Power Grid Resilience Optimization using Storm Surge and Inland Flooding Models

Ashutosh Shukla1, Sabiha Tabassum2, Dr. Wen-Ying Wu2, Brent Austgen1, Dr. Clint Dawson4, Dr. Zong-Liang Yang2, Dr. Surya Santoso1, Dr. Erhan Kutanoglu1, Dr. John Hasenbein1

Cockrell School of Engineering1, Jackson School of Geosciences2, Department of Aerospace Engineering and Engineering Mechanics4, The University of Texas at Austin

PRESENTED AT:

PROBLEM BACKGROUND

The United States has suffered 308 natural disasters each costing over $1B since 1980. These events - hurricanes, floods, drought, wildfires etc. have collectively inflicted over $2T in damages much of which is attributed to critical infrastructure systems such as the power grid. Just Harvey knocked out more than:

- 90 substations
- 800 transmission assets
- 6000 distribution poles
- 800 miles of power lines

which:

- led to peak power generation loss of 11GW
- affected more than 2 million people
- took 2 weeks and 12,000 crew members to restore power

MODELLING STORM SURGE

SLOSH: MEOW Maps

For every combination of direction, category and forward speed shown in Figure 1, we have a corresponding MEOW map. These maps represent a near worst-case flood profile for a set of storms. An example MEOW map is shown in Figure 2.

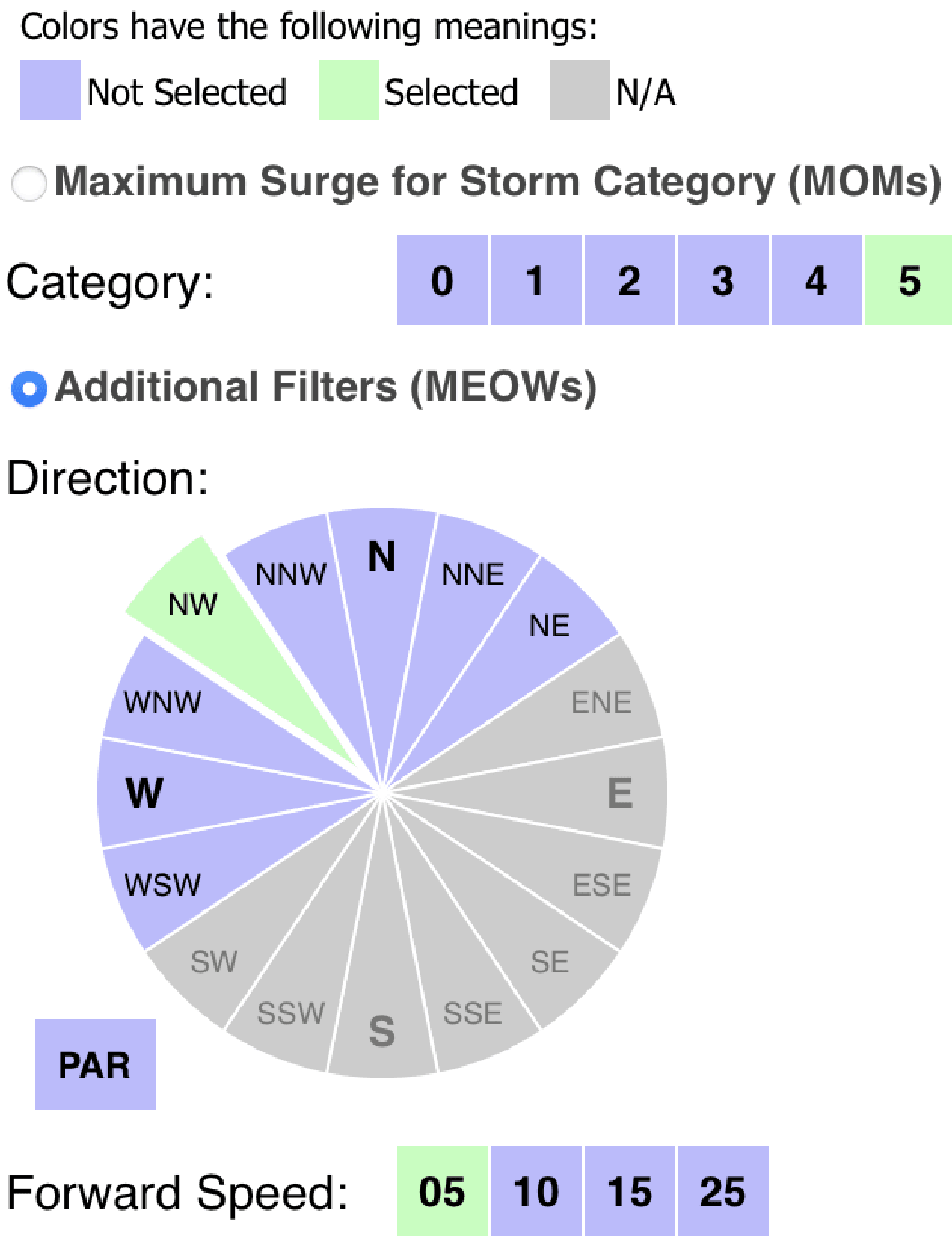


Figure 1: A dashboard showing different combinations of hurricane characteristics for which there is a corresponding MEOW map.

