FIU | Wall of Wind
NHERI Experimental Facility

SimCenter NHERI
Center for Computational Modeling and Simulation

Framework for Damage Fragility Models

PELICUN

Speaker: Adam Zsarnóczay, PhD,
Stanford University

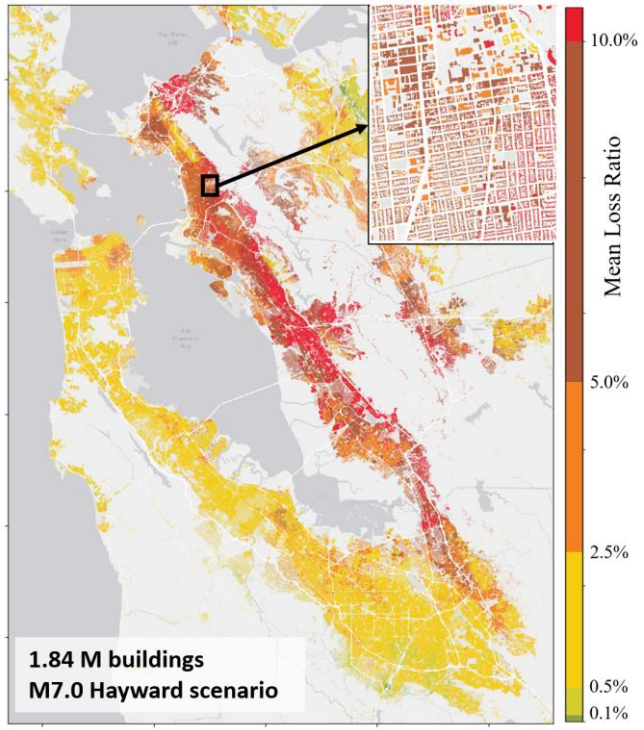
August 11, 2020
10:40 – 11:30 am PDT
1:40 – 2:30 pm EST

This workshop is coordinated by the Natural Hazards Engineering Research Infrastructure's (NHERI) Wall of Wind and the NHERI SimCenter and is supported by the National Science Foundation award CMMI 1520853 and 1612843. Any statements in this material are those of the presenter(s) and do not necessarily reflect the views of the National Science Foundation.

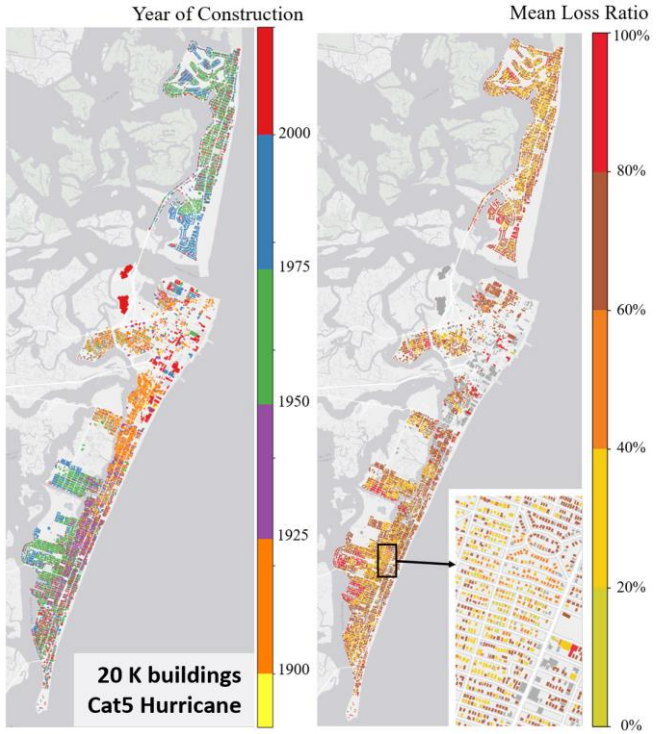
NSF

SimCenter

Facilitate research in regional natural hazard risk management by providing **open-source tools** for researchers to create **complex simulation workflows**.



San Francisco Bay Area



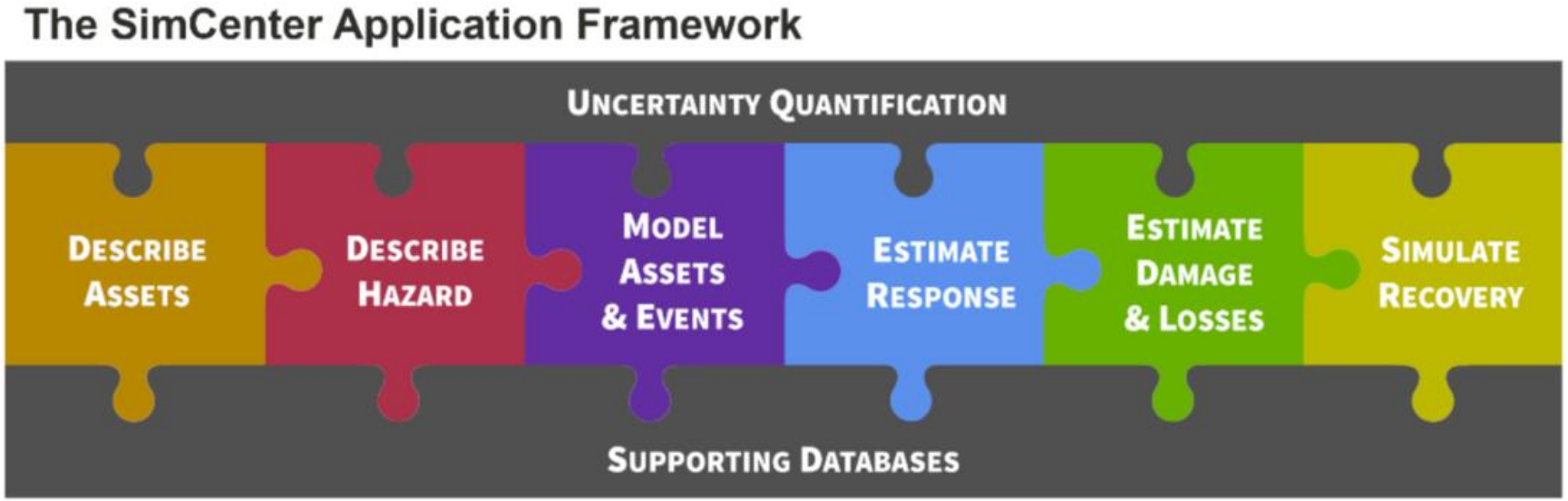
Atlantic City, NJ

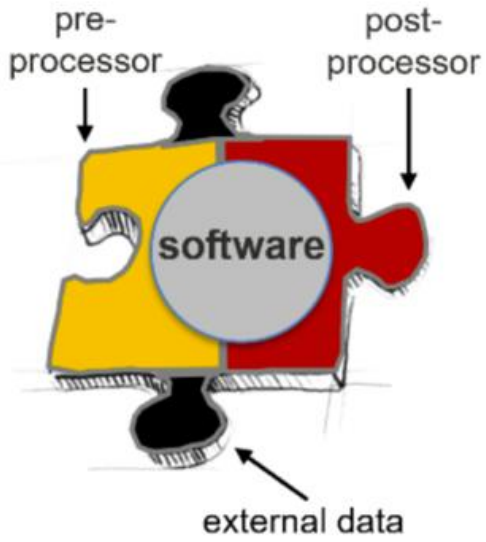
SimCenter

Develop **extensible tools** for researchers
and connect them with **high-performance computing** resources
to facilitate high-fidelity simulations and uncertainty quantification.

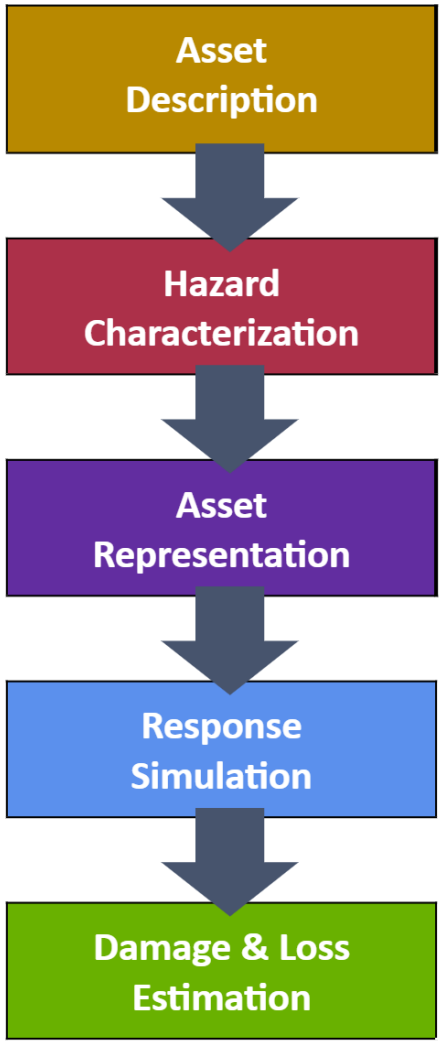
Data and HPC resources at

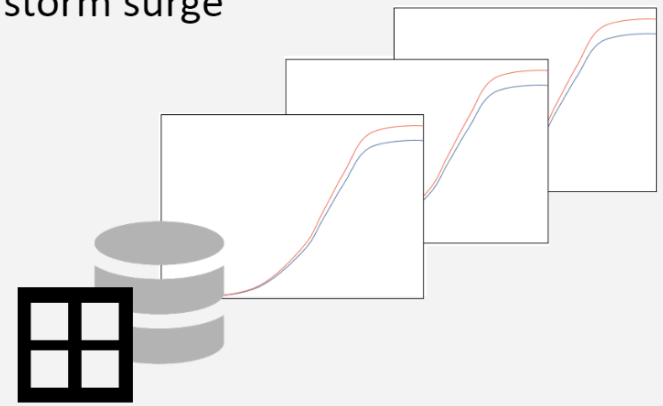
DESIGN SAFE-CI





rWHALE & Atlantic City Testbed

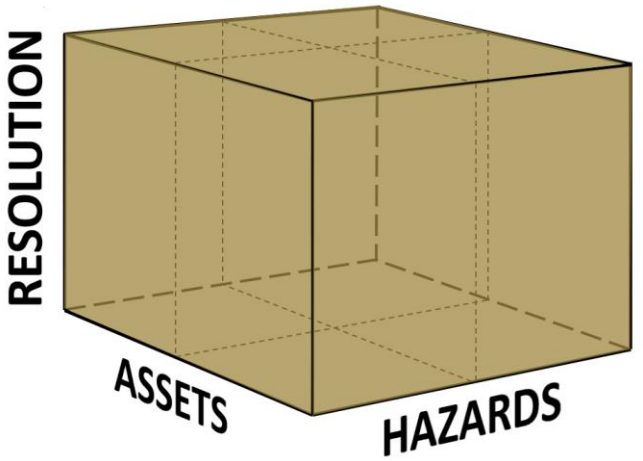


Level 1	Level 2
OBJECTIVE: Estimation of damage severity and corresponding losses associated with each parcel's simulated engineering demand parameters	
Vulnerability Description: Direct adoption of HAZUS-MH vulnerability functions, supplemented by other vulnerability descriptions for special cases ▸ Fit normal or lognormal CDFs to HAZUS damage data (more efficient storage, simulation) ▸ Couple loss assessment with damages, find expected loss ratio for each damage state	**Fragility Description:** Component fragility library for placeholder Generic Building Models (GBMs) with cascading damage and accounting for losses driven by wind vs. storm surge 
SUPPORTING DATABASES 1. HAZUS-MH Hurricane Damage and Loss Model (wind and flood)	**SUPPORTING DATABASES** 1. Damage and Loss functions for GBM components (compiled)

What does PELICUN offer?

PELICUN is a unifying framework:

- Open-source, platform independent
- Multi-hazard, multi-fidelity modeling
- Handle buildings & infrastructure



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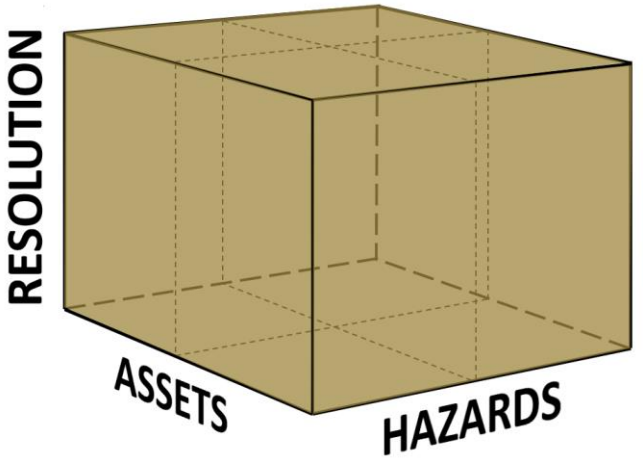
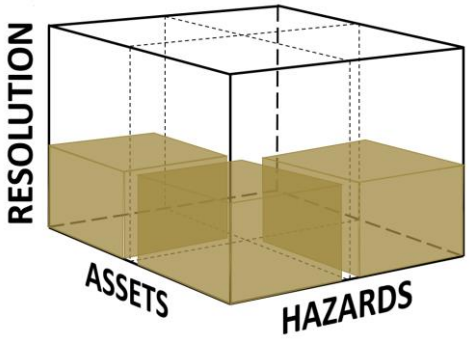


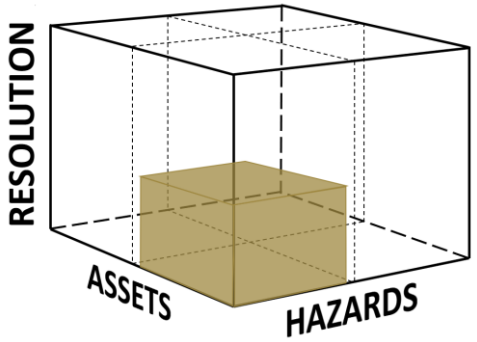
HAZUS MH 2.1

closed-source;
partially free; Windows



OpenQuake

open-source;
free; multi-platform

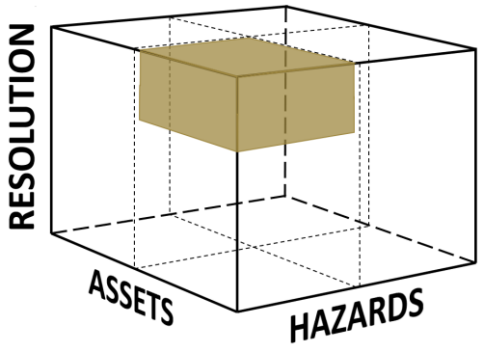


PACT

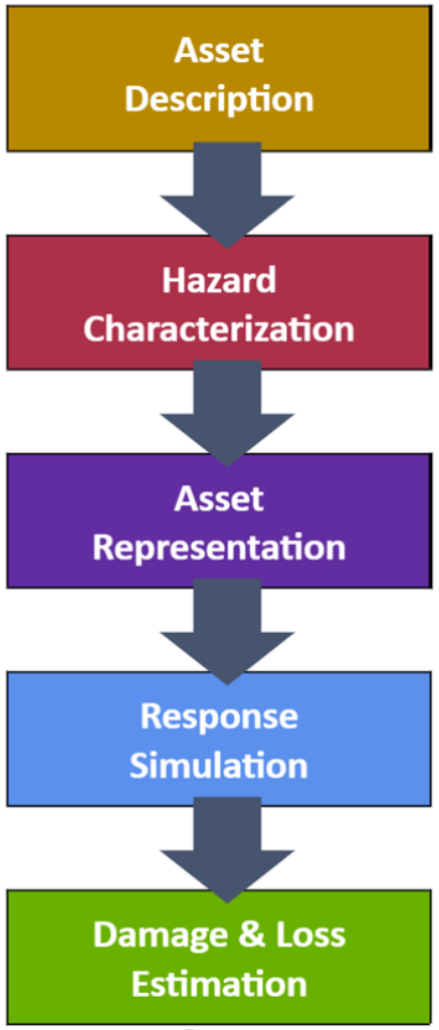
closed-source;
free; Windows

SP3

closed-source
commercial; web

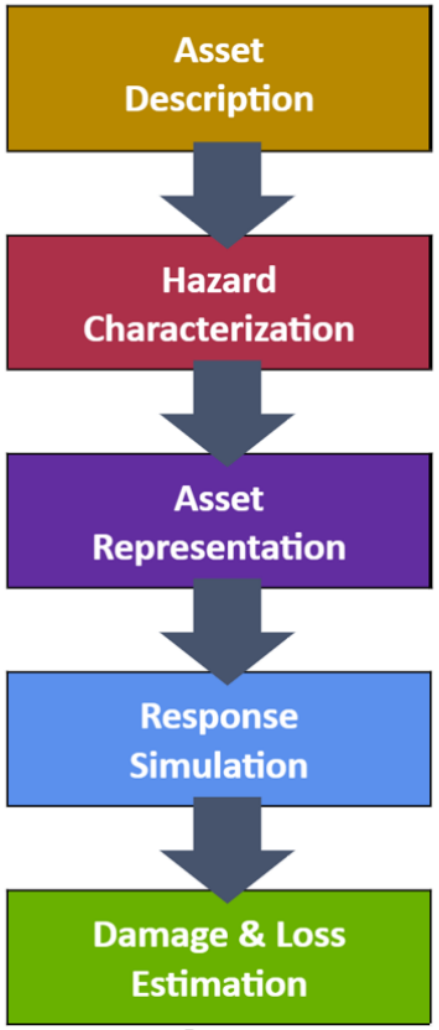


Scope



REGIONAL SIMULATION WORKFLOW (rWHALE)

