Seismic Risk Maps for Non-Ductile Concrete Buildings

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Golden, Colorado

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2: Research Structural Engineer
3: Postdoctoral Researcher

Outline of Presentation

- Motivation for Risk Maps
  - Pertaining to Non-Ductile Concrete
- Background on Risk
  - Components
  - Computation
- Discussion of Risk Maps
  - Original version vs. updated version
  - Methodology
  - Difference Maps
- Case Studies

Motivation of Risk Maps

Outline
Motivation
Risk
Risk Maps
Case Studies
Closing

- 1971 San Fernando Earthquake
  - Magnitude 6.6
  - Intensity XI
  - Property Damage: over $500,000k
  - Casualties: 65 deaths
- Majority of the damage and casualties were a direct result of the collapse of older concrete buildings
- These older concrete buildings were observed to behave in a non-ductile manner under seismic loading
- Initiated implementation of building code revisions in the mid-1970s to increase ductile behavior during cyclic loading and prevent catastrophic failure
  - However, there are still a great number of buildings built prior to building code revisions that pose a high risk of collapse in their lifetime

Motivation of Risk Maps

Top: Stair tower collapse at west end of Wing B in Olive View Hospital

Bottom Left: Partial collapse of first floor of Olive View Medical treatment and care unit

Bottom Right: Collapsed overpass at the Route 14-Route 5 interchange

Motivation of Risk Maps

- To prevent such catastrophic failures, concrete buildings built prior to the building code revision in 1976 are in need of seismic retrofit
- Current estimates approximate 40,000 non-ductile concrete buildings in the western US (Emmett Seymour, PEER intern)
- Given the enormous quantity of these buildings, a systematic method to identify the highest risk buildings is desired

Motivation of Risk Maps

Outline

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Closing

- Seismic Risk Maps address these issues by:
  - Identifying the most seismically problematic areas
  - Pinpointing the specific buildings in greatest need of retrofit
  - Prioritizing and quantifying retrofit

Components of Risk

- Hazard
- Exposure to Hazard
- Fragility/Vulnerability
- Resilience

Hazard

- Mean annual frequency of ground motion (spectral acceleration at a particular period of oscillation) exceeding some value at a particular location

Site Class Affect on Hazard

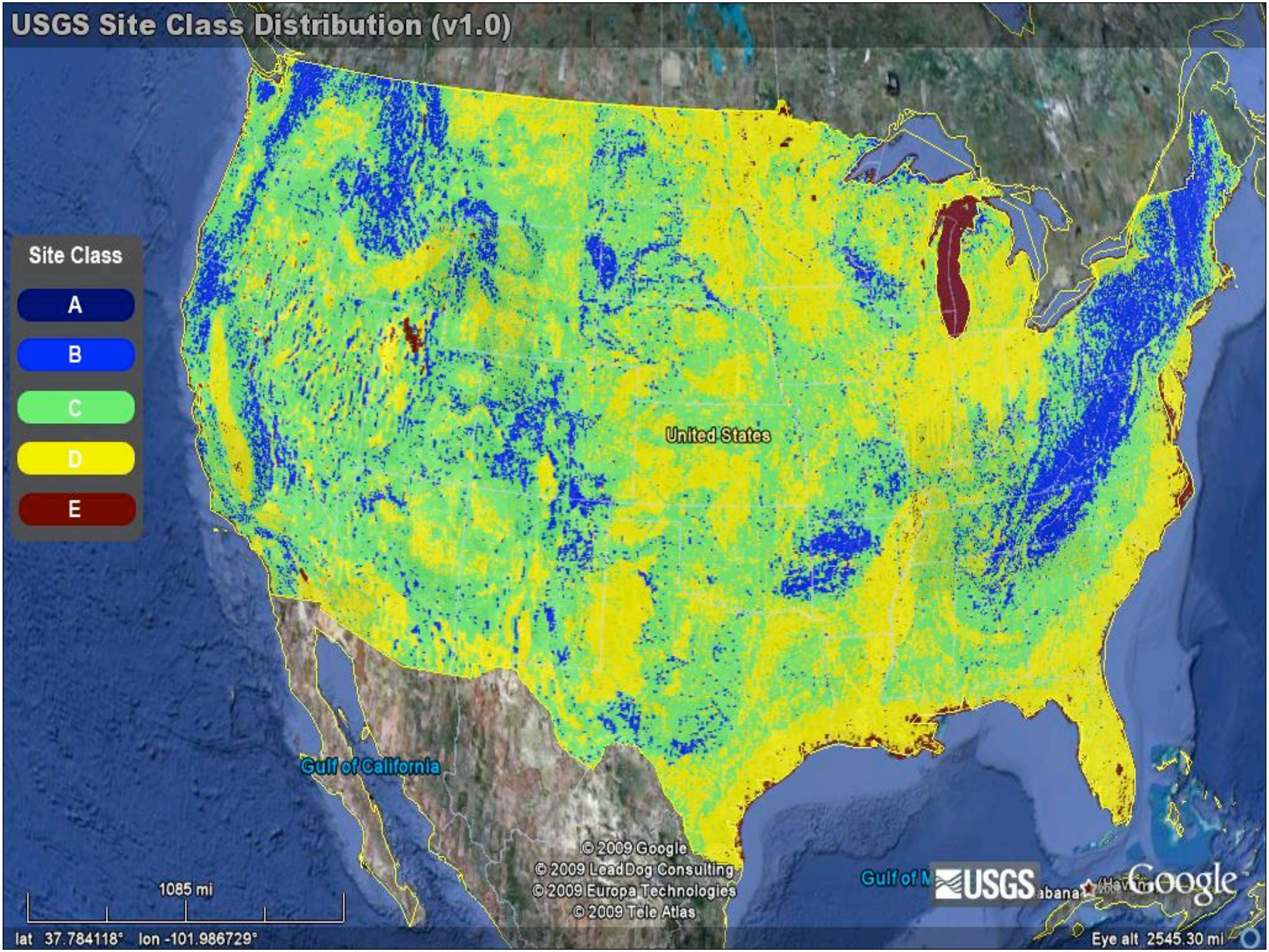
NEHRP Site Class Definitions

Site Class	Soil Profile Name	Soil shear wave velocity, V_S30 (m/s)
A	Hard rock	$V_S30 > 1500$
B	Rock	$1500 \geq V_S30 \geq 760$
C	Very dense soil and soft rock	$760 > V_S30 > 360$
D	Stiff soil profile	$360 \geq V_S30 > 180$
E	Soft soil profile	$V_S30 \geq 180$

- USGS Hazard data is specific to Site Class B/C Boundary
- Site Coefficients exist to scale the ground motion data for different site classes
  - Depends on: Spectral Acceleration and Period of Oscillation (or PGA)

Site Class Affect on Hazard

- My Hazard Tasks:
  - Adjust for the other 4 site classes as if each particular site class covers the continental US (“Site General”)
  - Using V_S30 values based on topography (Wald & Allen, 2007), assign each site class to its proper location (“Site Specific”)
  - Create a site specific hazard file


USGS Site Class Distribution (v1.0)
Site Class
A
B
C
D
E
United States
Gulf of California
© 2009 Google
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© 2009 Europa Technologies
© 2009 Tele Atlas
1085 mi
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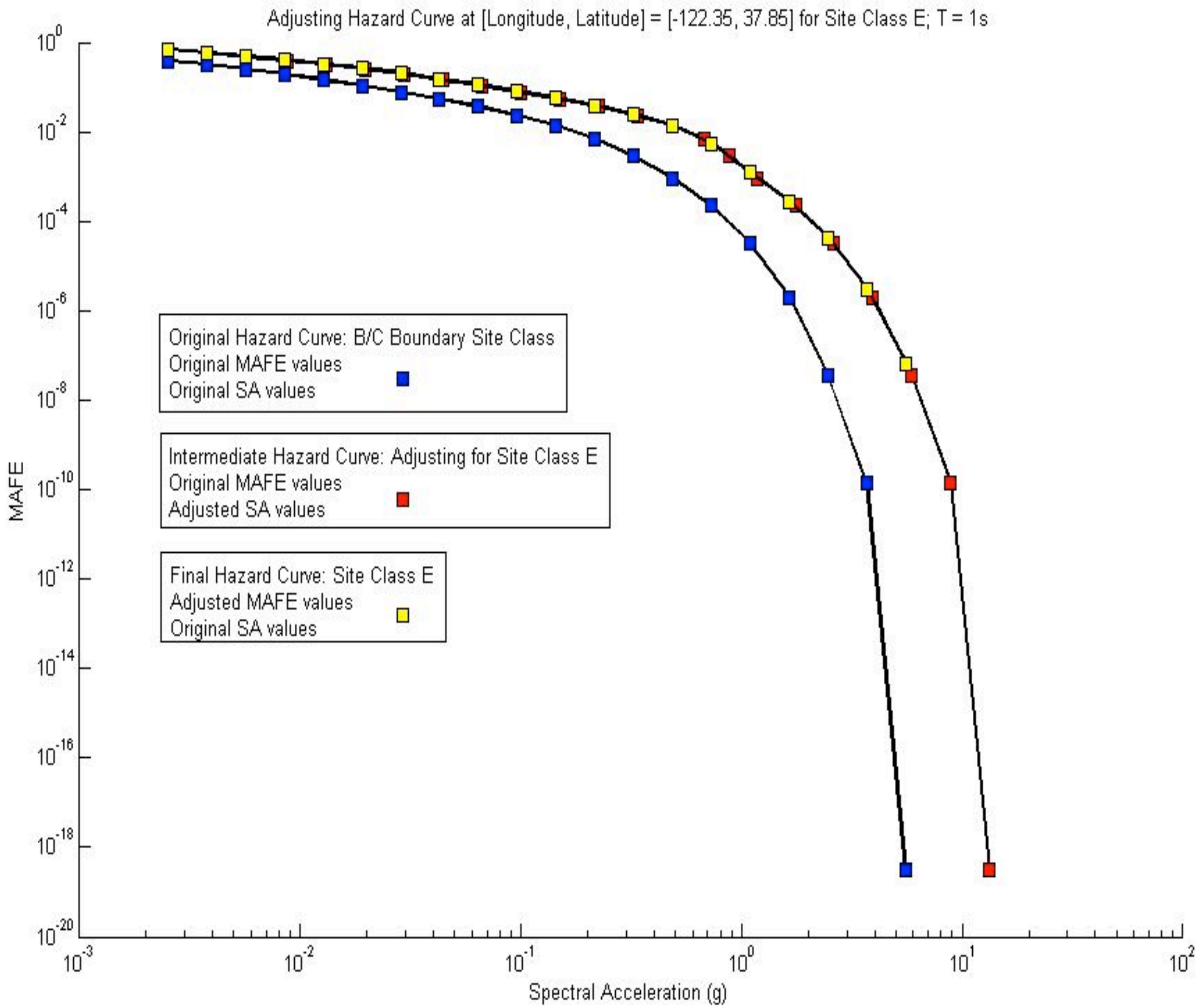
Eye alt 2545.30 mi
USGS
Google

Adjustment for Site Class



Exposure to Hazard: HAZUS

HAZUS Structural Types and Heights

Label	Description	Height Name	# Stories
C1L	Concrete Moment Frame	Low-Rise	1 - 3
C1M		Mid-Rise	4 - 7
C1H		High-Rise	8+
C2L	Concrete Shear Walls	Low-Rise	1 - 3
C2M		Mid-Rise	4 - 7
C2H		High-Rise	8+
C3L	Concrete Frame with Unreinforced Masonry Infill Walls	Low-Rise	1 - 3
C3M		Mid-Rise	4 - 7
C3H		High-Rise	8+