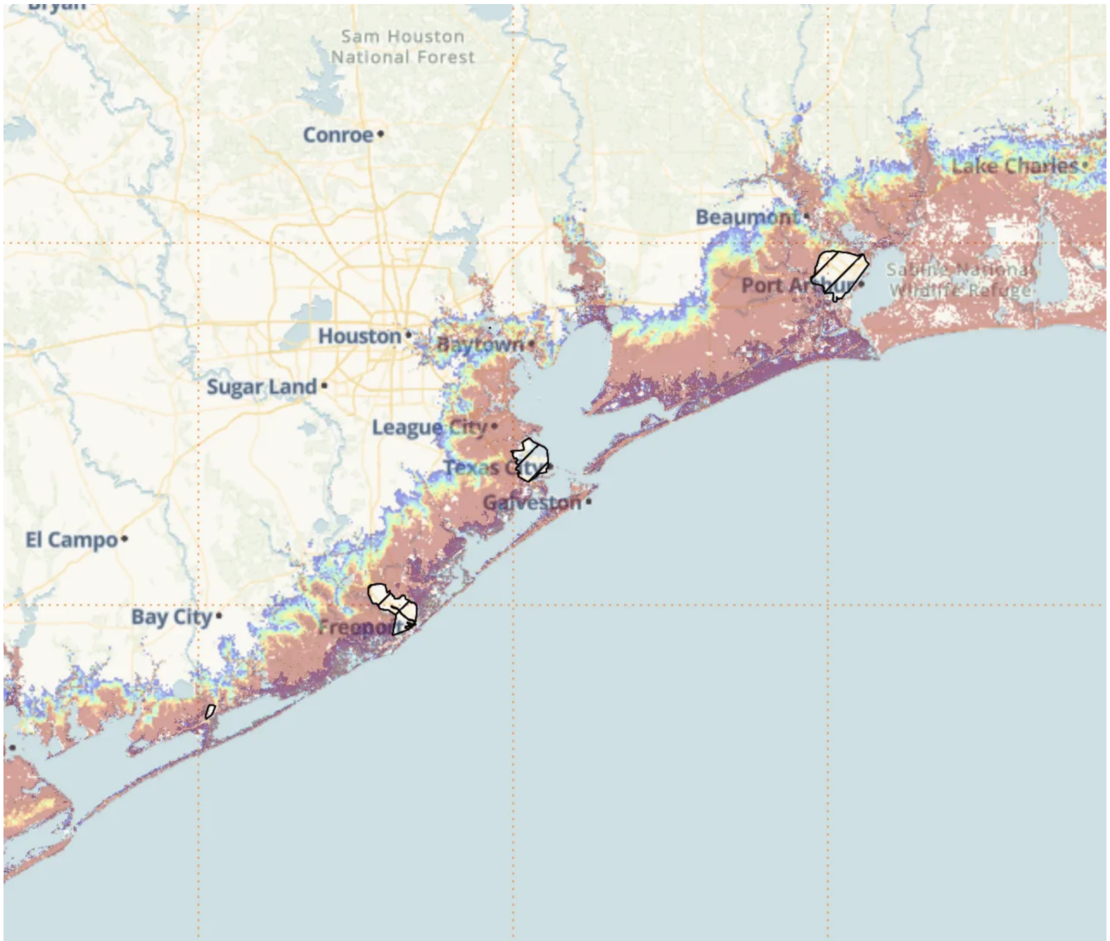


Figure 2: A sample MEOW for the Texas region

ADCIRC: Storm Surge

Figure 3 depicts a subset of simulated storms trajectories that were developed as part of a joint FEMA and USACE study. Figure 4 shows the water elevation profile for one of the storms from these simulated trajectories.