Scope



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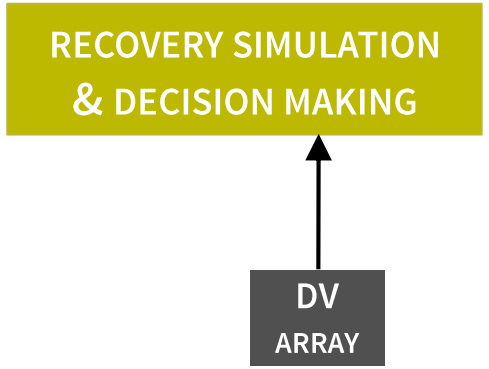
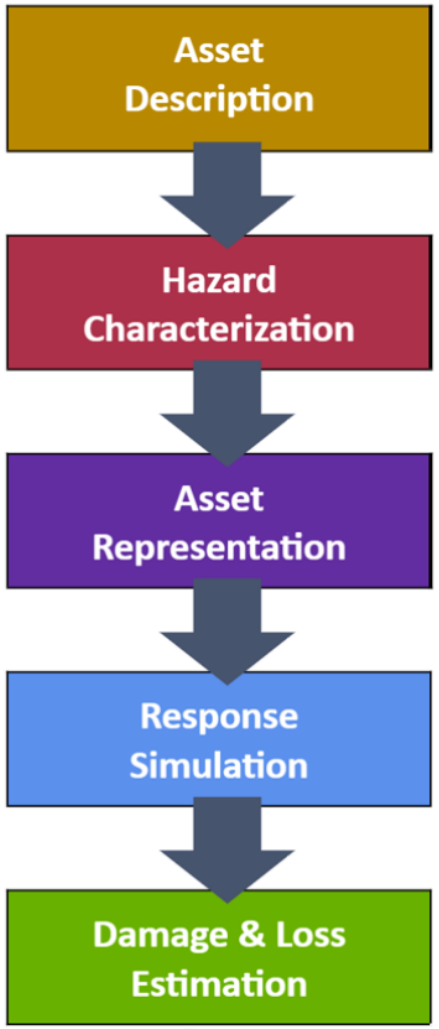


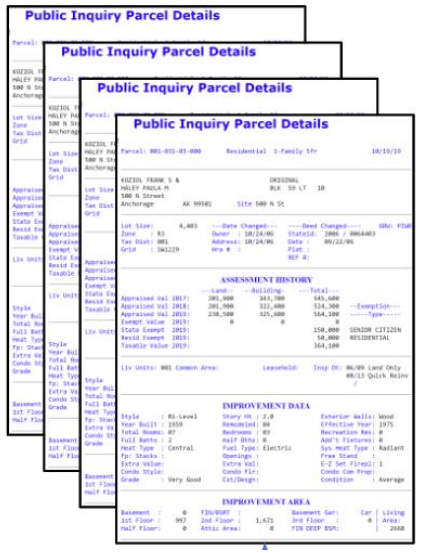
Decision Variable for each **asset**

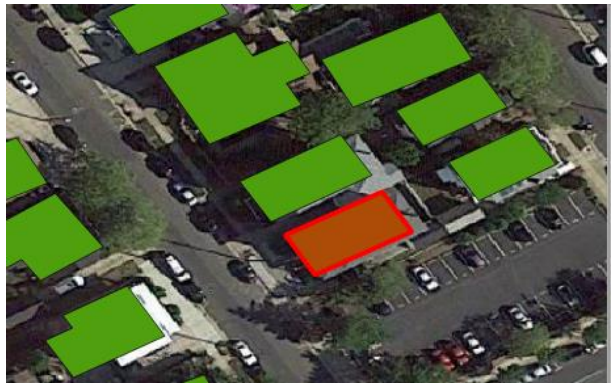
asset is a generic name we use for a component of the built environment building, bridge, pipeline, power station, etc.

Scope



Regional Simulation Workflow (rWHALE)





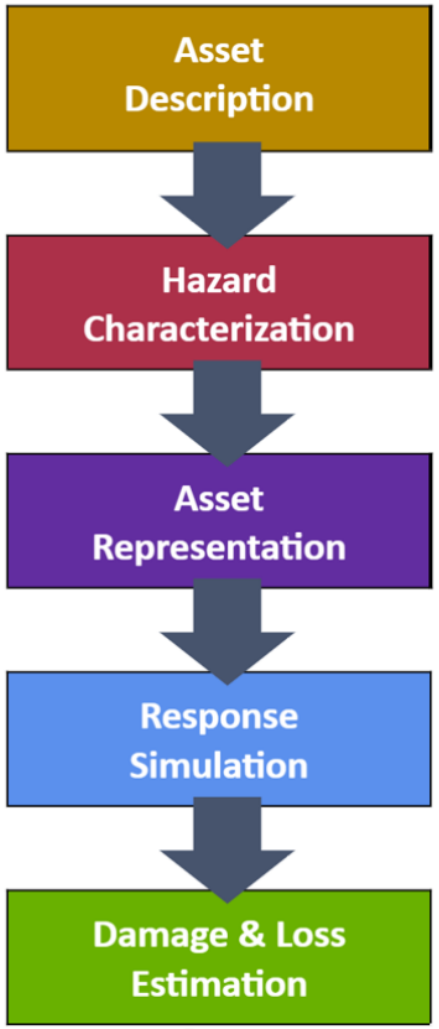
RECOVERY SIMULATION & DECISION MAKING

DV ARRAY

Asset Information Model for each asset

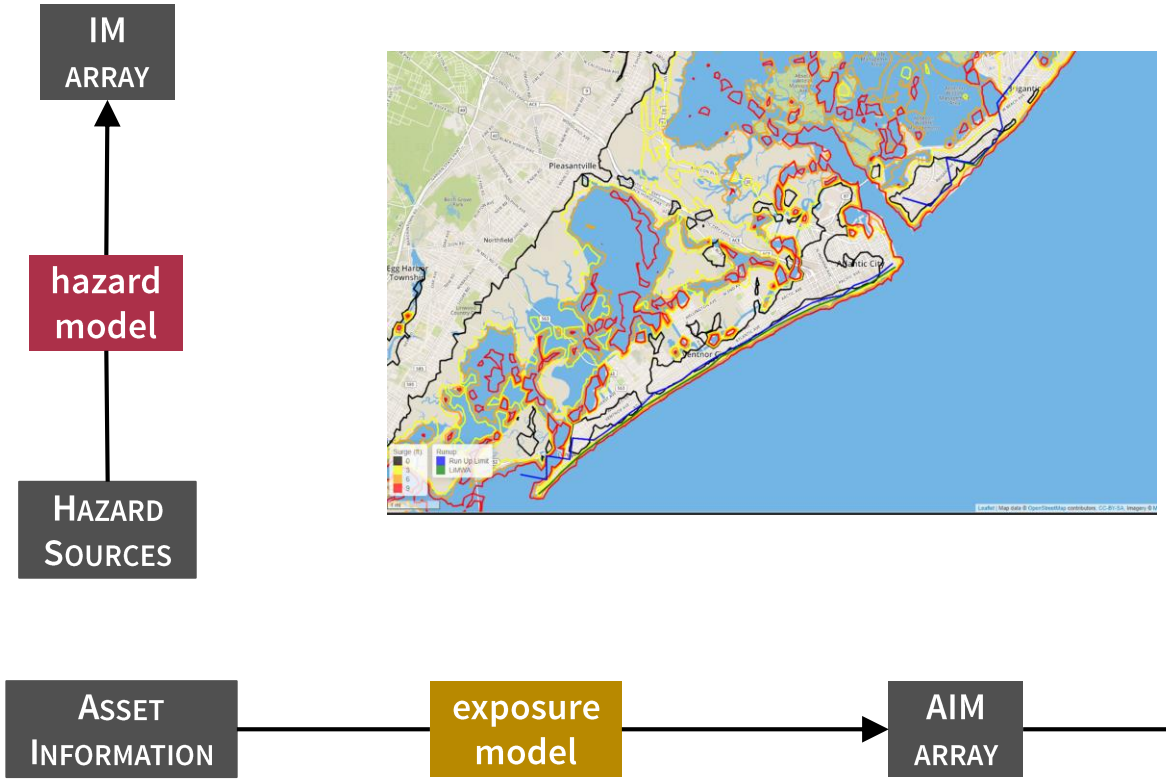
ASSET INFORMATION → exposure model → AIM ARRAY

Scope



REGIONAL SIMULATION WORKFLOW (rWHALE)

Intensity Measures
for a finite number of locations



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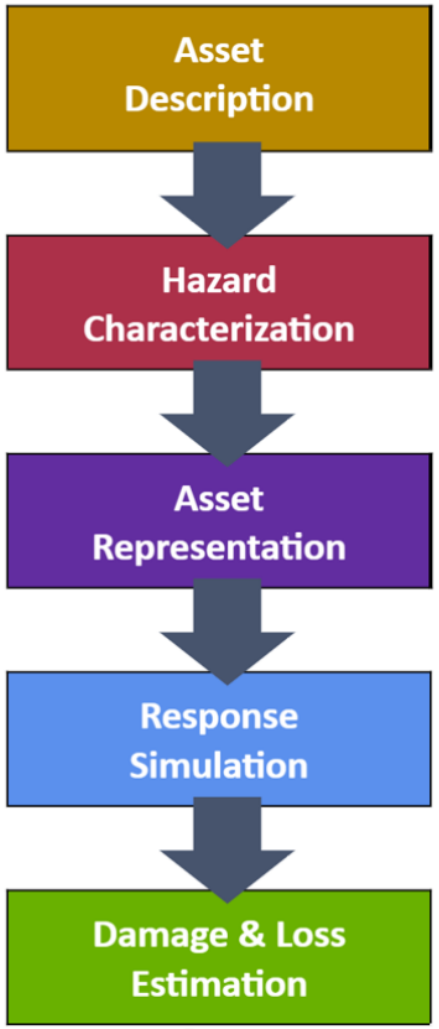
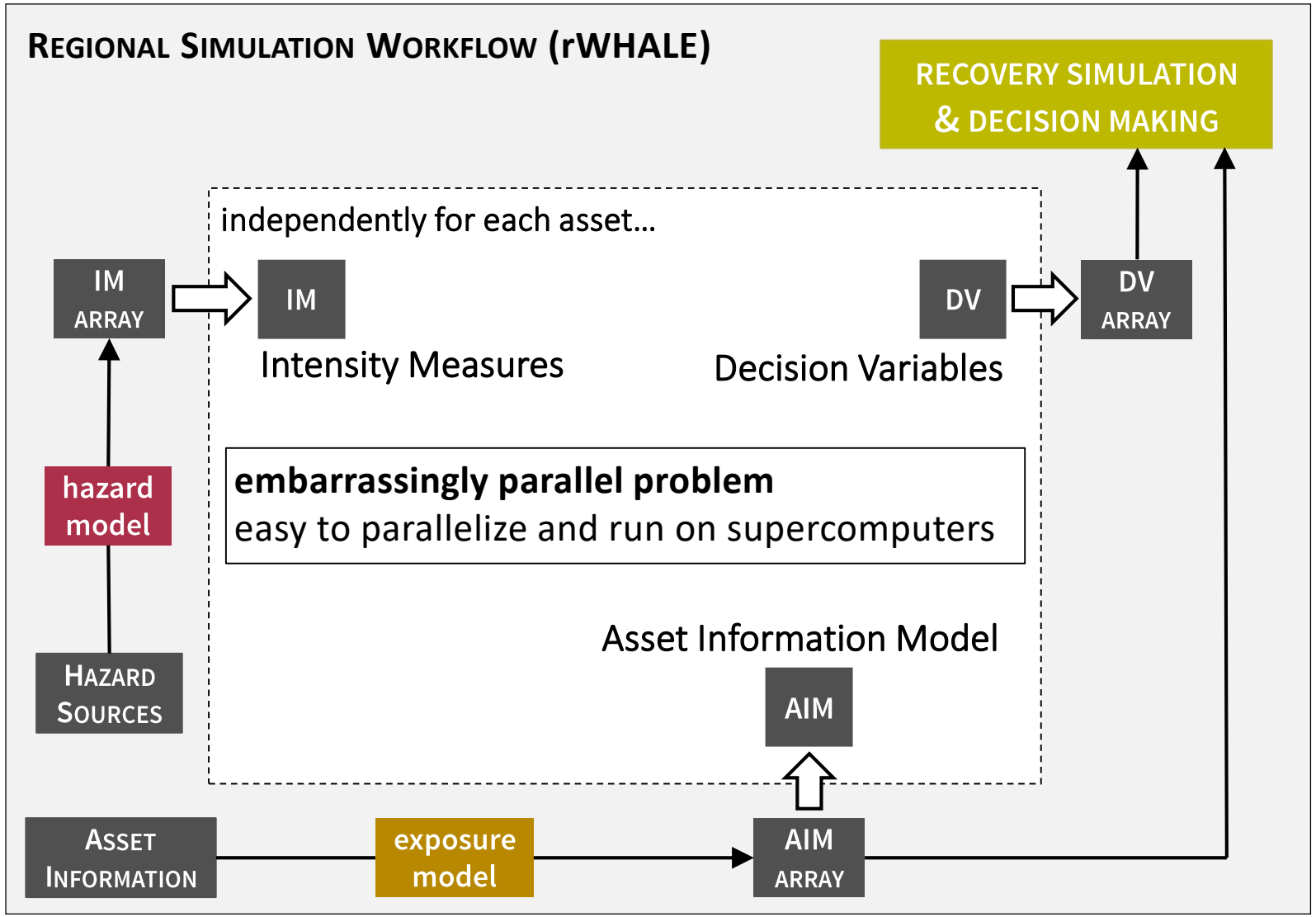
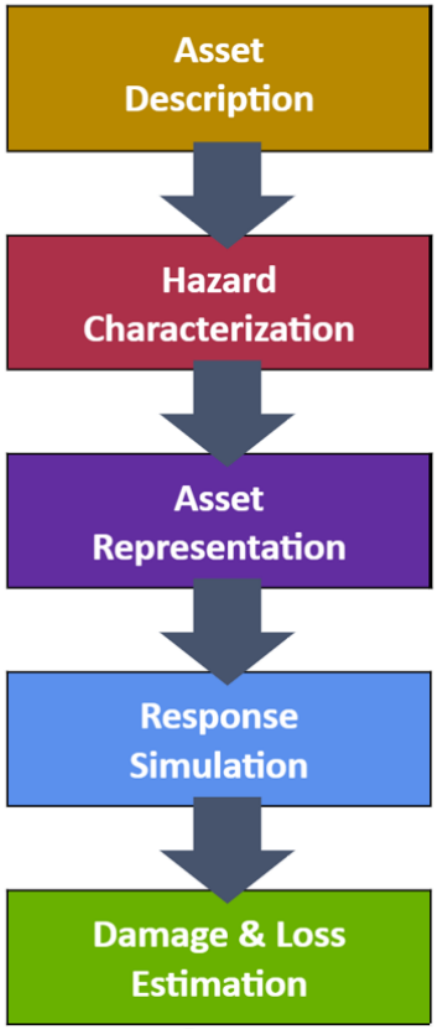

Asset Description
Hazard Characterization
Asset Representation
Response Simulation
Damage & Loss Estimation


REGIONAL SIMULATION WORKFLOW (rWHALE)
RECOVERY SIMULATION & DECISION MAKING
independently for each asset...
IM ARRAY
IM
Intensity Measures
DV
DV ARRAY
Decision Variables
hazard model
embarrassingly parallel problem
easy to parallelize and run on supercomputers
Asset Information Model
HAZARD SOURCES
AIM
ASSET INFORMATION
exposure model
AIM ARRAY