HAZUS Levels of Seismic Design

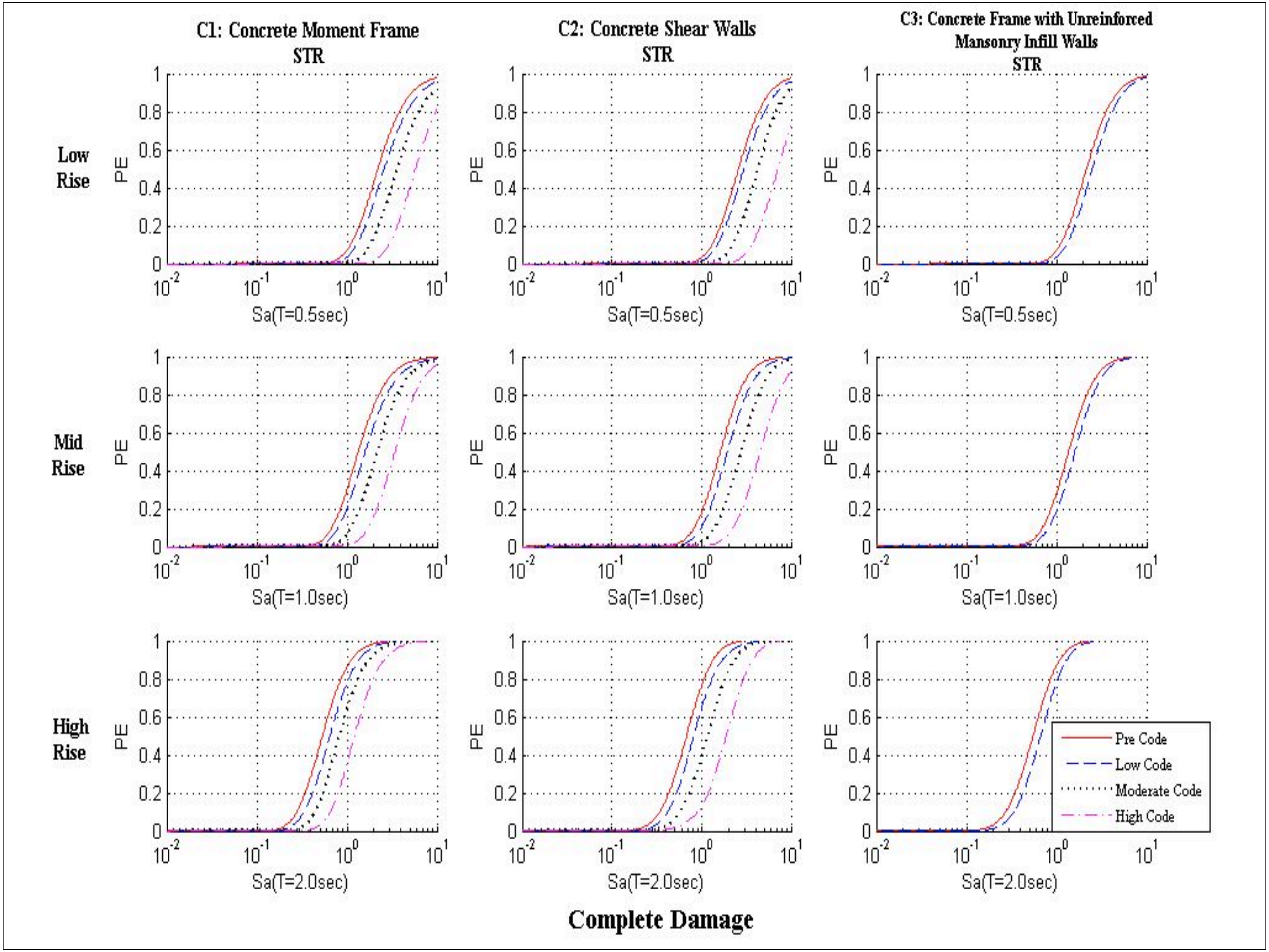
Seismic Level of Design	Description	Affect on HAZUS Concrete Structures
Pre-Code	Minimal Strength Minimal Ducility	Non-Ductile
Low-Code	Low Strength Low Ductility	Fairly Non-Ductile
Moderate-Code	Moderate Strength Moderate Ductility	Fairly Ductile
High-Code	High Strength High Ductility	Ductile

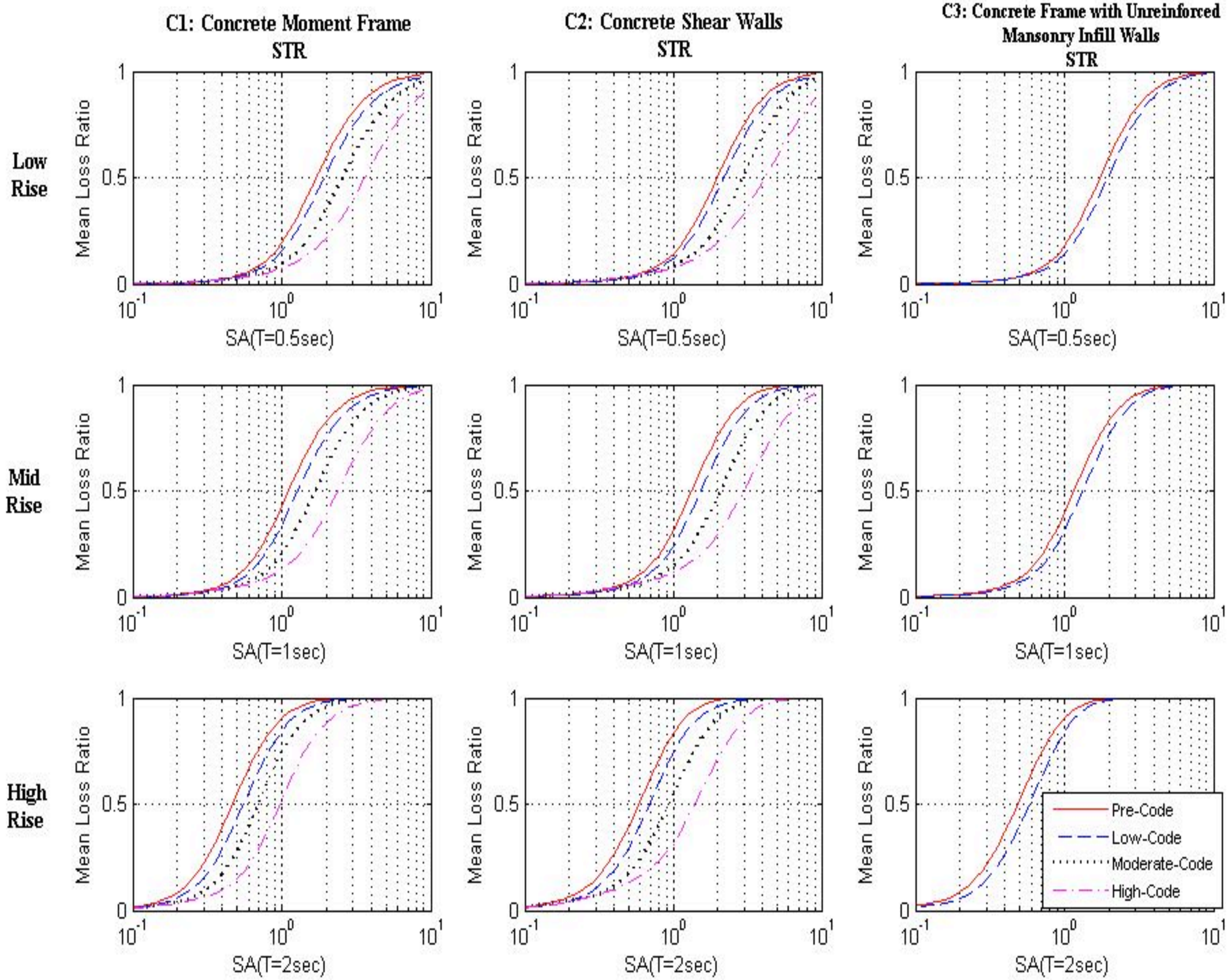
Fragility

HAZUS Damage States

Damage State	Description	Quantification
Slight	Flexural or Shear hairline cracks in some beams/columns near or within joints	~0%-5% of Replacement Cost
Moderate	Most beams/columns exhibit hairline cracks. Some larger cracks indicating yield capacity has been exceeded.	~5%-25% of Replacement Cost
Extensive	Some elements have large flexural cracks and spalling indicating ultimate strength has been reached. Some shear failures. Partial collapse may result.	~25%-100% of Replacement Cost
Complete	Structure is collapsed or in immenent danger of collapse due to brittle failure of non-ductile elements.	~100% of Replacement Cost

- Probability of exceeding a certain damage state given a certain ground motion (spectral acceleration at a particular period of oscillation) for a particular building


C1: Concrete Moment Frame
STR
C2: Concrete Shear Walls
STR
C3: Concrete Frame with Unreinforced
Mansonry Infill Walls
STR
Low
Rise
Mid
Rise
High
Rise
PE
Sa(T=0.5sec)
Sa(T=1.0sec)
Sa(T=2.0sec)
Pre Code
Low Code
Moderate Code
High Code
Complete Damage



Occpancy Class: COM4

Fragility & Hazard to Risk

- Risk Summation (risk of DS_i in 1 year)

$$\lambda[DS_i] = \sum_{0}^{\infty} P[DS_i | SA = a] |\Delta(\lambda[SA > a])|$$

- Assume Poisson Process to extend time interval
  - Approximation due to the associated assumptions
    - •Randomly occurring events
    - •Events are statistically independent
    - •Probability of events in small time intervals are proportional to the time interval
    - •Probability of more than one occurrence in a small time interval is negligible

Probability of Exceedance in t years:

$$PE \text{ in t years} = 1 - \exp(-\lambda[DS_i]t)$$

where: λ = mean annual frequency of exceedance

USGS science for a changing world

Vulnerability & Hazard to Risk

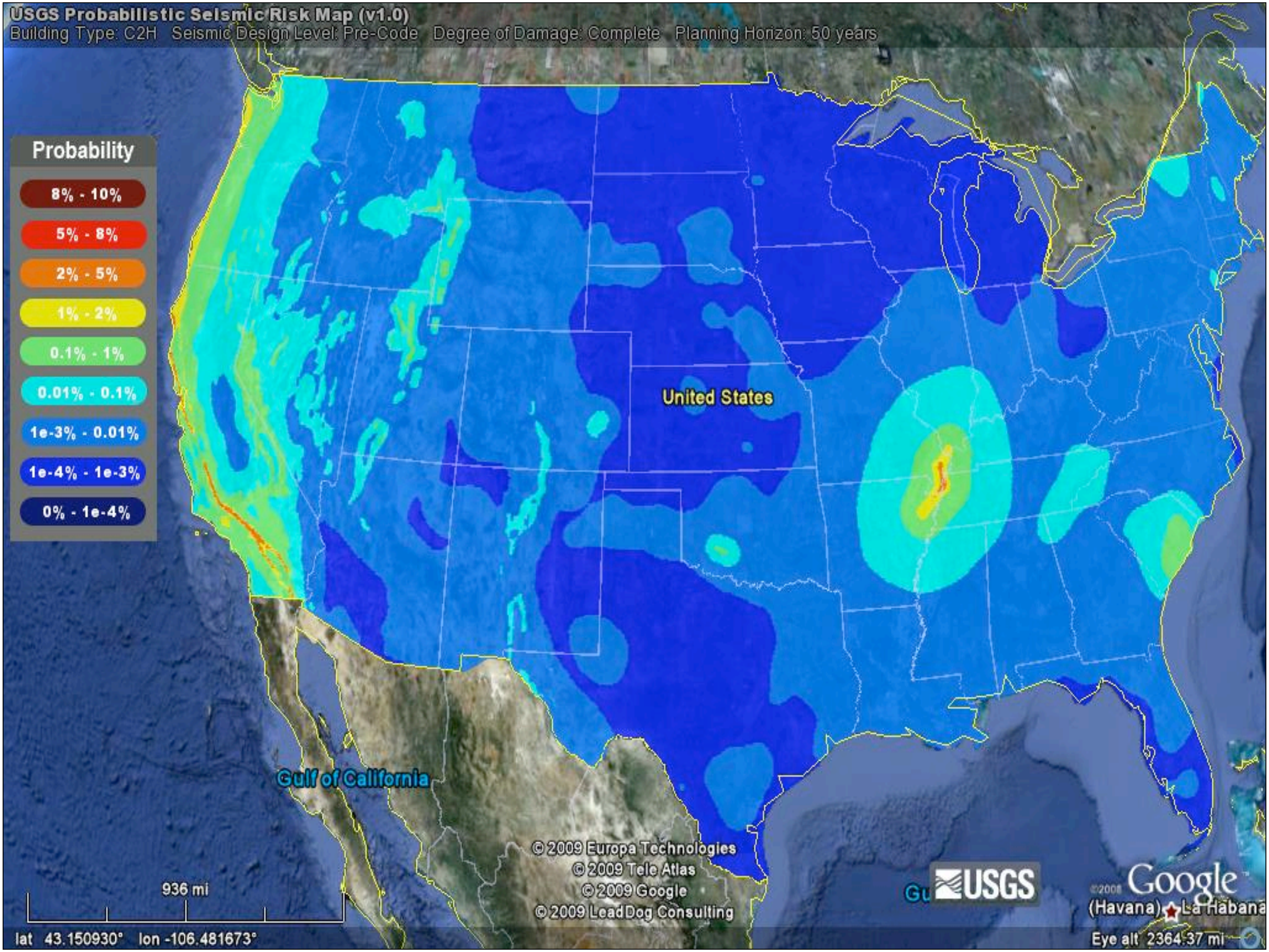
- Risk Summation (expected loss ratio in 1 year)

$$E[LR] = \sum_{0}^{\infty} E[LR|SA = a]|\Delta(\lambda[SA > a])|$$

- When E[LR] is multiplied by the value of a building, the expected annual loss, in monetary unit, of the building can be determined
  - Note: Expected values can be added across buildings

