

# Multi-Hazard Sustainability: From Seismic to Sea-Level Rise Uncertainties

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OPUS

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MARQUETTE UNIVERSITY

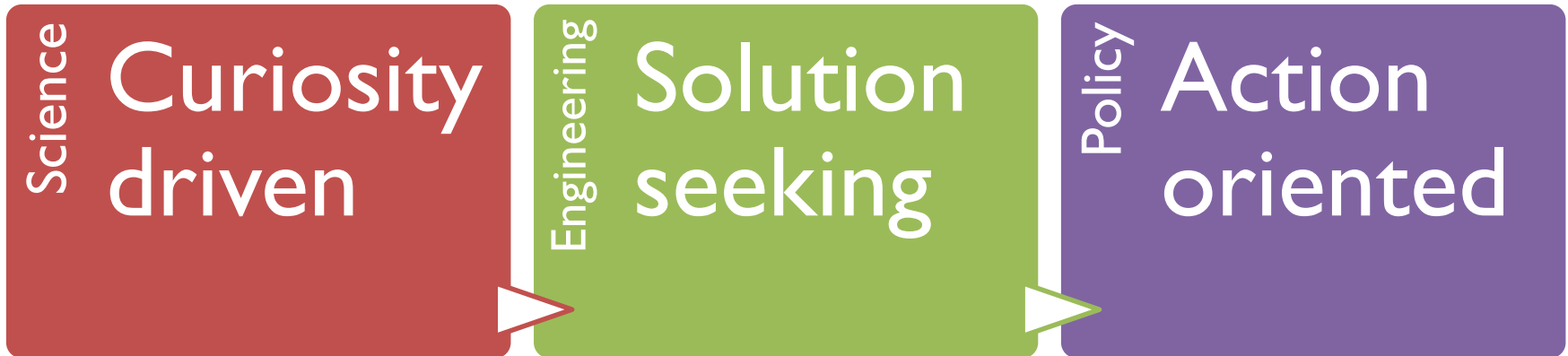
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# Systems Subjected to Multiple Hazards

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# Hazard-Consistent Ground Motion Selection Methodology



**USGS**  
science for a changing world

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EARTHQUAKES LANDSLIDES GEOMAGNETISM

FAQ Documentation 1996 Update 2002 Update Feedback

Site Name   
[Enter latitude/longitude instead](#)

Address

Exceedance Probability  in

Spectral Period

$V_{s30}$  (m/s)  [What values can I use at various locations?](#)

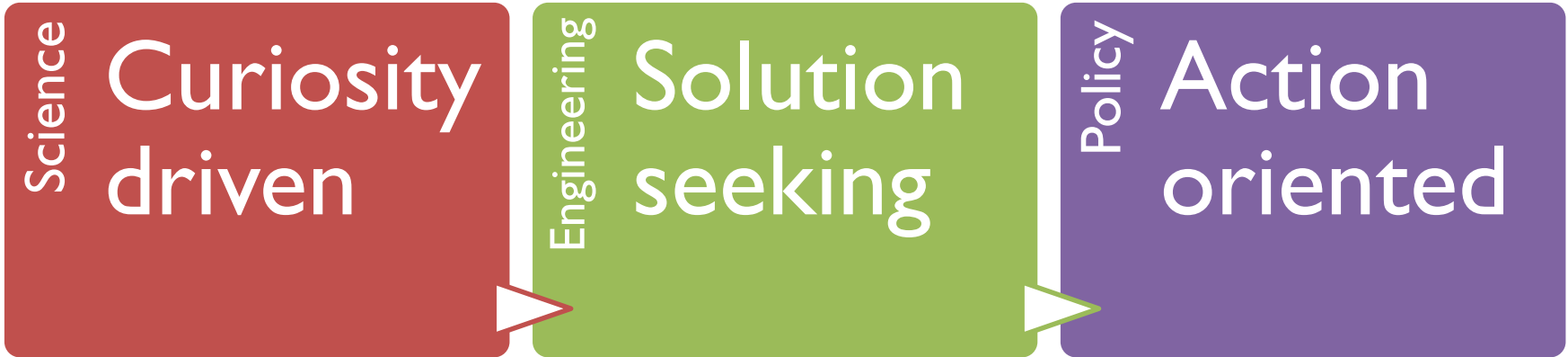
Run GMPE Deaggs?  Yes  No [What's this?](#)

Additional Output  Geographic Deagg [What's this?](#)  Conditional Mean Spectra  None

[\(Show Map\)](#)

Compute

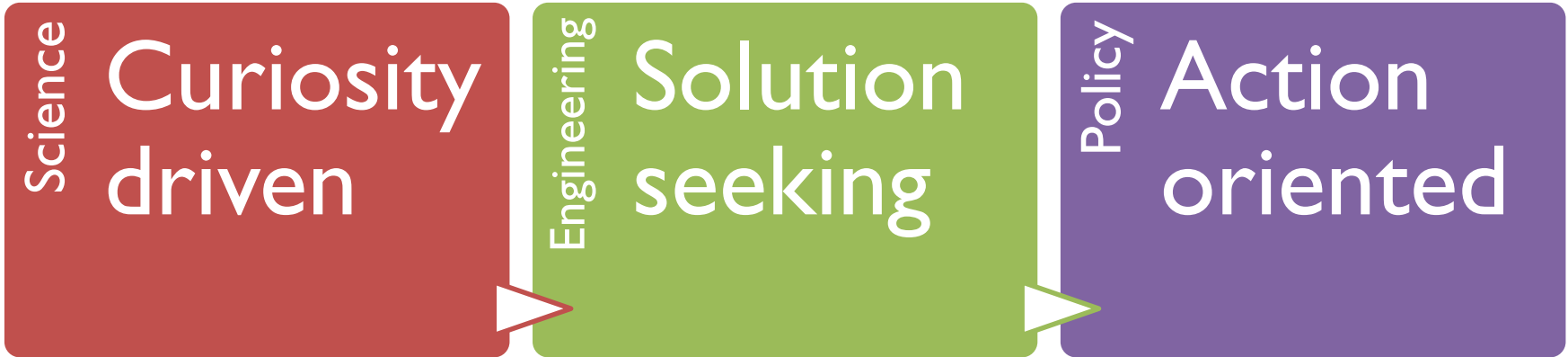
# Hazard-Consistent Ground Motion Selection Methodology



The screenshot shows the USGS Geologic Hazards Science Center website. At the top, it features the USGS logo and navigation tabs for 'EARTHQUAKES', 'LANDSLIDES', and 'GEOMAGNETISM'. Below this is a navigation bar with 'FAQ', 'Documentation', '1996 Update', and '2002 Update'. The main content area contains a form with the following fields: 'Site Name' (Palo Alto), 'Address' (Palo Alto, CA), 'Exceedance Probability' (2% in 50 years), 'Spectral Period' (1.0 second (1Hz)), and 'Vs30 (m/s)' (760.0). A red box highlights the 'Run GMPE Deaggs?' checkbox, which is checked 'Yes'. There is also an 'Additional Output' section with a radio button for 'Geographic Deagg'. A 'Compute' button is at the bottom.