Scope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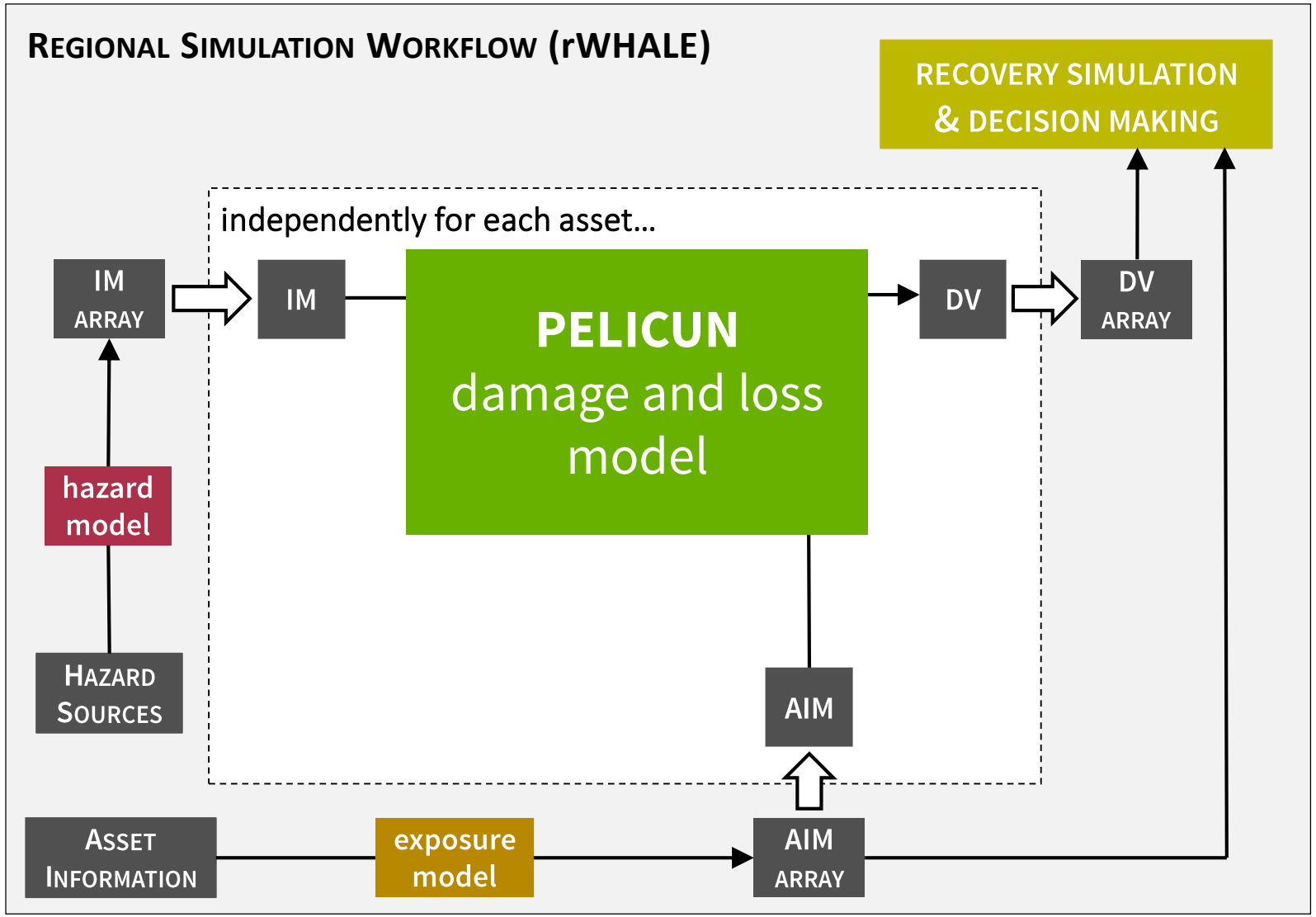
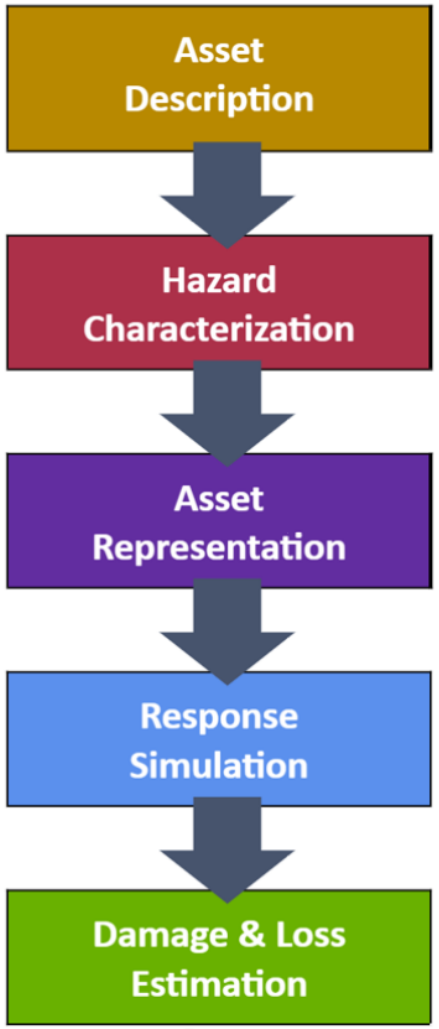

REGIONAL SIMULATION WORKFLOW (rWHALE)
RECOVERY SIMULATION & DECISION MAKING
independently for each asset...
IM ARRAY
IM
PELICUN damage and loss model
DV
DV ARRAY
hazard model
HAZARD SOURCES
AIM
ASSET INFORMATION
exposure model
AIM ARRAY

Scope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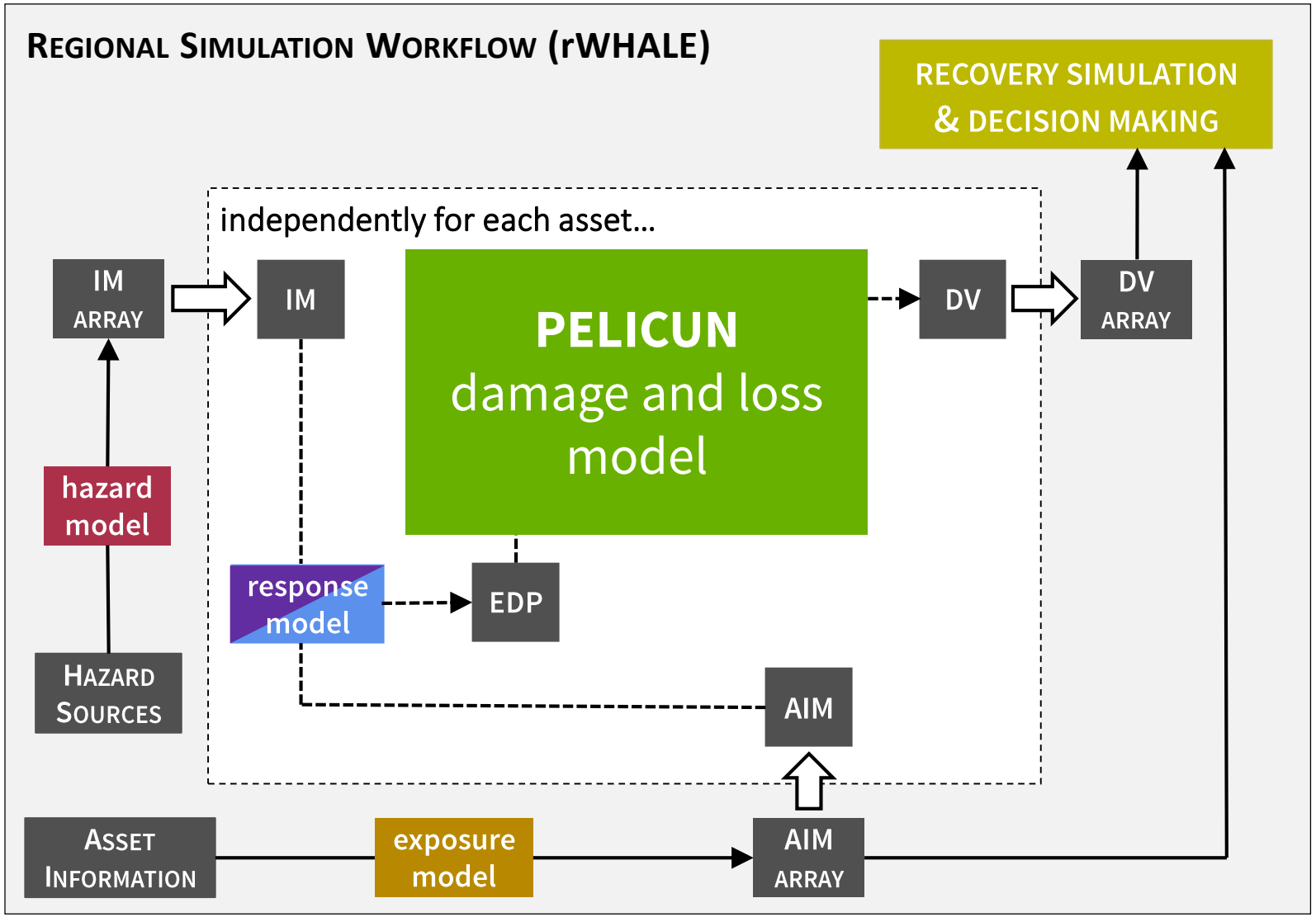
REGIONAL SIMULATION WORKFLOW (rWHALE)
RECOVERY SIMULATION & DECISION MAKING
independently for each asset...
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PELICUN damage and loss model
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EDP
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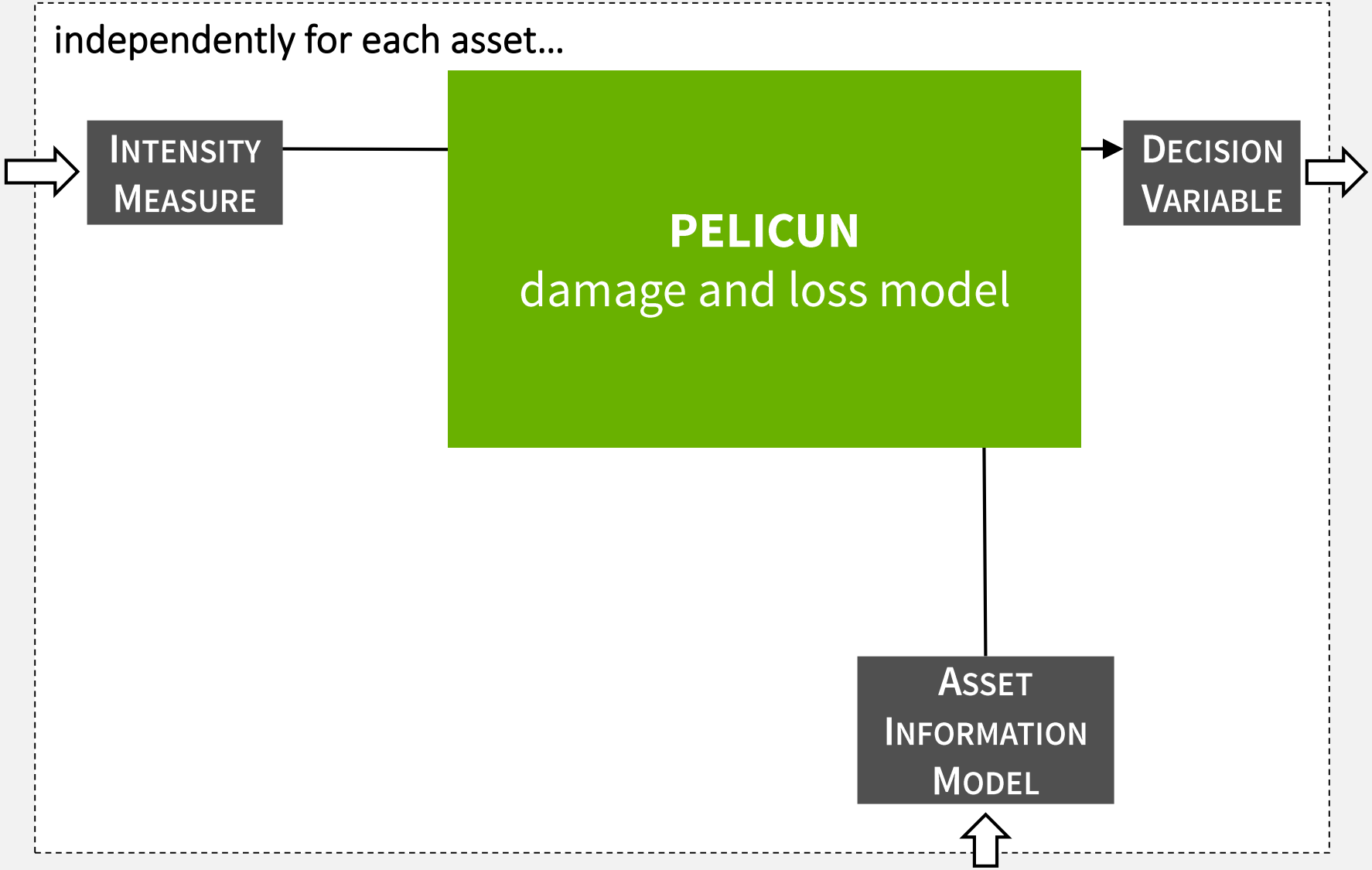
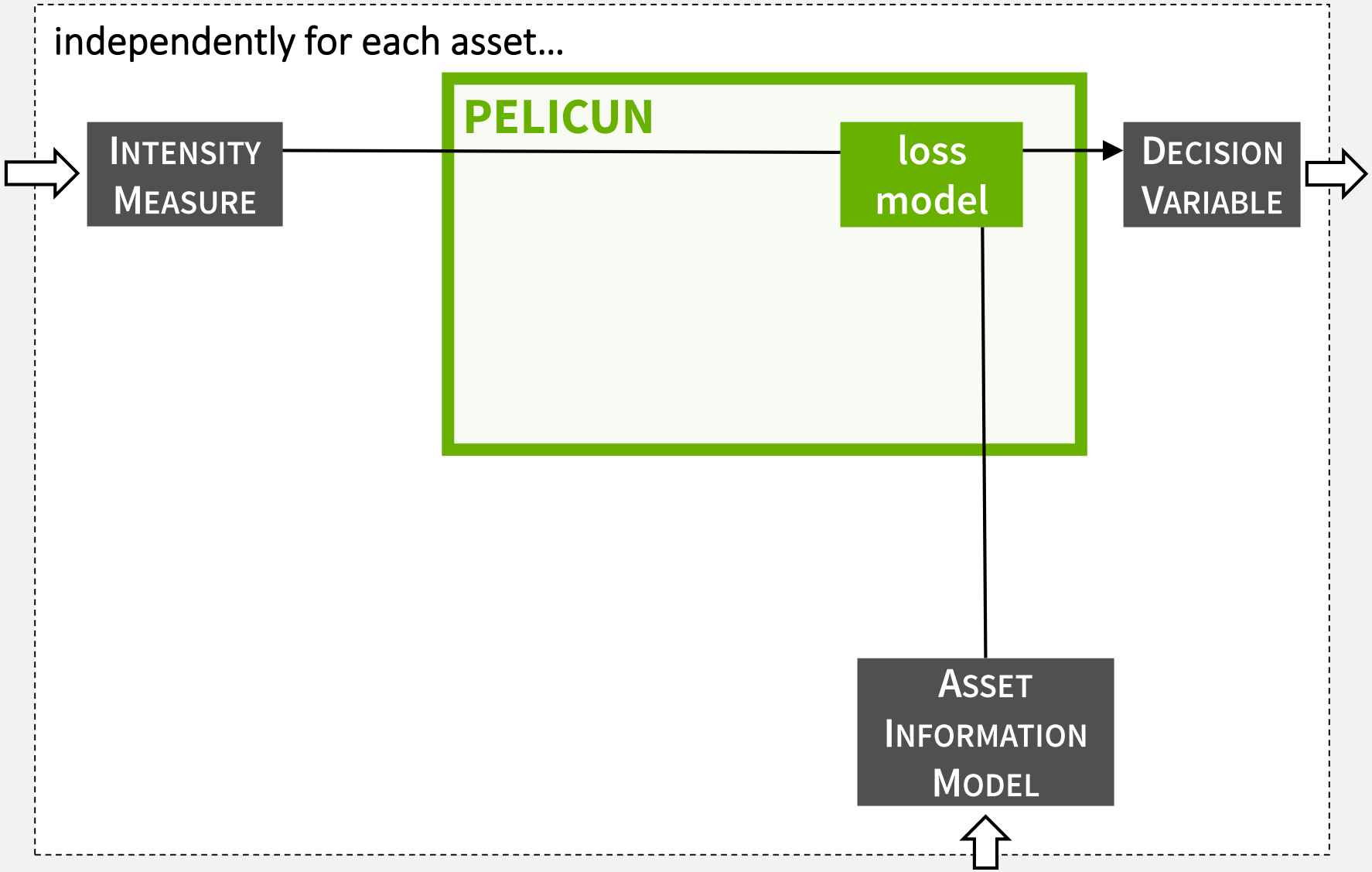
AIM ARRAY

Scope


independently for each asset...
INTENSITY MEASURE
PELICUN
damage and loss model
DECISION VARIABLE
ASSET INFORMATION MODEL