Seismic Risk Maps

- Contour/“Raster” Maps
- Several types to be discussed
  - General Risk Map
  - Inventory-Specific Risk Map
  - Loss Ratio Map
  - Difference Map


USGS Probabilistic Seismic Risk Map (v1.0)
Building Type: C2H   Seismic Design Level: Pre-Code   Degree of Damage: Complete   Planning Horizon: 50 years
Probability
8% - 10%
5% - 8%
2% - 5%
1% - 2%
0.1% - 1%
0.01% - 0.1%
1e-3% - 0.01%
1e-4% - 1e-3%
0% - 1e-4%
United States
Gulf of California
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936 mi
USGS
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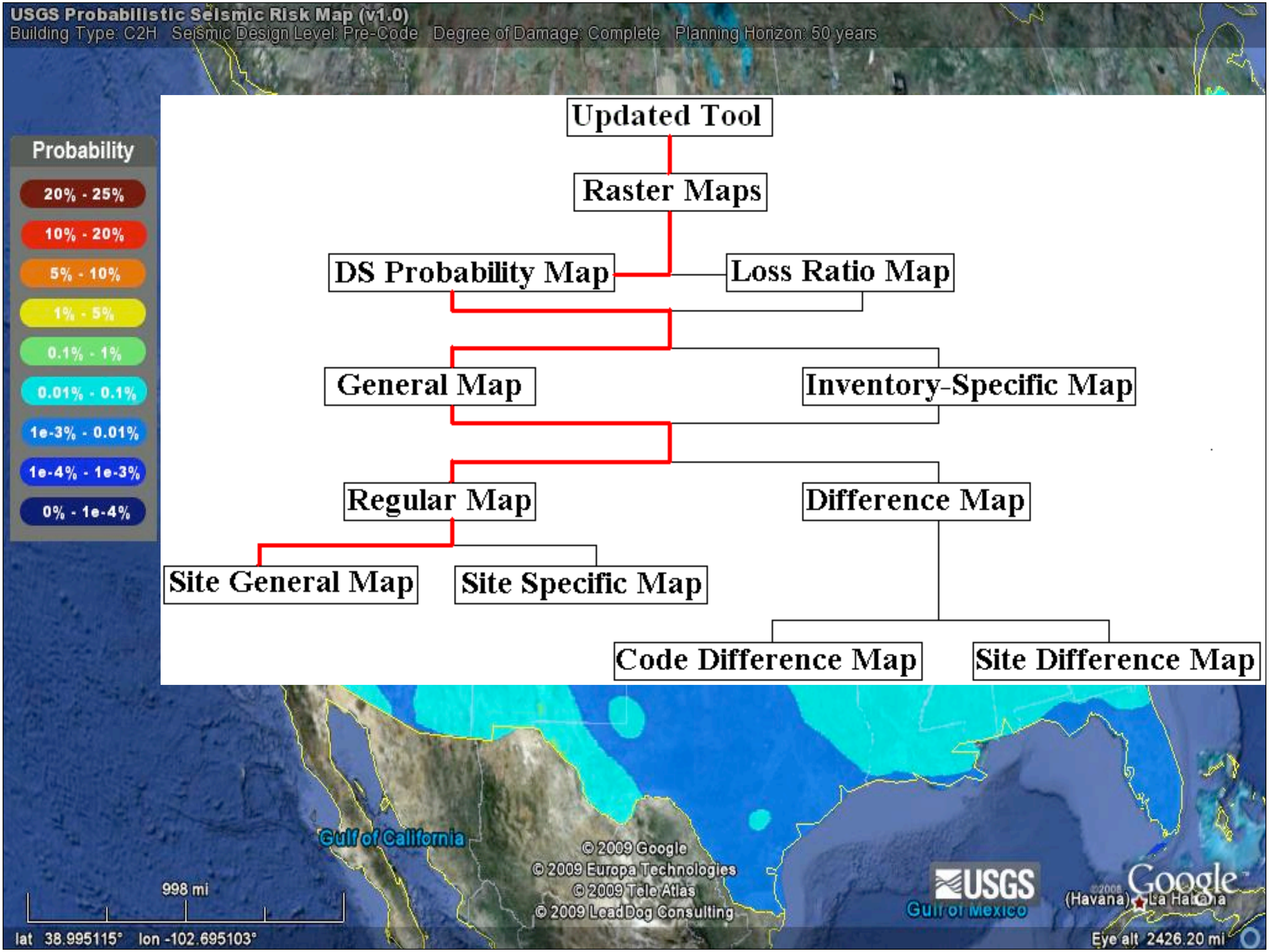
(Havana) La Habana
lat 43.150930° lon -106.481673°
Eye alt 2364.37 mi

Risk Maps – Updated Tool

- Updated Tool
  - “Raster” maps
  - Assume site class distribution based on VS30 values determined from topography (Wald and Allen 2007)
  - Inventory-specific risk maps
  - User-specified site class (Inventory maps only)
  - User-inputted fragility/vulnerability information
  - Difference maps – site distribution & code level
  - Loss Ratio maps