The screenshot shows the EERI website. At the top, it features the EERI logo and the text 'Earthquake Engineering Research Institute' with the tagline 'Dedicated to reducing earthquake risk'. Below this is a paragraph of text: 'This manuscript describes an approach for selecting ground motions whose response spectra match a target response spectrum mean and variance. While the papers describe the method, complete documentation of the project is best achieved by providing the software used to perform the analysis. This website serves to provide that documentation, allowing others to reproduce the results published in the manuscript.' To the right of the text is a spectral acceleration plot. The plot has 'Spectral accel' on the y-axis (log scale from 10<sup>-2</sup> to 10<sup>0</sup>) and 'Period (s)' on the x-axis (log scale from 10<sup>-1</sup> to 10<sup>1</sup>). The plot shows several thin grey lines representing 'Response spectra of selected ground motions', a thick solid blue line for the 'Median response spectrum', and two dashed blue lines for the '2.5 and 97.5 percentile response spectra'. Below the plot is the 'GEM' logo (GLOBAL EARTHQUAKE MODEL) and a 'Software' section with a globe icon.

# Hazard-Consistent Ground Motion Selection Methodology



The screenshot shows the USGS Geologic Hazards Science Center website. It features a search form with the following fields and options:
 

- Site Name: Palo Alto
- Address: Palo Alto, CA
- Exceedance Probability: 2% in 50 years
- Spectral Period: 1.0 second (1Hz)
- V<sub>s30</sub> (m/s): 760.0
- Run GMPE Deaggs?  Yes  No
- Additional Output:  Geographic Deagg

 A 'Compute' button is at the bottom.

The screenshot shows the EERI website with a graph titled 'Spectral accel'. The x-axis is 'Period (s)' on a log scale from 10<sup>-1</sup> to 10<sup>1</sup>. The y-axis is 'Spectral accel' on a log scale from 10<sup>-2</sup> to 10<sup>0</sup>. The graph shows several curves: a solid blue line for 'Median response spectrum', a dashed blue line for '2.5 and 97.5 percentile response', and multiple thin grey lines for 'Response spectra of selected ground motions'. The PEER logo is visible on the left.

The screenshot shows the cover of the NIST GCR 11-917-15 report. The title is 'Selecting and Scaling Earthquake Ground Motions for Performing Response-History Analyses'. It includes a graph of 'Spectral Acceleration [g]' vs 'Period [s]' with four data series: 'Conditional mean spectrum' (solid black), 'Conditional mean +/- conditional sigma' (dashed black), 'Individual record spectra' (multiple thin green lines), and 'Uniform hazard spectrum' (dotted black).

The screenshot shows the GEM (Global Earthquake Model) software interface. It features two globes showing global seismicity and the text 'Software GEM GLOBAL EARTHQUAKE MODEL'.

The logos for NIST, nehrp (National Earthquake Hazard Reduction Program), ATC (Applied Technology Council), and CUREE (California Center for Earthquake Research and Information) are displayed.

# AIDA: PSHA-Consistent IDA

## Structural response assessment

Static	Dynamic
Linear	Linear
Nonlinear	Nonlinear
Pushover	<b>Incremental Dynamic Analysis (IDA)</b>

Vamvatsikos & Cornell, "IDA," *EESD* (2002)