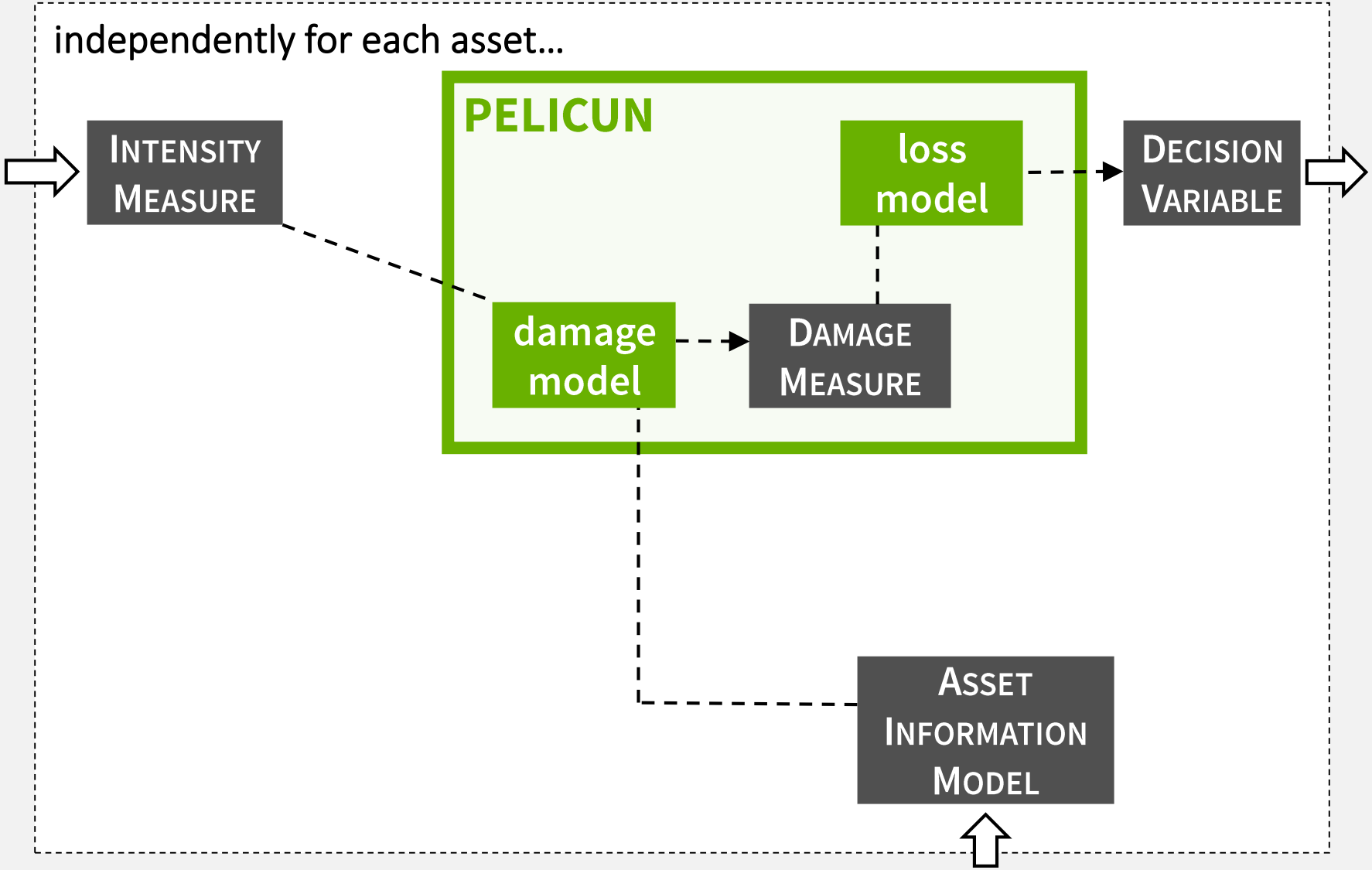
Scope

HAZUS flood damage & loss



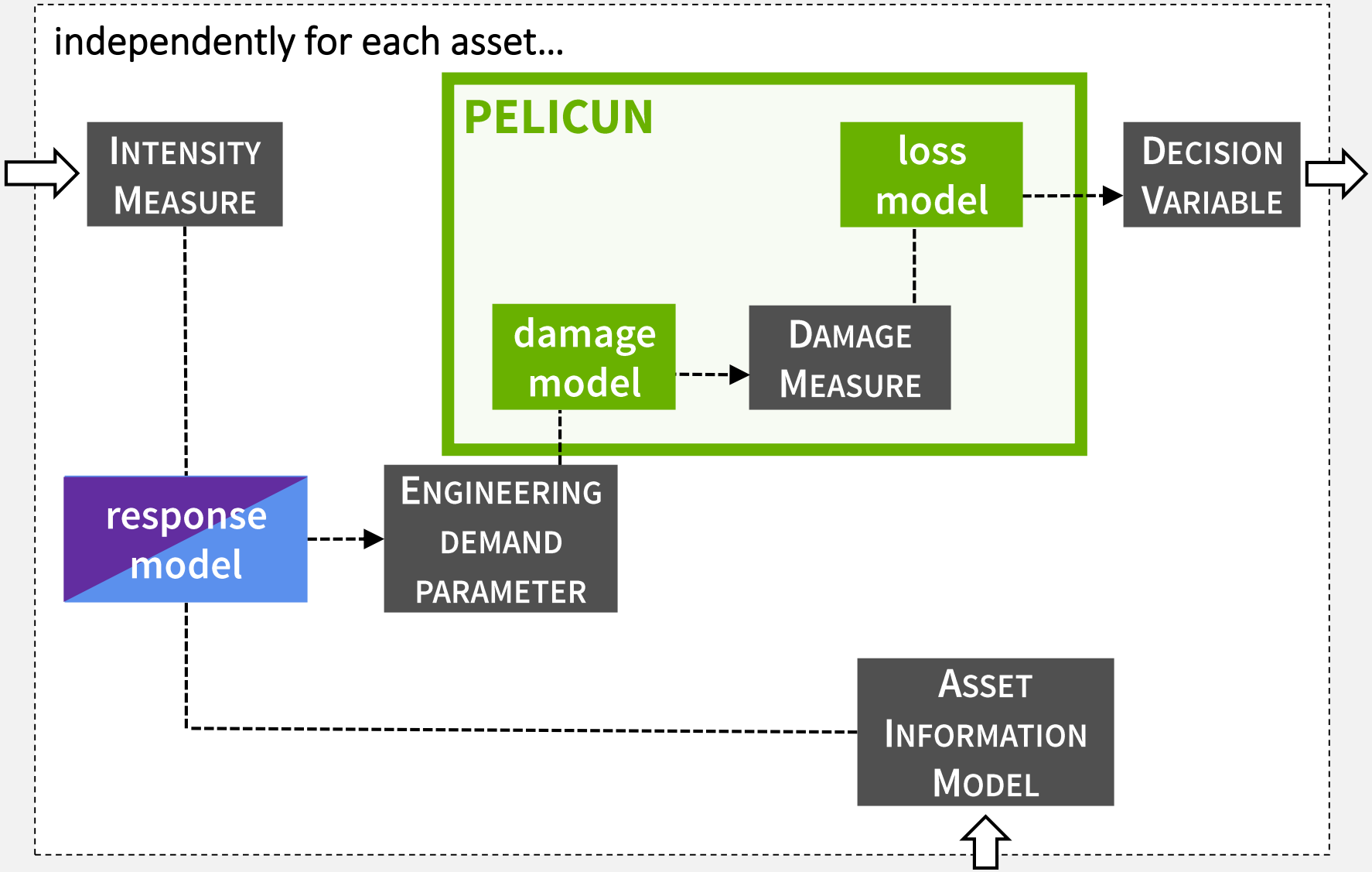
Scope

HAZUS earthquake damage & loss



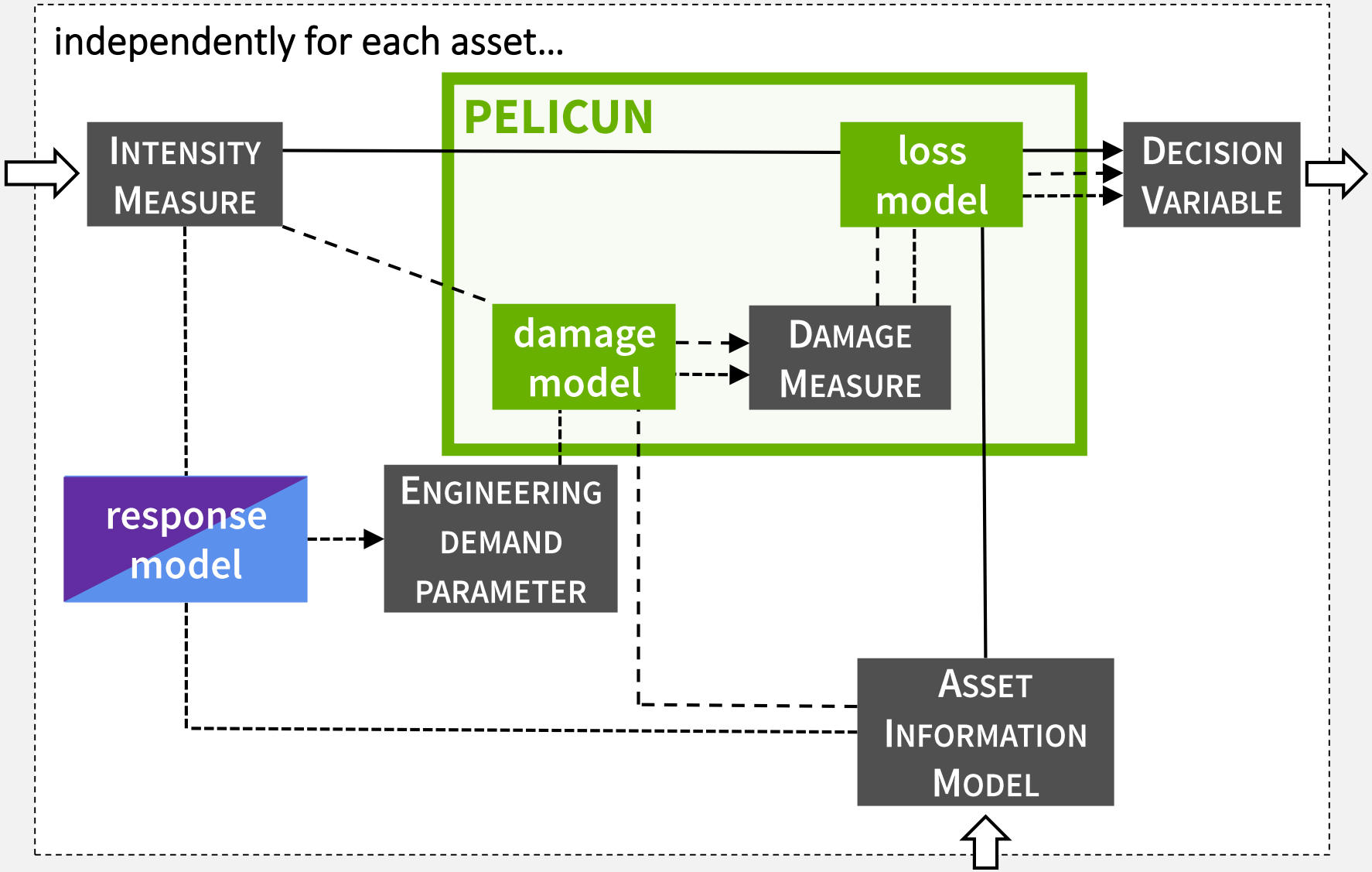
Scope

FEMA P58 earthquake damage & loss



Scope

PELICUN
is a unifying
framework



What is PELICUN?

Probabilistic **E**stimation of **L**osses, **I**njuries, and **C**ommunity resilience **U**nder **N**atural disasters

PELICUN is a conceptual framework for damage and loss assessment

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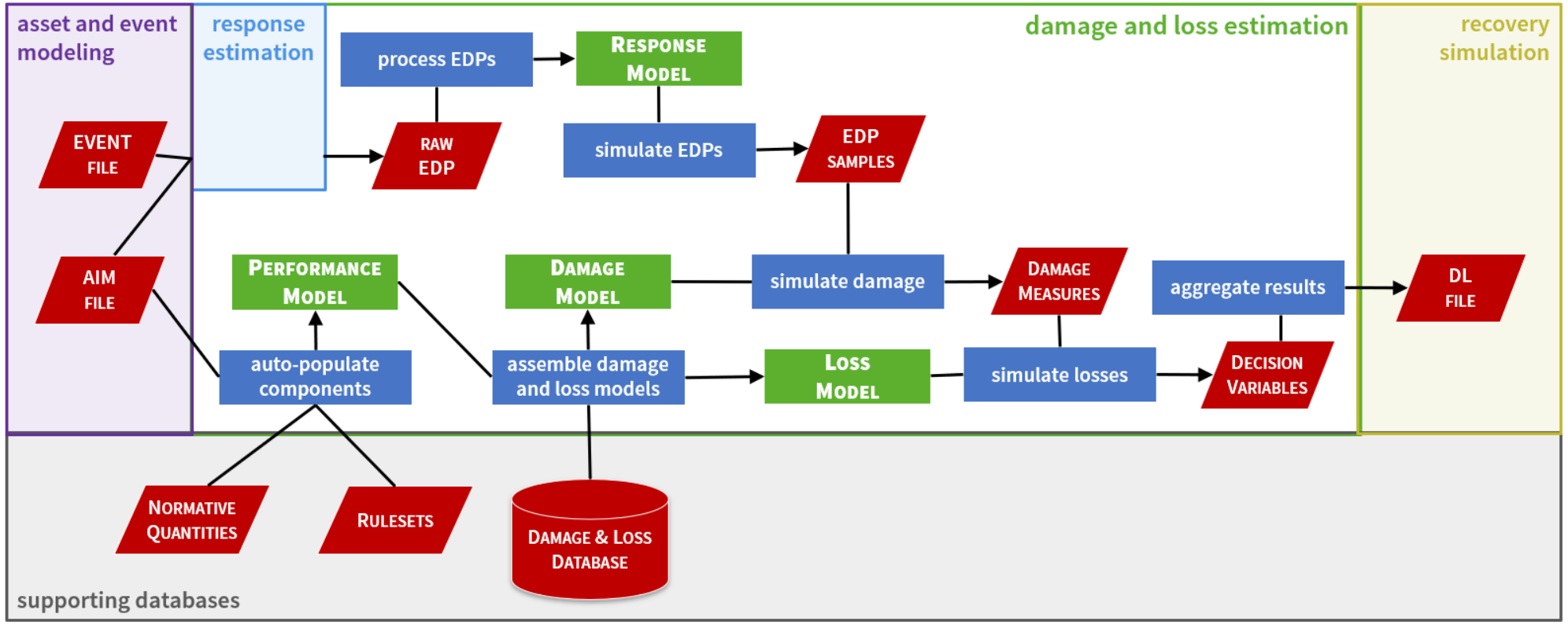


What is pelicun?

pelicun is an open-source Python library

What is pelicun?

pelicun is an open-source Python library

response estimation methods

fragility models

correlation models

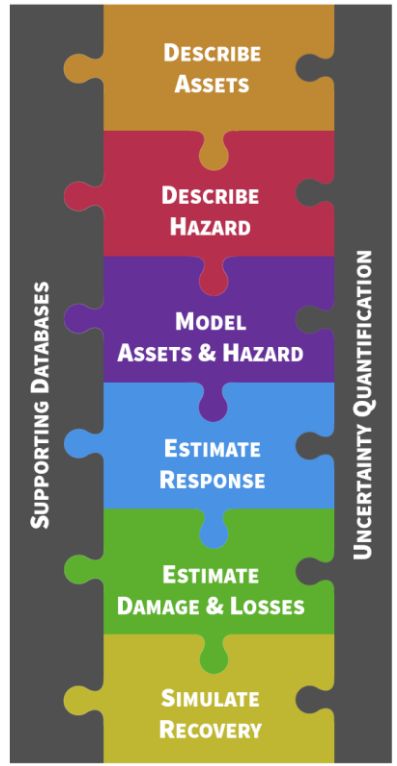
population distributions

fragility functions

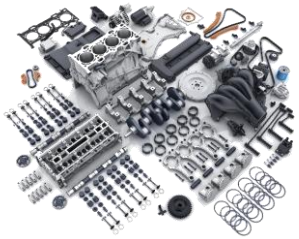
loss functions

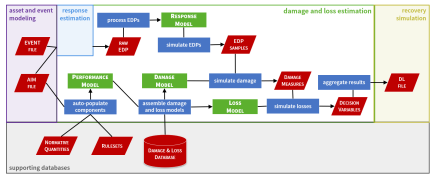
Estimate asset damage and its consequences

- Describe the asset, its response and fragility
- Estimate P(collapse)
- Estimate damages
- Estimate losses
- Aggregate results