USGS Probabilistic Seismic Risk Map (v1.0)
Building Type: C2H Seismic Design Level: Pre-Code Degree of Damage: Complete Planning Horizon: 50 years
Probability
20% - 25%
10% - 20%
5% - 10%
1% - 5%
0.1% - 1%
0.01% - 0.1%
1e-3% - 0.01%
1e-4% - 1e-3%
0% - 1e-4%
Updated Tool
Raster Maps
DS Probability Map
Loss Ratio Map
General Map
Inventory-Specific Map
Regular Map
Difference Map
Site General Map
Site Specific Map
Code Difference Map
Site Difference Map
Gulf of California
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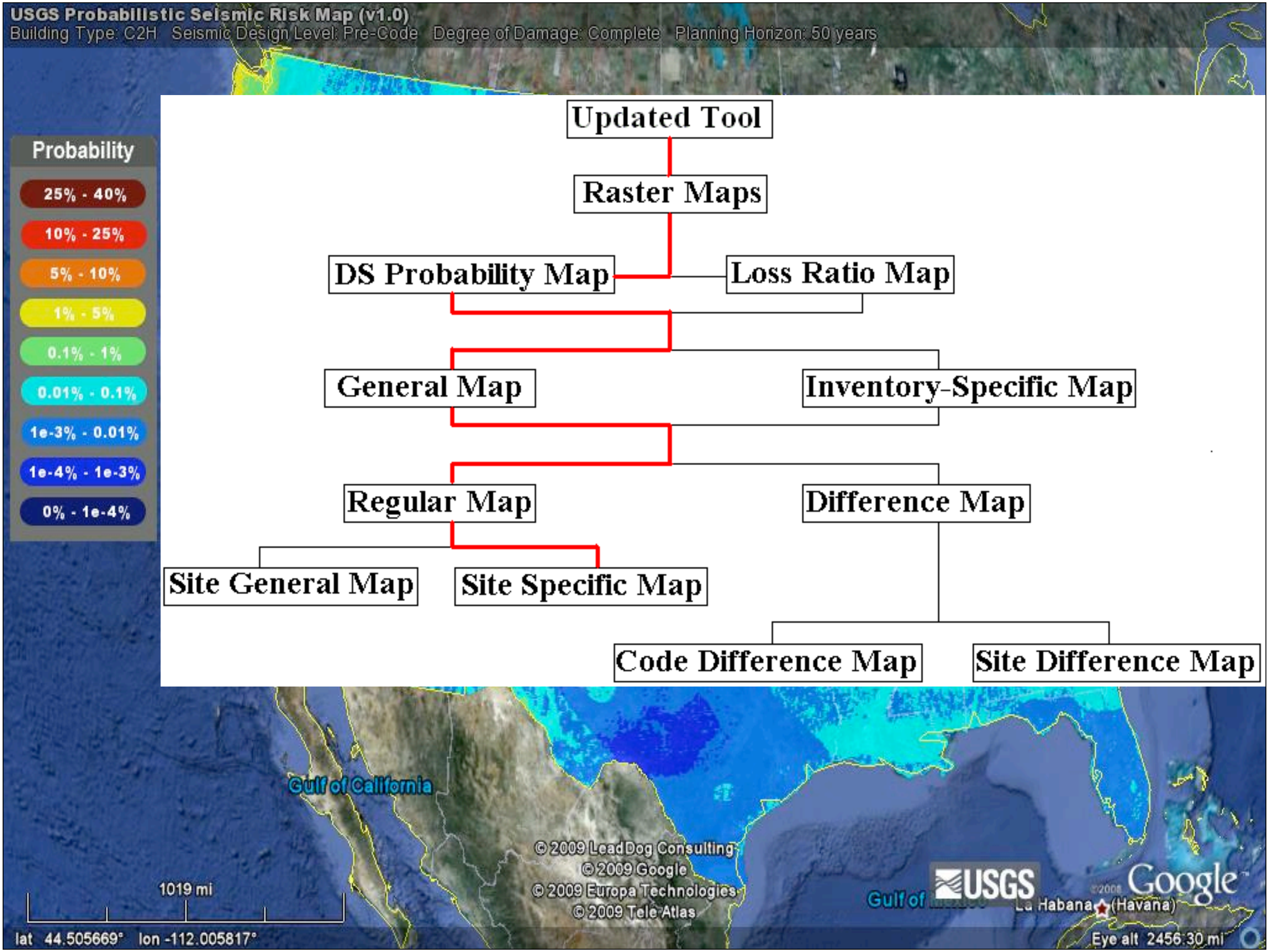
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Building Type: C2H Seismic Design Level: Pre-Code Degree of Damage: Complete Planning Horizon: 50 years
Probability
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10% - 25%
5% - 10%
1% - 5%
0.1% - 1%
0.01% - 0.1%
1e-3% - 0.01%
1e-4% - 1e-3%
0% - 1e-4%
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Site Specific Map
Code Difference Map
Site Difference Map
Gulf of California
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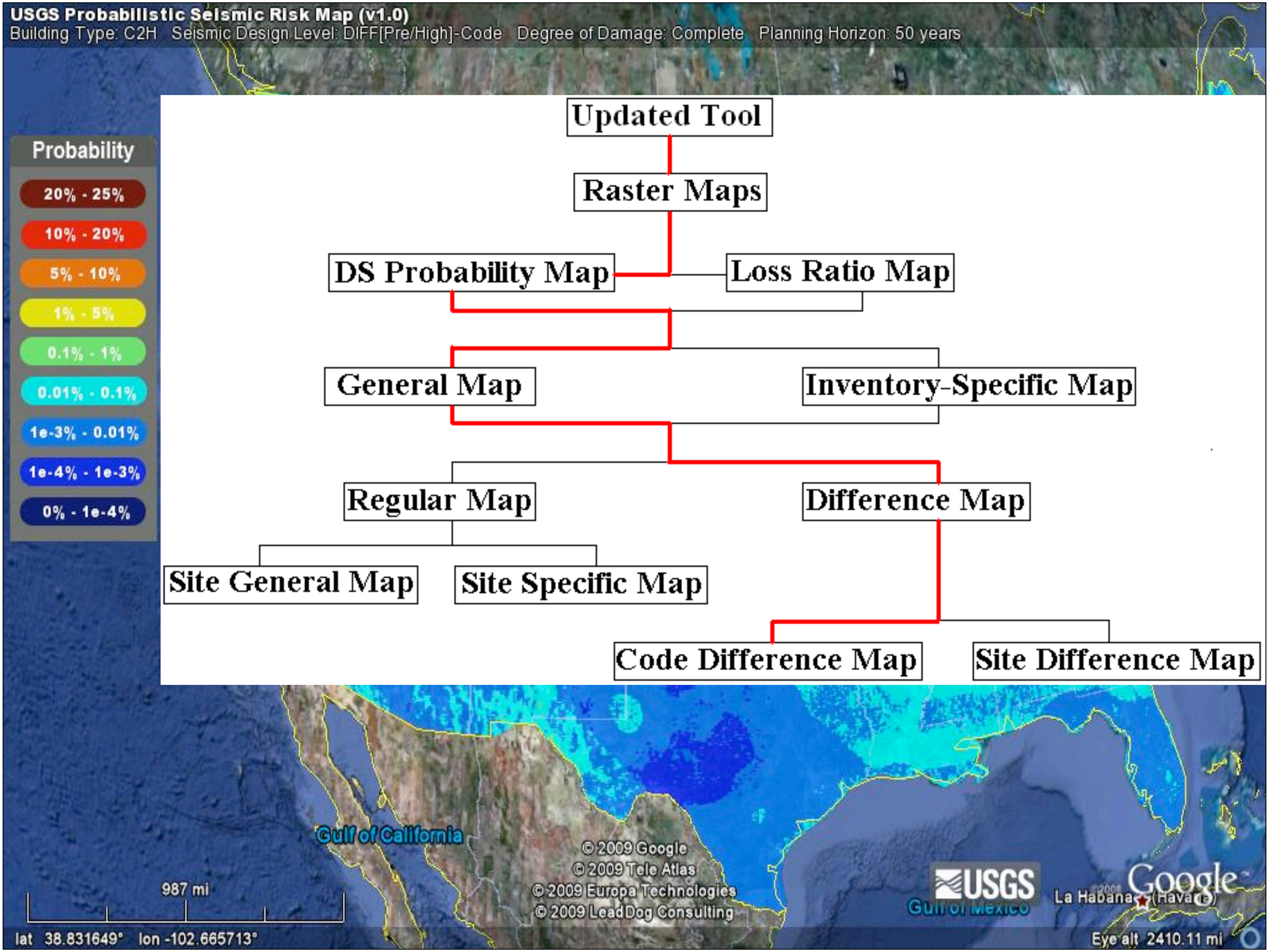
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Building Type: C2H Seismic Design Level: DIFF[Pre/High]-Code Degree of Damage: Complete Planning Horizon: 50 years
Probability
20% - 25%
10% - 20%
5% - 10%
1% - 5%
0.1% - 1%
0.01% - 0.1%
1e-3% - 0.01%
1e-4% - 1e-3%
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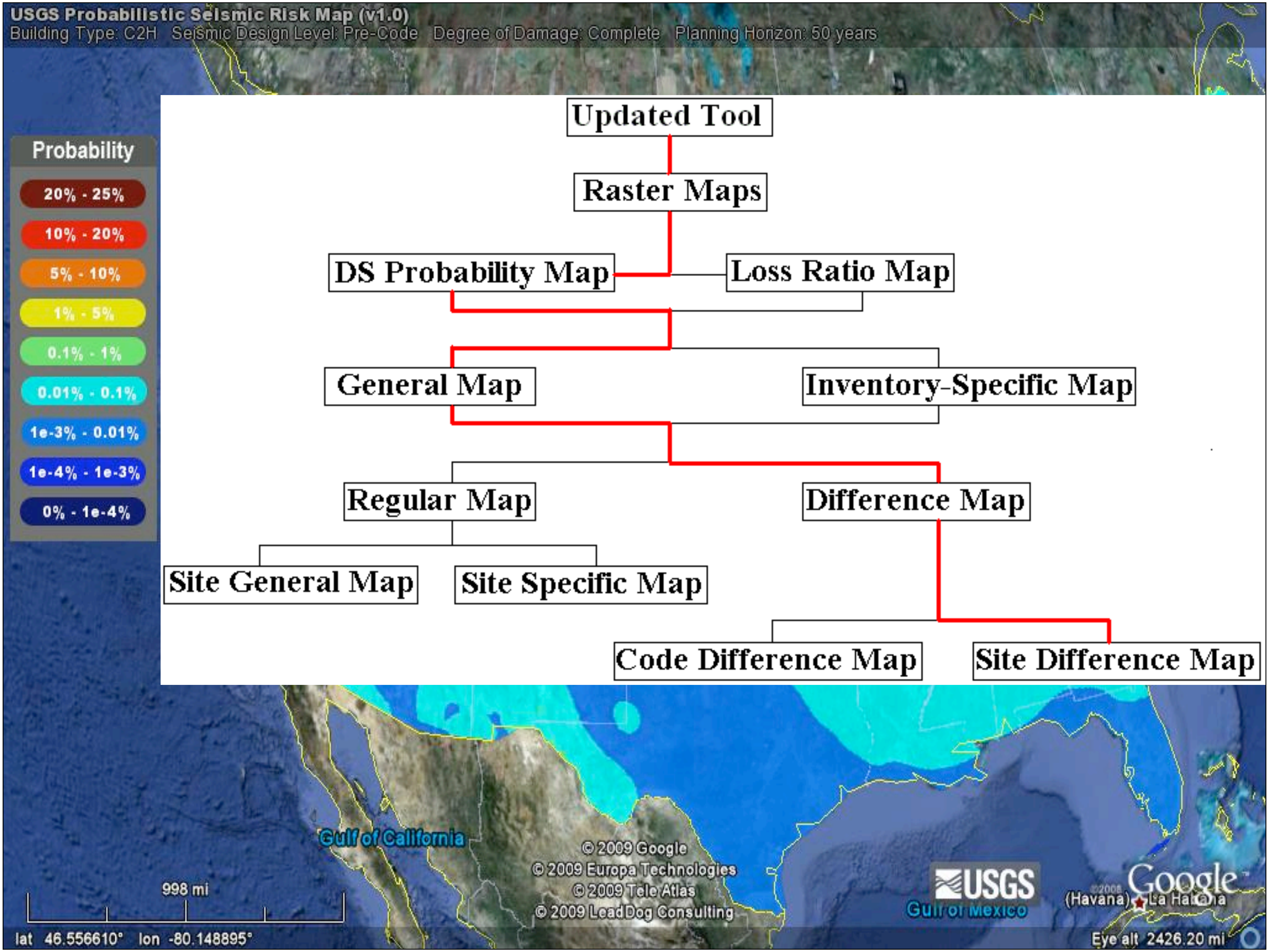
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0% - 1e-4%
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Risk Maps – Updated Tool