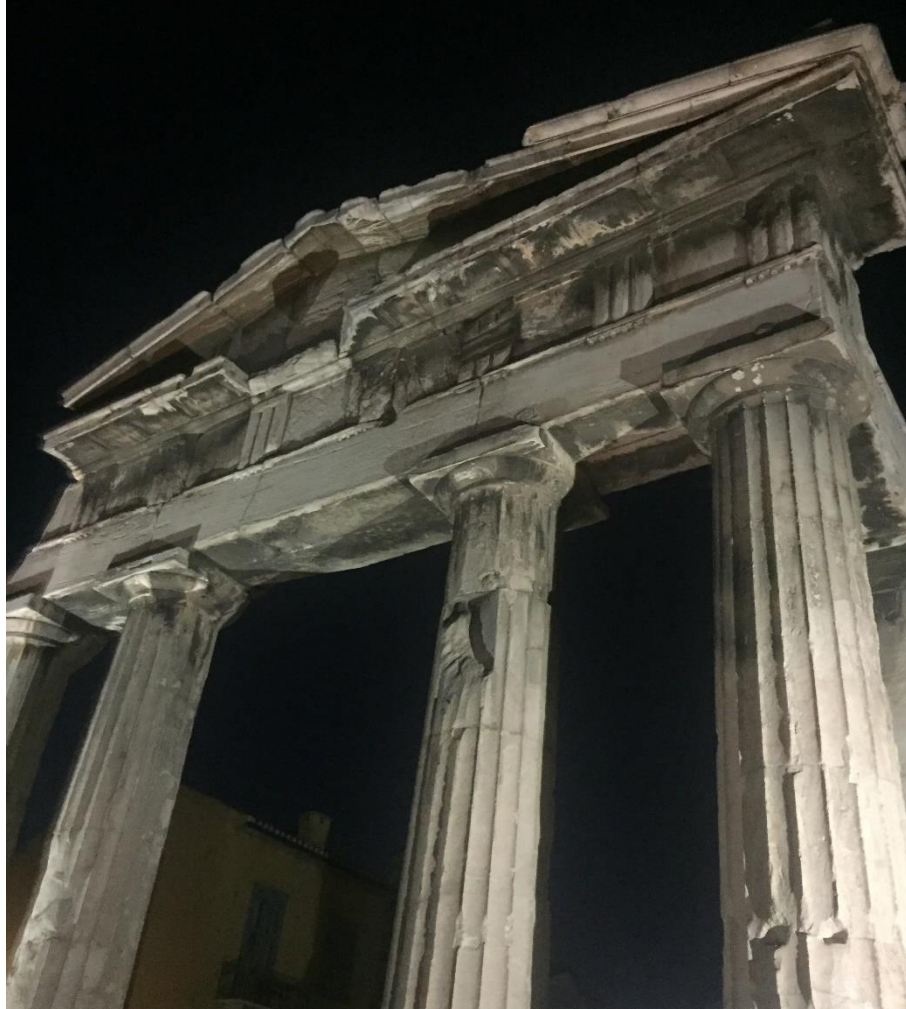
## Ground motion selection

Procedure	Method
Probabilistic Seismic Hazard Analysis (PSHA) and Deaggregation	<b>Multiple Stripe Analysis (MSA)</b>
Target response spectrum	<b>Conditional Spectrum (CS)</b>

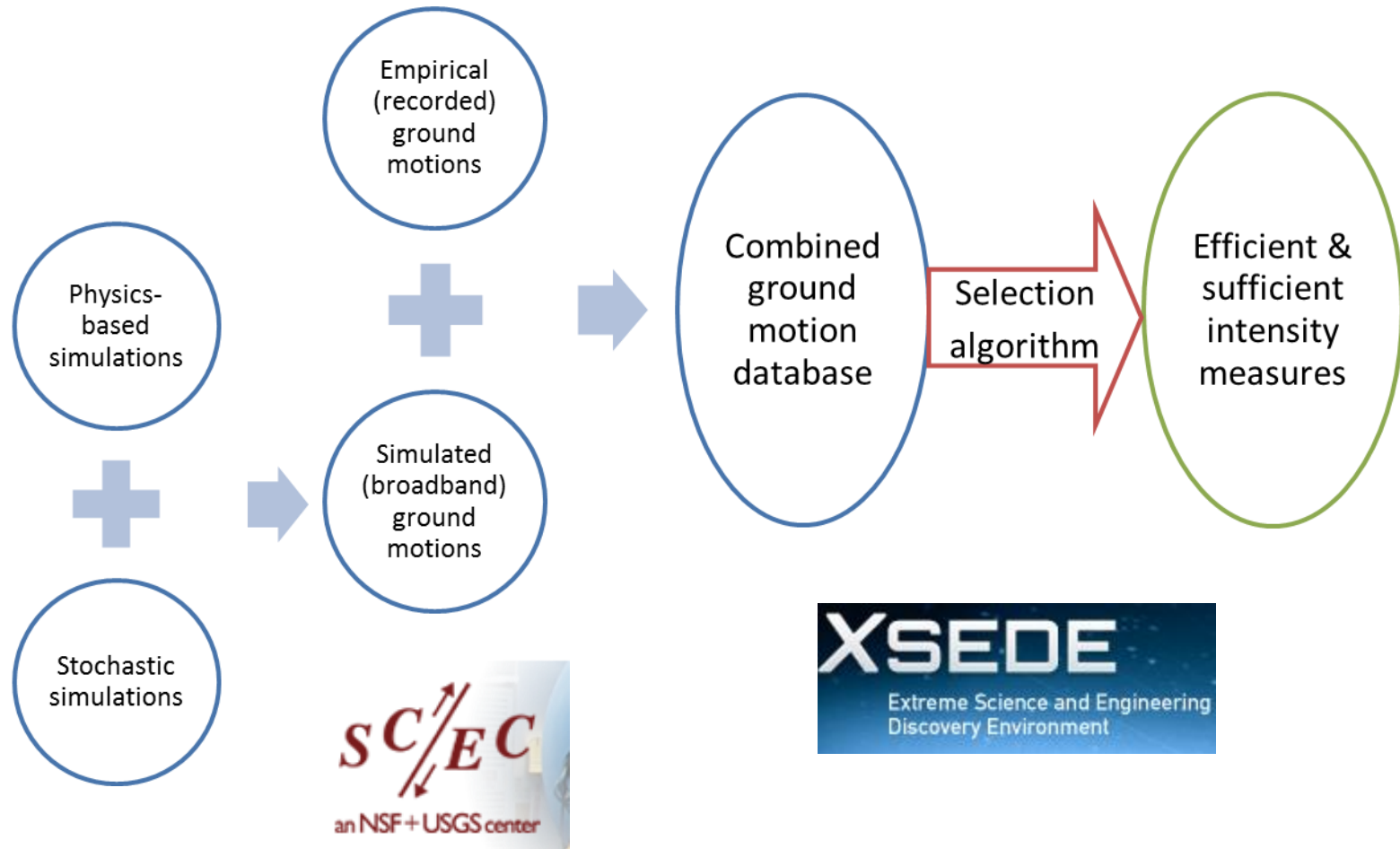


# History is history

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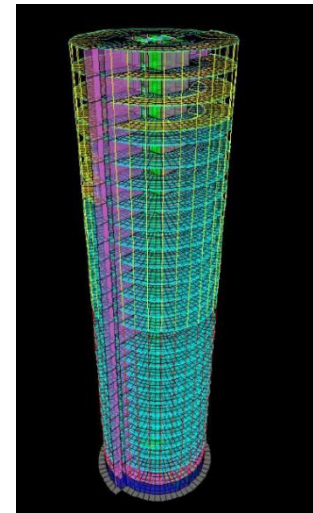
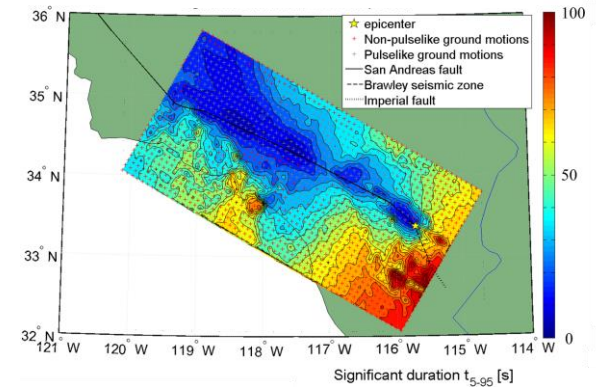
# The “future” of ground motion selection (Nov. 2012)