Library





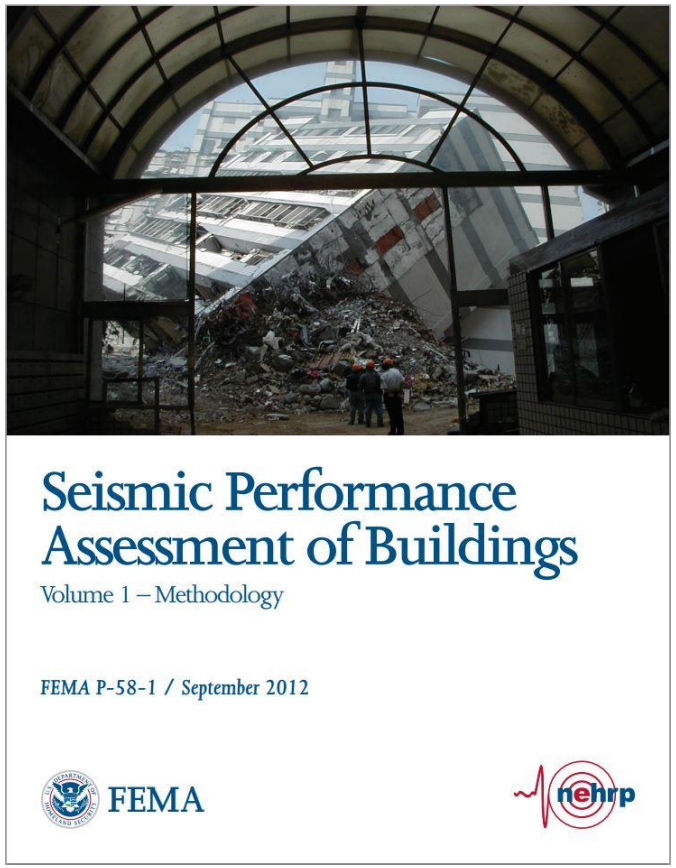
Application

Workflow

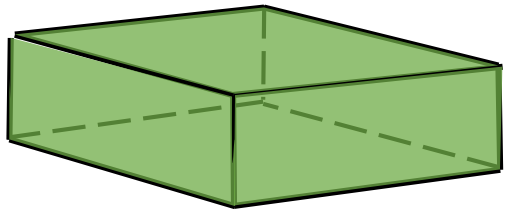
Capabilities

Foundation: Damage and loss assessment as per FEMA P58

earthquake, high-fidelity, buildings only



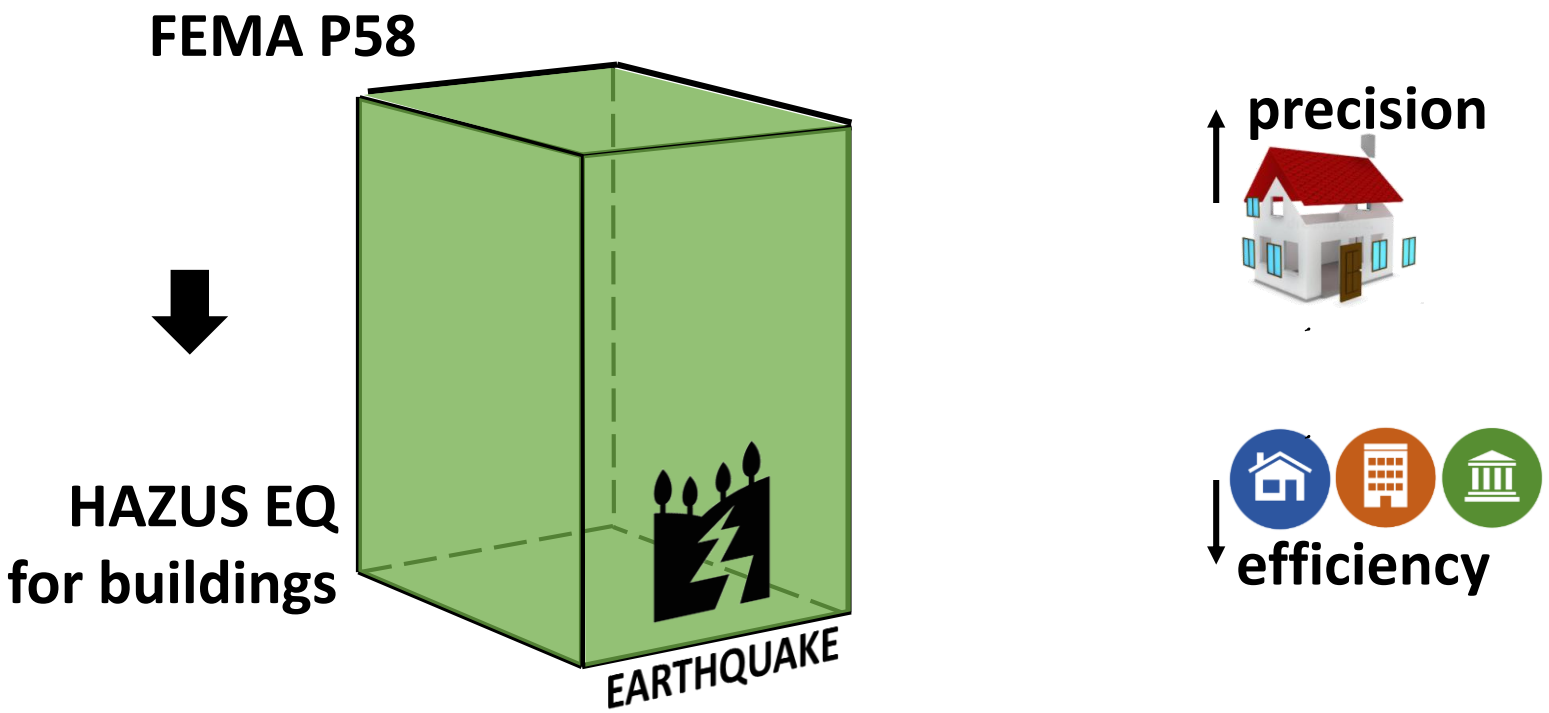
FEMA P58



models & supporting data come with pelicun

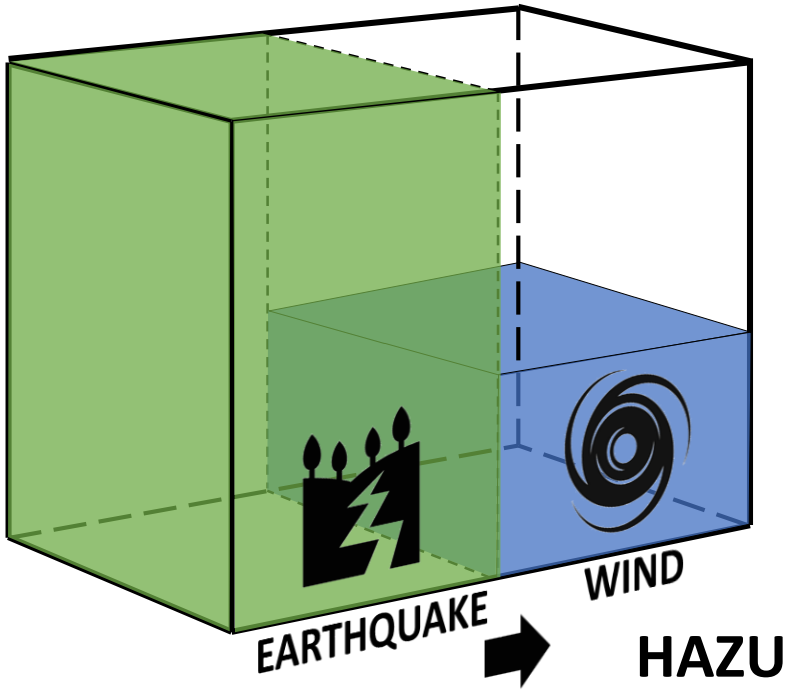
Capabilities

Integrate FEMA P58 and HAZUS earthquake damage models to support **multi-fidelity** damage and loss assessment



Capabilities

Integrate HAZUS hurricane wind damage models
to support **multi-hazard** damage and loss assessment

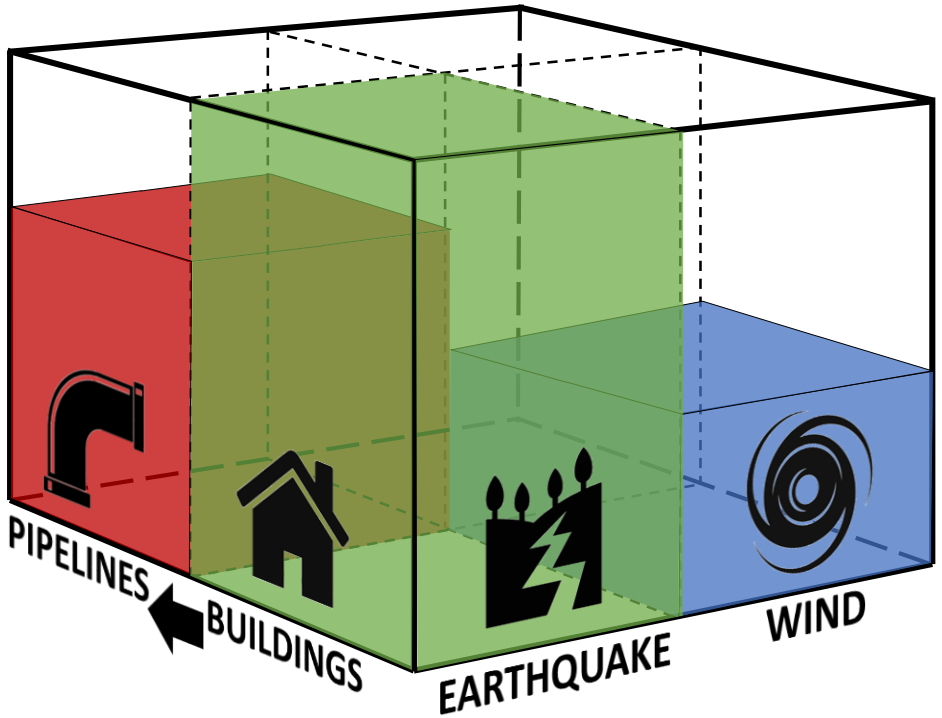


HAZUS HURRICANE WIND
for buildings

Capabilities

Integrate HAZUS damage models for pipelines
to support damage and loss assessment for **multiple asset types**

HAZUS EQ
for potable water



Capabilities

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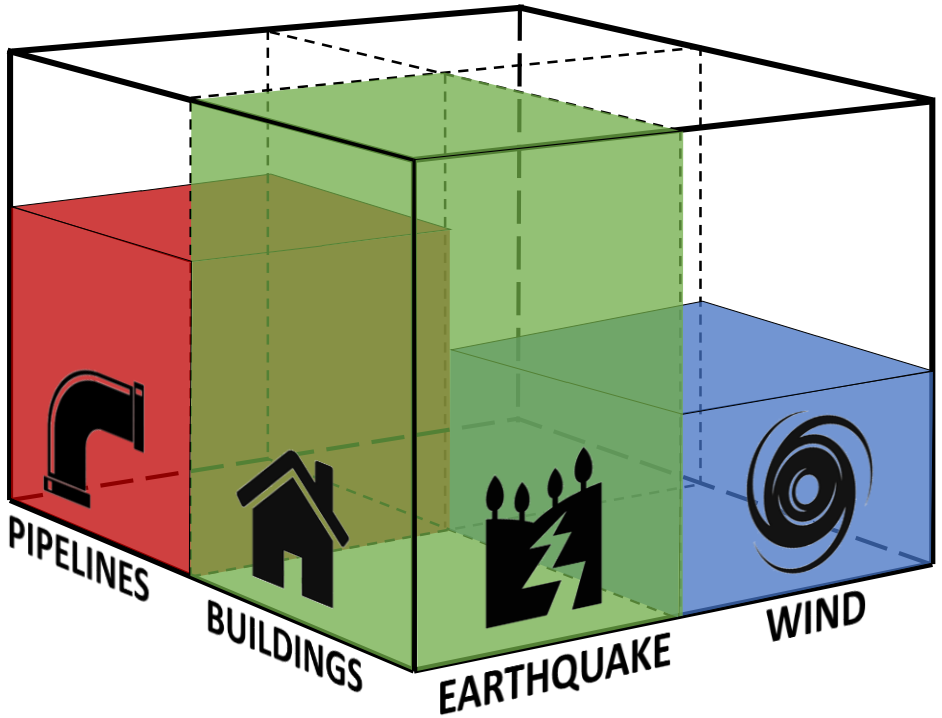
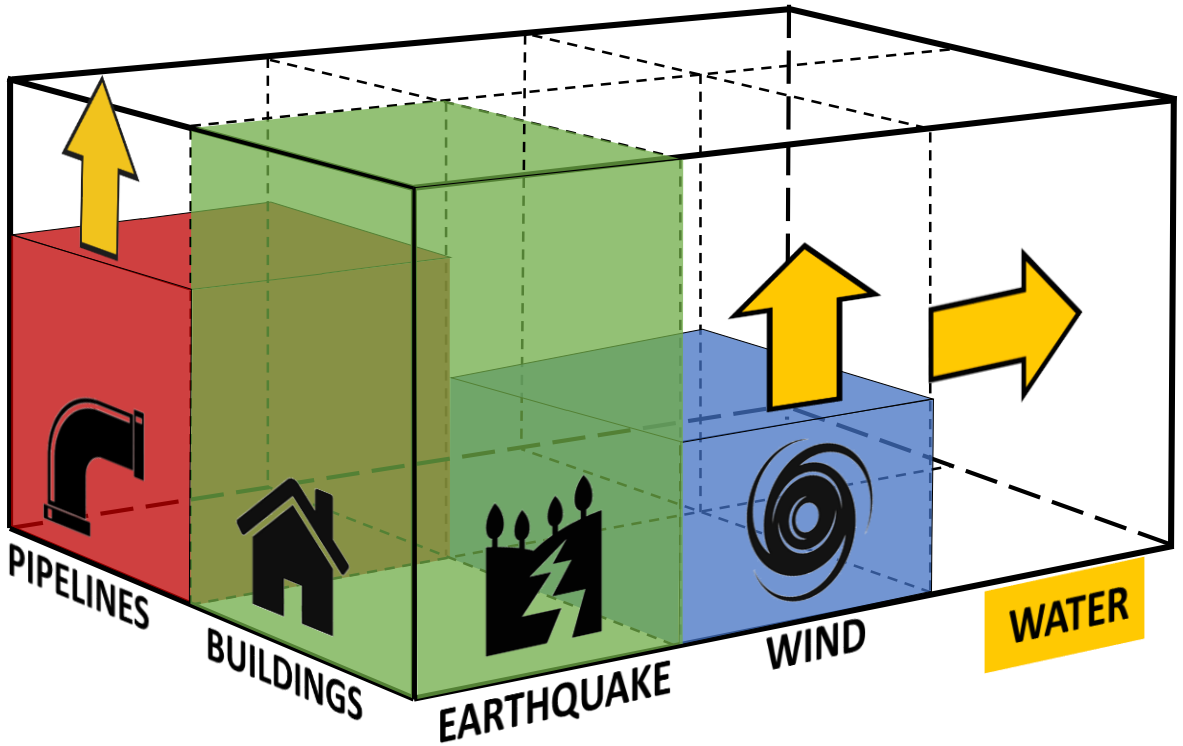


Capabilities

By the end of 2020…

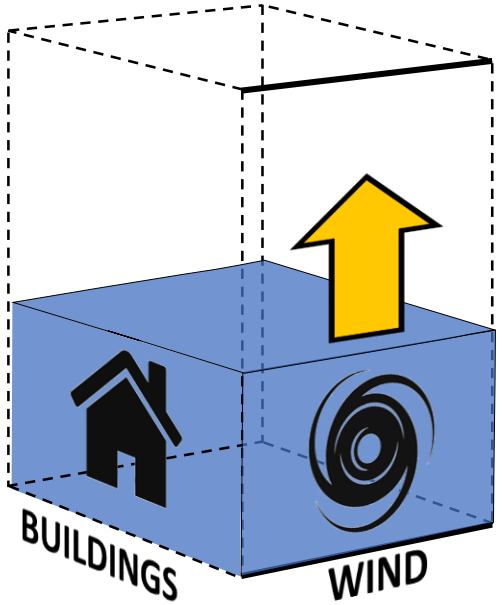


Opportunities in wind damage and loss assessment

Increase precision

Improve fidelity

Improve combination with water hazards



HAZUS Hurricane Methodology

INTENSITY MEASURE:Peak Wind Gust Speed at 10 m (open)

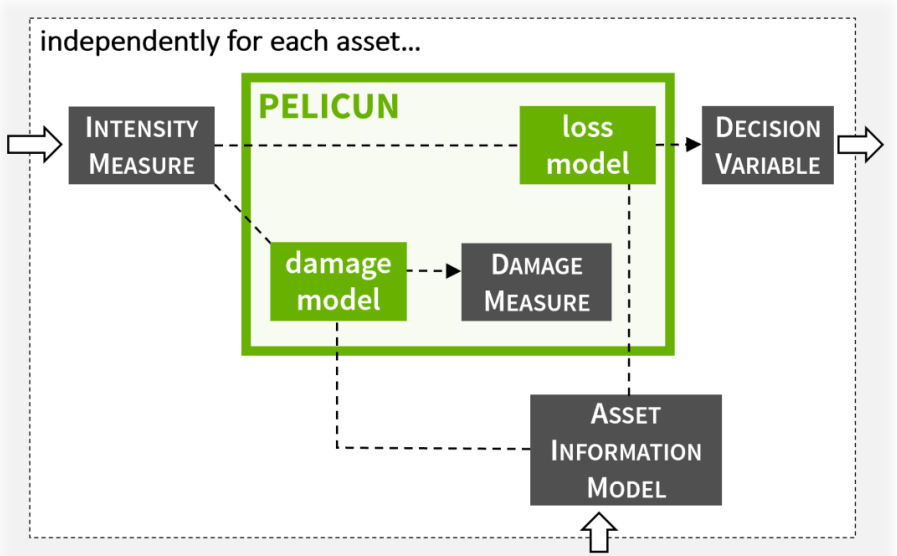
ASSET INFORMATION:

structure type (wood single-family, masonry multi-unit, etc.)

roof shape (gable, hip, flat)

terrain roughness (open, suburban, trees, etc.)

shutters, garage, secondary water resistance, roof-wall connection, window area, tie downs, etc.



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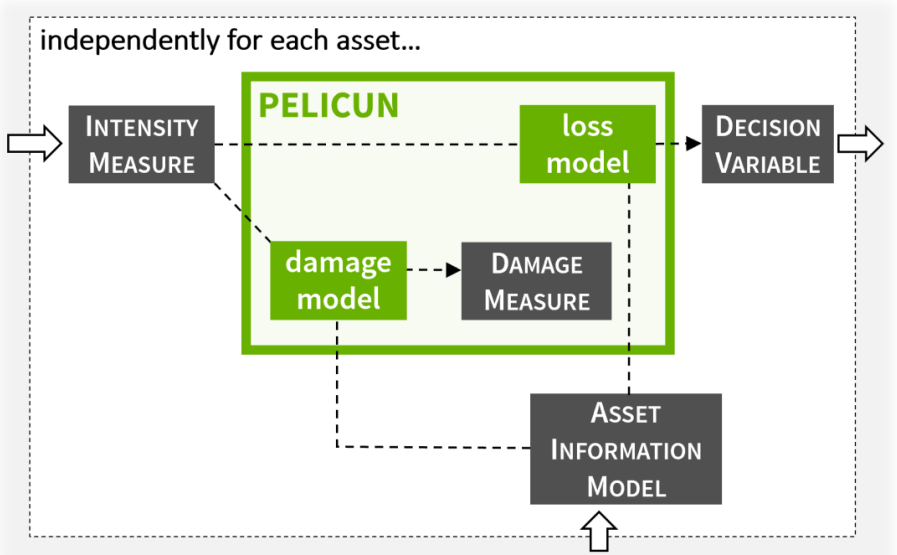
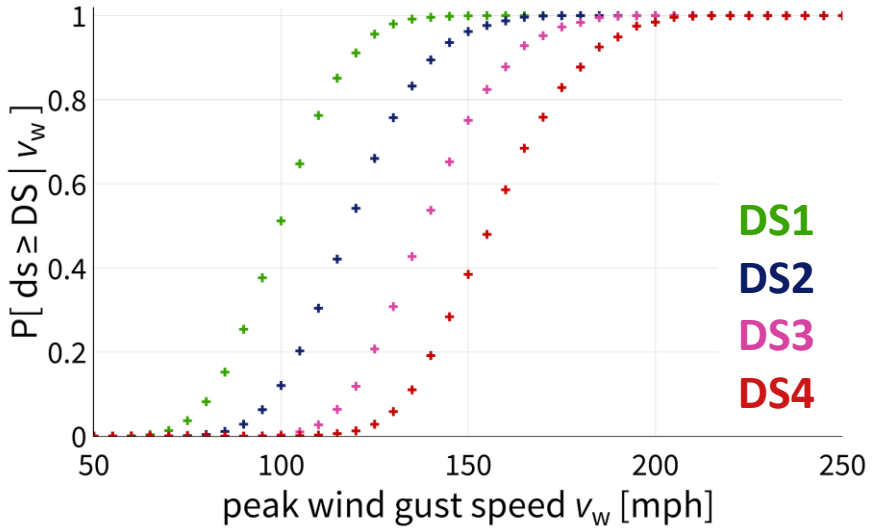
DAMAGE MODEL:

20,000+ building configurations; 4 damage states

Returns probability of damage state exceedance
for a discrete set of wind speeds
based on synthetic damage simulations





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structure type, roof shape, terrain roughness, etc.

