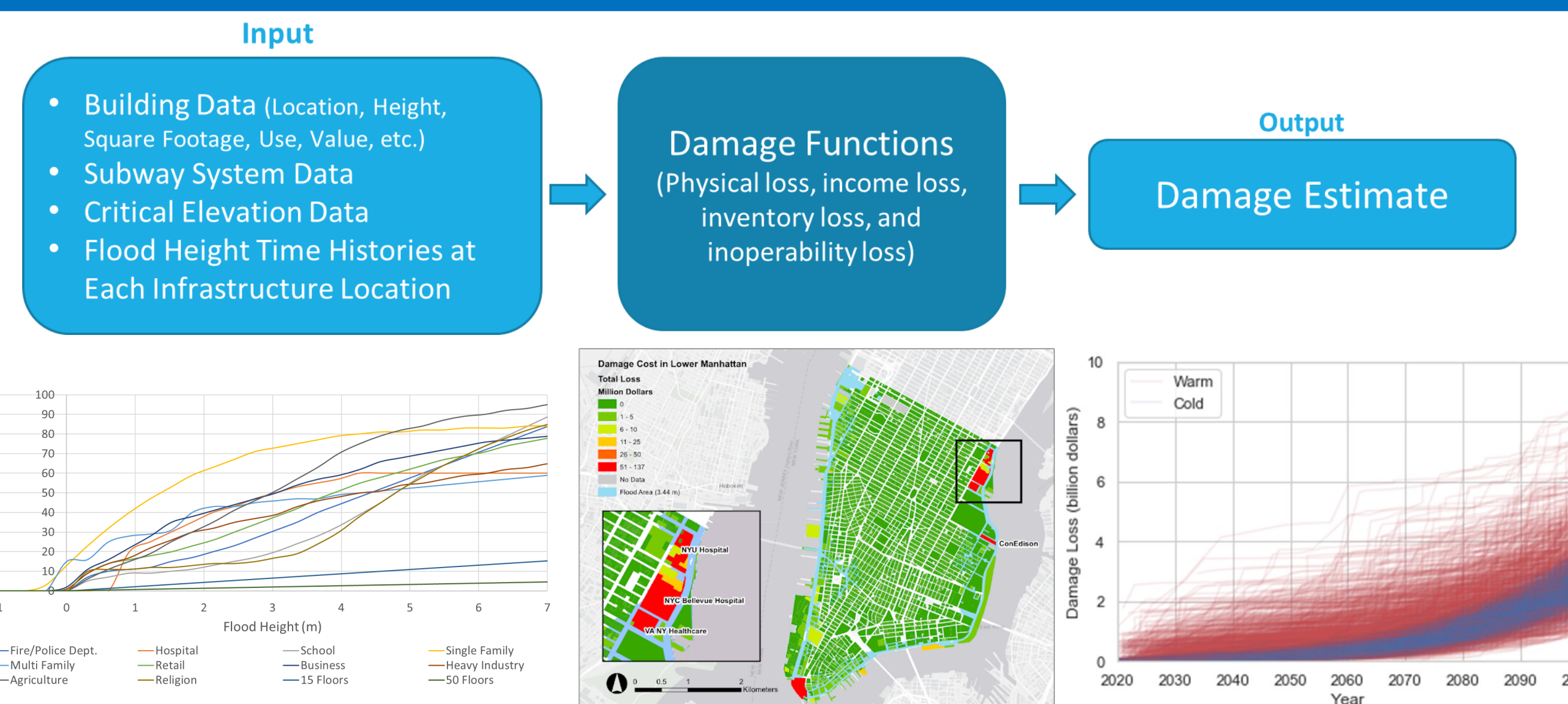Redistribution within division / Redistribution over entire area

Miura, Y., Mandli, K. T., & Deodatis, G. (2021). High-Speed GIS-Based Simulation of Storm Surge–Induced Flooding Accounting for Sea Level Rise. Natural Hazards Review, 22(3), 04021018.

GeoClaw

- Based on Finite Volume Method on Shallow Water Equation
- Output: Flooding height and momentum

Berger, M. J., George, D. L., LeVeque, R. J., & Mandli, K. T. (2011). The GeoClaw software for depth-averaged flows with adaptive refinement. Advances in Water Resources, 34(9), 1195-1206.

Damage Estimation

Input
- Building Data (Location, Height, Square Footage, Use, Value, etc.)
- Subway System Data
- Critical Elevation Data
- Flood Height Time Histories at Each Infrastructure Location

Damage Functions (Physical loss, income loss, inventory loss, and inoperability loss)

Output
Damage Estimate

Suitability
- Metrics
- Cost of Protection

Strategy
Parameterization of Protection

Optimization Algorithms

Stakeholder Interviews

Damage
GIS Damage Cost Estimations

Flooding
Sea Level Rise
- GIS models
- GeoClaw models

Stakeholder Observation for Interdependencies

To clarify the interdependencies of the infrastructures, interview has been conducted to local stakeholders