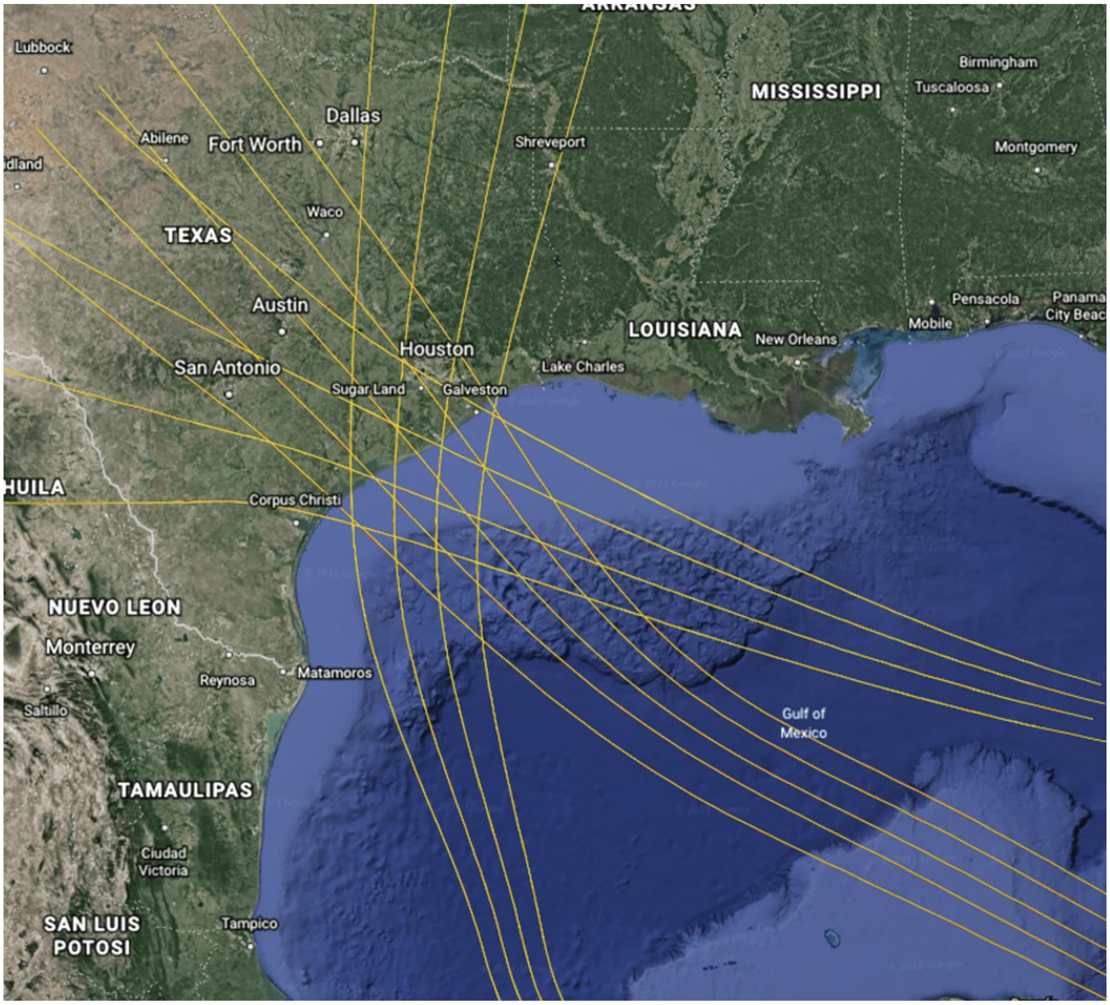


Figure 3: Hurricane trajectories

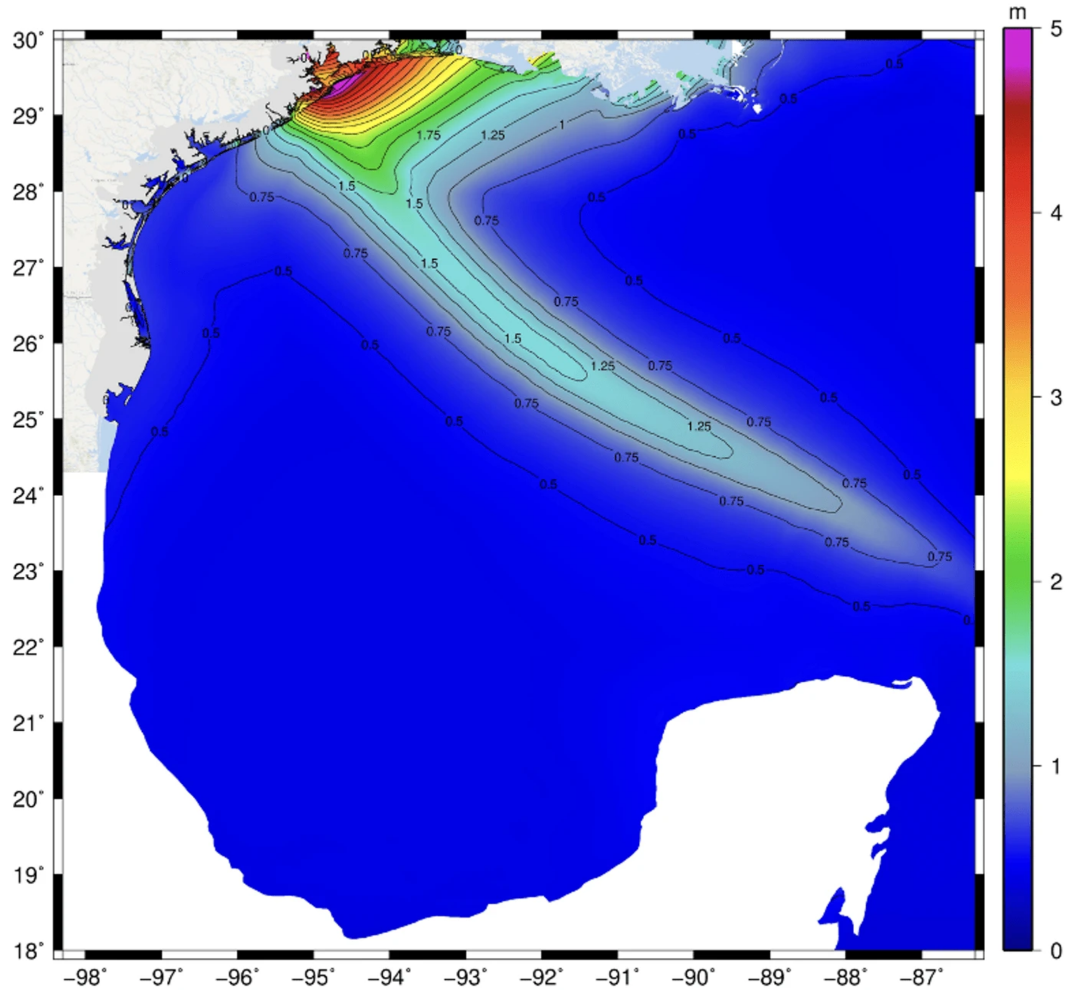
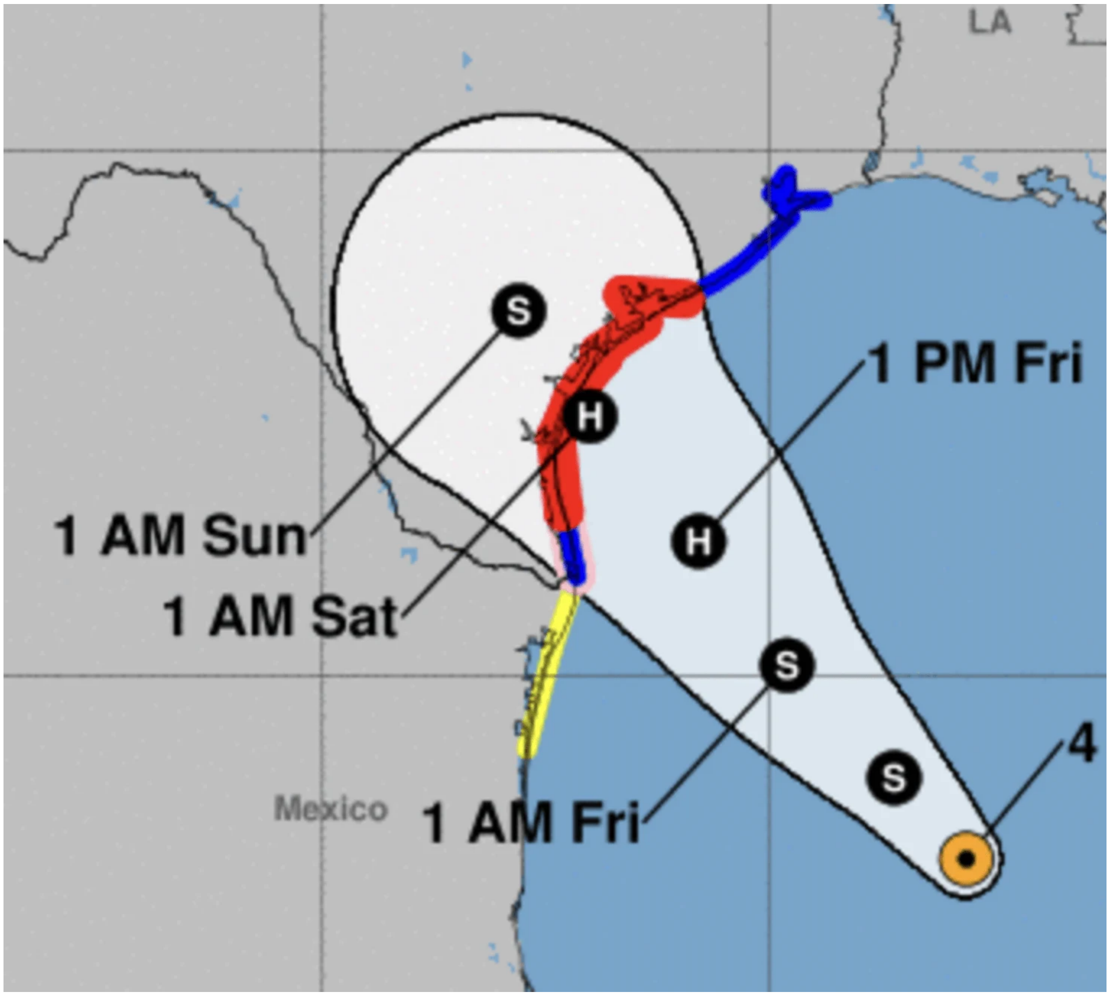


Figure 4: Storm-surge profile for a storm.

MODELLING INLAND FLOODING

Cone of uncertainty

In the first stage, we have a meteorological forecast for an imminent hurricane with an associated cone of uncertainty. This uncertainty can comprise of different possible directions, wind-speeds, landfall locations etc.