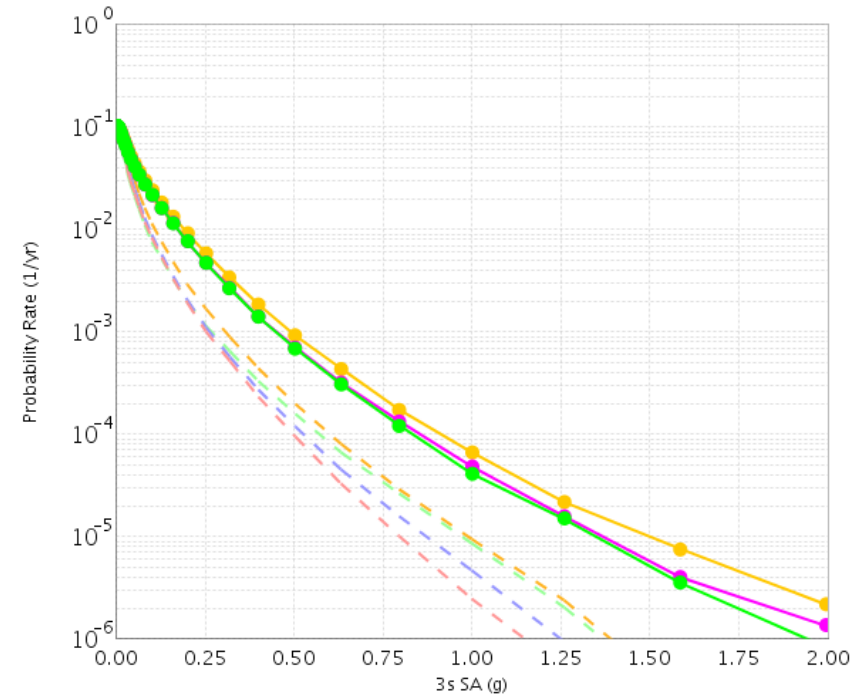
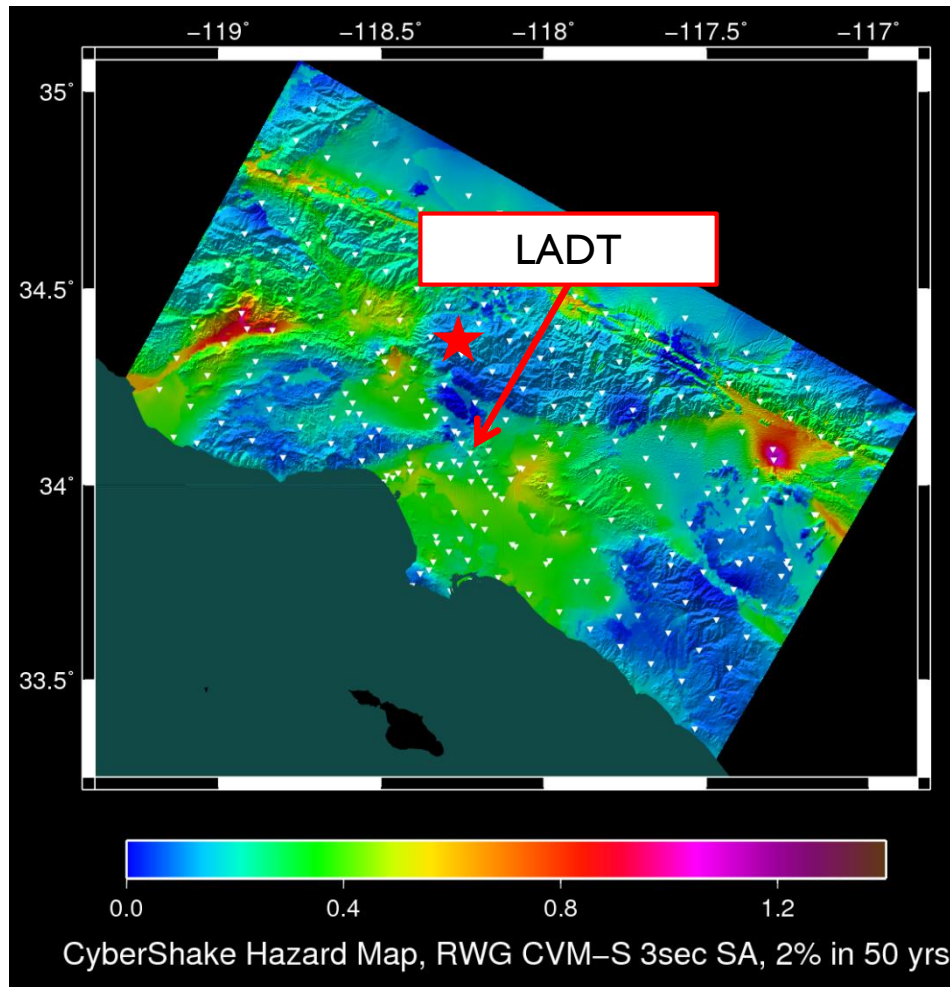
# Ground Motion Simulation Validation of Tall Buildings

- Examine ground motion properties
  - Consider (independently and jointly) spectral shape, duration and pulse-like characteristics
  - Select ground motions that satisfy a specified set of criteria or generate motions via direct simulations
- Develop archetype classes of tall buildings
  - Include different structural systems, height ranges and layouts
  - Capture important structural behavior such as structural collapse, cumulative damage and “in-cycle” strength and stiffness degradation
- Evaluate structural response subjected to simulated motions
  - Investigate important ground motion properties for nonlinear response history analyses
  - Provide recommendations on use of simulated motions