Outline

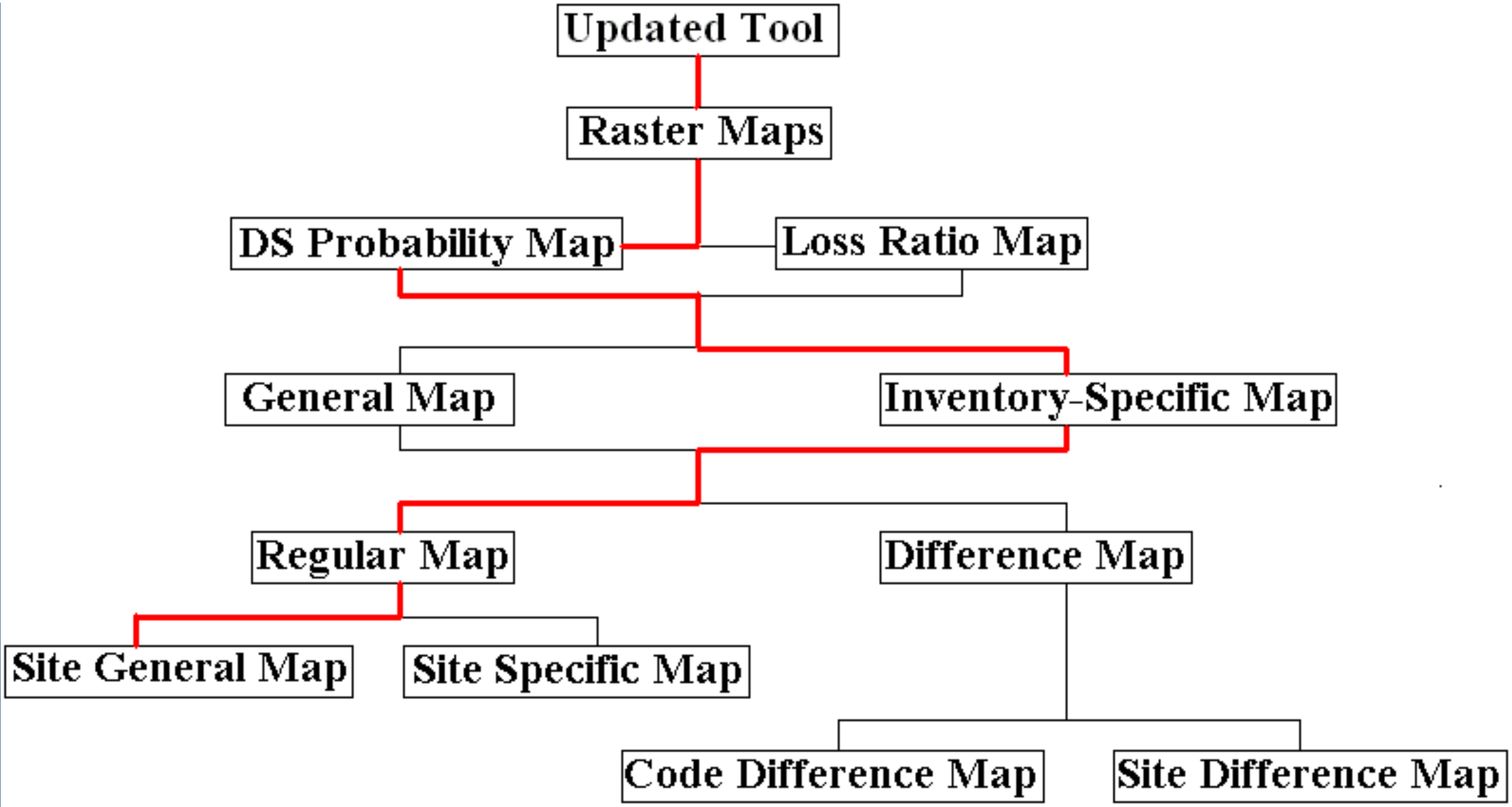
Motivation

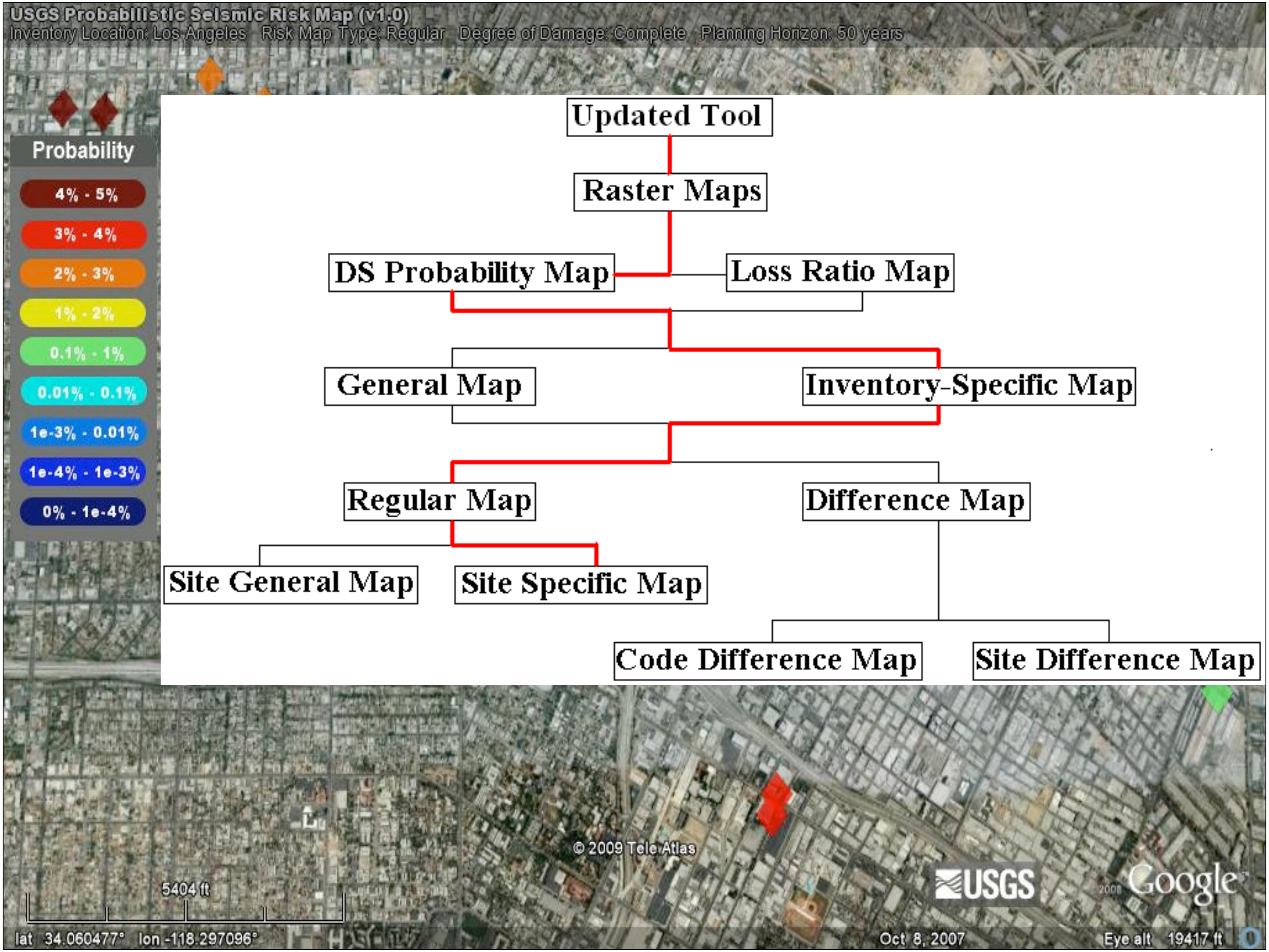
Risk

Risk Maps

Case Studies

Closing




USGS Probabilistic Seismic Risk Map (v1.0)
Inventory Location: Los Angeles Risk Map Type: Regular Degree of Damage: Complete Planning Horizon: 50 years
Probability
4% - 5%
3% - 4%
2% - 3%
1% - 2%
0.1% - 1%
0.01% - 0.1%
1e-3% - 0.01%
1e-4% - 1e-3%
0% - 1e-4%
Updated Tool
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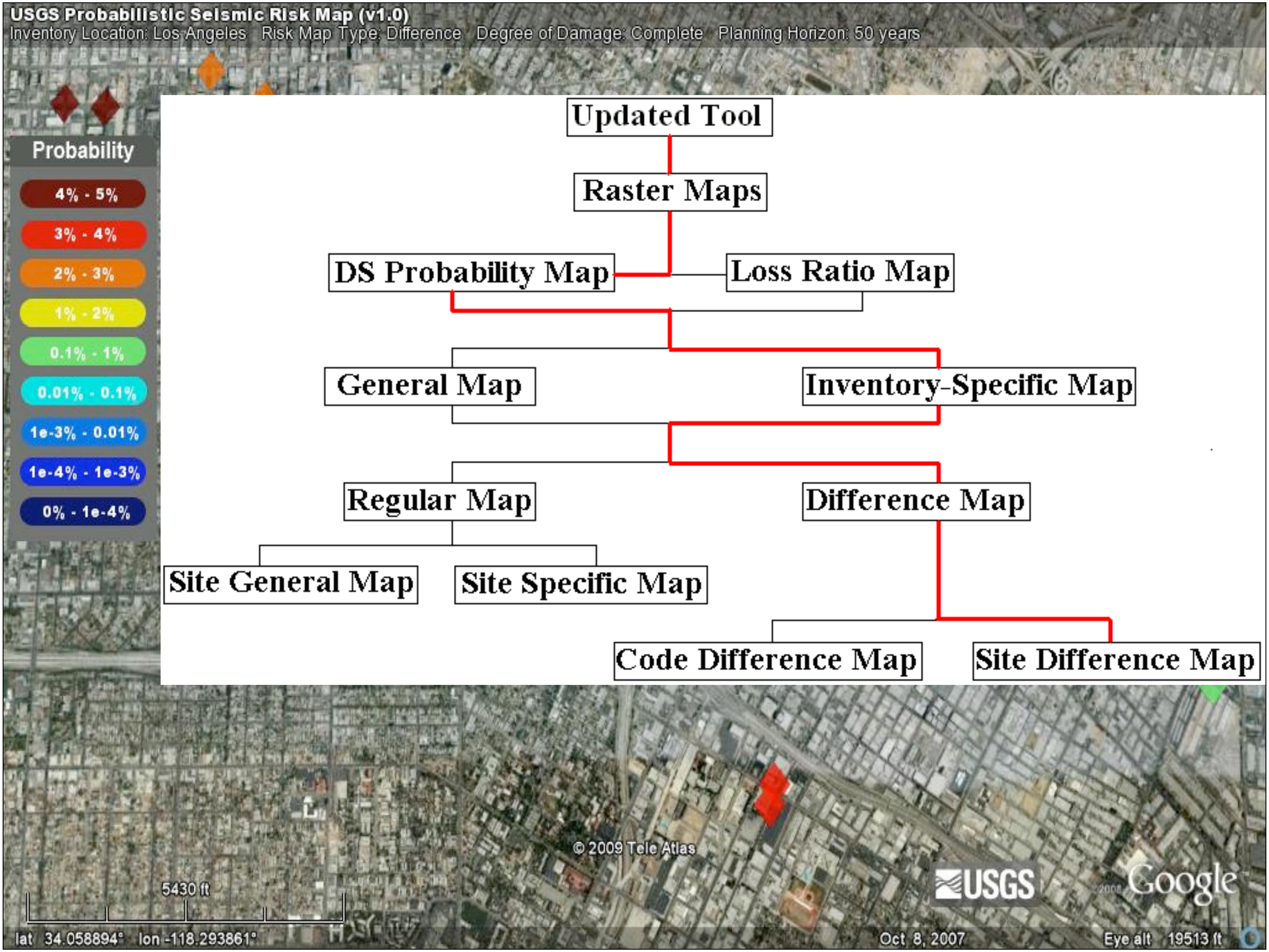

USGS Probabilistic Seismic Risk Map (v1.0)
Inventory Location: Los Angeles Risk Map Type: Difference Degree of Damage: Complete Planning Horizon: 50 years
Probability
4% - 5%
3% - 4%
2% - 3%
1% - 2%
0.1% - 1%
0.01% - 0.1%
1e-3% - 0.01%
1e-4% - 1e-3%
0% - 1e-4%
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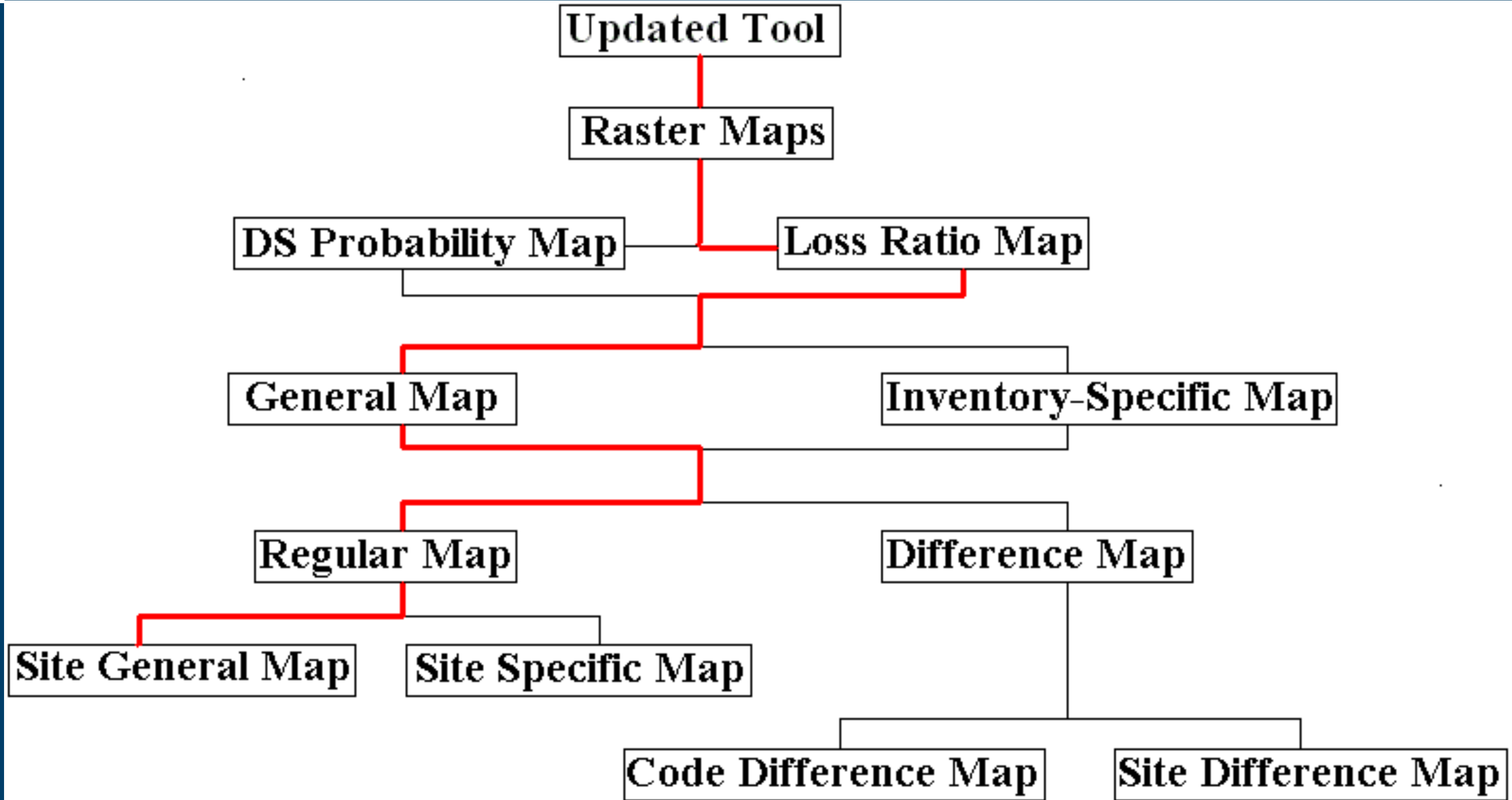
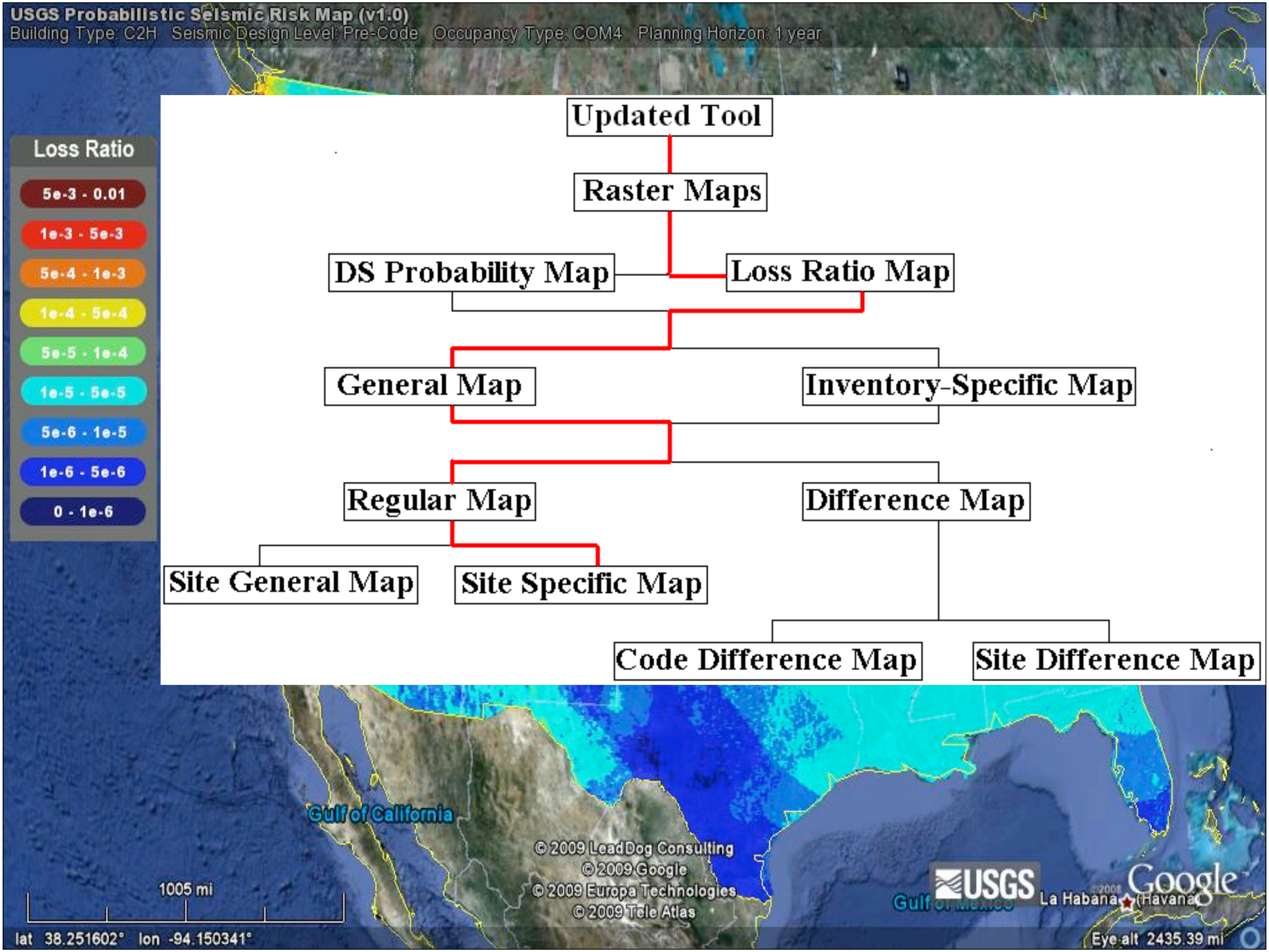
Risk Maps – Updated Tool