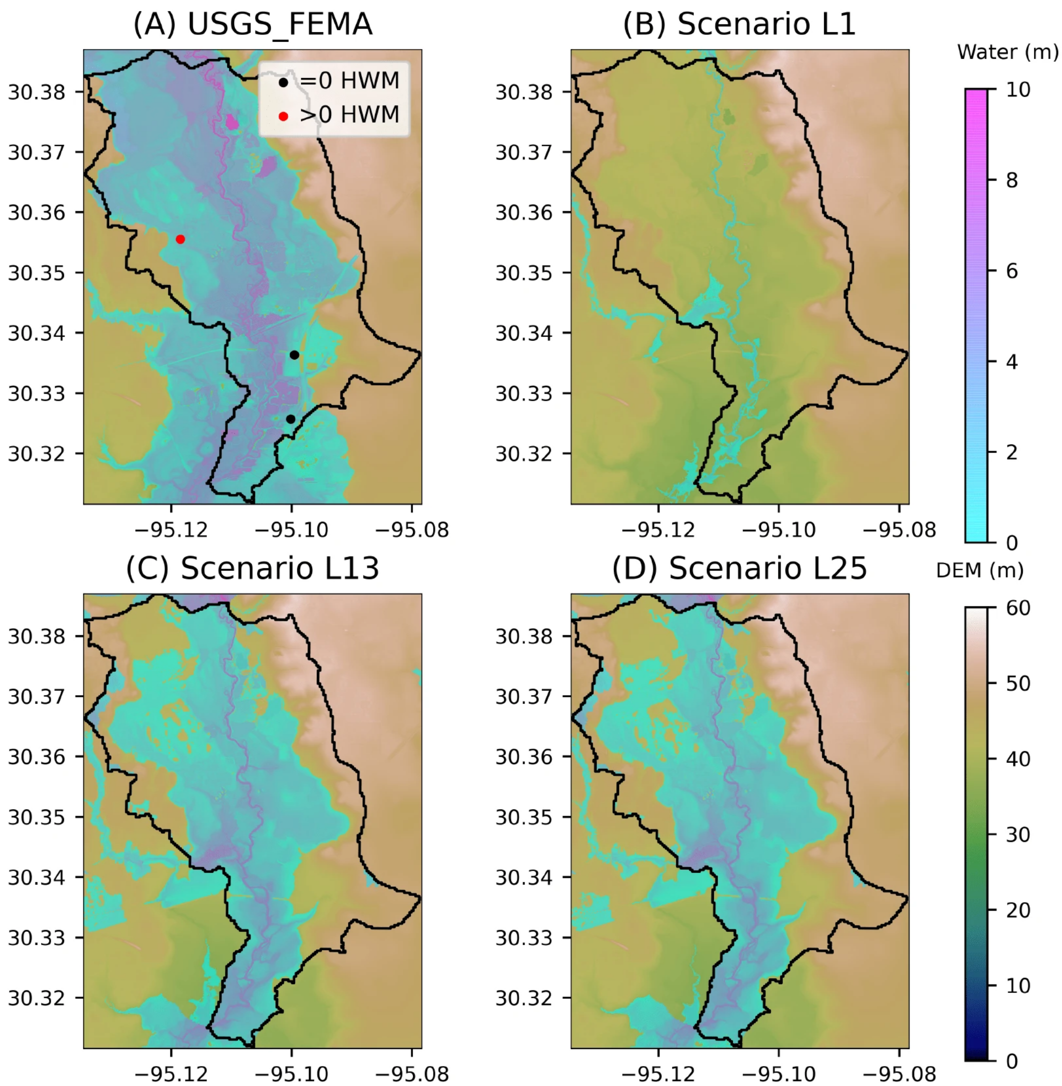


Sampled landfall locations

Given the uncertainty about the hurricane, we perform stratified sampling. In this case, we sample a set of landfall locations.