# Utilization of CyberShake hazard and ground motions

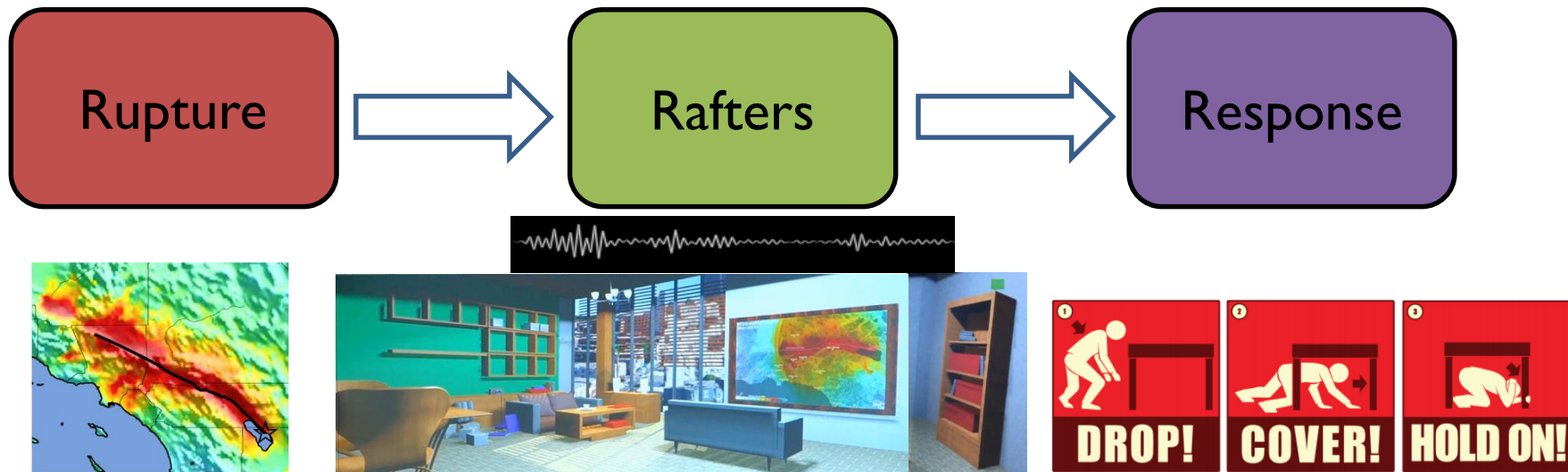
## SCEC CyberShake: Physics-based Probabilistic Seismic Hazard Analysis



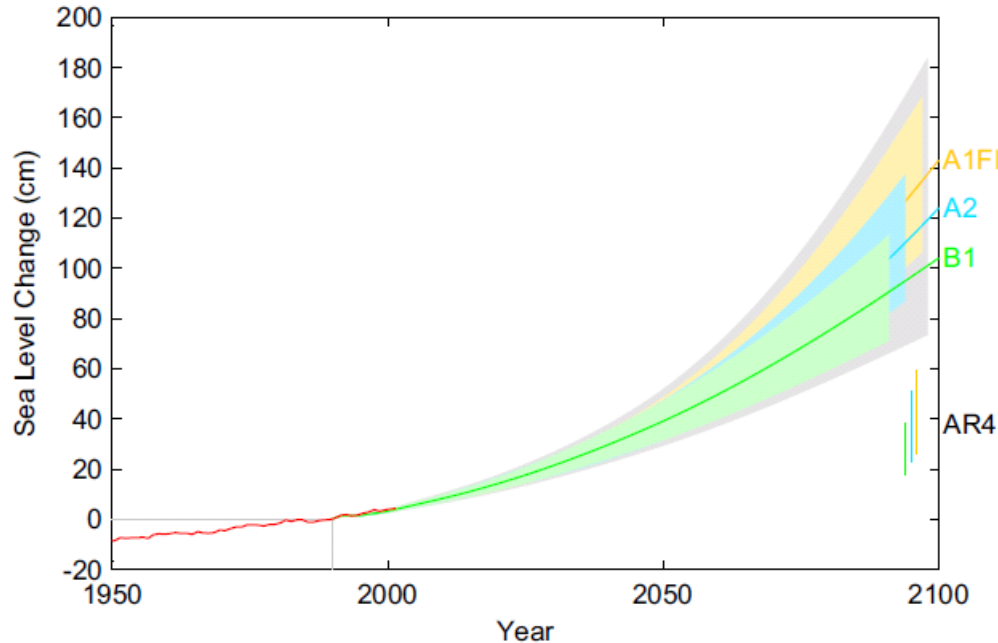
- 286 Sites (51 with broadband)
- Millions of ground motions
- Hazard curves and maps
- Deaggregation
- Ground motion selection
- Intensity- & risk-based assessments

# Visualizing Emergency Response Under Extreme Motions

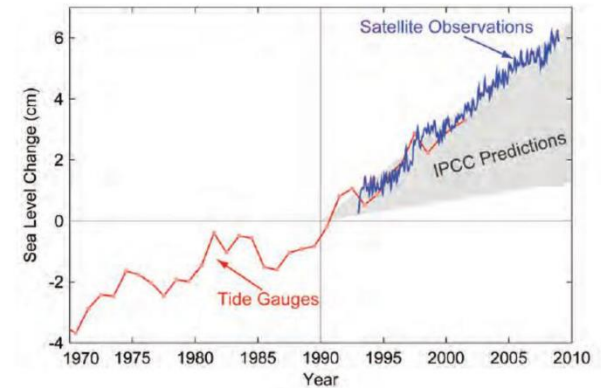
- Combining ShakeOut and Performance-Based Earthquake Engineering
- Site- and structure-specific scenarios for virtual rooms
- Component tagging based on fragility functions
- Audio feature varying with shaking intensity
- Emergency response practice via virtual reality



# Probabilistic Sea-Level Rise Hazard Analysis



Vermeer and Rahmstorf (2009)



Allison et al. (2009)