USGS Probabilistic Seismic Risk Map (v1.0)
Building Type: C2H Seismic Design Level: Pre-Code Occupancy Type: COM4 Planning Horizon: 1 year
Loss Ratio
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1e-3 - 5e-3
5e-4 - 1e-3
1e-4 - 5e-4
5e-5 - 1e-4
1e-5 - 5e-5
5e-6 - 1e-5
1e-6 - 5e-6
0 - 1e-6
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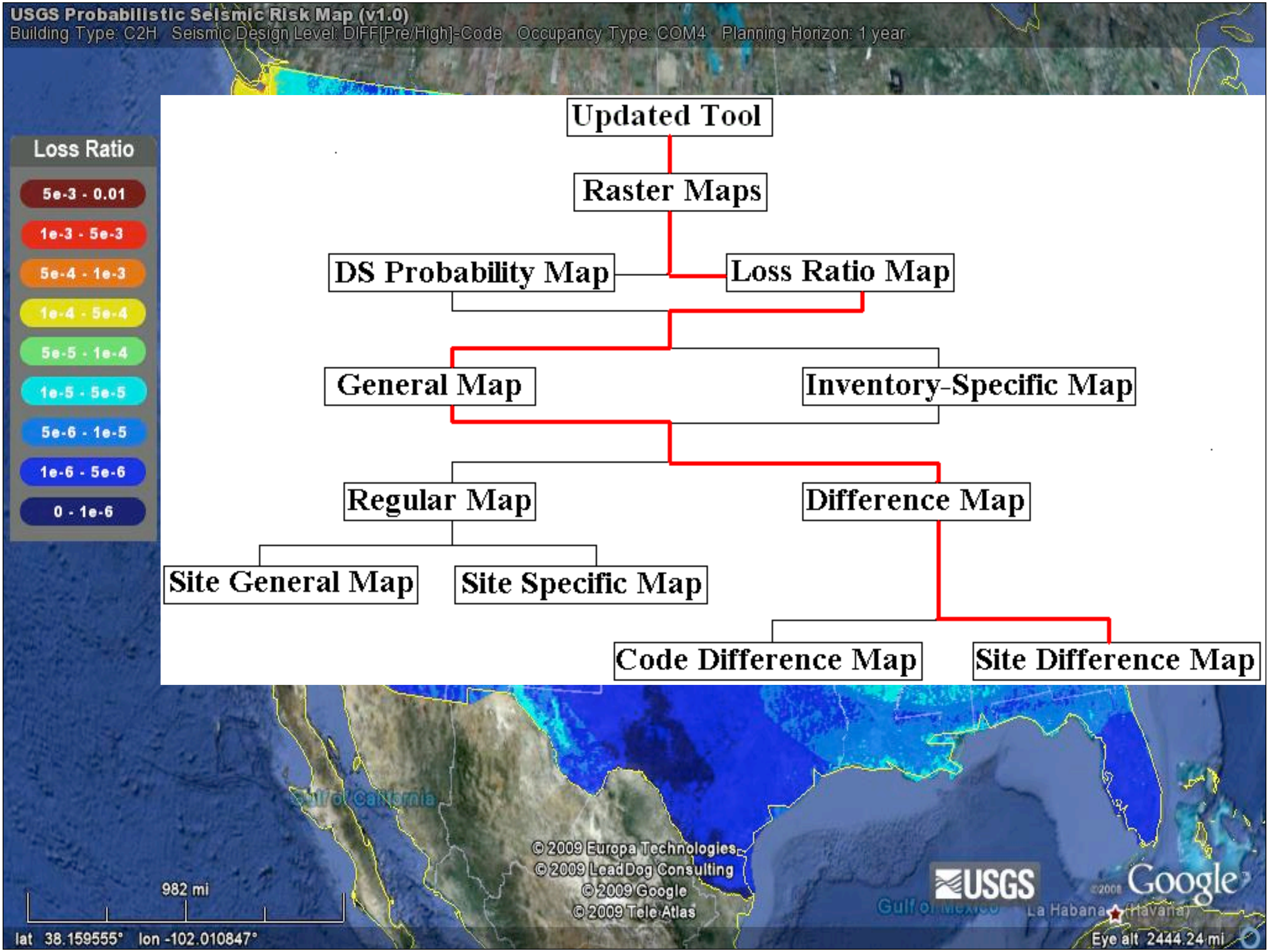
USGS Probabilistic Seismic Risk Map (v1.0)
Building Type: C2H   Seismic Design Level: DIFF[Pre/High]-Code   Occupancy Type: COM4   Planning Horizon: 1 year
Loss Ratio
5e-3 - 0.01
1e-3 - 5e-3
5e-4 - 1e-3
1e-4 - 5e-4
5e-5 - 1e-4
1e-5 - 5e-5
5e-6 - 1e-5
1e-6 - 5e-6
0 - 1e-6
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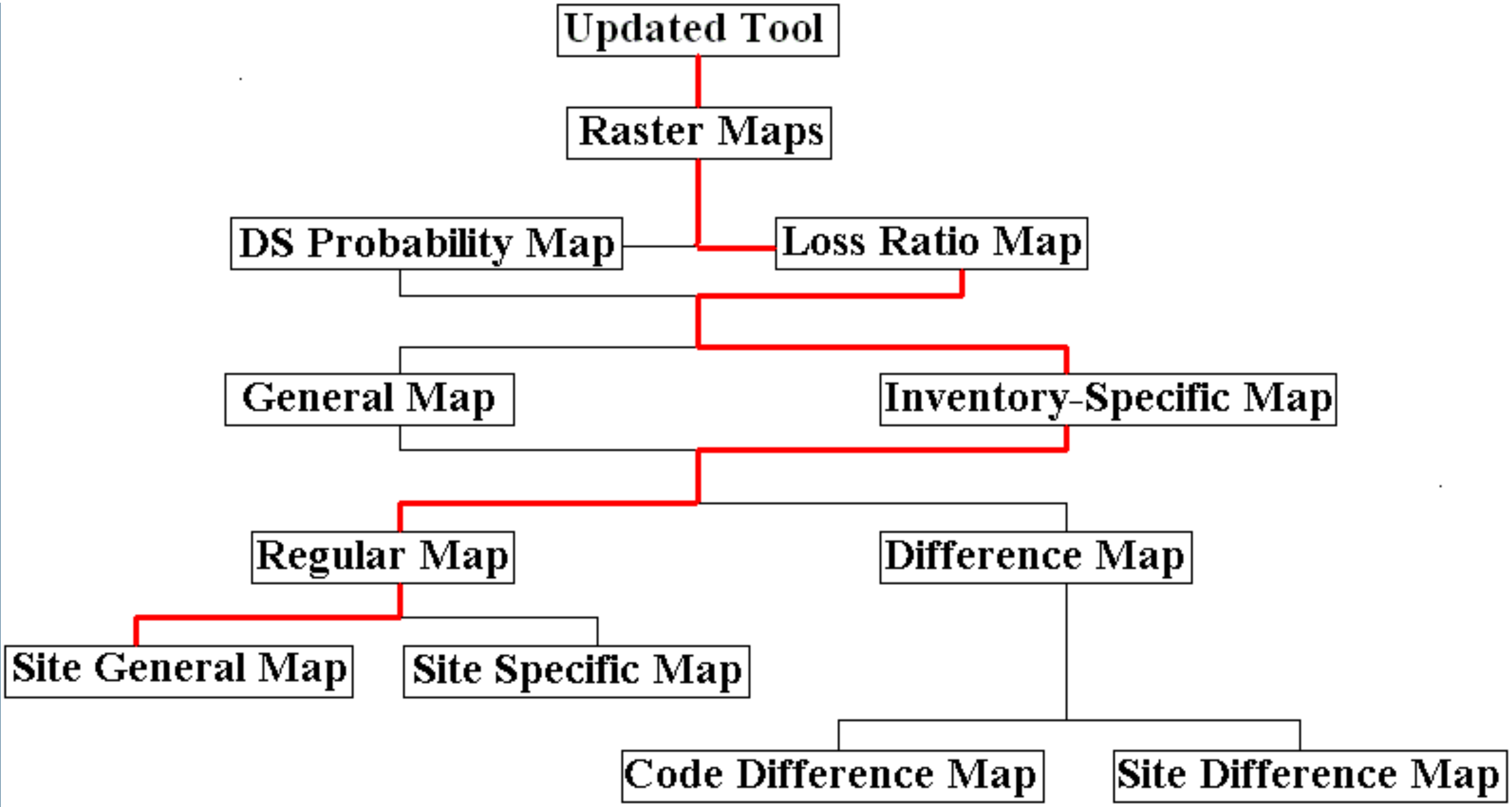
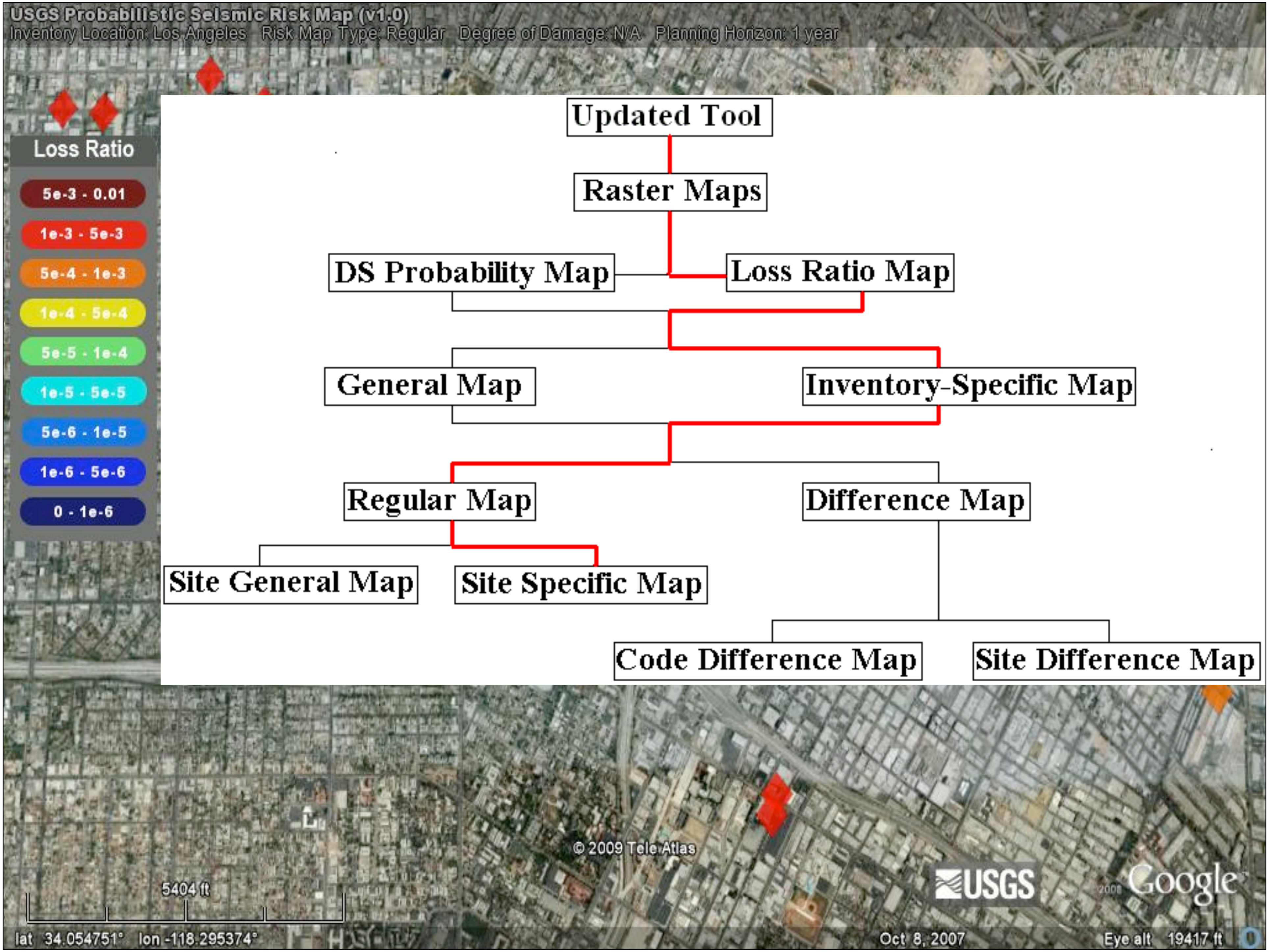
Risk Maps – Updated Tool