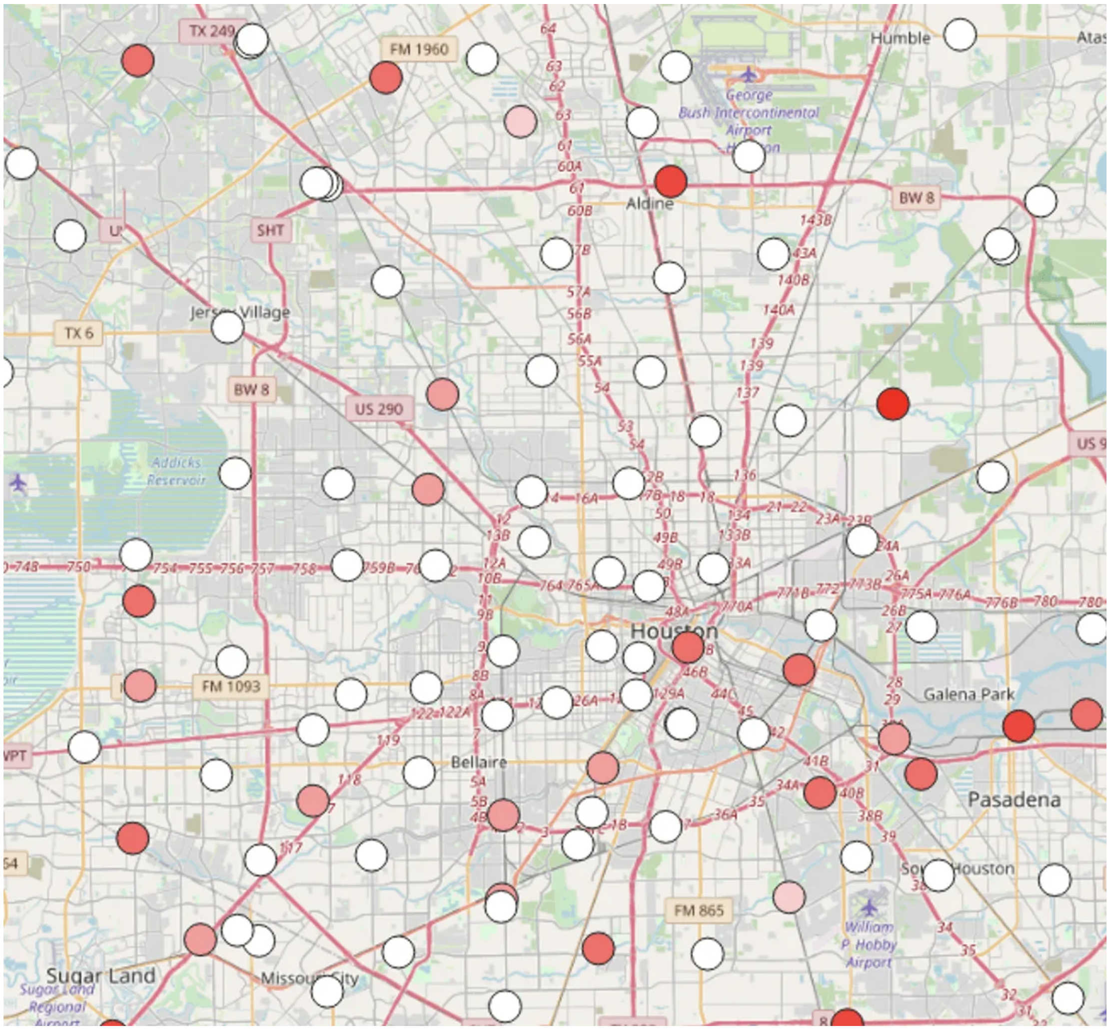
Flooding scenarios

For the set of sampled points, we run an inland flooding model to create a flood scenario associated with each member of the set.



Identifying damage

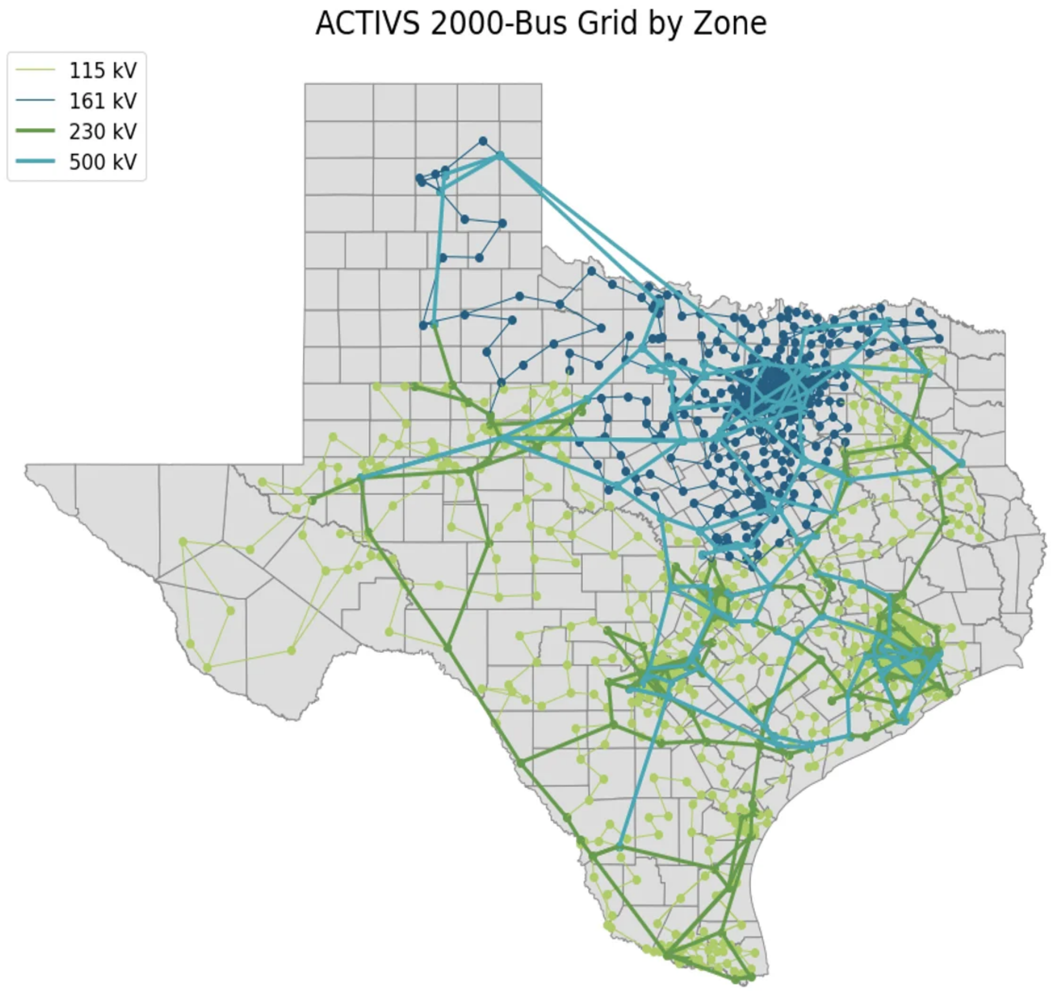
We overlay the flood maps over the electric grid to identfy substations susceptible to flooding in different scenarios.