DAMAGE MODEL:

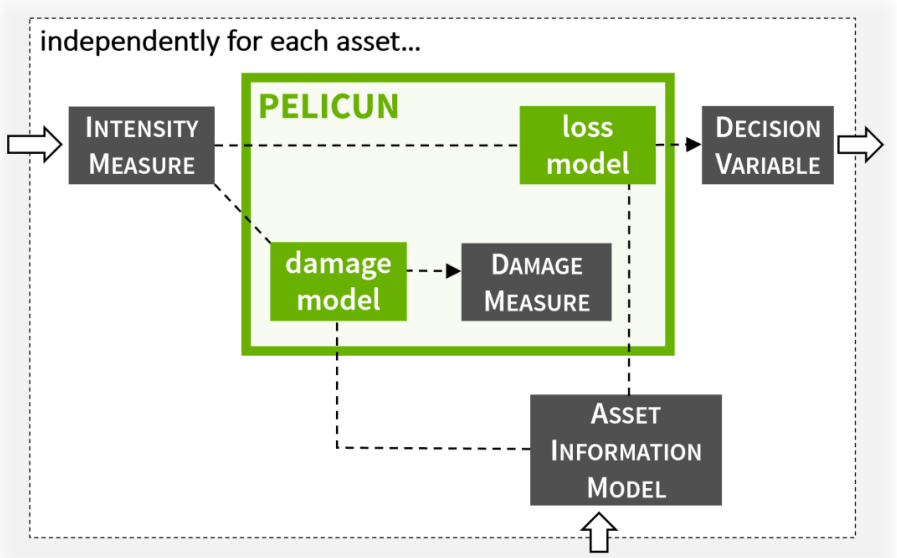
20,000+ building configurations; 4 damage states

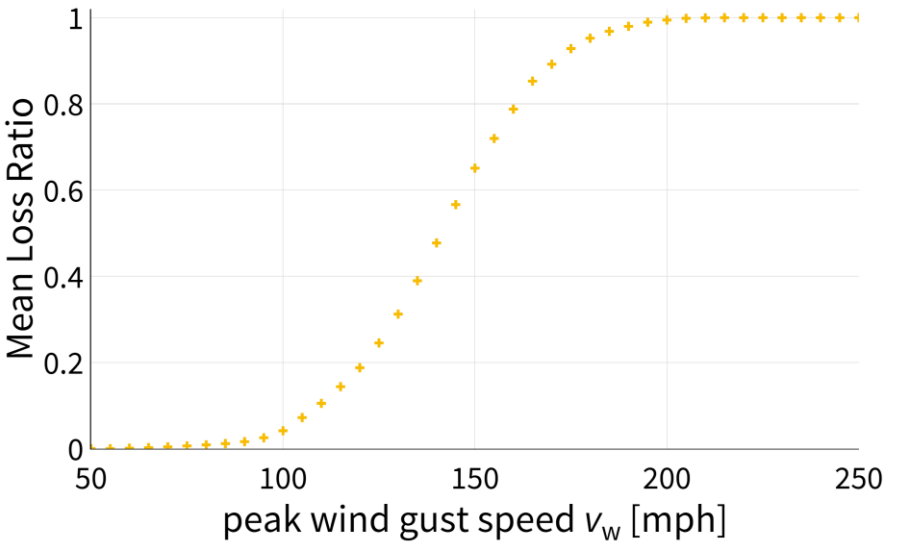
Returns probability of damage state exceedance
for a discrete set of wind speeds
based on synthetic damage simulations

LOSS MODEL:

same building configurations, returns loss ratio

decoupled from the damage model



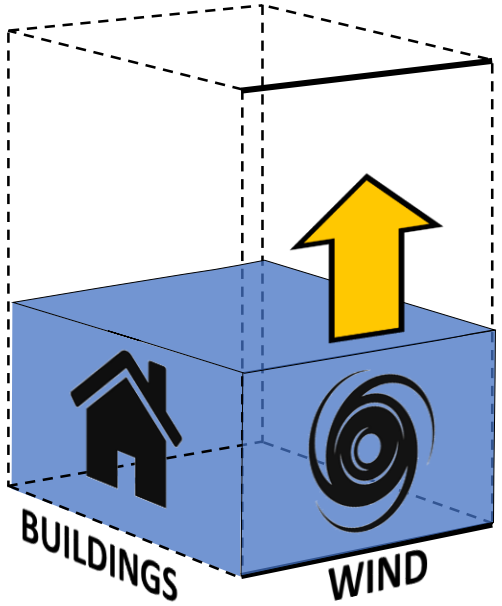


Opportunities in wind damage and loss assessment

Increase precision

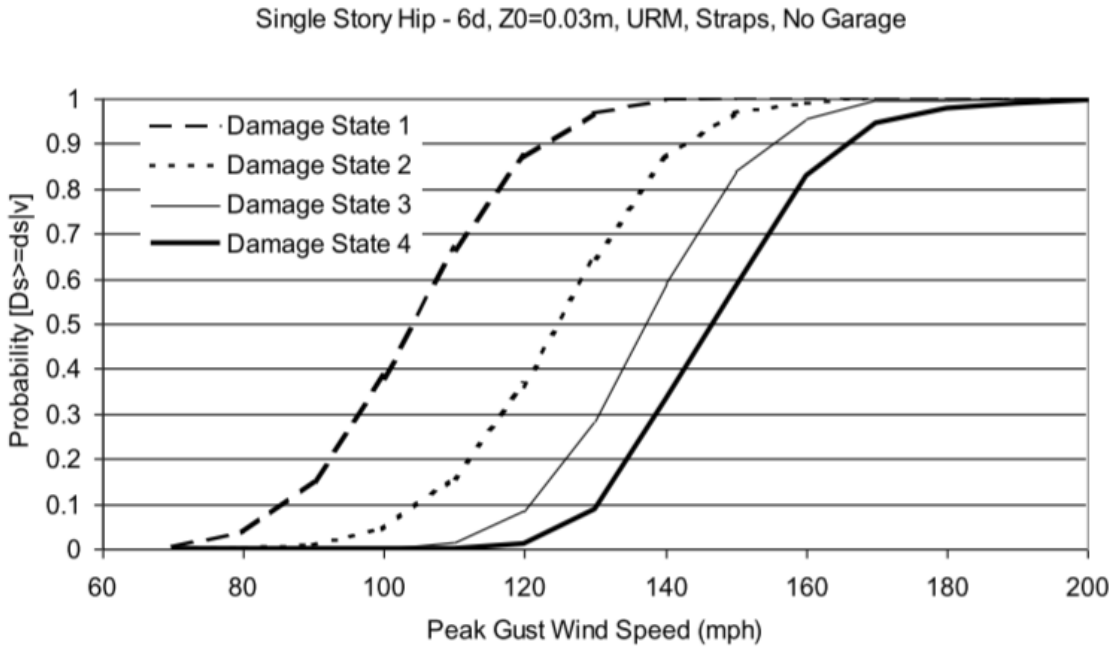
Improve fidelity

Improve combination with water hazards



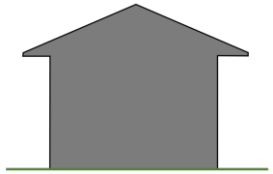
Increase precision

source: HAZUS MH 2.1 Hurricane Technical Manual



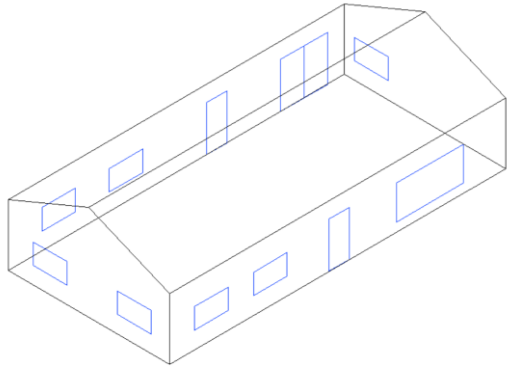
building-level

e.g. HAZUS hurricane methodology



Increase precision

source: HAZUS MH 2.1 Hurricane Technical Manual



No Garage – 50′ by 24′ Plan, 9′ Eave Height

Table 6-9. Damage States for Residential Construction Classes

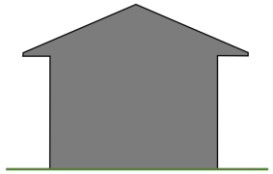
Damage State	Qualitative Damage Description	Roof Cover Failure	Window Door Failures	Roof Deck	Missile Impacts on Walls	Roof Structure Failure	Wall Structure Failure
0	**No Damage or Very Minor Damage** Little or no visible damage from the outside. No broken windows, or failed roof deck. Minimal loss of roof over, with no or very limited water penetration.	≤2%	No	No	No	No	No
1	**Minor Damage** Maximum of one broken window, door or garage door. Moderate roof cover loss that can be covered to prevent additional water entering the building. Marks or dents on walls requiring painting or patching for repair.	>2% and ≤15%	One window, door, or garage door failure	No	<5 impacts	No	No
2	**Moderate Damage** Major roof cover damage, moderate window breakage. Minor roof sheathing failure. Some resulting damage to interior of building from water	>15% and ≤50%	> one and ≤ the larger of 20% & 3	1 to 3 panels	Typically 5 to 10 impacts	No	No
3	**Severe Damage** Major window damage or roof sheathing loss. Major roof cover loss. Extensive damage to interior from water.	>50%	> the larger of 20% & 3 and ≤50%	>3 and ≤25%	Typically 10 to 20 impacts	No	No
4	**Destruction** Complete roof failure and/or, failure of wall frame. Loss of more than 50% of roof sheathing.	Typically >50%	>50%	>25%	Typically >20 impacts	Yes	Yes

subassembly-level

e.g. HAZUS synthetic hurricane simulations

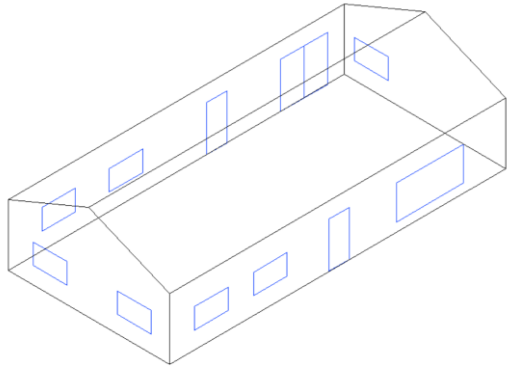
building-level

e.g. HAZUS hurricane methodology

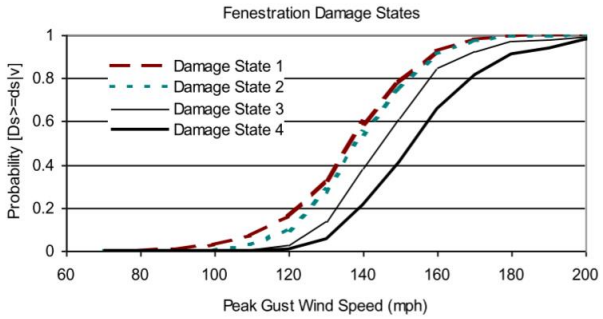


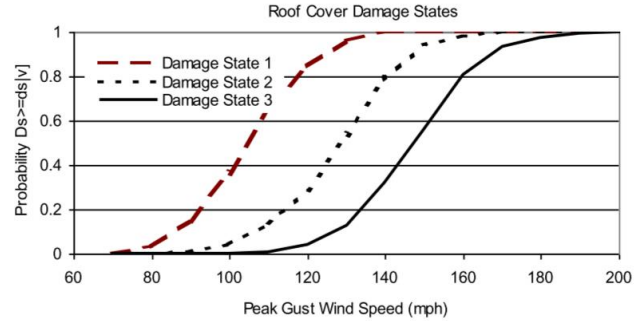
Increase precision

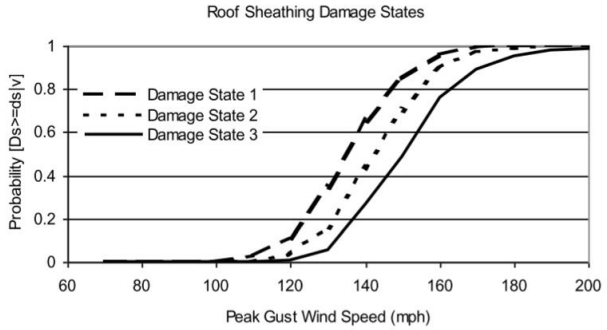
source: HAZUS MH 2.1 Hurricane Technical Manual