- Scenarios
- Models
- Observations

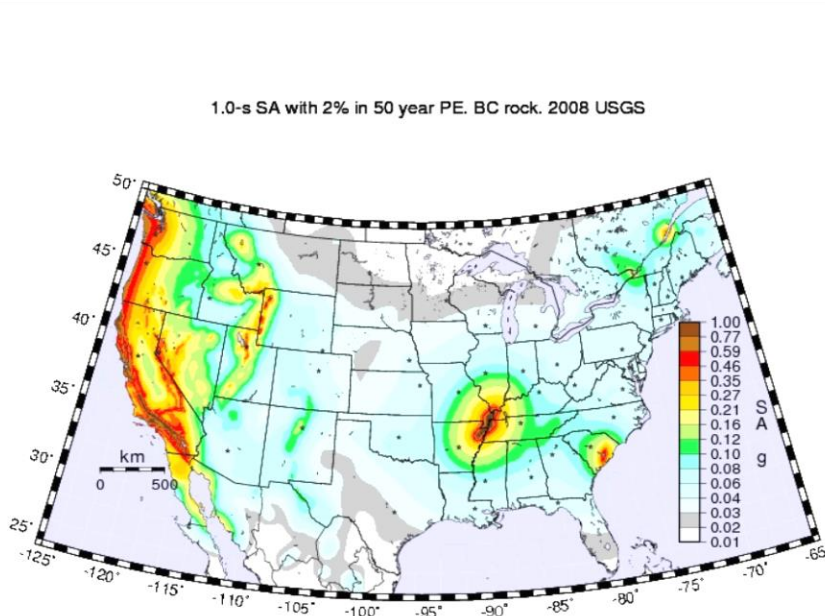
$$v(H > y) = \sum_k \sum_j v_j \iiint f_{\Theta_1, \Theta_2, \dots, \Theta_i}(\theta_1, \theta_2, \dots, \theta_i)$$

$$P(H > y | \theta_1, \theta_2, \dots, \theta_i, SLRPM_k) d\theta_1 d\theta_2 \dots d\theta_i P(SLRPM_k)$$

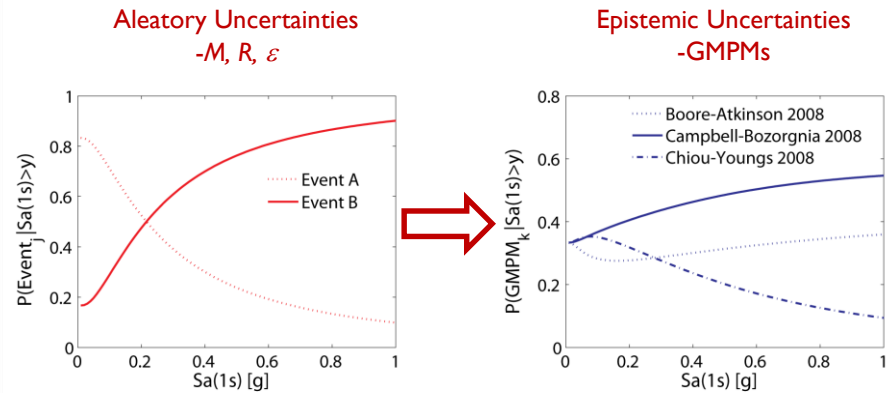
Lin (2012). "Probabilistic Sea-Level Rise Hazard Analysis,"  
*Sustainable Civil Infrastructures – Hazards, Risk, Uncertainty*, 593-598.

# Vision for Sea-Level Rise Applications

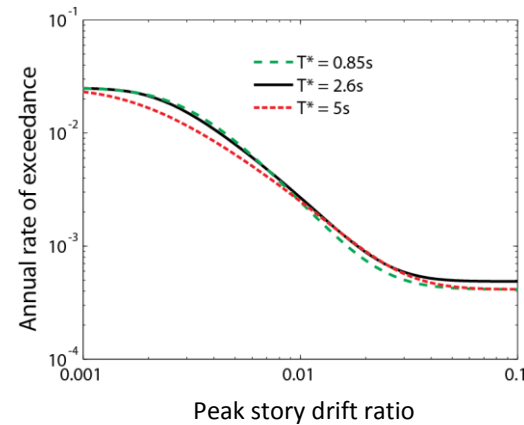
## Hazard map



## Deaggregation

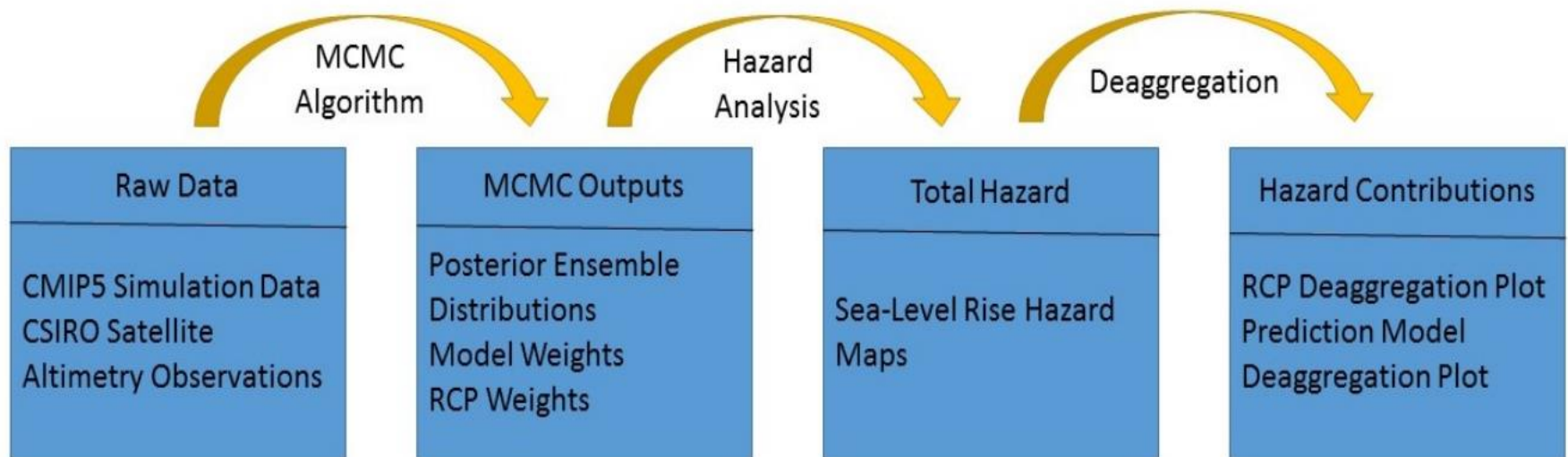


## Performance-based engineering



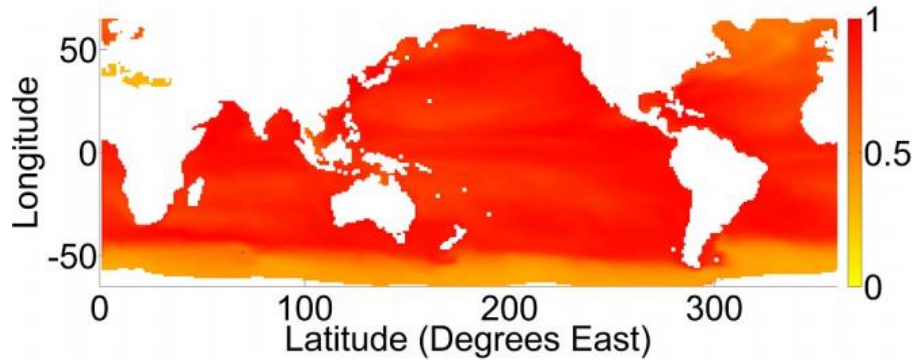
# Sea-Level Rise Hazard Analysis

- **Scenarios**: Representative Concentration Pathways
- **Models**: Process-based models with high-resolution ocean components
- **Observations**: Satellite altimetry datasets