TX 249
FM 1960
Humble
George Bush Intercontinental Airport
Aldine
BW 8
SHT
Jersey Village
TX 6
BW 8
US 290
Addicks Reservoir
Houston
Galena Park
FM 1093
Bellaire
Pasadena
FM 865
William P. Hobby Airport
Sugar Land
Sugar Land Regional Airport
Missouri City

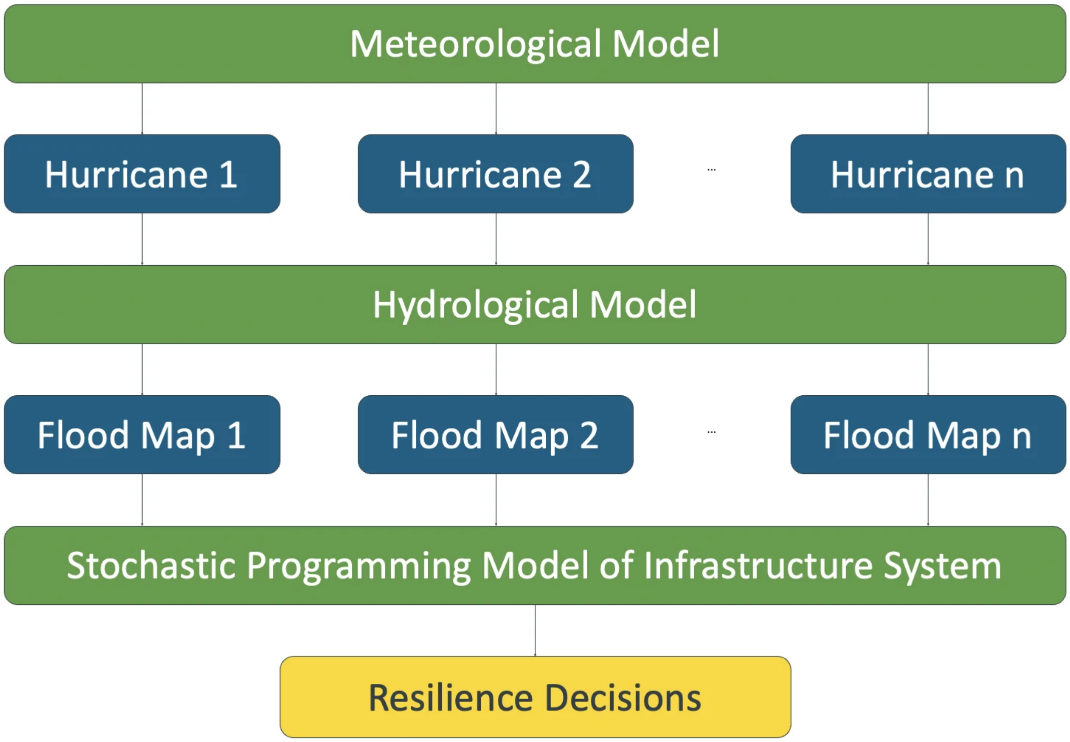
PROPOSED METHODOLOGY

Temporary and Permanent Hardening Measures

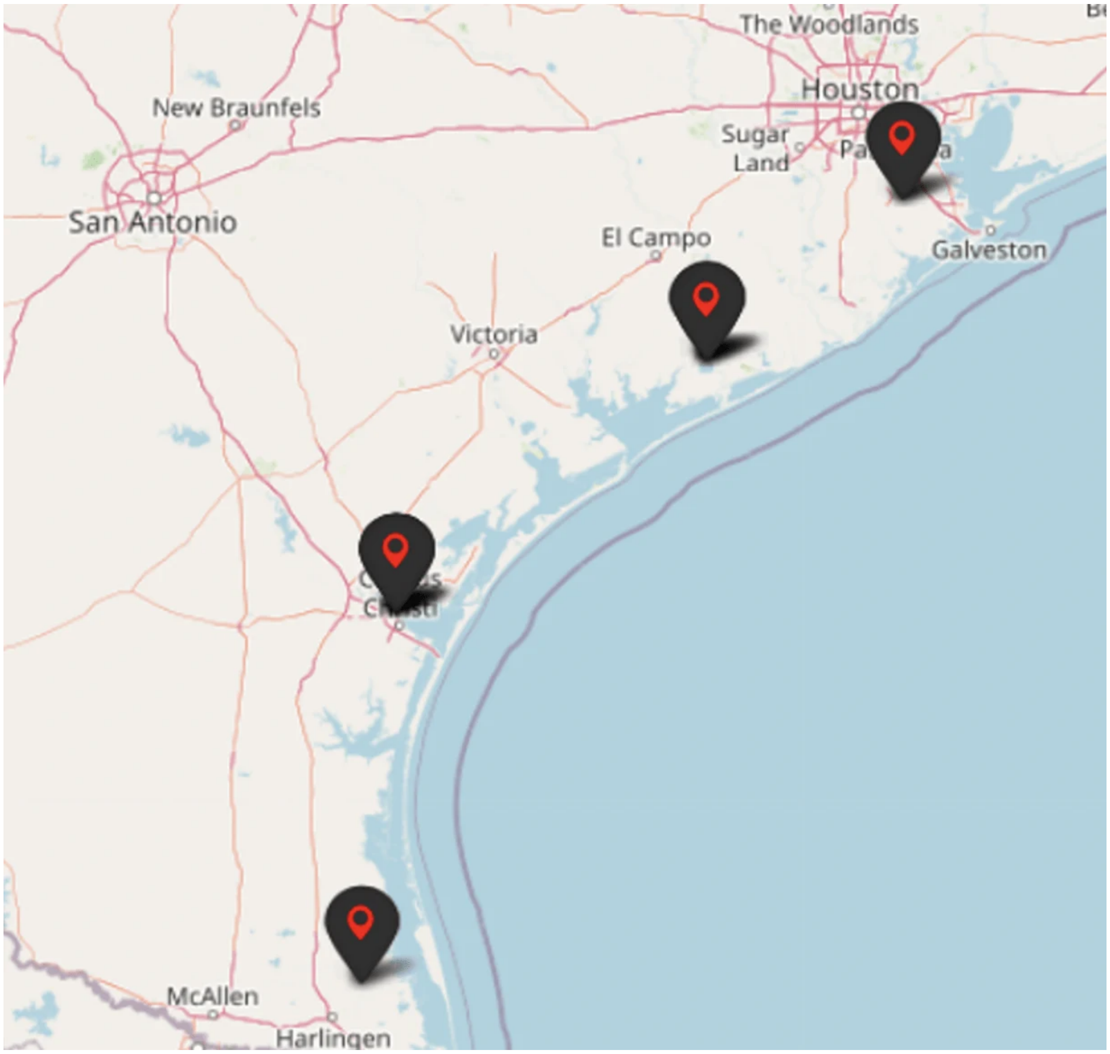
Synthetic yet realistic electric grid for the state of Texas



A schematic overview of the proposed approach



An example solution: Which substations to harden?



An example solution: How much to harden?

Substation	x_i
Corpus Christi Substation (600 MW)	6
South Texas (2708 MW)	1
Alvin (1508 MW)	11
Sebastian (150 MW)	1

RESEARCH MOTIVATION

Recent trends and future climate projections suggest more severe and frequent rainfall events. Therefore, it is of paramount importance to understand:

- How can such extreme flooding events impact critical infrastructures?
- What are the vulnerabilities of existing infrastructure and how should we address them while accounting for the uncertainty in meteorological and climate forecasts?
- How to allocate the total budget for resilience to different available options while accounting for topography, demography and existing resilience level of the critical infrastructure in a region?

To address the above questions, we first use state of the art storm-surge and inland flooding models to create a flood profile for the region of interest. While doing so, we account for uncertainty in the forecasts that go as input to physics-based hydrological models. Later on, we overlay these flood maps over the critical infrastructure network to identify the parts of the network that are susceptible to damage under different flood scenarios. Lastly, we leverage these predictions for power grid resilience decision making by integrating them with an approximate power system model using a two-stage stochastic optimization framework.

ACKNOWLEDGMENTS

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ABSTRACT

In the past four decades, Texas has experienced more than 80 hurricanes, including Harvey, which alone caused damages costing over $130B. Given this history and predictions of more frequent and/or more intense storms in the future, it is of paramount importance to make prudent investment decisions to enhance the resilience of the electric grid against such extreme weather events. In this work, we explore two storm-surge models and integration of these models with an inland flooding model to create representative future flood scenarios for the state of Texas. We then discuss how these flood scenarios can further be integrated with a synthetic power system model that accurately quantifies the loss of power in all contingencies for the same geographical region, using a stochastic optimization framework. Our proposed two-stage scenario-based stochastic optimization approach helps identify substations susceptible to flooding due to storm surge and inland flooding, and recommends optimal substation hardening solutions given a finite investment budget. The insights from our work can be used to decide substation hardening strategies to enhance the electric grid's resilience against a multitude of future storm scenarios.