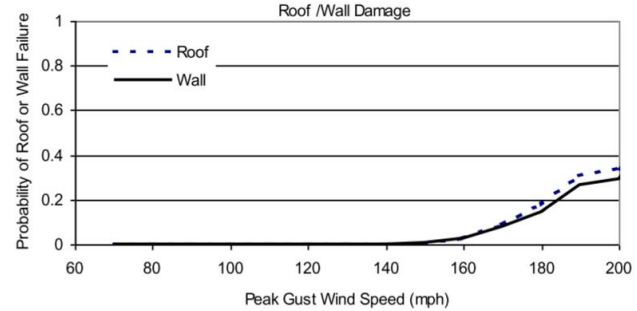


No Garage – 50′ by 24′ Plan, 9′ Eave Height







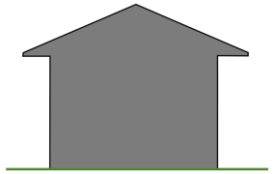


subassembly-level

e.g. HAZUS synthetic hurricane simulations

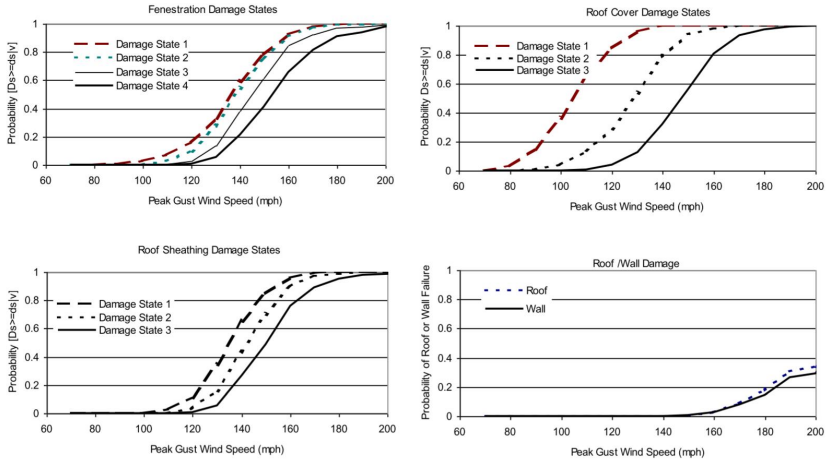
building-level

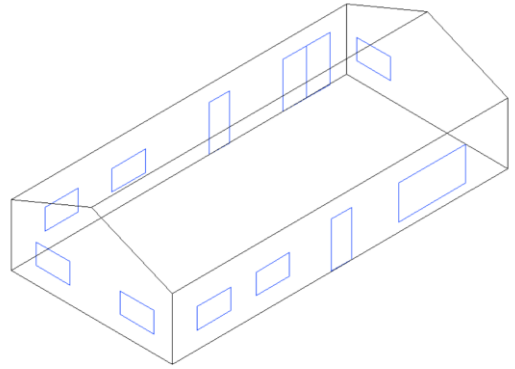
e.g. HAZUS hurricane methodology



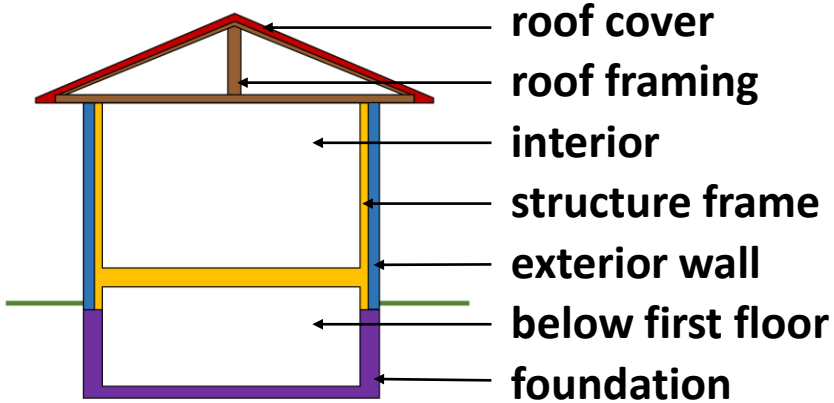
Increase precision

source: HAZUS MH 2.1 Hurricane Technical Manual





No Garage – 50′ by 24′ Plan, 9′ Eave Height

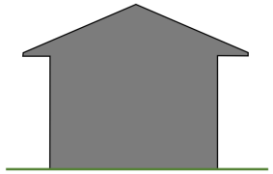


subassembly-level

e.g. HAZUS synthetic hurricane simulations

building-level

e.g. HAZUS hurricane methodology



Increase precision

component-level

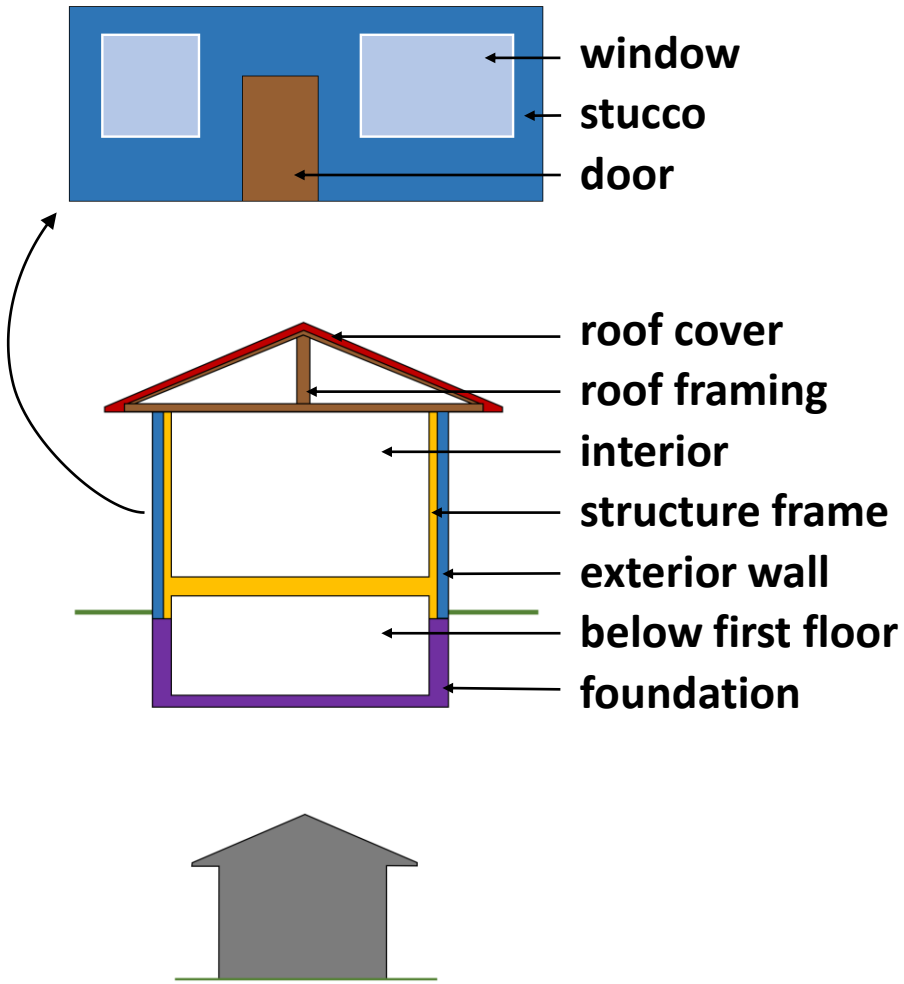
e.g. Performance-Based Wind Engineering

subassembly-level

e.g. HAZUS synthetic hurricane simulations

building-level

e.g. HAZUS hurricane methodology



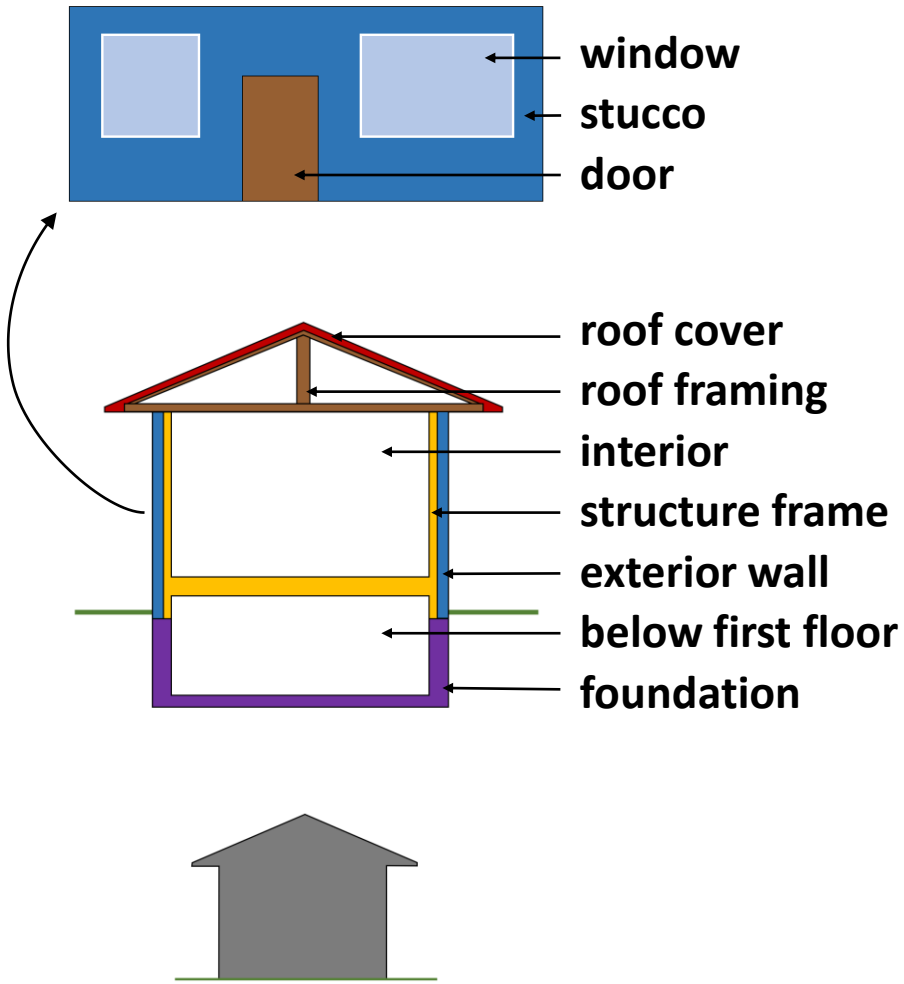
Increase precision

PELICUN supports analyses at all three levels

component-level
e.g. Performance-Based Wind Engineering

subassembly-level
e.g. HAZUS synthetic hurricane simulations

building-level
e.g. HAZUS hurricane methodology

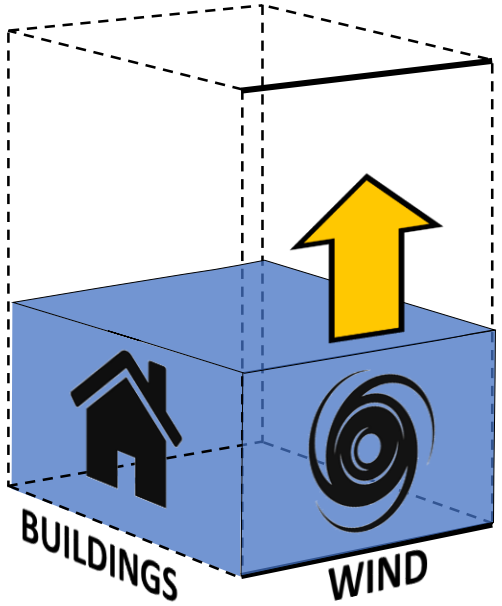


Opportunities in wind damage and loss assessment

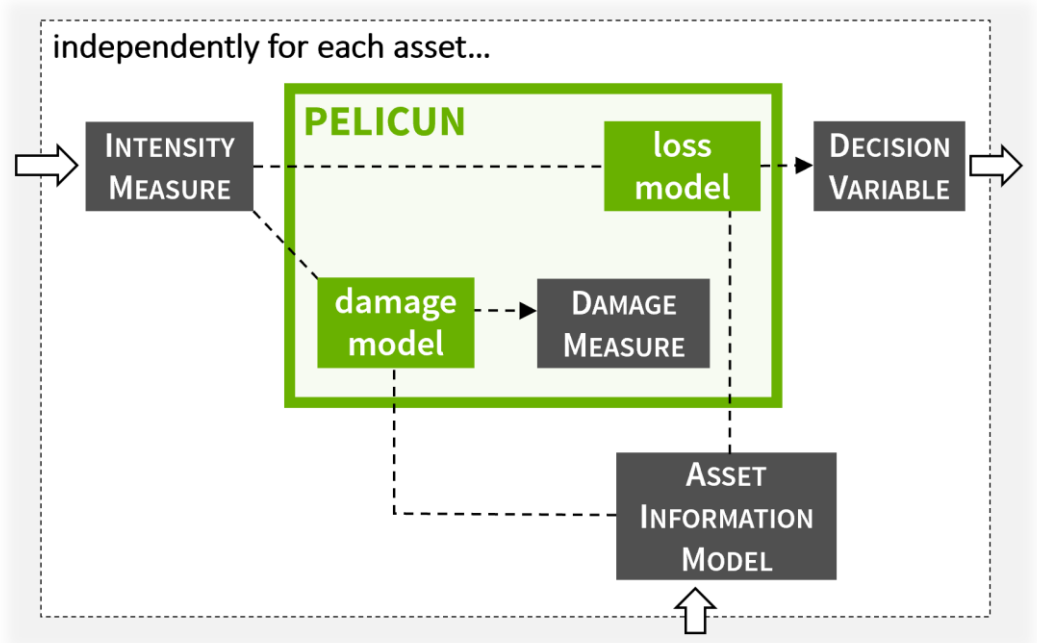
Increase precision

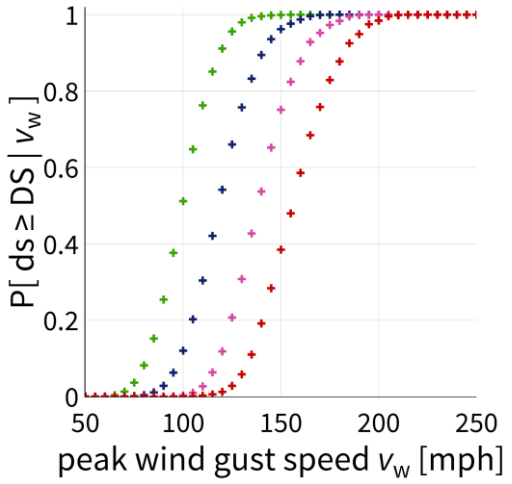
Improve fidelity

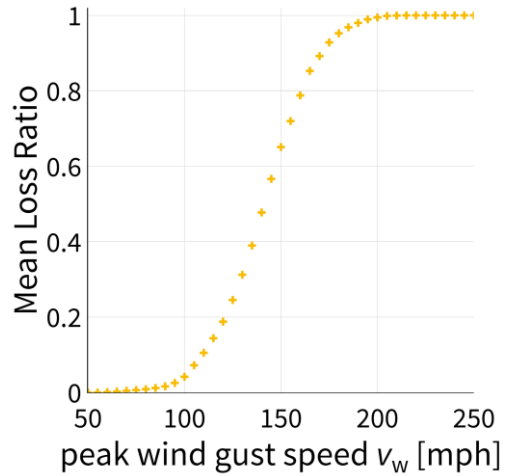
Improve combination with water hazards



Improve fidelity

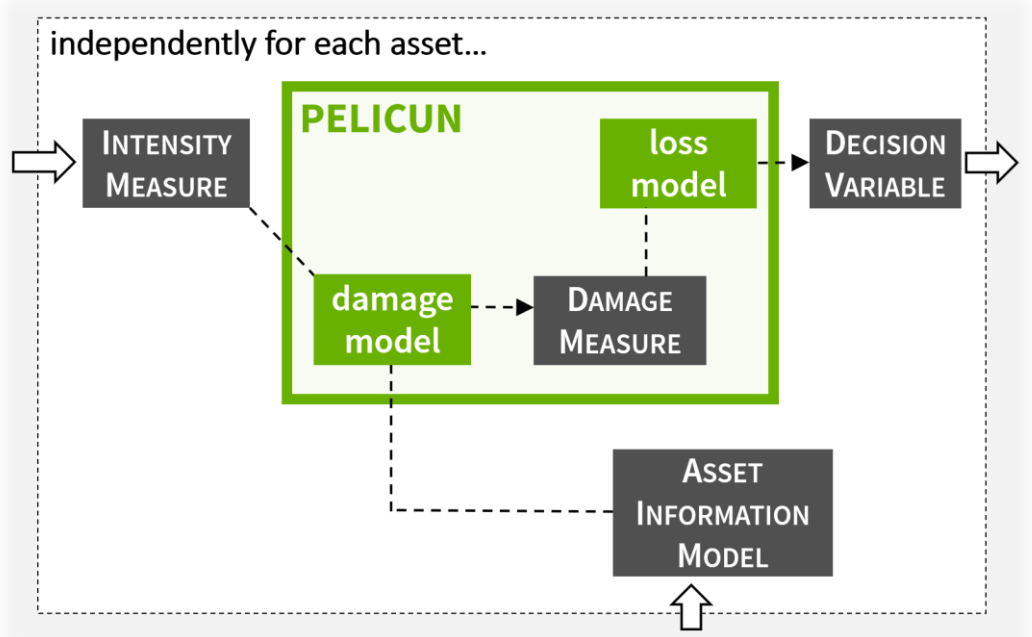






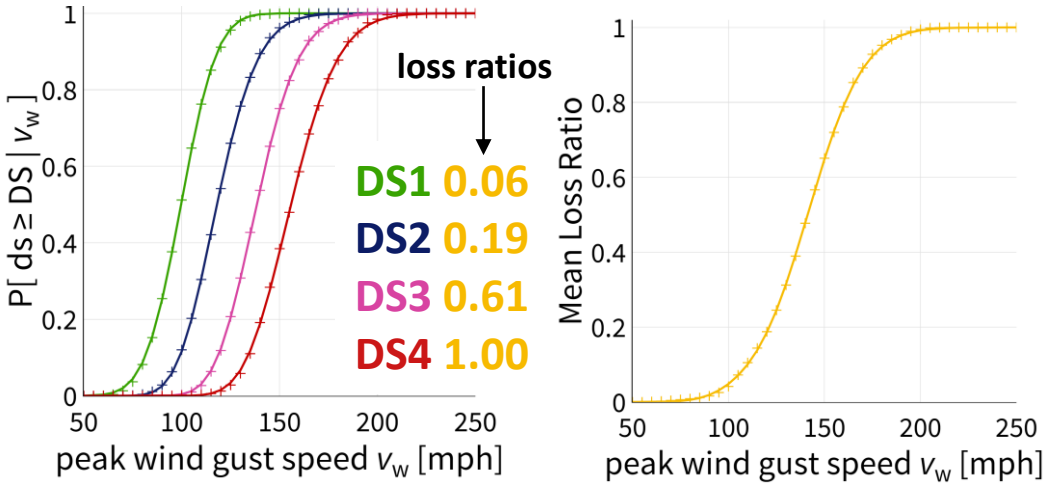
baseline: HAZUS hurricane methodology

Improve fidelity

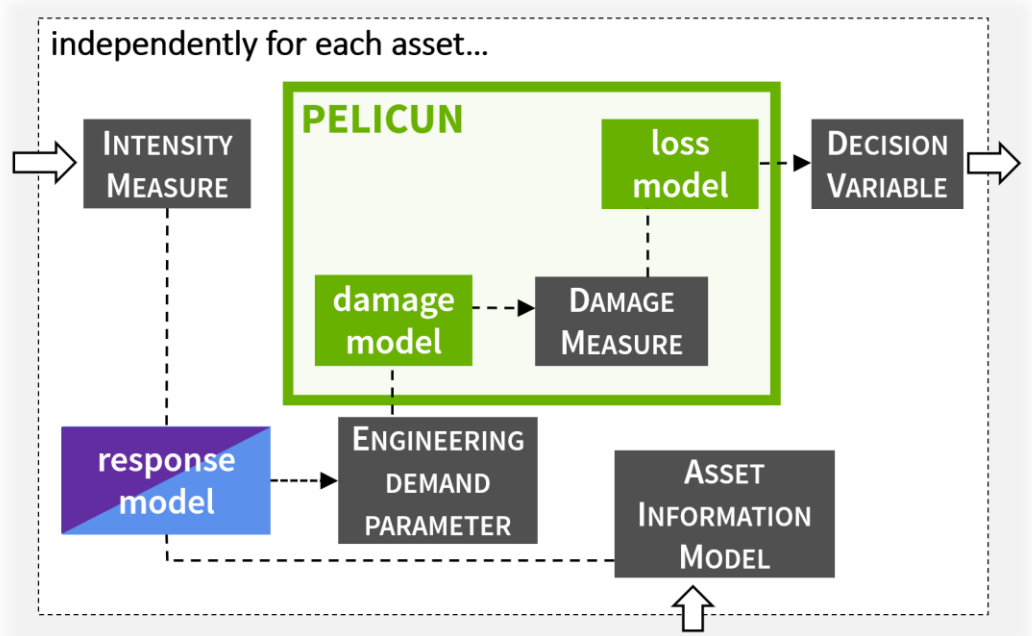


couple damage & loss models

baseline: HAZUS hurricane methodology



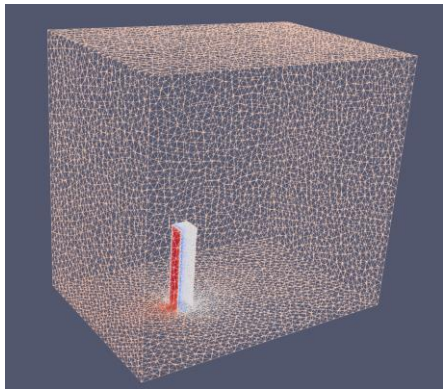
Improve fidelity



take advantage of response estimation

couple damage & loss models

baseline: HAZUS hurricane methodology



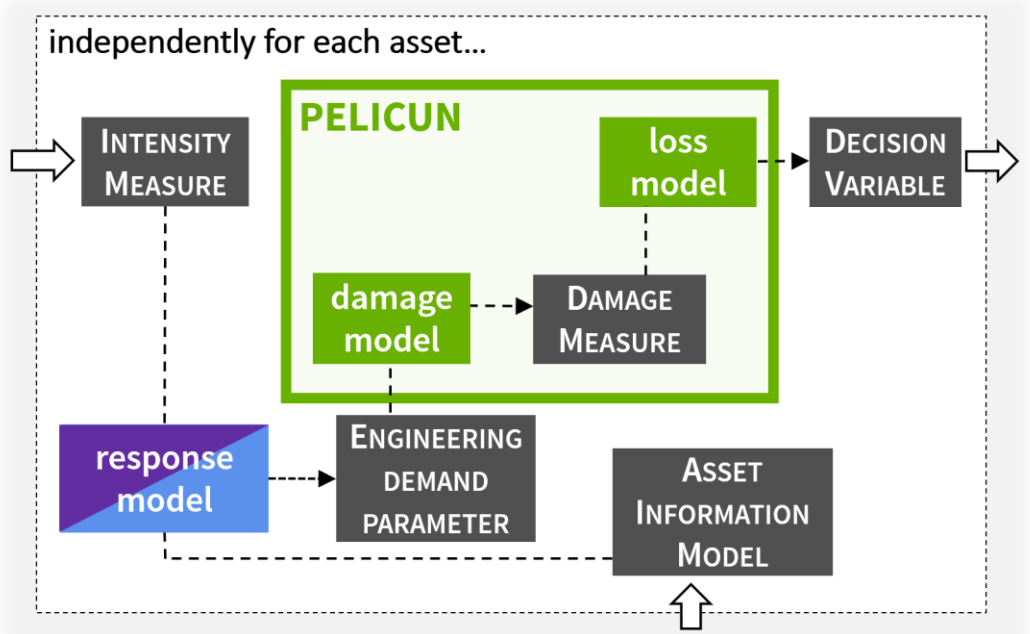
Improve fidelity

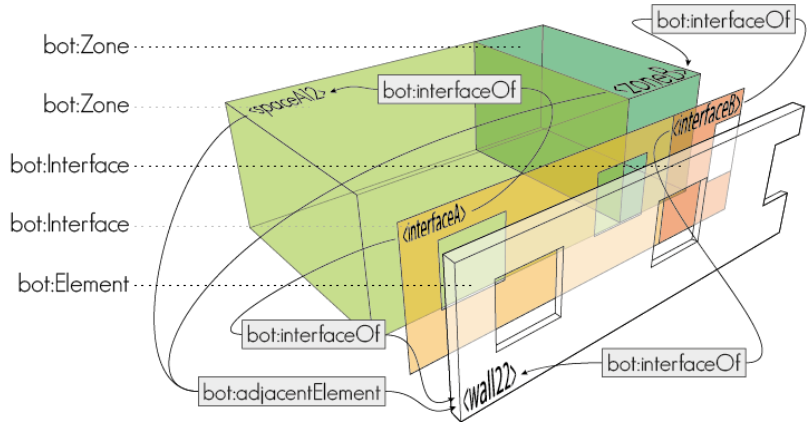
improve fragility & consequence functions

take advantage of response estimation

couple damage & loss models

baseline: HAZUS hurricane methodology



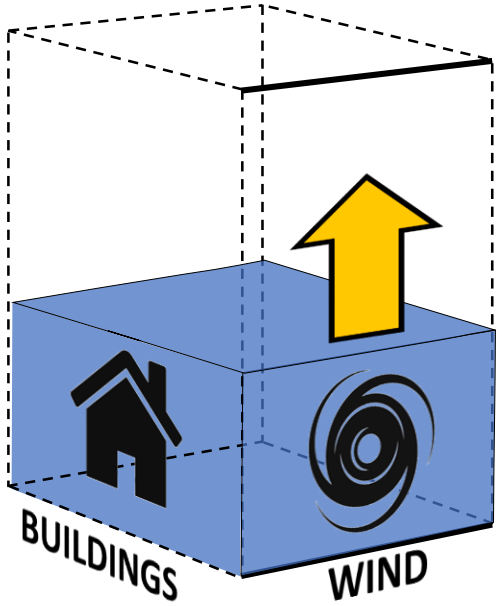


Opportunities in wind damage and loss assessment

Increase precision

Improve fidelity

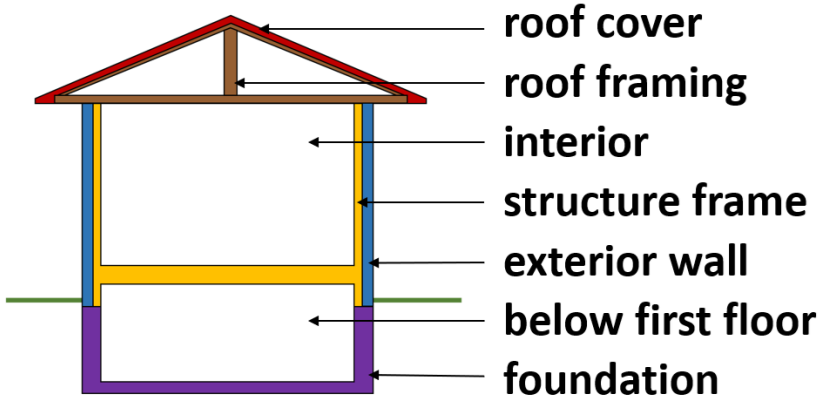
Improve combination with water hazards



Improve coupling with water hazards

baseline: HAZUS methodology for combining wind and storm surge losses

challenge: partial overlap in damage; how to avoid double counting?

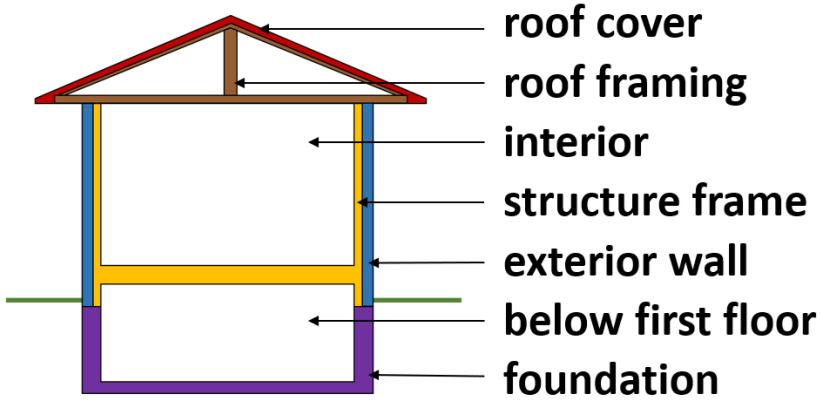


Improve coupling with water hazards

baseline: HAZUS methodology for combining wind and storm surge losses

challenge: partial overlap in damage; how to avoid double counting?

solution: building-configuration specific combination of losses



Flood-Only Building Loss	Wind-Only Building Loss										
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
0%	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
10%	10%	19.5%	28.7%	37.9%	47.1%	56.2%	65.3%	74.5%	84.4%	94.3%	100%
20%	20%	29.1%	37.5%	45.9%	54.3%	62.5%	70.9%	79.4%	89.1%	98.9%	100%
30%	30%	38.8%	46.7%	54.5%	62.3%	70.0%	77.8%	85.7%	95.0%	100.0%	100%
40%	40%	48.4%	55.7%	62.8%	69.9%	76.9%	84.0%	91.2%	100.0%	100.0%	100%