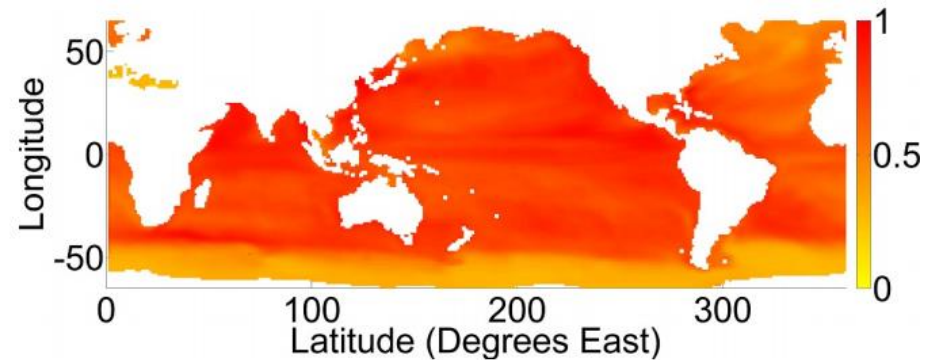


- Model and scenario ensemble data can be aggregated to create probabilistic hazard projections
- These projections can then be deaggregated to help us understand the modeling process better

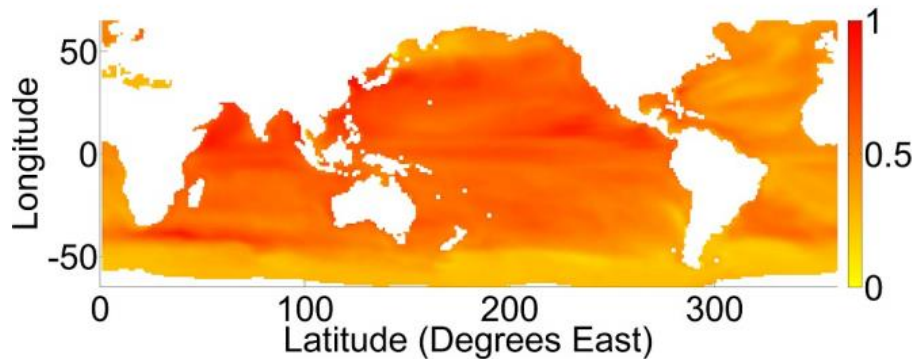
# Sea-Level Rise Hazard Maps



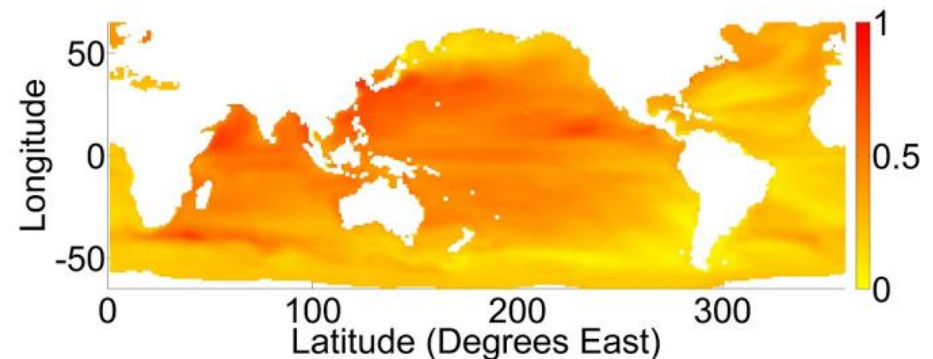
(a)



(b)



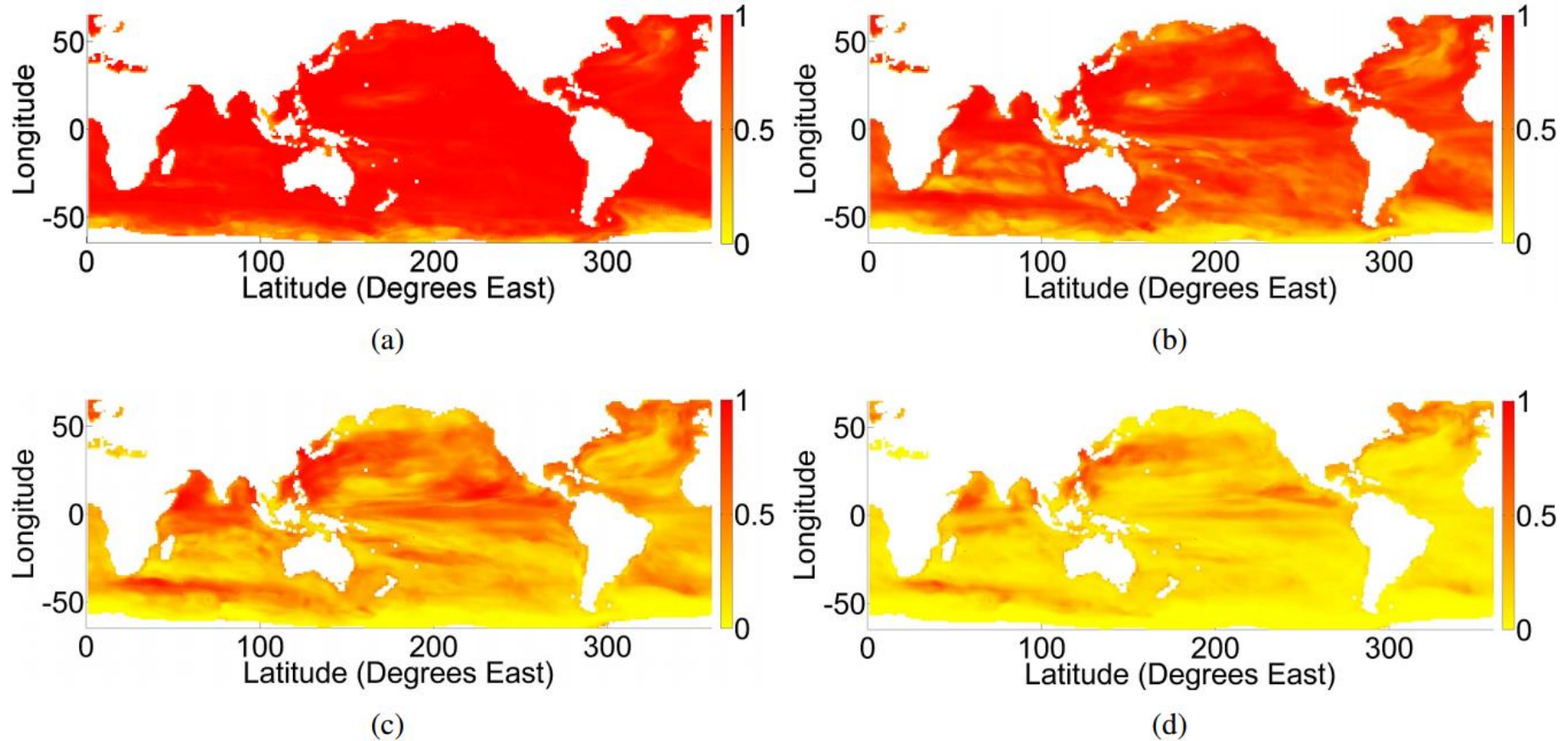
(c)