USGS Probabilistic Seismic Risk Map (v1.0)
Inventory Location: Los Angeles Risk Map Type: Regular Degree of Damage: N/A Planning Horizon: 1 year
Loss Ratio
5e-3 - 0.01
1e-3 - 5e-3
5e-4 - 1e-3
1e-4 - 5e-4
5e-5 - 1e-4
1e-5 - 5e-5
5e-6 - 1e-5
1e-6 - 5e-6
0 - 1e-6
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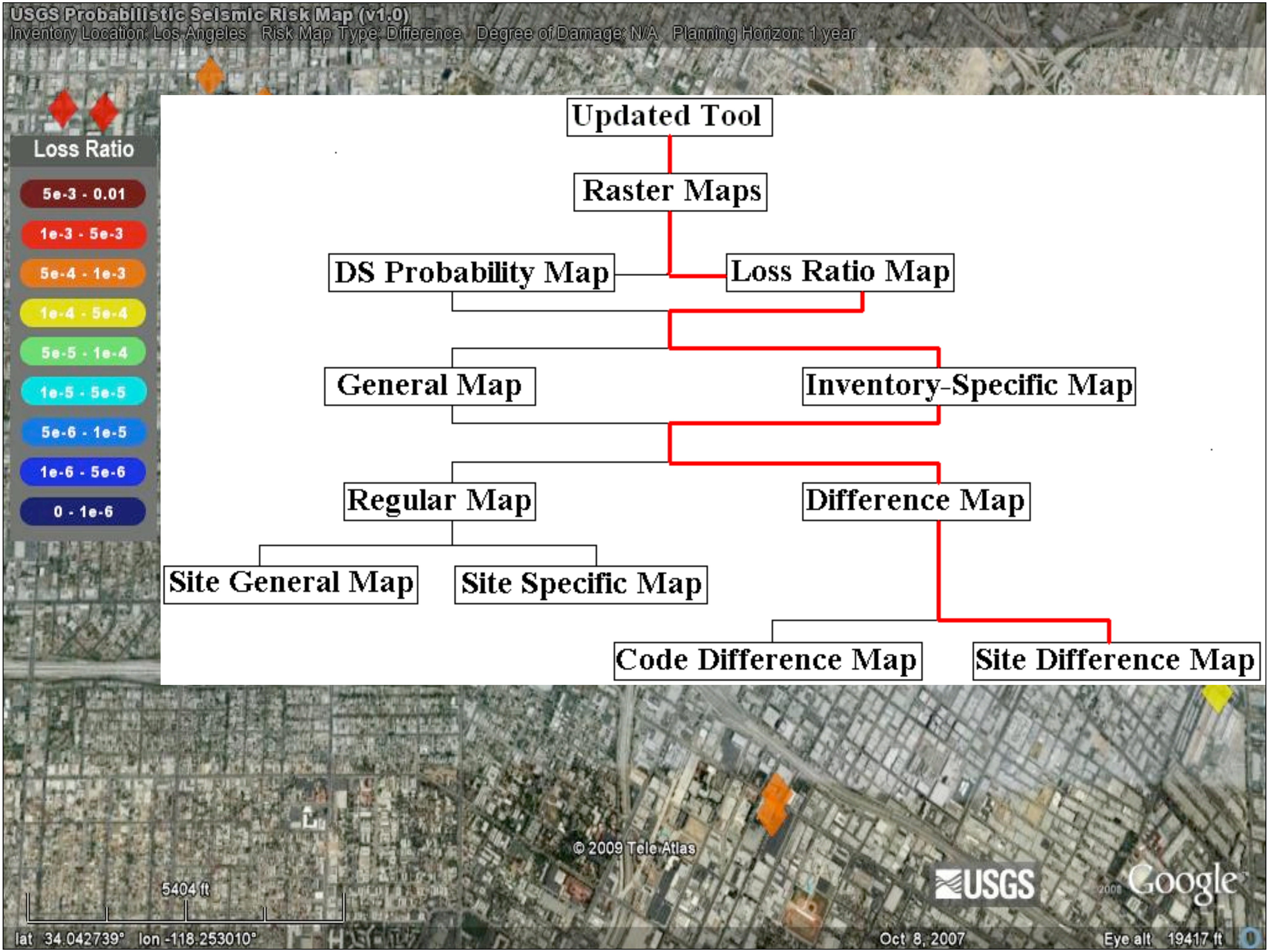

USGS Probabilistic Seismic Risk Map (v1.0)
Inventory Location: Los Angeles Risk Map Type: Difference Degree of Damage: N/A Planning Horizon: 1 year
Loss Ratio
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5e-4 - 1e-3
1e-4 - 5e-4
5e-5 - 1e-4
1e-5 - 5e-5
5e-6 - 1e-5
1e-6 - 5e-6
0 - 1e-6
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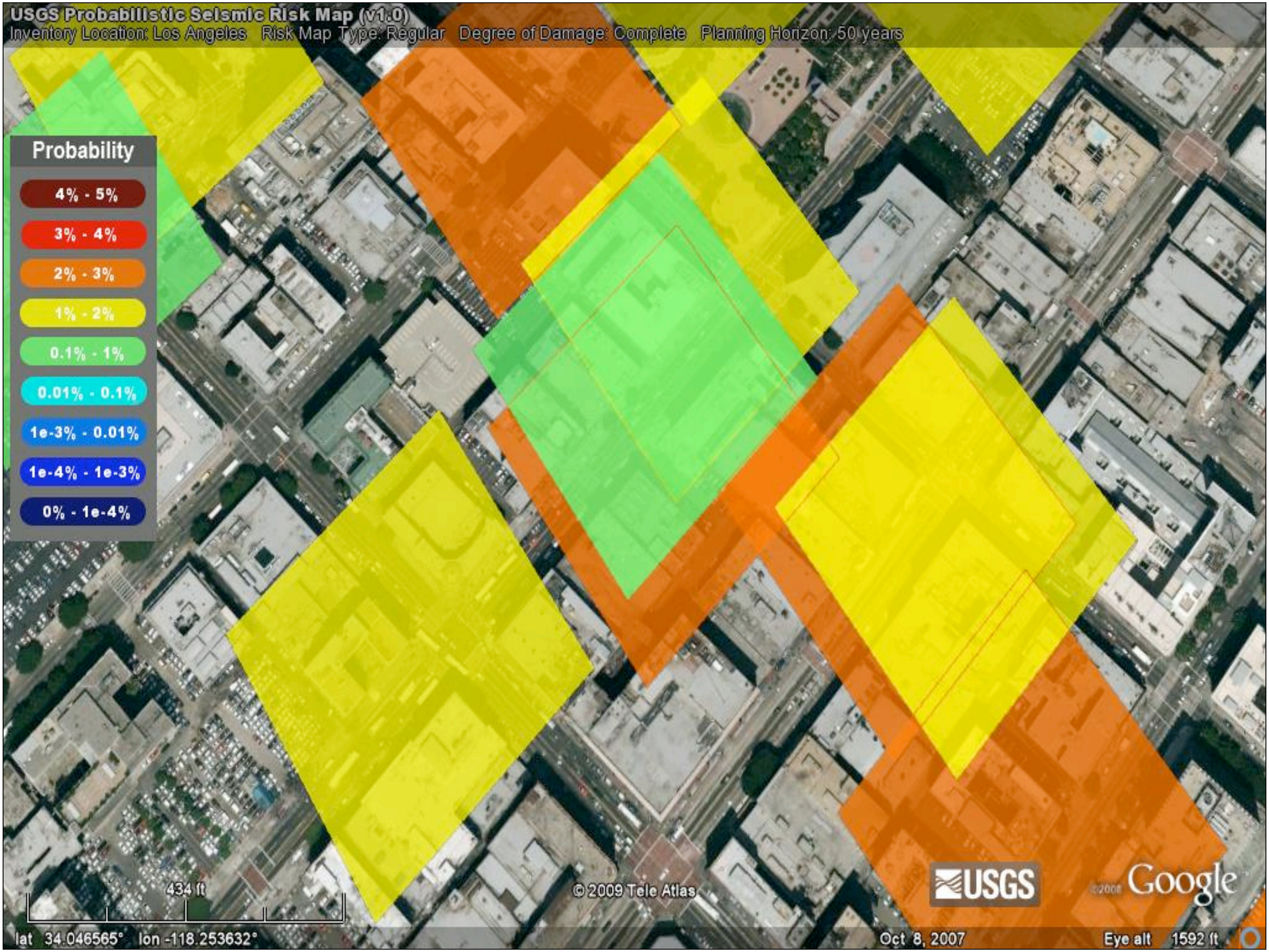