50%	50%	58.0%	64.6%	71.1%	77.5%	83.8%	90.3%	96.9%	100.0%	100.0%	100%
60%	60%	67.6%	73.5%	79.3%	85.0%	90.6%	96.4%	100.0%	100.0%	100.0%	100%
70%	70%	77.2%	82.4%	87.5%	92.5%	97.3%	100.0%	100.0%	100.0%	100.0%	100%
80%	80%	86.8%	91.4%	95.7%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100%
90%	90%	96.4%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100%
100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Figure 13.32. Combined Wind and Flood Loss Matrix Assuming Wind and Flood Losses are each Uniformly Distributed within each of Five Building Sub-Assemblies

source: HAZUS MH 2.1 Hurricane Technical Manual

Improve coupling with water hazards

baseline: HAZUS methodology for combining wind and storm surge losses

challenge: partial overlap in damage; how to avoid double counting?

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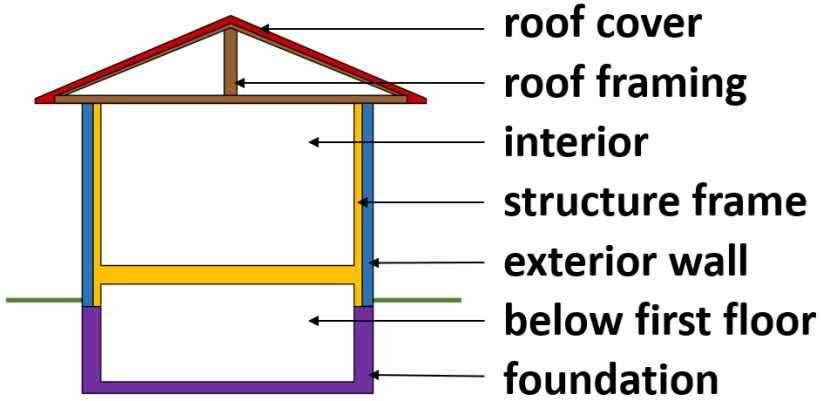


Flood-Only Building Loss	Wind-Only Building Loss										
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
0%	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
10%	10%	19.5%	28.7%	37.9%	47.1%	56.2%	65.3%	74.5%	84.4%	94.3%	100%
20%	20%	29.1%	37.5%	45.9%	54.3%	62.5%	70.9%	79.4%	89.1%	98.9%	100%
30%	30%	38.8%	46.7%	54.5%	62.3%	70.0%	77.8%	85.7%	95.0%	100.0%	100%
40%	40%	48.4%	55.7%	62.8%	69.9%	76.9%	84.0%	91.2%	100.0%	100.0%	100%
50%	50%	58.0%	64.6%	71.1%	77.5%	83.8%	90.3%	96.9%	100.0%	100.0%	100%
60%	60%	67.6%	73.5%	79.3%	85.0%	90.6%	96.4%	100.0%	100.0%	100.0%	100%
70%	70%	77.2%	82.4%	87.5%	92.5%	97.3%	100.0%	100.0%	100.0%	100.0%	100%
80%	80%	86.8%	91.4%	95.7%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100%
90%	90%	96.4%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100%
100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Figure 13.32. Combined Wind and Flood Loss Matrix Assuming Wind and Flood Losses are each Uniformly Distributed within each of Five Building Sub-Assemblies

source: HAZUS MH 2.1 Hurricane Technical Manual

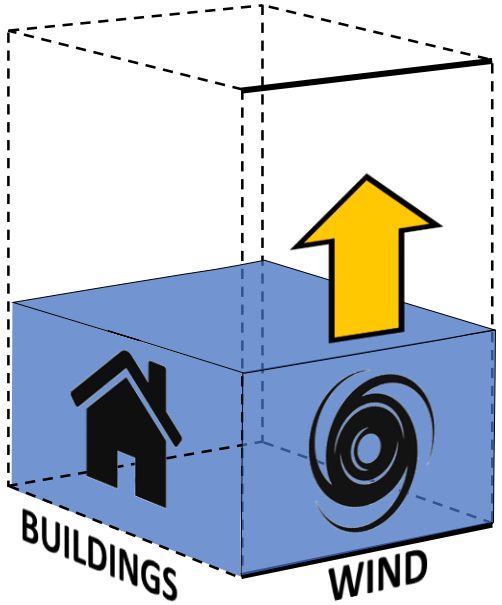
Working at the subassembly level or below will enable direct coupling between hazards and modeling cascading damages

Opportunities in wind damage and loss assessment

Increase precision

Improve fidelity

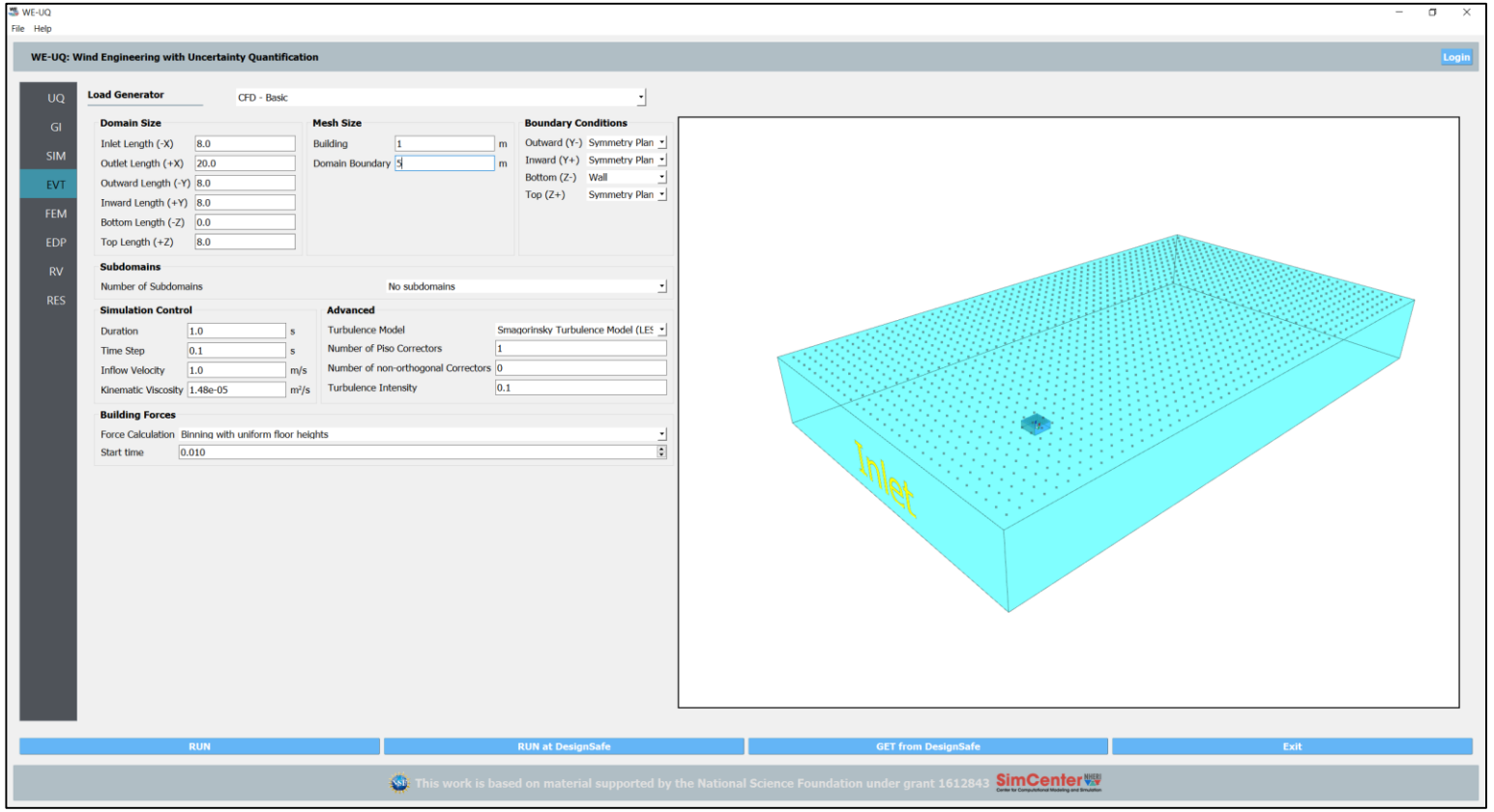
Improve combination with water hazards

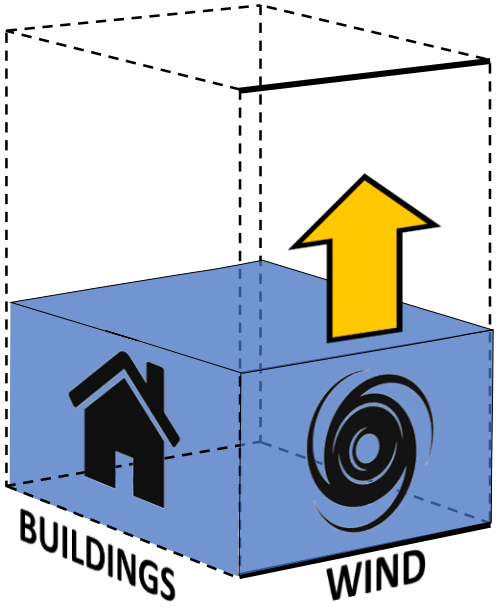


WE-UQ → PBE Application

By the end of 2020

our Performance Based Engineering Application will support Wind Events





Resources

source code: https://github.com/NHERI-SimCenter/pelicun

online documentation: https://nheri-simcenter.github.io/pelicun/

PBE tool training: https://youtu.be/00P5nmdo994

message board: https://simcenter-messageboard.designsafe-ci.org/smf/index.php

paper on PELICUN: 10.13140/RG.2.2.19716.48000

FIU | Wall of Wind
NHERI Experimental Facility

SimCenter NHERI
Center for Computational Modeling and Simulation

Thank you for your attention!

Adam Zsarnóczay, PhD
Stanford University

adamzs@stanford.edu

This workshop is coordinated by the Natural Hazards Engineering Research Infrastructure's (NHERI) Wall of Wind and the NHERI SimCenter and is supported by the National Science Foundation award CMMI 1520853 and 1612843. Any statements in this material are those of the presenter(s) and do not necessarily reflect the views of the National Science Foundation.

NSF