(d)

Probabilities of exceeding (a) 0.08 m, (b) 0.16 m, (c) 0.24 m, and (d) 0.32 m of thermosteric sea-level rise between 2006 to 2013 and 2093 to 2100 under equal weighting of models and scenarios

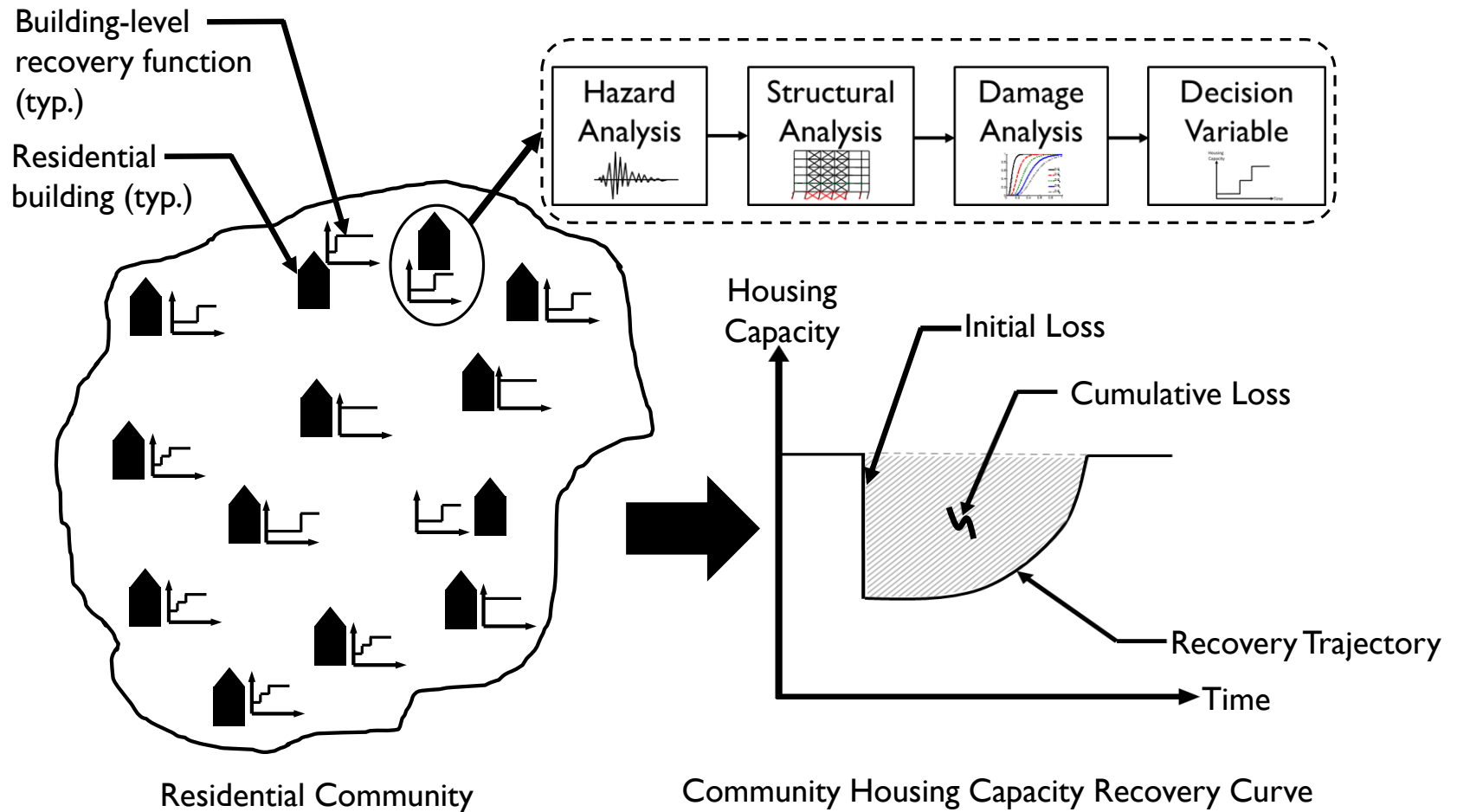
# Sea-Level Rise Hazard Maps



Probabilities of exceeding (a) 0.08 m, (b) 0.16 m, (c) 0.24 m, and (d) 0.32 m of thermosteric sea-level rise between 2006 to 2013 and 2093 to 2100 weighting models and RCPs with the MCMC algorithm



# Performance-based resilience assessment framework



# “Maybe.” What is the probability?

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