USGS Probabilistic Seismic Risk Map (v1.0)
Inventory Location: Los Angeles Risk Map Type: Regular Degree of Damage: Complete Planning Horizon: 50 years
Probability
4% - 5%
3% - 4%
2% - 3%
1% - 2%
0.1% - 1%
0.01% - 0.1%
1e-3% - 0.01%
1e-4% - 1e-3%
0% - 1e-4%
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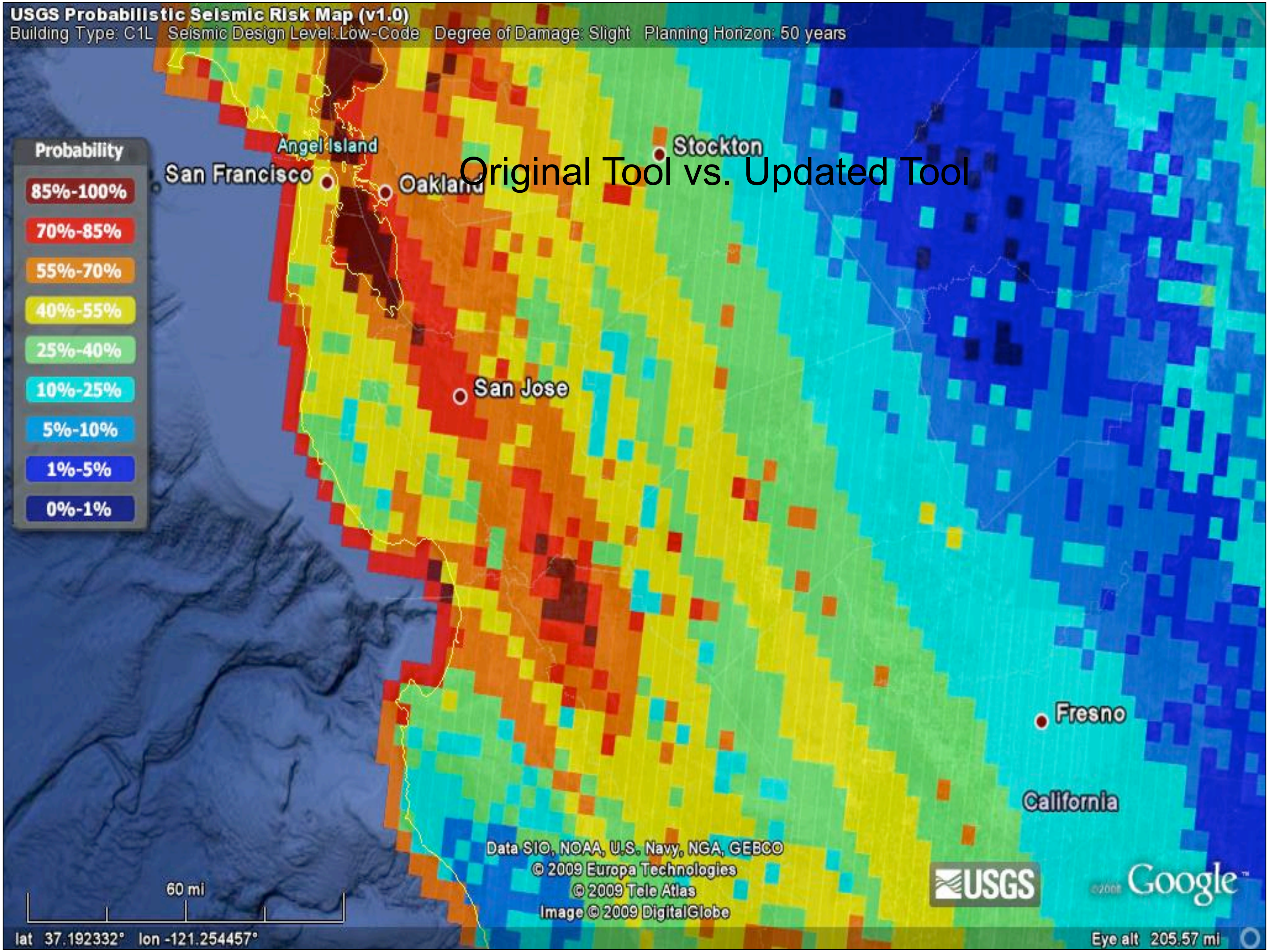
Original Tool vs. Updated Tool



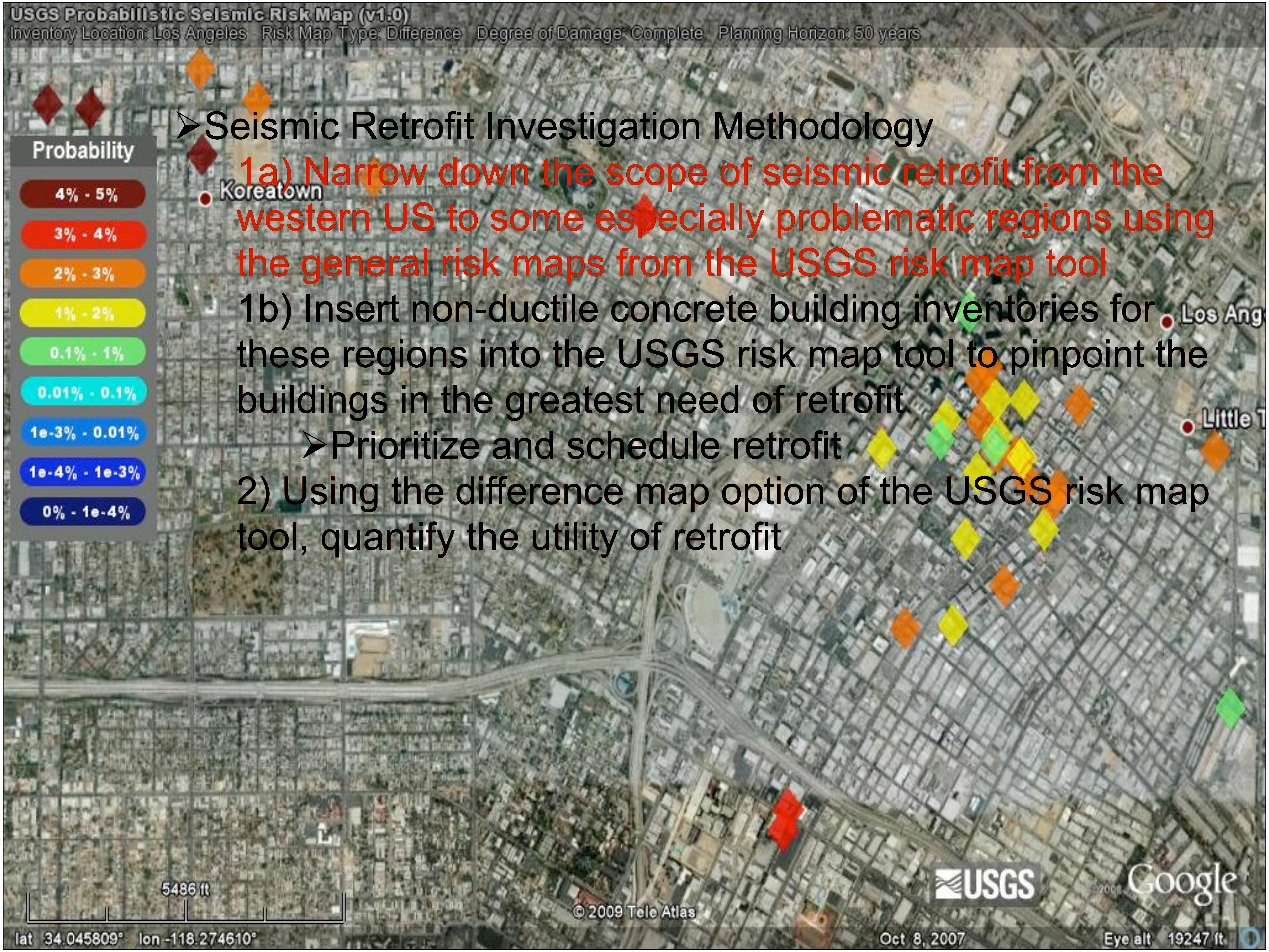
➢Seismic Retrofit Investigation Methodology

1a) Narrow down the scope of seismic retrofit from the western US to some especially problematic regions using the general risk maps from the USGS risk map tool

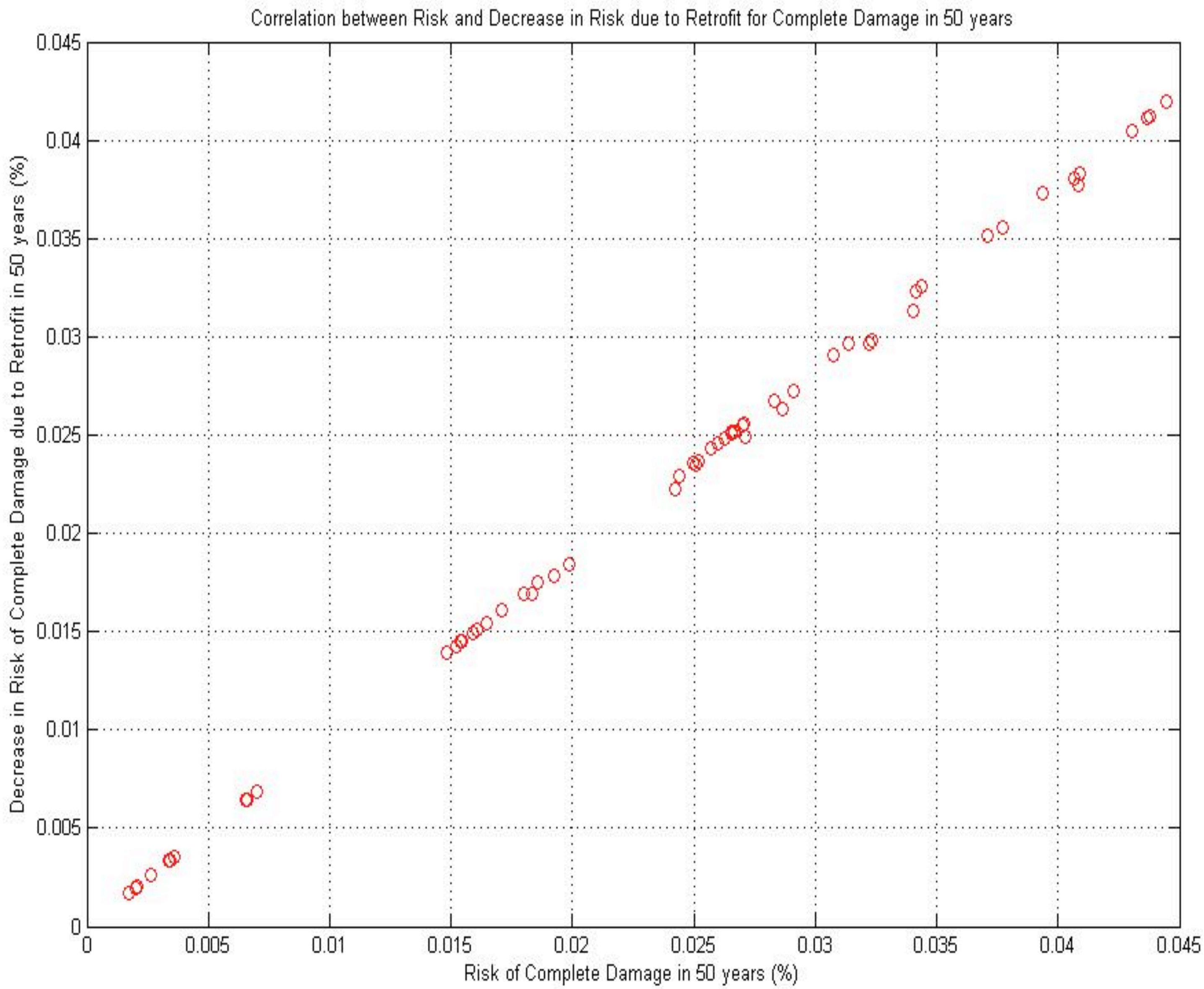
1b) Insert non-ductile concrete building inventories for these regions into the USGS risk map tool to pinpoint the buildings in the greatest need of retrofit

➢Prioritize and schedule retrofit

2) Using the difference map option of the USGS risk map tool, quantify the utility of retrofit



Risk Maps – Application



Closing

- Updated web tool currently exists only as a series of MATLAB functions
  - Next step: Integrate MATLAB and Java code using MATLAB Compiler and JA Builder to create web application
- Limitations of USGS Risk Map Web Tool:
  - User-specified inventory, fragility, or vulnerability information must be in XML format
  - Not capable of a complete cost-benefit analysis
    - Expected Loss vs. Cost of Retrofit
    - Requires:
      - Building Values
      - Cost of Retrofit
      - Discount Rate

Closing

- Possible Direction of Risk Map Web Tool:
  - Confidentiality protection
  - User-specified Hazard Data
  - Accept user-friendly specification formats
    - Excel files
- Currently searching for improved fragility functions
  - This project would benefit from specific non-ductile concrete fragilities

Lessons Learned

- Civil Engineering Concepts:
  - Hazard
  - Fragility/Vulnerability
  - Risk
  - Application of Total Probability Theorem
- Computer Science Concepts:
  - MATLAB – Efficiency and Self-Learning
- Exposure to the Research World
- Technical Writing, Poster & Presentation Creation

Questions?

Outline

Motivation

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Closing

- Thank you for your attention
- Any questions or comments?