Optimization of Protective Strategy
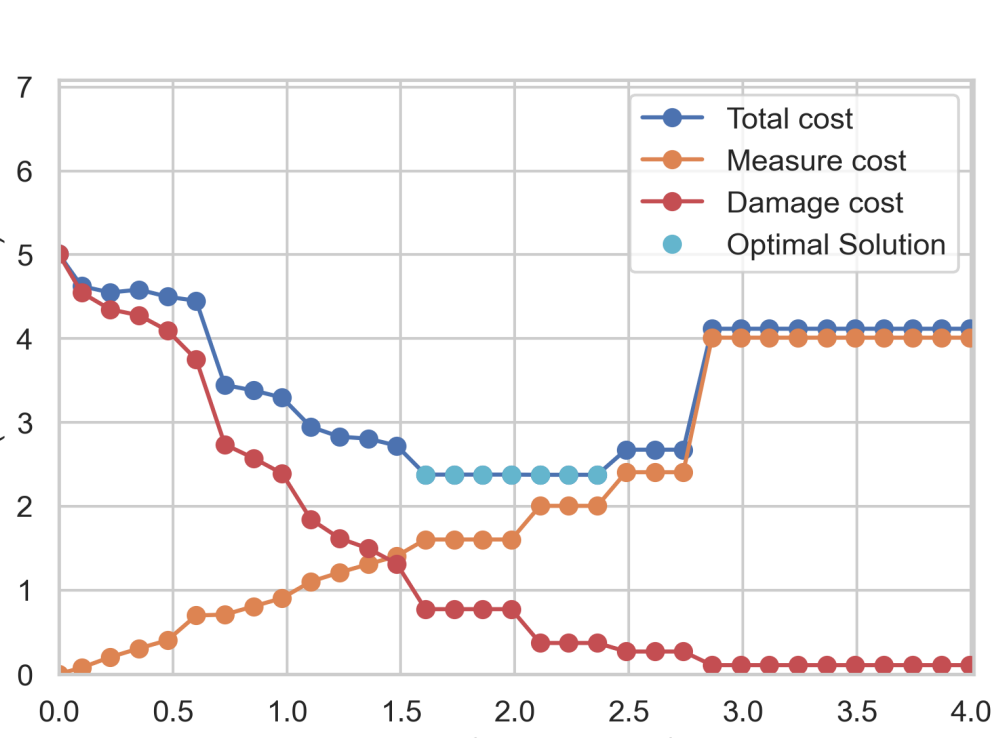
Objective Function:

$$\min_{x} \left\{ L_{co}(x) + \mathbb{E}_S \left[\sum_{s \in S_j} f(x;s) \right] \right\}$$
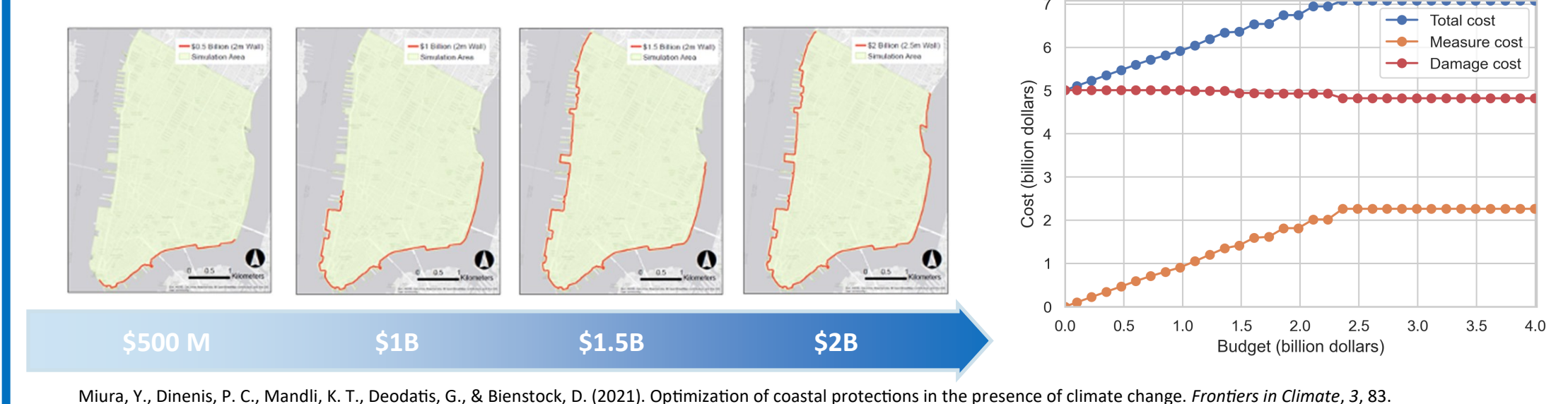
Constraints:

$$0 \leq h_{wall} \leq 5m$$
$$0 \leq i_{wall_0} \leq i_{wall_f} \leq i_{wall_F} \quad *$$
$$L_{co} \leq L_{budget}$$
$$P\left(\sum_{s \in S_j} f(x;s) < \text{threshold}\right) > 95\% \quad *$$

* Constraint (seawall)   * Constraint (fairness)

Optimal Solutions:

Non-Optimal Solutions:

$500 M $1B $1.5B $2B

Miura, Y., Dinenis, P. C., Mandli, K. T., Deodatis, G., & Bienstock, D. (2021). Optimization of coastal protections in the presence of climate change. Frontiers in Climate, 3, 83.

Damage Cost in Each Division